ALTERATION OF FOOT STRIKE PATTERN IN DISTANCE RUNNING

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Despite subjective differences in running technique, sagittal plane lower extremity angle kinematics at a given speed are relatively invariant (Martin, 1985). Preferred foot strike pattern (FSP) during distance running is one of the few parameters where individual differences are discernible to the naked eye. The initial point of sole contact may range from the heel (*hs*) to the forefoot (*ffs*). FSP may be manipulated by the individual; in fact, some coaches direct their runners to alter FSP. A more forward foot strike has been associated with increased running speed (Nigg, Denoth, Kerr, Luethi, Smith & Stacoff. 1984). The purpose of this study was to test the assumption that no differences exist in lower extremity kinematic measures between *hs* and ffs. This hypothesis has two windows: 1) *hs* vs. ffs regardless of preferred FSP, and 2) preferred FSP (*pf*) vs. non-preferred FSP (*npf*). The combined comparisons help answer the question of whether, for example, the kinematic differences in a change from *hs* to ffs are the same for a natural HS runner as for a natural FFS runner.

METHODOLOGY

The experimental design had a total of six conditions comprised of two FSP used at each of three different running speeds. Twelve highly skilled, male distance runners (10K/5-mile PR pace M = 5.07 min•mile^{-1}) were selected as either natural HS (n=6) or FFS (n=6). Before the initial session, each subject was classified as natural HS or natural FFS. Each subject performed all six conditions in a cross-over experimental design. Within each of the two groups, conditions were presented in a balanced order (Latin Square design) to minimize order effects.

The experimental setup included a 200 Hz high speed video camera with a lens-object distance of 5.5m and line of sight level with the subject's trochanter, to collect a left sagittal view. A high-mass treadmill was used for all testing. A thin, contact plate foot-switch, mounted to the rear of the sole and wired to an LED visible to the subject, was used as feedback. Heel compression resulted in illumination, required during *hs* conditions and not permitted during ffs conditions. Physiological energy expenditure data were collected concurrently using open-circuit spirometry and heart rate telemetry. Fingertip lactate samples were also drawn after the two fast running conditions.

The standard protocol entailed two test sessions separated by at least four days or as much time as a subject needed to fully recover from any calf muscle soreness. Subjects were asked to arrive rested and in a fasting state. Each condition lasted seven minutes and was preceded with ample rest. The three speeds corresponded to a nɯ-ɯǝ pace (5.5 min•mile^{-1}), a medium training pace (6.5 min•mile^{-1}) and a slower training pace (7.5 min•mile^{-1}) for this population. Before each session, reflective markers were placed on the appropriate lower extremity landmarks to calculate lower extremity angles. The distance between markers was recorded and duplicated for the second session by the same investigator to minimize placement error.

Five complete left strides for each condition (FSP x Speed) were digitized using a Motion Analysis VP110 microprocessor interfaced to a SUN minicomputer. The data were filtered using a fourth-order, recursive, low-pass Butterworth filter with independent x and y optimal cutoffs. Lower extremity angles were then calculated. The five-trial mean for each parameter was then analyzed using ANOVA. The main effects were FSP group (HS or FFS), FSP used (*hs* or *ffs*) and running speed.

RESULTS

Since there were no significant interactions between speed and the other main effects, lower extremity parameters for the medium speed are summarized in Table 1. The FSP used were compared within each subject group. Three *pf* vs. *npf* comparisons in FFS and one in the HS group were significantly different ($\underline{p}<.05$). Knee TD angle for FFS was also different between FSP. The differences were primarily at the ankle and may be more prevalent in FFS.

Table 1: Lower Extremity, 6.5 min•mile^{-1}
($\underline{M}$ ± $\underline{SD}$, degrees; $\underline{n}$=12)

FSP Group →	HS		FFS	
FSP Used →	*pf*	*npf*	*pf*	*npf*
Ankle				
TD	1.2 ± 1.3*	-10.4 ± 4.8*	-11.1 ± 5.9†	4.9 ± 4.4†
Max. Dorsi	25.0 ± 3.4	23.1 ± 3.1	23.5 ± 4.8†	25.8 ± 2.9†
Max. Plantar.	-26.1 ± 6.2	-28.9 ± [illegible]	-22.5 ± 7.2	-21.5 ± 7.1
Knee				
TD	18.1 ± 4.6	20.1 ± 6.3	[illegible] ± 3.2†	20.3 ± 3.2†
Max. Flexion	117.6 ± 9.8	119.5 ± 10.5	115.9 ± 7.6	113.5 ± 5.7
Max. Extension	15.0 ± 4.9	16.0 ± 5.9	15.5 ± [illegible]	15.1 ± 2.2
Hip				
TD	27.2 ± 5.5	27.8 ± 5.9	25.3 ± 4.3	26.6 ± 2.5
Max. Flexion	41.0 ± 4.1	41.6 ± 4.5	39.1 ± 2.7	40.4 ± 2.6
Max. Extension	-14.9 ± 4.2	-13.4 ± 4.6	-16.8 ± 5.3	-15.5 ± [illegible]

* $\underline{p}$ < .05 for HS; † $\underline{p}$ < .05 for FFS.

Comparisons between the two different subject groups within each FSP are presented in Table 2. This represents a comparison of pf in one group with the npf in the other subject group. Parameter values are a combined average for all three speeds. As with Table 1, significant differences. here between the two subject groups within FSP, are most prevalent in the ankle parameters. In fact, none appear at the knee or hip.

Table 2: Lower Extremity, all speeds
($\underline{M} \pm \underline{SD}$, degrees; n=12)

FSP Used →	*hs*		*ffs*	
	HS	FFS	HS	FFS
Ankle				
TD	-0.1 ± 2.7*	3.2 ± 4.1*	-10.5 ± 4.4†	-12.1 ± 4.6†
Max. Dorsi.	24.4 ± 3.1	25.1 ± 3.5	22.3 ± 3.4	22.7 ± 4.3
Max. Plantar.	-27.5 ± 6.4*	-22.0 ± 6.7*	-29.0 ± 6.6†	-23.2 ± 6.4†
Knee				
TD	17.9 ± 4.5	19.9 ± 3.0	20.1 ± 5.1	22.4 ± 4.6
Max. Flexion	117.1 ± 10.3	112.9 ± 7.3	119.7 ± 10.3	115.7 ± 8.6
Max. Extension	14.2 ± 4.9	14.2 ± 4.2	15.9 ± 4.9	14.8 ± 3.4
Hip				
TD	27.2 ± 5.4	27.2 ± 4.3	27.5 ± 5.7	25.5 ± 4.7
Max. Flexion	41.3 ± 4.6	40.5 ± 3.6	42.0 ± 3.1	39.8 ± 5.4
Max. Extension	-14.9 ± 4.6	-15.7 ± 4.7	-14.2 ± 4.6	-16.4 ± 5.4

* $\underline{p} < .05$ for *hs*; † $\underline{p} < .05$ for *ffs*.

ANOVA ($\underline{n}$=12) over all speeds showed significant effects ($\underline{p}$<.05) for FSP on all ankle and knee parameters and on hip TD angle. Running speed had a significant effect on all hip parameters and on maximum plantarflexion and maximum knee flexion. For all subjects and speeds. ankle TD angle $\underline{M}_{hs} \pm \underline{SD} = 1.3 \pm 3.9°$ and $\underline{M}_{ffs} \pm \underline{SD} = -11.3 \pm 4.5°$. Figure 1 illustrates the difference between FSP over speed; the *hs* conditions are clearly more positive for both groups and reflect the FSP chosen by subjects to comply with the protocol. Overall, there appears to be a slight inverse trend between FSP and speed; however, as stated previously, the interaction was not significant.

Separate ANOVA on the data partitioned into *hs* and *ffs* revealed similar sources of variation in both categories. Within FSP category, running speed was not a significant source of variation only for maximum dorsiflexion and maximum knee extension. Subject group (HS or FFS) had a significant effect only on ankle TD angle and only during *hs* conditions. This is consistent with the different values for the two groups on this parameter (see Table 2).

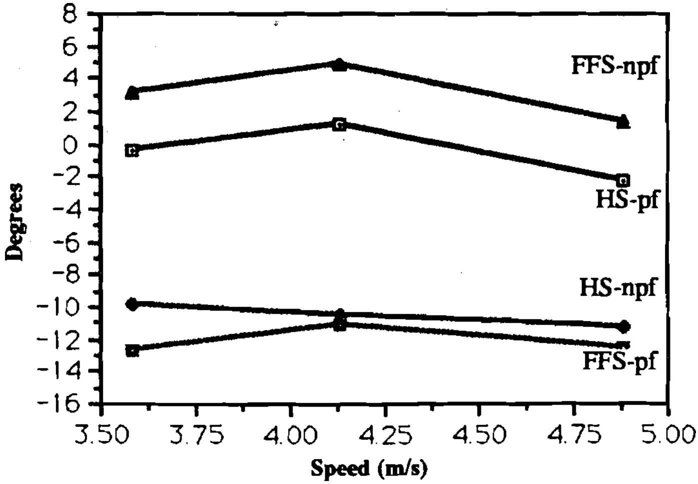

Figure 1 Ankle TD: **(FSP$_{group}$ x** FSP) over speed

DISCUSSION

This investigation confirmed that **running** speed is a major source of variation in lower extremity **kinematics,** as **shown previously** (Mason,1980). The significant **within-**group differences ($p<.05$) in ankle TD angle **confirm** subjects successfully altered **FSP** in accordance with experimental protocol. Likewise, the lack of significant interaction between **FSP** and speed also suggests that the protocol adequately **negated** an **otherwise** expected interaction between **FSP** and **speed.**

There was a trend to greater **maximum** knee flexion for **HS** runners for **both FSP** (see Tables **1,2**). There also appears to be greater variation in **knee** angle parameters for **HS** regardless of **FSP** used; all six standard deviations are greater than corresponding values for **FFS** (see Table **2**). The equivalent statement is that **HS** runners have greater variation in knee angle when using not just npf but also pf. If **FFS** exhibit less flexion and are more consistent, the mechanism may be increased stiffness at the **knee** (and hip) joints since **FFS customarily** train and race with the ankle **as** a third active joint for **attenuating** impact Hip and ankle parameters have similar variability in both subject groups, eliminating compensatory variability at another joint This suggests that variability is not associated with a novel task ***(npf)*** **as** much as it is with a strongly entrained motor pattern. It is possible, **too,** that the task here is relatively simple, with a rapid learning curve.

One limitation to the study is evident In the protocol, the boundary between HS and FFS runners was not discrete. Perhaps due to their level of training, most subjects could be categorized in a relatively narrow band around midfoot strike. This finding might suggest that skilled runners learn to converge on a common FSP, perhaps to minimize the forces or cumulative strain of intense training, maximize performance or a combination. This is consistent with data for elite female distance runners, who were categorized as midfoot strike using overground ground reaction force criteria, while an untrained control group were decidedly *hs* at the same speed (Williams, Cavanaugh, & Ziff, 1987).

There are some practical implications. Coaches who instruct athletes to alter their FSP will probably not see noticeable changes in angle kinematics above the ankle. If this subject pool is any indicator, it is possible an increase in training volume or intensity may bring about a more moderate FSP for athletes with excessive *hs* or *ffs* FSP. It has been shown that changes in FSP allowed to occur volitionally rarely go more than one stage on the heel-midfoot-forefoot spectrum; HS may become midfoot but not FFS and vice-versa (Mason. 1980).

Future investigations of FSP might include continuous overground evaluation in conjunction with ground reaction force data, the latter apparatus also useful for a more quantitative categorization (Cavanagh & LaFortune, 1980). Results might be different when subjects are monitored for use of *npf* over weeks or months to allow any long term muscular and motor unit recruitment pattern adaptations.

CONCLUSIONS

It appears that angle kinematics are strongly stereotyped in distance running. The imposition of *hs* and *ffs* over a range of speeds served as a new perturbation to gait. In a highly skilled runner population, only parameters associated with the ankle - the joint most directly involved in effecting the changes mandated by the protocol - displayed differences between the two FSP and between the two subject groups with any consistency.

REFERENCES

Cavanagh, P.R., and LaFortune, M.A. (1980). *Journal of Biomechanics*, 13; 397406.

Mason, B.R. (1980). Unpublished doctoral dissertation. University of Oregon.

Nigg, B.M., Denoth, J., Kerr, B., Luethis, S., Smith, D., & Stacoff, A. (1976). In: *Sport Shoes and Playing Surfaces*, E.C. Frederick *(Ed)*. Champaign, Il: Human Kinetics. pp. 21-22.

Williams, K.R., Cavanagh, P.R., and Ziff, J.L. (1987). *International Journal of Sports Medicine*. (Suppl.), *8;* 107-118.

Martin, P.E. (1985). *Medicine and Science in Sports and Exercise, 17*(4), 427433.