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Does restricting arm motion compromise short sprint running performance?

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ABSTRACT

Background: Synchronized arm and leg motion are characteristic of human running. Leg motion is an obvious gait requirement, but arm motion is not, and its functional contribution to running performance is not known. Because arm-leg coupling serves to reduce rotation about the body's vertical axis, arm motion may be necessary to achieve the body positions that optimize ground force application and performance.

Research question: Does restricting arm motion compromise performance in short sprints?

Methods: Sprint performance was measured in 17 athletes during normal and restricted arm motion conditions. Restriction was self-imposed via arm folding across the chest with each hand on the opposite shoulder. Track and field (TF, n = 7) and team sport (TS, n = 10) athletes completed habituation and performance test sessions that included six counterbalanced 30 m sprints: three each in normal and restricted arm conditions. TS participants performed standing starts in both conditions. TF participants performed block starts with extended arms for the normal condition and elevated platform support of the elbows for the crossed-arm, restricted condition. Instantaneous velocity was measured throughout each trial using a radar device. Average sprint performance times were compared using a Repeated Measures ANOVA with Tukey post-hoc tests for the entire group and for the TF and TS subgroups.

Results: The 30 m times were faster for normal vs. restricted arm conditions, but the between-condition difference was only 1.6% overall and < 0.10 s for the entire group (4.82 ± 0.46 s vs. 4.90 ± 0.46 s, respectively; $p < 0.001$) and both TF (4.55 ± 0.34 vs. 4.63 ± 0.32 s; $p < 0.001$) and TS subgroups (5.01 ± 0.46 vs. 5.08 ± 0.47 s; $p < 0.001$).

Significance: Our findings suggest that when arm motion is restricted, compensatory upper body motions can provide the rotational forces needed to offset the lower body angular momentum generated by the swinging legs. We conclude that restricting arm motion compromised short sprint running performance, but only marginally.

1. Introduction

Human running occurs with synchronized arm and leg movements. Leg movements are necessary for both the contact and swing phases of the stride. However, the arm movements that are equally characteristic of running are clearly not required. Humans can run with essentially no arm motion at all, whether the arms are fixed across the chest, to the sides, or in some other manner [1,2].

Given these observations, what explains arm motion during running, and its tight synchronization with the motion of the legs [3–5]? The foundational work of Hinrichs [5] demonstrated that the synchronization of upper and lower body motion acts to minimize rotation about the body's vertical (head-to-toe) axis. Runners accomplish this by timing arm motion to generate angular momentum in a direction that opposes the angular momentum imposed by the swinging legs (Fig. 1) [6,7]. Presumably, minimizing vertical rotation enables the lower torso and pelvic positions required for ground force application.

Mechanically, any effect of arm motion on performance must be mediated via the foot-ground forces that determine a runner's velocity. The possibility that arm motion could influence ground force application was experimentally demonstrated by Miller et al. [2], who reported modest alterations in patterns of ground force application when participants jogged with restricted arm motion.

However, the fundamental insights on limb synchronization and limited gait kinetic data presently available do not answer the longstanding questions regarding the importance of arm motion for performance. As early as 4th century BC, Aristotle suggested that arm-leg coupling enables arm swing to contribute to forward speed [8]. Given this

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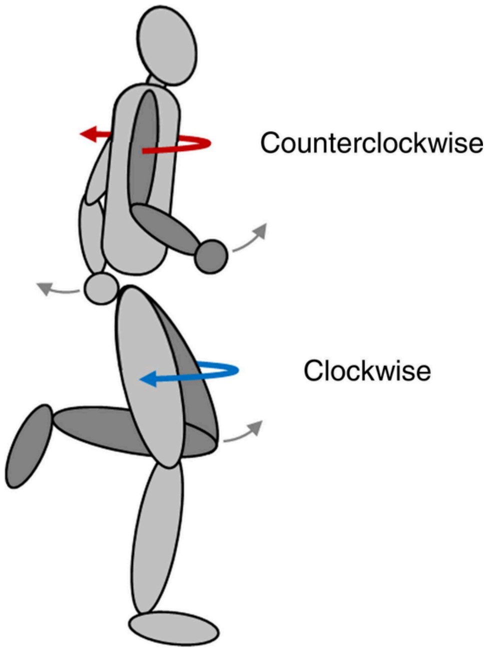

Fig. 1. The direction and timing of arm swing acts to offset the angular momentum about the body's vertical (or head-to-toe) axis introduced by leg swing in the opposite direction. Upper and lower body motion reverse direction with each step to remain out of phase throughout the stride cycle.

idea's intuitive appeal, the universal observation of the characteristic upper body movement pattern, and an absence of evidence to the contrary, belief in the performance benefits of arm motion is widespread today. This is perhaps most evident in the athletics community where arm drills designed to improve running performance are commonly prescribed [9–11].

Are conventional beliefs regarding the performance benefits of arm motion during human running valid? Here, we directly investigated the effect of arm motion on sprint running by measuring the performances of the same runners under both normal and restricted arm motion conditions. We chose to examine maximal-effort sprint running of short duration because: 1) this exercise provides a familiar, well-defined task that allows performance to be repeatedly measured in a well-controlled, indoor environment, and 2) short sprints generalize more broadly across team and individual sports than longer sprints do. Given that synchronized arm-leg coupling is universally observed and acts to constrain lower torso and pelvic rotation that could compromise ground force application, we expected participants' sprinting speeds would be reduced when their arm motion was restricted.

Accordingly, we tested the hypothesis that restricting arm motion would significantly impair short sprint running performance.

2. Methods

2.1. Participants

A total of 17 participants (ten males and seven females) volunteered and provided written informed consent in accordance with the local university Institutional Review Board, which had approved the study. This sample size was greater than prior research comparing running mechanics during normal and restricted conditions [1,2]. Five males and two females (age: 22.0 ± 1.0 years, mass: 72.2 ± 9.9 kg, height: 1.77 ± 0.07 m) were former collegiate track and field (TF) athletes with extensive experience performing track block starts. Additionally, five male and five female participants (age: 20.9 ± 2.2 years, mass: 74.3 ± 17.1 kg, height: 1.74 ± 0.11 m) were experienced team-sport (TS) athletes. All participants were less than two years removed from competitive status at the time of the study. Complete participant descriptive characteristics are listed in Table 1. Per inclusionary criteria, all participants were healthy and regularly active (exercise ≥ three times per week) at the time of testing.

2.2. Experimental design and procedures

Participants reported to the lab on three, non-consecutive days to complete the protocol: an initial habituation followed by two sprint performance testing sessions. During the first session, participants reviewed and signed consent forms, were measured for height using a standard measuring tape and weighed on a digital scale (Supac Model EB-8008, Shanghai, China). They were fitted with compression clothes and standardized footwear (Nike Waffle Racer v.9, Beaverton, Oregon) before completing a standardized full-body warm-up including dynamic drills, stretches, and submaximal sprints. They then completed six submaximal 30 m sprints of progressively increased effort, alternating between normal and restricted arm conditions, for gradual habituation to the restricted arm sprinting task.

Testing took place on a 50 m indoor runway to eliminate the potentially confounding wind and temperature variability present in an outdoor testing environment. Participants utilized the same clothing/footwear and warm-up protocol during the remaining sessions. Following the warm-up, participants completed six 30 m maximal-effort sprint trials, alternating between the two experimental conditions with full recovery between trials. Trial order during the second session was: normal arms on trials one, three, and five and restricted arms on trials two, four, and six. This order was reversed for session three.

The TF participants performed four-point sprint starts, while the TS participants performed two-point standing starts. The four-point starts were performed using track blocks, with hands supporting the body (Fig. 2A). In the restricted arms condition, participants supported their elbows on two custom, padded platforms to support their bodyweight in lieu of placing their hands on the ground (Fig. 2B), allowing them to assume the arms-crossed position throughout the entire sprint. The TS participants performed standing starts with their preferred foot forward in both the normal arms and restricted arms trials (Fig. 2C-D) and were instructed to perform the start from a completely stationary position, avoiding any form of 'drop-step'. Beyond this simple instruction, participants received no further technical cues (Fig. 2E-F).

2.3. Data collection and analysis

Instantaneous velocity was measured throughout each 30 m trial using a radar system (Stalker ATS, Plano, TX, USA). The radar was mounted to a tripod at 1 m in height and placed 10 m behind the partic-

Table 1
Physical and descriptive characteristics of participants.

Group	Mass (kg)	Height (m)	Age (y)	Sex	Event/Sport
Track & Field	72.9	1.86	21	M	Sprints
Track & Field	89.4	1.87	22	M	Multi
Track & Field	78.2	1.80	24	M	Sprints
Track & Field	71.3	1.77	22	M	Hurdles
Track & Field	58.3	1.69	22	F	Sprints
Track & Field	64.3	1.70	21	F	Hurdles
Track & Field	70.9	1.72	22	M	Sprints
Team Sports	63.4	1.67	23	F	Soccer
Team Sports	107.0	1.90	18	M	Lacrosse
Team Sports	71.2	1.79	23	M	Soccer
Team Sports	81.8	1.78	24	M	Football
Team Sports	88.2	1.82	21	M	Baseball
Team Sports	58.0	1.68	18	F	Field Hockey
Team Sports	91.2	1.88	23	M	Baseball
Team Sports	66.2	1.62	20	F	Soccer
Team Sports	62.8	1.67	20	F	Soccer
Team Sports	53.4	1.59	19	F	Rugby

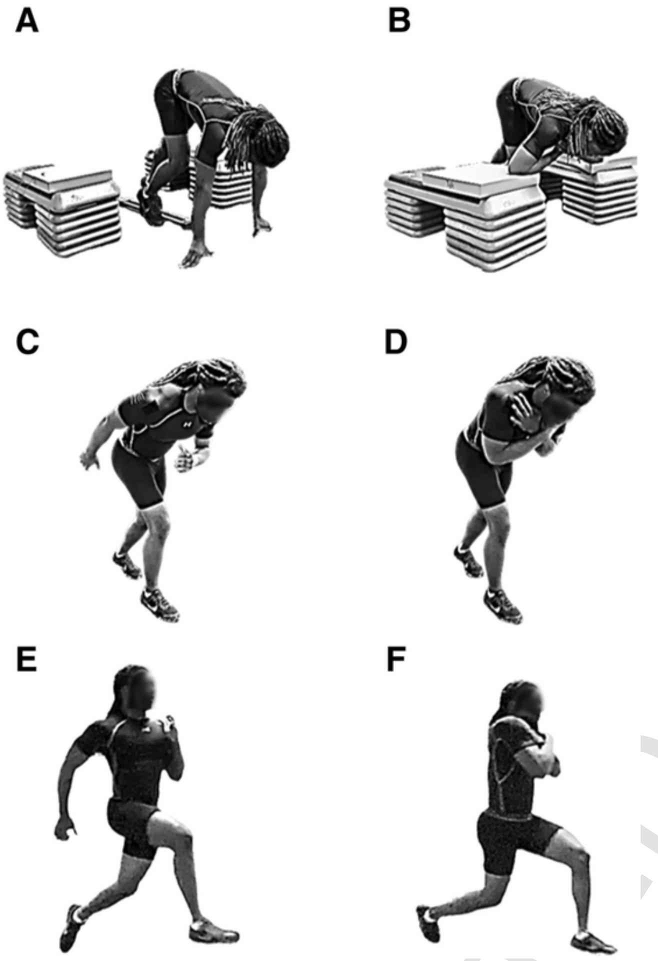

Fig. 2. A) The normal four-point block starting position of the Track and Field participants. B) Block starting position of the Track and Field participants using custom platforms to allow crossed arms starts during restricted trials. C) Normal standing start position used by Team Sport participants. D) Standing start position used by Team Sport participants with arms crossed over the chest. E) Typical arm positions used during normal arm trials. F) Restricted arm position during restricted arm trials.

ipant [12]. Data were collected at 46.9 Hz, and then exported to Microsoft Excel for analysis. Velocity vs. time data were fit with a mono-exponential equation using an iterative least-squares regression routine [13–15]:

$$v(t) = v_{\max} \times (1 - e^{-t/\tau}) \tag{1}$$

where v_{max} is the maximum running velocity limit during the trial and τ is the time constant. Distance at each time, t, was determined from the product of time and velocity. From the position-time data, split times were determined for 0–10 m, 10–20 m, 20–30 m, and 0–30 m. The accuracy and reliability of using radar data to determine split times in short sprints has been previously established [12,15]. For both the second and third testing sessions, sprint times for the three trials in each experimental condition were averaged for the full 30 m distance and each 10 m segment.

2.4. Statistical analysis

To evaluate the possibility that participants were not fully habituated to restricted arm sprinting during the second session (as this was their first exposure to maximal-effort restricted arm sprinting), a preliminary analysis was performed to compare 30 m sprint times from the second and third sessions in the restricted arms condition. Separate 2 × 2 (Session x Arm Condition) Repeated Measures ANOVAs with Tukey post-hoc tests were completed for the TF and TS subgroups. This revealed significant performance improvements from the second to third session for the TF athletes in the restricted arms condition (see Results). Therefore, the final between-condition analysis was performed using only the data from the third session.

For the data from the third session, average sprint performance times for the full 30 m and each of the three 10 m segments (0–10 m, 10–20 m, and 20–30 m, and 0–30 m) were compared using a 4 × 2 (Segment x Arm Condition) Repeated Measures ANOVA with Tukey post-hoc tests for the entire group and for the TF and TS subgroups. The a priori threshold for all significance tests was set at $\alpha = 0.05$.

In addition to statistical hypothesis testing, we determined the relative performance difference across arm conditions as:

$$\%\ diff. = \frac{(Restricted_{mean} - Normal_{mean})}{Normal_{mean}} \bullet 100 \tag{2}$$

To assess the within-participant consistency across trials during both normal and restricted arm conditions, coefficient of variation (CV) statistics were calculated for the full 30 m time and each 10 m segment, as well as mean between-trial differences in 30 m time for each participant in both arm conditions.

All statistics were completed using Microsoft Excel and GraphPad Prism software (version 9.1, San Diego, California, USA).

3. Results

3.1. Results from second vs. third session

The between-session analysis revealed that 12 out of 17 athletes (six of seven TF and six of 10 TS) demonstrated faster 30 m times in the restricted arms condition during session three compared to session two. Although there were no significant differences in 30 m times in the restricted arm condition for TS athletes between sessions two and three (5.08 ± 0.46 vs. 5.08 ± 0.47 s, respectively; $F_{1,9} = 1.08$; $p = 0.998$), 30 m times in the restricted arm condition for TF athletes did differ significantly between sessions two and three (4.67 ± 0.30 vs. 4.63 ± 0.32 s, respectively; $F_{1,6} = 14.70$; $p = 0.026$).

3.2. Individual data and measures of between-trial variability

The mono-exponential equation provided a good fit to the radar data ($R^2 = 0.98 \pm 0.01$ [mean ± SD] across all trials). Velocity vs. time data appear in Fig. 3 for two individual participants, one male TF athlete and one male TS athlete. For each athlete, velocity vs. time data for six sprint trials (three from each experimental condition) are included. The minimal variability within and between conditions for these participants resulted in trial curves that are largely superimposed upon one another.

For all participants across the three trials in the normal arms condition, CVs were less than 2% (0–10 m: 1.9%, 10–20 m: 1.1%, 20–30 m: 1.2%, 0–30 m: 0.9%), with CVs similar or slightly greater in the restricted arms condition (0–10 m: 2.2%, 10–20 m: 1.2%, 20–30 m: 1.1%, 0–30 m: 1.2%). Mean individual between-trial differences in 30 m time were 0.05 ± 0.03 s in the normal arm condition and 0.08 ± 0.06 s in the restricted arm condition, indicating greater between-trial variation for the restricted arm condition.

3.3. Group means

The 4 × 2 Repeated Measures ANOVA revealed a significant main effect for arm condition for the entire group ($F_{1,16} = 38.3$; $p < 0.001$), and for the TF ($F_{1,6} = 11.9$; $p = 0.014$) and TS subgroups ($F_{1,9} = 27.6$;

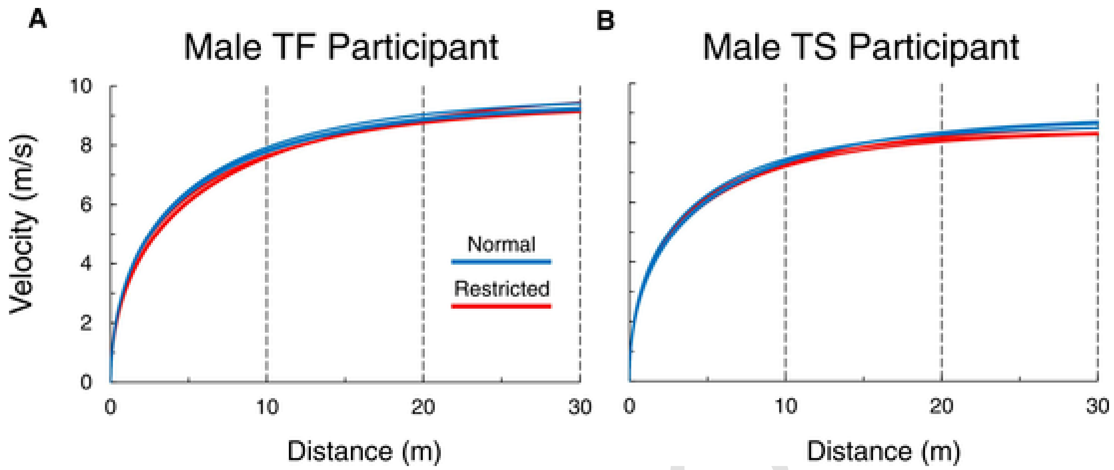

Fig. 3. Velocity vs. distance data for two participants, including all six total trials (three normal arm and three restricted arm) for each participant. A) Male Track and Field (TF) participant. B) Male Team Sport (TS) participant.

$p < 0.001$). For the entire group of participants, mean 30 m performance times were 4.82 ± 0.46 and 4.90 ± 0.46 s for normal and restricted conditions, respectively ($p < 0.001$, $\Delta = 1.6\%$). The mean respective split times for the normal and restricted conditions and % differences at each of the 10 m intervals were as follows - 0–10 m: 2.19 ± 0.19 vs. 2.22 ± 0.19 s, ($p = 0.023$, $\Delta = 1.1\%$), 10–20 m: 1.35 ± 0.14 s vs. 1.38 ± 0.14 s ($p = 0.005$, $\Delta = 1.9\%$), 20–30 m: 1.27 ± 0.14 s vs. 1.30 ± 0.14 s ($p = 0.003$, $\Delta = 2.2\%$).

The between-condition differences in mean 30 m performance for both TF and TS were 0.08 s or less, and the three 10 m segment means for both subgroups differed by 0.03 s or less (Fig. 4). For the TF subgroup, 30 m times were significantly different between the two conditions ($p < 0.001$, $\Delta = 1.9\%$), but there were no significant differences for any of the three 10 m segments times (all $p > 0.34$, $\Delta \leq 2.5\%$). For the TS subgroup, significant between-condition differences were observed for 30 m time ($p < 0.001$, $\Delta = 1.5\%$), 10–20 m ($p = 0.043$, $\Delta = 1.8\%$), and 20–30 m time ($p = 0.028$, $\Delta = 2.0\%$), but not 0–10 m time ($p = 0.146$, $\Delta = 0.9\%$).

4. Discussion

4.1. Main findings

The answer to our question of whether arm motion restriction would impair short sprint running performance was predominantly positive as hypothesized, but extremely small in margin. Between-condition differences for the total 30 m time were less than 0.10 s and ≤ 1.9%, regardless of whether evaluating the entire group mean, or the TF and TS subgroups. Similarly, each of the ten-meter race segments differed significantly when the entire group was considered, but did so by only three-hundredths of a second and 1.7% on average. Within the TS and TF subgroups, the majority of the segment comparisons were not statistically different.

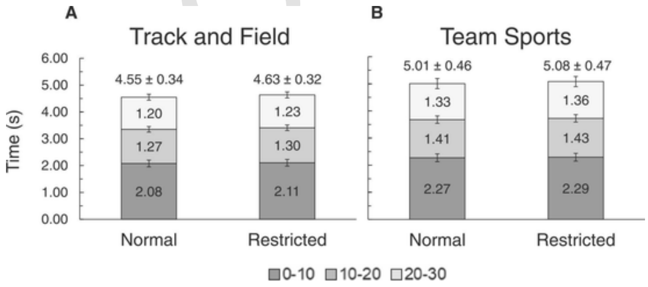

Fig. 4. Group mean split times for Track and Field and Team Sport subgroups in both normal and restricted arm conditions). Error bars indicate standard deviations. [Note: for Track and Field subgroup in the restricted condition, the mean 30 m time differs slightly from the sum of the mean split times when the third decimal place is not included].

One immediate conclusion that can be drawn from the marginal differences observed is that the popular postulate from Aristotle that "runners run faster if they swing their arms" [8] is not well supported. Clearly, if normal arm swing somehow translated into forward speed as widely conceived, our participants would not have been able to sprint nearly as fast in the restricted arm condition.

4.2. The functional importance of arm motion

Just as clearly as our results answer the experimental question posed, they prompt a puzzling new one. Why would virtually all human runners select essentially the same arm motion pattern when trying to maximize their speed if there is only a marginal performance benefit to doing so?

The foundational work establishing the mechanical basis for arm swing during human locomotion provides an important part of the answer. Originally for walking, and later for running, Elftman [16] and Hinrichs [5], respectively, demonstrated that the timing and direction of arm swing serves to offset the lower body rotational or angular momentum generated in the opposite direction by the swinging legs (Fig. 1). Subsequent research demonstrated that the magnitude of the angular momentum generated by the arms increases in parallel with that of the legs from slow to moderate speeds [7]. These and additional observations from upper-body interventions during jogging [17] suggest that runners adjust arm swing as needed to offset the angular momentum generated in the opposite direction by the swinging legs. Thus, the partial answer regarding natural running arm swing is that this motion minimizes rotation of the runner's body about its vertical axis when running in a straight line.

Given this basic understanding, our present results demonstrating that arm motion restriction reduces sprinting speed only marginally might therefore have two possible explanations. First, restricting arm motion may have resulted in greater vertical rotation of the body during sprint trials with only marginal effects on ground force application and performance. Second, compensatory upper body motion may have effectively replaced arm swing, thereby constraining the body's vertical rotations to levels approximating the normal arm condition. Qualitative observations and the existing literature indicate the latter conclusion is likely correct. We consistently witnessed exaggerated upper torso rotation when our participants ran in the restricted arm condition (see supplementary movie). The same response to arm restriction has been quantified and reported insightfully by Pontzer and colleagues [17]. The increases and decreases in shoulder rotation observed by these authors under respective arm weighting and arm restriction conditions, suggest that the body has a broad range of upper body motion patterns capable of providing the rotational forces needed to offset the lower body angular momentum generated by the swinging legs.

Supplementary material related to this article can be found online at 10.1016/j.gaitpost.2022.03.001.

Our habituation data appears to offer the final piece of the puzzle posed by essentially all runners adopting a similar motion pattern when attempting to maximize performance. In the restricted arm condition, our qualitative observations indicated participants had substantially greater torso rotations. However, this alternative upper body motion pattern took at least one (TS athletes) or two (TF athletes) habituation sessions to acquire before sprint performance approached that measured under the normal arm condition. The larger trial-to-trial variability demonstrated in the restricted arm condition compared to the normal arm condition suggests that further habituation sessions may decrease the between-condition differences even further, especially for the TF group. Therefore, we conclude that under normal circumstances, runners use arm swing as the most immediate and natural upper-body motion solution to constrain the vertical rotations of the body during straight-line running.

4.3. Practical implications

The mean difference observed at 30 m of 0.08 s is arguably remarkably small considering the overt, whole-body motion differences introduced by the intervention. Indeed, this difference was small enough to equal, or only slightly exceed the average trial-to-trial difference observed for individuals within the restricted (0.08 s) and normal arm (0.05 s) conditions, respectively. Of course, from the standpoint of timed sprint events or competitions, 0.08 s or 1.6% is obviously highly important. For example, in the 2020 Olympics Men's 100 m Final, the difference between Gold and Bronze Medal was 0.09 s, and the difference between Gold Medal and sixth place was approximately 1.8% (9.80 s vs. 9.98 s; [18]). Therefore, the differences observed in our results could be critical to finishing place in competitive sprints.

However, considerations of effect magnitude should also recognize that additional habituation could potentially reduce the between-condition performance effects to less than the 1.6% difference quantified here. This possibility seems particularly plausible for the TF athletes who had a more difficult motor task to acquire when starting from a modified 4-point starting position.

5. Conclusions

Do our findings have practical implications for training the sprint speeds of human athletes? Conservatively, our results bring into question whether drills and strength training targeting the arms have direct performance benefits for sprint running. However, we cannot preclude the possibility that cueing or targeting specific motion patterns involving the arms may provide indirect benefits, particularly in younger and developing athletes.

Finally, our results also prompt a basic curiosity question regarding the mechanics of speed in swift avian bipeds that lack the arms to offset the rotational momentum of their legs. Perhaps the relatively long, light distal leg segments of ostriches and emus do not introduce the vertical angular momentum challenges imposed by the relatively more massive human leg segments. Alternatively, vertical angular momentum fluctuations may be generally present among two-legged runners, but largely without functional effects on the straight-line speeds they can attain.

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Conflict of Interest

The authors have no financial or other conflicts of interest and received no external funding for this project.

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