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Research article

Internal and External Oblique Muscle Asymmetry in Sprint Hurdlers and Sprinters: A Cross-Sectional Study

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Abstract

The abdominal muscles are vital in providing core stability for functional movements during most activities. There is a correlation between side asymmetry of these muscles and dysfunction. Thus, the purpose of this study was to evaluate and compare trunk muscle morphology and trunk rotational strength between sprint hurdlers, an asymmetrical sport, and sprinters, a symmetrical sport. Twenty-one trained collegiate sprint hurdlers and sprinters were recruited for the study (Hurdlers: 4M, 7F; Sprinters: 8M, 2F), average age (years) hurdlers: 20 ± 1.2; sprinters: 20.4 ± 1.9, height (cm) hurdlers: 172.6 ± 10.2; sprinters: 181.7 ± 4.5, and weight (kg) hurdlers: 67.6 ± 12.0; sprinters: 73.9 ± 5.6. Using real-time ultrasound, panoramic images of the internal oblique (IO) and external oblique (EO) were obtained at rest and contracted (flexion and rotation) in a seated position for both right and left sides of the trunk. While wearing a specially crafted shoulder harness, participants performed three maximal voluntary trunk rotational contractions (MVC). The three attempts were then averaged to obtain an overall MVC score for trunk rotation strength. Average MVC trunk rotational strength to the right was greater among all participants, $p < 0.001$. The IO showed greater and significant thickness changes from resting to contracted state than the EO, this was observed in all participants. The IO side asymmetry was significantly different between groups $p < 0.01$. Hurdlers, involved in a unilaterally demanding sport, exhibited the expected asymmetry in muscle morphology and in trunk rotational strength. Interestingly, sprinters, although involved in a seemingly symmetrical sport, also exhibited asymmetrical trunk morphology and trunk rotational strength.

Key words: Asymmetry, internal oblique, external oblique, trunk muscle thickness, panoramic ultrasound

Introduction

Efficiency in athletic function is dependent upon core stability which provides strength as a base for movements in the extremities and for balance (Kibler et al., 2006). Core musculature comprises muscles of the trunk and pelvis. The external oblique (EO), rectus abdominis, latissimus dorsi and superficial erector spinae fibers make up the superficial core muscles and work to generate torque and general core stability (Bergmark, 1989). The internal oblique (IO), transversus abdominis, quadratus lumborum, psoas major, multifidus and deep erector spinae fibers make up the deep core muscles and contribute to segmental stabilization (Bergmark, 1989; Kibler et al., 2006).

The IO aids in increasing intra-abdominal pressure (Grevious et al., 2006). When contracted, it helps pull on the thoracolumbar fascia creating a rigid compartment, decreasing the cross-sectional area of the trunk, and increasing the intra-abdominal pressure, thus stiffening the spine (Akuthota et al., 2008; Grevious et al., 2006; Mitchell et al., 2019). Recruitment patterns show that stabilizing core musculature are recruited prior to any movement in the extremities (Hodges and Richardson, 1996; Hodges and Richardson, 1998). The engagement of core muscles prior to distal segmental movement suggests that the core muscles provide key proximal stability necessary for functional mobility in the extremities (Hodges and Richardson, 1996; Hodges and Richardson, 1998).

The level of muscle activation of the different abdominal muscles varies according to the activity performed and the intensity of that activity (Saunders et al., 2005). At walking speeds the EO and IO are minimally activated (Saunders et al., 2005). However, as speed increases to a fast running pace (i.e. in our sprinters), there is distinct activation of these muscles in coordination with an increase in lumbo-pelvic motion (Saunders et al., 2005; Schuermans et al., 2017). EO also aids in the control of anterior pelvic tilting that occurs with acceleration of the back swing phase in running (Akuthota et al., 2008). Research has shown a significant correlation between an increase in this anterior pelvic tilt and injury, particularly in the hamstrings (Schuermans et al., 2017). Thus, if the EO is not sufficiently activated there may be a lack of controlling ability with the increase in anterior pelvic tilt that occurs during this running phase, which may increase the risk of additional injury.

Sprint hurdling, by nature, is an asymmetric sport. In order to clear the hurdles, a forceful unilateral rotation of the trunk must occur which adds additional torque forces (Payne and Payne, 1981). The IO and EO both play a role in forward flexion and counter rotation of the trunk that occurs during take-off (Payne and Payne, 1981). Additionally, studies have shown that the abdominal muscles are bilaterally activated during trunk rotation (Carman et al., 1972; Juker et al., 1998) in order to help stabilize the lumbar spine (Gardner-Morse and Stokes, 1998). This stabilization is especially vital upon the athlete's landing after clearing the hurdle because it facilitates their balance as they quickly have to return to sprinting formation (Payne and Payne, 1981). Sprint hurdling inherently favors rotation to one side as the athlete uses the same leading leg for each hurdle. A functional between-side muscle asymmetry would therefore be expected among hurdlers.

Computerized tomography (CT) and magnetic resonance imaging (MRI) have been considered reference standards for assessing in vivo muscle thickness (Bemben, 2002; Lang et al., 2010; Reeves et al., 2004). However, there are some limitations and contraindications to using

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these modalities including x-ray exposure with CT scans and the costly nature of MRI scans. Alternatively, ultrasonography (US) has been proven valid and reliable in the assessment of muscle size during rest and contraction (Ahtiainen et al., 2010; Koppenhaver et al., 2009; Schneebeli et al., 2014; Tanaka et al., 2021; Teyhen et al., 2011). Due to its portability, low costs, and low risk factors, US has become a popular method for muscle imaging. Abdominal muscles have been studied via ultrasound to visualize their thickness and changes in thickness during contraction. However, one drawback is it has been rather difficult to image them in a complete anterior to posterior view.

Panoramic ultrasound imaging is a method where the ultrasound probe is moved along an anatomical structure in order to capture it in its entirety. Panoramic ultrasound imaging has been used in previous studies to analyze various skeletal muscles, such as the medial gastrocnemius (Rosenberg et al., 2014), quadriceps (Scott et al., 2017), and anterolateral abdominal muscles (Tanaka et al., 2017). This technique has been reported to be valid for monitoring atrophy and hypertrophy of the quadriceps (Scott et al., 2017), reliable for simultaneous assessment of both muscle size and quality (Rosenberg et al., 2014) and to have high repeatability for measuring cross-sectional area, length and thickness of the anterolateral abdominal muscles (Johnson et al., 2021; Tanaka et al., 2017).

The purpose of this study is to measure, via panoramic ultrasound imaging, and compare muscle thickness asymmetry in the IO and EO among hurdlers and sprinters. Our hypotheses are as follows: 1) Muscle morphology asymmetry between hurdlers and sprinters will be significantly different. 2) There will be greater trunk rotational strength on the ipsilateral side to the hurdler's leading leg.

Methods

Research Design

This is a cross-sectional study.

Participants

Twenty-one collegiate hurdlers and sprinters (11 hurdlers,10 sprinters) volunteered for the study. An estimated mean difference of 1.4 and a standard deviation of 1.2 was used in a power analysis based on a similar study that helped establish test-retest reliability of muscle measurements using LogicView US imaging (Johnson et al., 2021). Thus, based on an alpha of 0.05, a sample of 20 participants per group for a total of 40 participants is needed to have 80% power. However, due to limited access to athletes as a result of COVID-19 and the closure of the university, we performed a statistical analysis before the required sample size was reached. The results showed statistical significance which we are reporting here. Total sample means (standard deviations) are age (years) 20.2 ± 1.5, height (cm) 176.9 ± 9.1, and weight (kg) 70.6 ± 9.8; with 12 males and 9 females (hurdlers: 4M, 7F; sprinters: 8M, 2F). Training between hurdlers and sprinters were the same; five days a week for two hours each day in addition to weight training four days a week for one hour. At the collegiate level it is generally accepted that athletes have at minimum of 2 years experience in their respective sport. Inclusion criteria consisted of (1) being 18 years of age or older, (2) currently being a practicing member on a collegiate track and field team and (3) not having an injury within the last six weeks which prevented them from normal participation. Approval from Brigham Young University's Institutional Review Board was obtained prior to testing, IRB ID#2020-350.

Procedure

Two researchers, one with one year and the second with two years of musculoskeletal ultrasound training, collected the data images. A set of ultrasound images was taken with the participant sitting at the edge of a treatment table. Each individual image scan lasted approximately 5 seconds. Additionally, the participants performed a trunk rotational maximal voluntary contraction in the sitting position.

Ultrasound Imaging at Rest: With the participant sitting at the edge of a treatment table, their knees and hips were positioned at a 90-degree angle and fixed to the table using soft fabric straps. Foam padding was placed between the participant's knees so that the legs remained parallel. The arms were crossed against the chest (Figure 1A). Panoramic images of the IO and EO were taken at the level of the umbilicus. To assure that the probe remained parallel to the level of the umbilicus during imaging, a soft Velcro strap was placed horizontally around the participant's waist as a guide for the probe.

Figure 1. Subject positioning during ultrasound imaging. Figure 1A shows how each participant was positioned for ultrasound imaging at rest. Figure 1B shows the action the participants performed to image the EO and IO when contracted.

A 6 - 15 MHz probe and 12L probe (Logiq s8 and Logiq e, GE Healthcare, Chicago, IL, USA) were used for image collection. The following were settings used for the ultrasounds machines; frequency: 12MHz, frame rate 25, depth: 4cm and a gain of 48. With the probes placed in transverse orientation the posterior aspect of the muscles at their attachment site was visualized then were moved anteriorly with slow continuous movement until the anterior attachment site came into view. With the participant maintaining a calm, shallow, at-rest breathing pattern, two panoramic images were taken of both right and left sides for later analysis.

Maximal flexion-rotation strength measurement

The participants put on a specially constructed shoulder harness that was fixed to a dynamometer on a pole. The table was positioned the same for each participant, at a 20-degree angle to the dynamometer. The participant made three separate attempts for a maximal isometric strength flexion-rotation. For the strength assessment for rotation to the right the athlete tried to bring their left shoulder diagonally forward and down to their right hip, keeping the core tight (Figure 1B). The process was then repeated for the strength assessment for rotation to the left, where the right shoulder was pulled diagonally forward and down towards the left hip. Instruction and practice of this isometric contraction occurred prior to data collection. For the ultrasound imaging with contraction, 25% of the total average of the three maximal voluntary contractions (MVC) was calculated. Hodges et al. 2003 studied the sensitivity of ultrasound imaging in identifying thickness changes in muscles. They found that for the IO ultrasound was only sensitive up to about 20% MVC. Anything more than about 20% detected little change. Thus, we choose to use 25% MVC to ensure we acquired majority of the detectable muscle change while still obtaining quality images.

Ultrasound imaging with contraction

Contraction of the EO and IO in the sitting position. Since contralateral EO and IO muscles contract on any given rotation, two sonographers imaged the participant's trunk simultaneously, one on the left and one on the right side. While maintaining a calm, shallow, at-rest breathing pattern, the participant performed trunk rotation to the right, as previously described (Figure 1B), while performing at only 25% of their MVC. An additional investigator monitored the dynamometer and informed the participant when they needed to adjust their contraction in order to stay on their 25% contraction force mark. Two images were captured for both right and left trunk rotations for later analysis.

Measurement Analysis

Intratester and intertester reliability for measurement outcomes proved to be excellent. Intratester reliability had a correlation coefficient of 0.96 at rest and 0.99 during contraction with a 95% confidence interval of 0.90 - 0.98 and 0.98 - 0.99 respectively. Similarly, the intertester correlation coefficient was 0.96 at rest and 0.98 during contraction with a 95% confidence interval of 0.93-0.98 and 0.95 - 0.99 respectively. Measurement of the IO and EO muscles was completed using Horos medical imaging software (Pixmeo SARL, 266 Rue de Bernex, CH-1233 Bernex, Switzerland). The open polygon tool was used to measure the transverse length of each muscle individually. The line remained equidistant between the superior and inferior fascial borders extending from the most anterior point to the most posterior point of the muscle. Half of the muscle's length was then calculated based on the total length (Figure 2). Three thickness lines were then placed. The first line positioned at the halfway mark of the total muscle length. Two additional lines were positioned on either side of the midline measurement equidistant from midline to the end of the muscle (Figure 2). The three lines (at 25%, 50% and 75% of overall muscle length) were averaged together for an inclusive estimate of muscle thickness.

Statistical Analysis

Independent variables for this study were the athletic event in which the participants are involved, sprint hurdling or sprinting. Both have similar movements they perform during their respective events; however, hurdlers have additional trunk and hip rotational movements necessary for hurdle clearance. Therefore, sprinters were used as a comparison group in relation to hurdlers. The dependent variables were ratios between sides of resting and contracted muscle thickness and strength between left and right sides. For hurdlers, the ratios were calculated as the value of the side corresponding to their leading leg over the side corresponding to the trail leg. The ratios for sprinters were calculated as the value of the side corresponding to the front leg in the starting block over the side corresponding to the

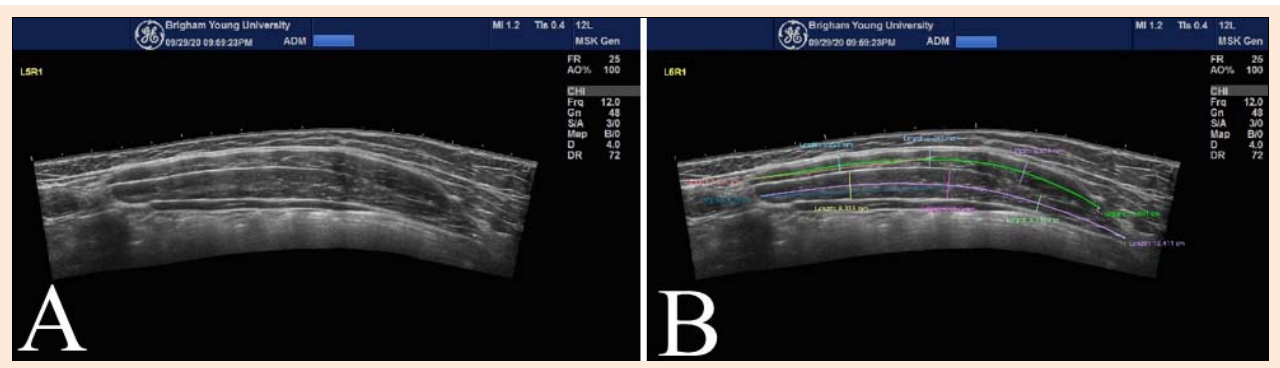

Figure 2. **Measurement of IO and EO muscles. Figure 2A shows the image prior to measurement. Figure 2B shows placement of lines used to measure the thickness of each muscle.**

back leg. Determining whether asymmetry exists for the dependent variables was completed using a mixed-model analysis with alpha set at 0.05. Additionally, a paired t-test between right side rotational strength and left side rotational strength was run to compare strength ratios amongst the hurdlers. One outlier that was greater than two standard deviations was excluded from the data set. Analysis was conducted in R (R Core Team, 2014, Vienna, Austria).

Results

Participant characteristics are shown in Table 1. Only height showed a statistically different value between the two groups ($p = 0.01$), all other variables had p-values > 0.05. Average trunk rotation to the right was greater among all participants, $p < 0.001$.

Muscle thickness for both groups in rest and contracted conditions for the IO and EO are shown in Table 2. Across all participants, the IO had greater changes in thickness from rest to contraction than the EO (Hurdlers: Left IO 41.6%, EO 11.15%; Right IO 18.2%, EO 5.0%; Sprinters: Left IO 28.5%, EO 22.2%; Right IO 54.5%, EO 12.5%). The left IO thickened the most among the hurdlers ($p = 0.002$), but the right IO thickened the most among the sprinters ($p < 0.001$). The asymmetry, between left and right sides, was significantly different between hurdlers and sprinters for the IO, $p = 0.001$. When in the contracted state, there was a 0.4 cm thickness difference between the hurdlers' left and right IO, $p = 0.01$, with the left IO being thicker. There was no difference in asymmetry between conditions. The sprinters and hurdlers' asymmetry did not change differently between conditions.

Table 1. **Participant characteristics including trunk rotational strength measures.**

Variables	Sprinters	Hurdlers
n	10 (2F)	11 (7F)
Age (years)	20.4 (± 1.9)	20 (± 1.2)
Height (m)	1.82 (± 0.05)	1.73 (± 0.10)
Weight (kg)	73.9 (± 5.6)	67.6 (± 12.0)
BMI	22.4	22.7
Average right trunk rotation strength (kg)	32.4 (± 6.1) * p < 0.001; d = 0.721	27.7 (± 9.4) * p < 0.001; d = 0.404
Average left trunk rotation strength (kg)	28.0 ± (8.0)	23.9 (± 7.2)
Front Foot in Starting Block	Right (n = 2) Left (n = 8)	Right (n = 5) Left (n = 6)
Leading Leg (Hurdlers Only)		Right (n = 8) Left (n = 3)

Data are mean (± standard deviation) within-group. Following mean (± standard deviation) are p-values and Cohen's d effect size for statistically significant values. *Right trunk rotation is significantly greater than left.

Table 2. **Average muscle thicknesses (cm).**

	Variable	Sprinters		Hurdlers	
		Rest	Contracted	Rest	Contracted
Left	IO Thickness	1.4 (± 0.2)	1.8 (± 0.6)	1.2 (± 0.3)	1.7 (± 0.5) * p = 0.002; d = 1
	EO Thickness	0.9 (± 0.2)	1.1 (± 0.2) * p = 0.003; d = 1	0.9 (± 0.1)	1.0 (± 0.2) * p = 0.017; d = 0.5
Right	IO Thickness	1.1 (± 0.2)	1.7 (± 0.3) * p < 0.001; d = 2	1.1 (± 0.3)	1.3 (± 0.4) * p = 0.018; d = 0.5
	EO Thickness	0.8 (± 0.1)	0.9 (± 0.1)	0.8 (± 0.1)	0.8 (± 0.1)

Data are mean (± standard deviation) within-group. p-values are compared to rest within group. Following mean (± standard deviation) are p-values and Cohen's d effect size for statistically significant values (*).

Discussion

This study assessed differences in thickness between sides of the IO and EO muscles between collegiate hurdlers and sprinters. Data showed that hurdlers exhibited a 40% side difference while sprinters exhibited a 67% side difference. Additionally, hurdlers presented with an 86.3% greater trunk rotation to the right, while sprinters had an 86.4% greater trunk rotation to the right compared to the left. We also observed that the EO had smaller changes in thickness between resting and contracting states when compared to the IO (Hurdlers: Left EO 0.1cm difference, Left IO 0.5cm difference, Right EO 0.0cm difference, Right IO 0.2cm difference; Sprinters: Left EO 0.2cm difference, Left IO 0.4cm difference, Right EO 0.1cm difference, Right IO 0.6cm difference).

When comparing side asymmetry between the groups, a significant difference was found in the IO. In hurdlers the left IO was larger when contracted. We would have expected the right IO to be larger since it contributes to right trunk rotation, which we found to be greater than left trunk rotation. To our knowledge, no other studies have looked at side asymmetry compared to trunk rotational strength in hurdlers and sprinters.

Because we assessed athletes from two different running sports, with differing rotational components, we need to discuss findings by individual sport. For sprint hurdlers, using the leading leg as the reference side to compare trunk rotational strength is ideal as they typically have the same leading leg as they clear each hurdle. During the take-off phase the athlete flexes their leading leg at the hip and knee approaching the hurdle, then extends it and passes over the hurdle. It is critical that during this phase there is a forward lean (trunk flexion) and counter rotation of the upper body towards the leading leg to offset the angular momentum the leading leg creates (Payne and Payne, 1981). As the majority of our hurdlers have a right leading leg (n = 8) and need to therefore perform a counter rotation of the trunk to the right, it could explain the stronger right side trunk rotational strength found. To our knowledge, the relationship of trunk rotational strength and leading leg has not been studied.

Sprinters, performing a seemingly symmetrical repetitive motion, need to exhibit a high block-exit velocity in order to be successful in their sport (Sandamas et al., 2018). This is obtained by executing explosive forces to propel the athlete forward. Contralateral rotation of the trunk is needed to counter these forces and keep body position square to the front. Most of our sprinters had a forward left leg in the start block (n = 8). This necessitates a strong trunk rotation to the right with the first step out of the block, possibly explaining the stronger right trunk rotational strength. The biomechanics of sprint starts have been studied (Bergamini et al., 2013; Bezodis et al., 2019; Harland and Steele, 1997), however to our knowledge, none discuss the rotation of the trunk.

We observed that the EO had smaller thickness changes in general when compared to the IO. The discrepancy in changes of EO and IO thickness between muscles could have various explanations. One, the fiber orientation pattern may not allow us to fully investigate the contraction capabilities of the EO. The most posterior fibers of the EO run in a nearly vertical orientation and the anterior fibers take an increasingly more medial direction with the most anterior fibers approaching horizontal (Moore et al., 2018). As we only imaged at one level in the transverse plane, a complete representation of the EO contraction may not have been represented. Two, the ultrasound method used only images in two dimensions while muscle contraction occurs in three dimensions (Hodges et al., 2003). The EO may have greater changes occurring in width rather than thickness, which we did not image via ultrasound.

Interestingly, within our hurdler sample, the left IO displayed greater thickness changes with contraction than the right IO (difference of 0.5 cm and 0.2 cm, respectively). We expected the right IO to show a greater change in thickness as the participants' trunk rotational strength was greatest to the right. Conversely, there was a significant thickness change in the left EO from rest to contraction which also produces right trunk rotation and therefore could be a factor in the greater right side rotational forces.

Furthermore, our sprinters showed a greater thickness change in their right IO, which could be related to their greater right side trunk rotational strength. Rankin et al. (2006) and Teyhen et al. (2012) both found no significant differences between sides with contraction in a normal population (Rankin et al., 2006; Teyhen et al., 2012). However, neither of them had subjects placed in the same position as the current study and only captured ultrasound images at one location. Capturing a panoramic image and placing the subjects in a more functional position may allow our findings to be more representative of the muscle as a whole.

Very few studies have used real-time ultrasound to study the EO. Hodges et al. (2003) stated that ultrasound cannot detect changes of the EO due to inconsistent contraction thicknesses of the muscle when compared to EMG readings (Hodges et al., 2003). However, Hodges et al. (2003) only had a sample size of three and did not have the subjects perform movements that elicit the primary function of the EO, which is flexion with contralateral rotation. Rather the action he used was abdominal hollowing, a movement usually used to isolate the transversus abdominis. Even with a larger sample size of 57 the EO still only showed minimal changes in thickness with this hollowing maneuver (Mannion et al., 2008). One study tested abdominal muscle activity during respiration and also showed no changes in EO thickness with maximal expiratory efforts (Misuri et al., 1997). However, when measuring thickness changes of the EO with isometric trunk rotation, significant changes were found using real-time ultrasound (John and Beith, 2007). This demonstrates that thickness changes can be visualized and measured when the subject performs the appropriate movement for muscle contraction.

Subject positioning needs to be taken into consideration when assessing thickness changes of the abdominal muscles, which varies across studies. One study showed a significant difference in thickness of the IO with the subject in a horizontal side-support position with a contracted-to-rest thickness ratio of 1.88 ± 0.52 (Teyhen et al., 2008). Another study tested in the supine position and with contraction via abdominal hollowing and observed a significant thickness increase in the IO (Hides et al., 2006). Our participants were in an upright seated position performing a flexion-rotation contraction which also provided significant results. We chose to put the participants in a seated position to facilitate proper contraction of the EO and IO (a flexion-rotation motion). This poses the question of which muscle contraction command used, and what position of the subject, is most representative for these muscles. A study comparing the various positions using ultrasound to EMG may be warranted.

Limitations: Data for the current study was collected during COVID-19. Due to closure of the university our sample size was smaller than the required size according to our power analysis. In future studies a larger sample size may strengthen the outcomes.

Conclusion

An asymmetrical sport, like hurdling, produces an asymmetry in trunk rotational strength in addition to a functional asymmetry in trunk muscle morphology. Sprinting, a seemingly symmetrical sport, would be expected to produce symmetric trunk muscles and trunk rotational strength. However, this is not the case in collegiate sprinters as they exhibit a significantly greater trunk rotational strength to the right.

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Key points

- The internal and external oblique muscles exhibit a morphological asymmetry in collegiate hurdlers and sprinters.
- A greater thickness change from rest to contraction was seen in the internal oblique compared to the external oblique among the hurdlers and sprinters.
- A statistically significant difference in asymmetry of the internal oblique between left and right sides was seen between the hurdlers and sprinters.

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