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Role of Arm Mechanics During Sprint Running: A Review of the Literature and Practical Applications

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ABSTRACT

THE IMPORTANCE OF ARM ACTION DURING SPRINT RUNNING HAS BEEN AN ONGOING DISCUSSION AMONG PRACTITIONERS. ALTHOUGH SOME COACHES BELIEVE THAT THE ARMS SERVE TO MERELY PROVIDE BALANCE TO THE ROTARY MOMENTUM OF THE LEGS, OTHERS BELIEVE THAT THE ARMS ARE VITAL TO SPRINT RUNNING PERFORMANCE AND CONTRIBUTE TO PROPULSIVE FORCES. ALTHOUGH A LARGE BODY OF RESEARCH HAS BEEN UNDERTAKEN INTO THE EFFECTS OF LEG KINEMATICS AND KINETICS ON SPRINT RUNNING PERFORMANCE, THE ROLE OF ARM ACTION REMAINS AMBIGUOUS AND UNDERINVESTIGATED. THEREFORE, THE PURPOSE OF THIS REVIEW IS TO IMPROVE UNDERSTANDING RELATED TO ARM MECHANICS DURING SPRINT RUNNING AND PROVIDE PRACTICAL CONTEXT GUIDELINES.

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INTRODUCTION

Arm swing is a distinctive characteristic of sprint running with the arms working in a contralateral manner with the legs to propel the body in a horizontal direction. To achieve high acceleration and maximum velocity, the arm-leg movements have to be coordinated (19). To date, a large body of research has been undertaken into the effects of lower-limb kinematics and kinetics on sprint running performance (16,20,23,26,27). A systematic literature review found a strong relationship between lower-limb strength and sprint running performance (33); however, the role of arm action and subsequent strengthening remains ambiguous and underinvestigated. Because sprint running has distinctive phases (i.e., start, acceleration, and maximum velocity) and the body's position varies throughout these phases, it is quite likely that the role of the arms may change in accordance with these phases (Figure 1). Furthermore, in team sport events, different starting positions are used to optimize sprint performance, for example, a crouch start (American football, track and field running) or a standing start (soccer, rugby, and basketball) (36). Figure 2 highlights the difference between body and arm positions during a block, 2-point contact, and 3-point contact positions.

Given that evidence is limited on how arm contribution affects track and sport speed, understanding and refining the role of the arm during the different phases of sprint running would seem important due to the potential to improve performance outcomes. The

KEY WORDS:
acceleration; kinematics; kinetics; maximum velocity; sport-specificity; upper limbs

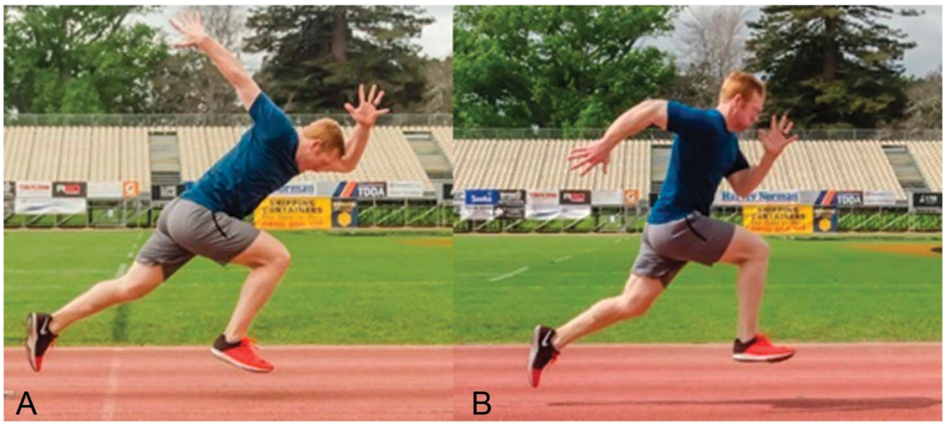

Figure 1. Start phase (A) and maximum velocity phase (B) sprint running.

purpose of this review, therefore, is to improve understanding related to arm mechanics during sprint running and provide guidelines on how this information may be used in a practical context. Peer-reviewed journal articles were retrieved from electronic searches of ScienceDirect, Web of Science, PubMed, Google Scholar, and SPORTDiscus databases, in addition to relevant bibliographic hand searches with articles limited to English language. The search strategy included the terms arm, upper limb, sprint, run, acceleration, and velocity. The month of the last search performed was September 2017. Articles that discussed the role of the arms during sprint running performance were considered eligible for this review. Due to the small amount of research in sprint running in this area, articles that assessed arm action during running were also included in the discussion. A total of 28 studies met the inclusion criteria for this review.

THE ROLE OF THE ARMS DURING RUNNING AND SPRINT RUNNING

The importance of the arms during running has been highlighted by Egbuonu et al. (7) who reported a 4% increase in the energetic cost of treadmill running without arm swing (i.e., arms held behind the back). Similarly, treadmill running with the arms crossed in front of the chest resulted in a significant increase (8%) in the net metabolic power demand compared with running with arm swing (2). Moreover, running without arm swing did not change the average step width but significantly increased step width variability (9%) and step frequency (2.5%) compared with running with arm swing (2).

Regarding sprint running, the role and importance of arm action during sprint running has been an ongoing discussion among researchers for several decades. For example, Bosch and Klomp (4) suggested that arm action during sprint running had a greater function than merely maintaining balance or compensating for the small disturbances in body posture. The arm action was thought to contribute to an increase in velocity by the development of an increased thrust in the direction of progression (4), which has particular importance for the start and acceleration phase. When the body is upright during maximum-velocity sprint running, Bunn (6) and Hay (10) proposed that the arms served as a balancing action for the hips, whereas during running, Hopper (15) proposed that the main function of the arm swing was to help lift the

Figure 2. Block (A), 2-point contact (B), and 3-point contact (C) start positions.

Figure 3. Wearable resistance forearm loading.

runner off the ground. Sayers (31) suggested that the arm drive had 2 main purposes: (a) to increase both stride rate and ground reaction forces, and, (b) to improve balance by countering the body's rotation initiated by the pelvis. Given the different point of views on the contribution of the arms to sprint running, the following sections discuss the start and acceleration phase and maximum velocity phase separately.

START AND ACCELERATION PHASE

During the start of the sprint, the body's center of mass leans forward, suggesting that the relative momentum of the horizontal component of both arms may not be canceled (28). Schnier (32) and Embling (8) proposed that a vigorous arm action would assist forward drive during the start of a sprint. It would seem that for the start and early acceleration phases at the very least, that understanding the importance of arm action may benefit sprint running performance.

At the beginning of the pushing phase during 10-m sprints from a block start, the joint angular velocity of the rear shoulder was linked to an extension movement that is mainly related with the raising of the thorax (35). It is thought that the hands have an action on the ground, which is associated with the shoulder joint angular velocity because of this extension movement (35). After a block start, Lockie et al. (19) reported flexion-extension joint range of motion (ROM) for the shoulder (45.6–52.5° and 46.4–55.0°, first and second steps, respectively) and the elbow (53.8–66.3° and 56.9–67.3°, first and second steps, respectively) in football players, with the authors noting small shoulder flexion (<30°) may relate to the subject's lack of proper sprint technique. During early sprint acceleration, the flexion and extension angular velocity of the humerothoracic joint is high (approximately 700°/s) (35), indicating that the ROM of the scapulothoracic joint is important during sprint running. Slawinski et al. (35) reported that a greater variance in joint angular velocity was found in the arms compared with the legs, which may be related to individual morphological properties and starting techniques. The importance of scapulothoracic joint ROM is highlighted when arm drive motion was restricted by constraining scapular motion with tape, step length (−4.6%) and whole body lean position (−3.9%) during the first step was significantly decreased, subsequently reducing the sprinting speed (−3.2%) (28). Furthermore, Otsuka et al. (28) found that the forward leaning position of center of mass (−3.9%)

Figure 4. Sled-resisted sprint running with wearable resistance.

Figure 5. Medicine ball first step release.

and the ROM of humerothoracic extension (−5.2%) were significantly smaller than that in the free condition. These changes in forward lean are of interest, given that Kugler and Janshen (18) reported higher horizontal accelerations were generated by more forward leaning of the body at take-off, suggesting that the forward leaning position of the center of mass at take-off is important for enhancing sprint speed and undoubtedly the arms contribute to this position.

Bhowmick and Bhattacharyya (3) proposed that the horizontal acceleration of the arm swing may assist in increasing stride length. Moreover, the authors suggested that during the start of a sprint, the vertical component of the arm movement may create a situation for enhanced leg drive during ground contact, and therefore helps to increase the forward velocity of the main movement indirectly (3). As previously mentioned by Lockie et al. (19), arm-leg coordination is required to optimize sprint running performance. This proposal is supported by Slawinski et al. (35) who reported that in elite sprinters, a greater synchronization between the arm-leg increased the efficiency of pushing on the blocks from a sprint start. During 10-m sprint running from a block start, it was found that although the leg and head-trunk segments contributed the greatest proportion of kinetic energy of the total body, the arms still contributed 22% of the body's kinetic energy, indicative of the importance of these segments during the pushing phase of the block start (35). Slawinski et al. (34) also investigated the initial 2 steps after a block start and found that elite sprinters had the ability to move their center of mass further forward than well-trained sprinters partially due to the movement of their arms.

Although block starts are used in sprint races up to 400 m, athletes will often practice from a standing position, whereas team sports require athletes to sprint from an upright position (21). Although research has investigated acceleration performance from a standing start, no authors have examined the contribution of the arms during this start position and how they differ from a block start. Salo and Bezodis (30) found that in using a split-stance standing start, an athlete is able to increase acceleration in the initial phase of the sprint to a greater extent than in block start. In a standing start, the distance between the front and rear foot is naturally long, causing the athlete to push

Figure 6. Plate overhead step up.

Figure 7. Standing transition arm drive.

for longer on the front foot once the rear foot has cleared the ground (30). Majumdar and Robergs (21) noted that during the acceleration phase, it was important to orient the body so that the location of the body's center of mass and the center of gravity is as forward as possible to allow for continued forward acceleration. Given the body's change in orientation during the transition through the acceleration phase, future research is required into how changes in arm action from a standing start can contribute to enhancing start and acceleration phase performance.

MAXIMUM VELOCITY PHASE

During the maximum velocity phase, the body is upright, and the momentum of the horizontal component of the arm is not directly associated with the body's center of mass as the swinging backward and forward motions of the arms are in opposite directions and the momentum is canceled (11,14). Two-dimensional quantitative studies by Mann (22) and Mann and Herman (23) found that there was a minimal amount of muscular contribution from the shoulder and elbow joints during the maximum velocity phase of sprint running. Mann and Herman (23) compared the performance of the first- and eighth-place sprinter during the maximum velocity phase of a 200-m race. The faster sprinter had a greater arm displacement from the shoulder (135° versus 118°) and elbow (84° versus 67°) joints with a greater average speed from the shoulder (525°/s versus 490°/s) (23). From the analysis of muscle moments from 15 sprinters who ranged in experience from collegiate to world class, Mann (22) proposed that activity from the shoulder joint related to maintaining balance, and activity from the elbow indicates that its purpose is to maintain the forearm in a flexed position; however, the optimum positions are yet to be established. Furthermore, it was suggested that no relationship existed between arm action and sprint running performance (22). Consequently, the authors suggested that the role of the arms during sprint running was to maintain balance (22,23). However, due to the limited number of subjects and the difference in their levels of sprint running experience, understanding arm action during the maximum velocity phase clearly requires further research.

Researchers analyzing the effects of arm swing during treadmill running using 3-dimensional motion analysis found that the vertical ROM of the body center of mass was increased 5–10% by arm swing (14). The authors proposed that the primary lift mechanism occurs during the mid-contact phase whereby the upward acceleration of the arms, relative to the trunk, produces a greater vertical impulse on the body as a whole (14). The lift provided by the arms was found to increase as running speeds increased, therefore highlighting their potential importance at higher sprint running speeds. This finding may be of significance during the start phase as Young et al. (38) reported that when the body has a significant forward lean, the vertical lift provided by the arm drive has a horizontal propulsive component. Hinrichs et al. (13) reported that the arms were involved in reducing total-body angular momentum about a vertical axis through the body's center of mass when running in an upright position. However, Hinrichs (12) reported that the arms possess the potential to compensate for each other and for asymmetries elsewhere in the body during treadmill running. Bunn (6) suggested that a vigorous backswing of the arms caused an increased leg stride and assisted to maintain velocity when the legs fatigued. More research into the role of the arms during the maximum velocity phase is required coupled with understanding the transition through all phases of sprint running.

Figure 8. Double-arm pillar press.

TRAINING STRATEGIES FOR ARM DRIVE

Although coaches believe that the arms play a vital role in sprint running (17,37), the training strategies to improve arm mechanics for sprint running remain relatively unexplored. Young et al. (38) proposed that the muscles that drive the arms may be relatively more important for short sprints. However, although the standing and seated arm swing exercises are commonly implemented to enable an athlete to focus on the actions of the upper limbs (5), only a few researchers have specifically investigated the effects of training interventions on arm mechanics for sprint running. This section discusses the findings of these articles in relation to the start and acceleration, as well as the maximum velocity phase.

START AND ACCELERATION PHASE

Acute changes were examined during 40-m overground sprint running with wearable resistance of 0.5 kg attached to each arm using a weighted sleeve on 10 male recreationally trained athletes from field-based sporting clubs (25). No significant differences were found at the start phase between loaded and unloaded conditions in 10-m best time (−0.4%) and 10-m average time (−1%), with Cohen effect sizes trivial (<0.2) for both changes (25). The loads were positioned on the dorsal side of the forearm, held to the arm by an elastic sleeve extending from the wrist to above the elbow, and secured with velcro straps. Subject's body mass (BM) was not reported; therefore, the magnitude of this load as a percentage of BM was unknown. McNaughton and Kelly (25) proposed that as no detrimental effects were found in performance, the forearm loads may provide a suitable overload stimulus during speed training sessions without negatively impacting technique or performance. An earlier study on 24 male physical education students used loads of 0.2, 0.4, and 0.6 kg (0.3–0.9% BM) lead rods, held in each hand, during 30-m over the ground sprint running (29). Similarly, Ropret et al. (29) reported no changes in velocity, stride rate, or stride length with any loaded condition over the initial 15 m compared with the unloaded sprint. From these findings, it may be concluded: (a) that arm loads

Figure 9. Single-arm pillar press.

of ≤0.6 kg do not seem to interrupt spatiotemporal variables and hence introduce technique breakdown, (b) preference would be to affix load to the lower area of the arms, which increases the rotational inertia and ensures that the hands are not gripping a load, which may increase unwanted tension in the arm and shoulders, and, (c) it may be that the magnitude of loads used in the aforementioned studies may not have been sufficient to significantly overload arm mechanics during the initial 15 m, and future research with heavier wearable resistance is required.

When sprint running was performed with a sled resistance, the athlete's body position was forced into an increased forward lean (19,24). Consequently, Lockie et al. (19) reported that athlete's arm drive exhibited a greater range of shoulder joint flexion over the initial 2 steps (~2–3°) after an 8-week sled training study. As athletes are cued at the start of the sprint to take-off in a more horizontal position, sled-resisted sprint running with 20% BM resulted in a 9% more horizontal take-off angle from a block start (24). Therefore, the subsequent forward lean position achieved with sled-resisted sprint running partly mirrors the start phase of a sprint and may be an effective training modality for practitioners seeking changes in early sprint arm drive kinematics. Whether this is the case, especially because the arms are not directly overloaded, needs to be investigated further.

MAXIMUM VELOCITY PHASE

During the maximum velocity phase, sprint running with a loaded arm condition of 0.5 kg per arm had no significant effect on 40-m best time (−0.2%) and 40-m average time (−0.2%), with Cohen effect sizes trivial (<0.04) for both changes (25). Moreover, no significant effect was found for average velocity (−0.5%, effect size = 0.08) (25). Ropret et al. (29) reported that no acute effects were found in sprint performance over 15–30 m until the heavier loads (0.6 kg, 0.9% BM) were used, which resulted in a significant 1% decrease in velocity between the unloaded and handheld loaded sprint conditions. No significant changes were found in stride frequency or stride length during the maximum velocity phase, although stride length was reduced ~3 cm with the 0.6 kg loaded condition (29). A dearth of quantitative research exists relating to the optimum mechanics of the arms during sprint running. Moreover, from qualitative research, coaches believed that arm mechanics differ between the maximum velocity phase and the earlier phases of sprint running. Coaches identified that the arms assist in stabilizing the trunk, and work in tandem with the legs to stabilize and balance the body when an athlete is upright and maintaining maximum speed (17).

PRACTICAL APPLICATIONS

Although coaches recognize the importance of the arm drive in sprint running, the role of the arms during the different phases of the sprint, and the training of the arms has not been

Figure 10. Shoulder asymmetry assessment during standing arm drive. (A) neutral shoulders. (B) elevated left shoulder.

articulated to any great detail. This review attempted to synthesize the available information by first enhancing the understanding of the role of the arms during the start and acceleration versus the maximum velocity phases of sprint running. By understanding these differential roles and subsequent mechanics, programing needs to become clearer. The following section describes a small selection of exercises that may assist the practitioner in the training of the arms specific to the phase of sprinting.

START AND ACCELERATION PHASE

Two previous sprint running studies that used loads attached to the arms or hands were found to not overly alter the spatiotemporal variables. Therefore, sprint running with wearable resistance attached to the arms (Figure 3) may be a suitable training stimulus without unduly affecting start and acceleration kinematics, which may lead to positive performance adaptations. Wearable resistance attached to the forearms may create a greater horizontal propulsion at take-off due to the greater amount of rotational inertia from the distal loading of the arms.

Due to the orientation of body (i.e., more of a horizontal lean) during the start phase, the vertical lift provided by the arm drive has a horizontal propulsive component, and therefore, optimizing arm action may enable a greater horizontal propulsion. At the start of a sprint, there is a technical emphasis for athletes to take-off in a more horizontal position. Moreover, research has found that the forward leaning position of the center of mass at take-off is important for enhancing sprint speed. Therefore, sprint running training with resisted sleds (Figure 4) is one modality that enables this body position to be maintained, which results in a greater arm drive action from a larger shoulder joint ROM. Although there is no direct overload of the arms in this position, the orientation of the body may enable a training stimulus for greater arm velocity and limb coordination to be achieved. In addition, with wearable resistance attached to the forearms (Figure 4), an overload of the arm action can be achieved. However, this proposal is speculative and future research is needed to disentangle whether this type of training has any effect on arm drive kinematic and kinetics, and therefore, sprint performance.

Future research is required to find an optimum magnitude of wearable resistance because a load too heavy may result in negative arm kinematics as the athlete struggles to maintain a high velocity arm drive. Given the importance of the arm drive during push-off and acceleration, practitioners should focus on arm-leg coordination and their contralateral positions.

In addition to traditional sprint and resistance training, a series of exercises used by coaches to improve arm drive function and arm-leg coordination during the start and acceleration phase are illustrated in Figures 5–7. The medicine ball first step release (Figure 5) is a loaded arm exercise that may be used to enhance arm drive extension and propulsion required during the initial first step. The plate loaded overhead step (Figure 6) may be used to enhance arm drive to assist arm-leg coordination and horizontal propulsion by overloading the shoulder and elbow joints in conjunction with the lower limbs. The standing transition arm drive (Figure 7) may be used by coaches to improve arm drive technique and rate-of-rise rhythm through transitioning from the start to maximum velocity phase by coordinating the timing of the arms with the change in the body's orientation from a leaning forward position to an upright position. The reader needs to be cognizant that there may be limitations to these exercises because: (a) the upward propulsion of the ball and plate may result in significant thoracic extension, (b) the exercises bias vertical force production, and (c) there is no counterbalance from (for example) the opposite arm.

MAXIMUM VELOCITY PHASE

During the maximum velocity phase of sprint running, the body is upright. When sprint running in this position, the arms contribute to the total vertical propulsive forces applied to the ground; therefore, optimizing arm mechanics in symmetry with the legs should be a consideration for training planning. Athletes should train to achieve an effective arm swing that originates from the shoulder and has a flexion and extension action at the shoulder and elbow that is matching to the flexion and extension occurring at the ipsilateral shoulder and hip. The double-arm pillar press exercise (Figure 8) and the single-arm version (Figure 9) can be used to strengthen the shoulders and triceps. In addition, exercises similar to those illustrated in Figures 8 and 9 may be used to concomitantly reinforce postural integrity, balance, and arm-leg coordination.

It may be argued that the vertical plane–only exercises, depicted in Figures 8–9, are somewhat nonspecific, given the discussion of the role of the upper body in maximum-velocity running. Given such a contention, the utilization of some track drills to challenge the coordination of the arms with the trunk and hips should also be considered to help identify training needs. For example, an upright version of the arm drill (Figure 10)—starting on flat foot and coming up to plantar flexion—could demonstrate/challenge asymmetry from the hip to the shoulder to better effect. In this example, Figure 10B clearly demonstrates the impact that poor function in the left shoulder can have on the trunk (side flexion) and the pelvis (left anterior/medial rotation). This in turn may lead to a series of antirotation trunk and shoulder mobility exercises with the aim of improving relative stiffness between the shoulder and the hip.

CONCLUSIONS

The role of arm drive remains a contentious topic among sprint coaches and in the published literature. Although the arms do seem to counterbalance the rotary momentum of the legs during sprint running, it would seem that the arms may additionally have an important role during the start and early acceleration phase of the sprint. Although the horizontal force capabilities of the arms are very limited, owing to the simultaneous forward-backward action of contralateral arms when an athlete is upright, due to the early forward lean position, the relative momentum of the horizontal component of both arms may not be canceled. Moreover, the arms may contribute up to 10% of the total vertical propulsive forces an athlete is capable of applying to the ground (14), highlighting the importance of an efficient arm action. Elite sprinters exhibit a greater arm-leg synchronization, increasing the efficiency of pushing on the blocks; therefore, optimizing arm mechanics in synergy with the legs should be a programming consideration.

The importance of this arm-leg synchronization is supported in neuroscience research, where Frigon et al. (9) demonstrated that rhythmic arm movement affected reflexes in leg muscles independent of arm position. Moreover, arm swing frequency also regulated not only hip-shoulder interaction at low frequencies but predominantly ankle-shoulder in-phase coordination at higher frequencies, suggesting a tight coupling between arm swing and postural coordination (1). Although not related directly to sprint running, the findings do suggest that more research is needed on arm-leg coordination and the effects of training the arms alone to quantify changes in sprint performance.

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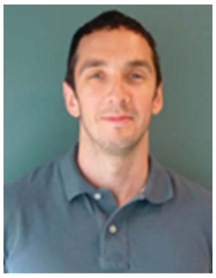

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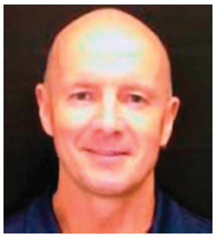

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