FATIGUE-INDUCED CHANGES IN SPRINTING TECHNIQUE

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By studying fatigue-induced running tech- ue, it is possible to reduce the sprinter's speed s at the end of the race. The technique changes it occur during the uncompensated fatigue ase, when speed slows, are of most interest. We ed to understand the nature of these changes: they distortions we should correct, or are they ective fatigue-induced compensations that sen its negative effect?

Data concerning fatigue-induced changes in nning technique are scarce. Research in the 400 has shown that fatigue causes these effects:

1. Reduces the amplitude and speed of the leg nt movements.
2. Reduces the push-off force.
3. Increases the lead-leg braking force.
4. Increases the hip joint's vertical splacement, which suggests an increase in the ternal mechanical work spent on vertically splacing the body's center of gravity (CG).

Later, these data were confirmed: research in 400 m showed that the push-off force creases during the fatigue phase and that the take-off angle increases. In the 200 m, fatigue uses a braking force during the foot plant; the knee-joint angle increases significantly, and the leg lands in a straighter position.

However, the prematureness of any definitive conclusions is clear if one considers the small number of studies on this topic and the scant statistical material they are based on. Our goal: to uncover the changes in sprinting technique and external mechanical work that occur during the fatigue phase.

Methods

We computed the external mechanical work from the support reactions. We used a tensodynamographic platform placed 5 meters before the finish line. Running speed was recorded using photodiode leads. Stride length was measured by tracings on the track; stride time was measured by using a seismic lead and a tensoplatform.

We studied twenty 100-meter sprinters, twenty 200-meter sprinters, and twenty-five 400-meter sprinters, 65 sprinters in all, ranging in skill from Class II to World-Class Master of Sport. We first recorded biomechanical indices for a 30-meter sprint, asking the runners to try for a personal best.

Table 1. Fatigue-induced changes in spatial-temporal characteristics.

Indices	Indices								
	Speed, m/sec			Stride length, m			Stride frequency/sec		
	I	II	III	I	II	III	I	II	III
Start" of running	8.93	8.80	7.42	2.16	2.14	2.05	4.18	4.10	3.55
	0.81	0.73	0.85	0.16	0.15	0.20	0.40	0.35	0.36
inish	8.42	7.42	5.87	2.18	2.11	1.88	3.87	3.51	3.05
	0.76	0.88	0.71	0.18	0.21	0.21	0.36	0.26	0.26
ifference, %	-5.7	-15.7	-20.9	0.8	-1.6	-8.4	-7.3	-14.2	-14.1
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ote: Here and afterward, underscored numbers are statistically significant at least at the 5% confidence level; –100 m, II–200 m, III–400 m.

Then we had them sprint their competition distance, again asking them to try for a personal best. We recorded biomechanical indices over the last 5 meters of the distance. We were thus able to develop a model of the finish, the uncompensated fatigue phase, and the "start" of the race, when runners reach top speed after the starting acceleration.

Also, to derive the angular indices of body movements, we filmed four World-Class Masters of Sport in a 30-meter sprint and during the last 5 meters of a 200-meter sprint, using a 200 frame/second camera and a 200-meter track. We compared the "starting" and "ending" biomechanical indices.

Results And Discussion

In the 100 and 200-meter distances, the slowing of speed toward the finish stemmed from a slower stride frequency. In the 400 meters, where fatigue is the most acute, the drop in speed stemmed from a drop in both components: stride frequency and stride length (Table 1).

Stride frequency slowed more than stride length shortened. The stride frequency slowed because of a longer support period, in which the braking phase grew more than the push-off phase. In the 200-meter run, support time increased from 114 ± 10 to 135 ± 18 ms; at the same time, braking time grew from 40 ± 8 to 56 ± 11 ms, or 40%, whereas push-off time grew only 5.4%.

Similar changes occur in the external work, with the negative increasing more than the positive decreased (Table 2). This is seen in the large losses that occur in the CG's longitudinal speed in the braking phase of all three distances. Also, in the change in the CG's longitudinal speed during the push-off phase of the 200 and 400 m (Table 3).

In other words, during the uncompensated fatigue phase, the sprinter brakes with more force and pushes off with less force, which fits with researchers' earlier conclusions. Also, there is more vertical displacement of the CG and more mechanical work expended on the displacement (see Tables 2 and 3).

A person would naturally expect that these breakdowns stem from changes in body-limb movements. Analysis of the cinematogram showed that the direct cause of the increased negative work is the more extended foot plant (see drawing).

For example, at the start of the 200 m, the longitudinal CG displacement in the support phase up to the vertical moment was 34.4 ± 6.2 cm; but at the finish it was 40.4 ± 5.9 cm. The cause of this excessively long foot plant? The sprinters did not pull their shin toward themselves (paw back).

At the start of the run, the horizontal rearward displacement of the swing-leg foot relative to the hip joint (from the extreme forward position of the shin to the point of planting) was 27.1 ± 1.6 cm; but at the finish it had shrunk to 17.5 ± 2.7 cm. Because of this, there is, as it was, a "collision" on the far forward extended shin, which causes unfavorable changes in all aspects of the braking phase.

Table 2. Fatigue-induced changes in external work.

Indices		Indices								
		$-W_{ext}$, J/Kg M			W_{ext}, J/Kg M			W_V, J/Kg M		
		I	II	III	I	II	III	I	II	III
"Start" of running	$\bar{X}$	0.813	0.755	1.089	1.903	1.889	1.647	0.285	0.300	0.402
	σ	0.149	0.142	0.210	0.229	0.233	0.249	0.054	0.048	0.109
Finish	$\bar{X}$	0.980	1.016	1.371	1.729	1.582	1.507	0.322	0.428	0.580
	σ	0.330	0.340	0.251	0.172	0.296	0.205	0.035	0.077	0.147
Difference, %		20.5	34.5	25.9	-9.1	-16.2	-8.5	13.0	42.7	44.3
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Note: $-W_{ext}$ and W_{ext} refer to negative and positive external work; W_V refers to the vertical function of positive external work.

Table 3. Fatigue-induced changes in kinematic characteristics of CG movement.

Indices		Indices								
		- *DV*, M/C			Δ*V*, M/C			S_V, CM		
		I	II	III	I	II	III	I	II	III
"Start" of running	$\bar{x}$	0.155	0.143	0.238	0.386	0.086	0.358	3.4	3.6	4.6
	σ	0.047	0.040	0.055	0.043	0.043	0.071	0.7	0.6	1.1
Finish	$\bar{x}$	0.211	0.245	0.369	0.367	0.332	0.304	4.0	5.1	6.3
	σ	0.075	0.093	0.093	0.052	0.076	0.080	0.4	0.9	1.6
Difference, %		36.1	71.8	55.0	-4.9	-14.0	-15.1	17.6	41.7	36.9
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Note: -Δ*V* and Δ*V* refer to the intracyclic losses and higher longitudinal CG speed. S_V refers to the CG's vertical displacement.

The cinematographic drawing of fatigued leg movement shows a smaller thigh-separation angle at the take-off point, and also a low lift of the swing-leg thigh, which retards the carrying forward of the shin. The angular displacement and the average speed of thigh convergence have shrunk greatly. The latter fell from 17.3 ± 2.2 to 6.9 ± 0.7 rad/sec, that is, it more than halved, which was a disproportionate decrease compared to the slowdown in running speed.

It almost seems that the conclusion suggests itself: these changes in leg-limb movement are fatigue-specific symptoms. Yet the link between leg-limb kinematics and running speed suggests the opposite: none of the changes in technique are specific to the fatigue phase.

Running speed near the end of the race does not decrease because the sprinter plants his leg farther and farther out. What happens is this: the slower the running speed (in an unfatigued state, speeds ranging from 5 to 11 meters/sec), the less the swing and the speed of limb movement and the farther out the leg plant, that is, the "collision" on the leg becomes ever greater.

Running at slower speeds would seem unnatural. Hence, kinematic drawings of both fatigued and unfatigued running at the same speeds are the same. If running speed slows for whatever reason, whether voluntary or from fatigue, the swing of the leg movements decreases, while the braking effect of the foot plant increases.

However, one fatigue-induced change in the leg-movement structure still appeared: the more extended leg plant. At the start of the 200-meter run, the knee-joint angle was 142.7 ± 2.6°; but near the finish it had grown to 155 ± 3.6°.

Other researchers have observed similar changes in middle-distance running. In unfatigued running, the pattern was different: the slower the running speed, the smaller the angle in the support-leg knee and ankle joints and the lower the runner's posture.

Thus, a fatigued sprinter plants his leg more extended. It is unclear whether the more extended leg plant is an unavoidable, fatigue-induced violation of running technique or whether it is a compensatory reaction designed to avoid further speed loss. For now, we must note the hypotheses that favor both possibilities.

The First Hypothesis. A sprinter cannot lift his swing-leg thigh high and carry it forward fast. Yet the despite the shin's slower speed, it can still "whip" forward as before, because stride time lengthens near the end of the race. The result is that the knee-joint angle increases at the point of foot plant, a change you can see in Figure 1. Under this hypothesis, the more extended knee-joint angle is a natural, fatigue-induced distortion in technique.

The Second Hypothesis. A more rigid foot plant does not have to accent pulling the foot in close (paw back) (more accurately, toward the vertical projection of the CG on the support). This apparently occurs subconsciously in order to optimize the push-off under adverse conditions; for example, to better exploit the effect of preliminary stretching of the support-leg muscles, particularly the foot's plantar flexors.

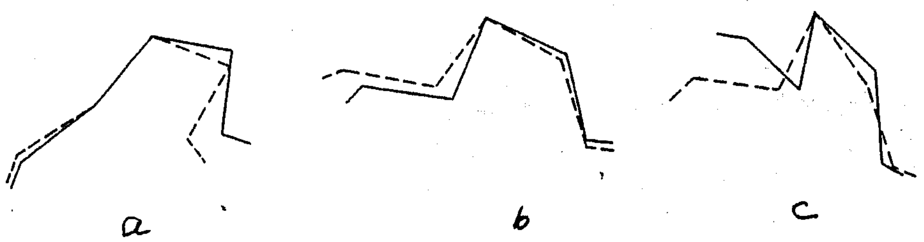

Figure 1: The points of take-off (a), shin carry-forward (b), and foot- plant (c) during a 200-meter run. The unfatigued running speed is 9.4 m/sec.; but at the finish it is 8.6 m/sec. The solid line shows the "start" of running; the broken line shows the finish.

Also, a survey of the runners showed that they could not explain the changes in their leg movement, specifically, at the point of foot-plant. Their answers centered on feelings of general fatigue and local leg-muscle fatigue (especially the thigh flexors. This is essentially because the support-leg ankle joint is the prime mover during the push-off phase.

Hence, a more rigid foot-plant can help a fatigued sprinter reduce the loss of mechanical energy and better exploit his muscle stretching. Such foot-plant helps make up for the disadvantageous interaction with the track — the longer shock-absorption time, the muscle-stretching time, and the lower muscle elasticity, an unavoidable part of fatigue. Both of the above hypotheses need to be researched.

Conclusions

The following changes occur during the uncompensated fatigue phase of sprinting:

1. Positive external work decreases and negative work increases, while its vertical fraction increases.

2. The thigh's angular displacement and speed diminish. Also, the foot-plant's braking effect increases, which stem from the longer braking time and the loss of CG longitudinal speed.

3. The knee-joint angle at the time of foot-plant is greater. This change cannot be explained by the slower running speed; instead, it is specific to the uncompensated fatigue phase. ❖