

Quantitative Motion Analysis of University of Tennessee Lady Volunteer Track Runners At Maximum Speed

by

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ABSTRACT: A quantitative study was performed to aid the University of Tennessee Lady Volunteer Track and Field Department on the evolution of the training and development of their athletes. The topic of maximizing the runners' sprinting performance is discussed. At Tom Black Track on the University of Tennessee campus, the runners were filmed at maximum speed using a 16-mm high-speed rotating prism camera system. The two-dimensional sagittal plane biomechanical data was input into the computer with a GP-8 sonic digitizer and then analyzed with a film analysis system. The resultant data is compared with "elite" female averages. In each athlete's case, performance indicators point to possibilities for mechanical improvement. The elite data seem to serve as a useful benchmark for performance variables. It is concluded that the comparison of sprinting parameters to elite averages gives useful, if indirect, insight into the strengths and weaknesses of the athlete. The need for a better model is discussed. Recommendations are made for further study.

Purpose

This study, in the general sense, was conducted to aid the Lady Volunteer Track and Field Department on the evolution of the training and development of their athletes. An underlying specific purpose is to set up a pathway that other researchers may use to continue pursuing that goal.

Theoretical Background

A Note on Potentials

In sprinting, as in any sport, success of performance relies on a runner's ability to balance a variety of limiting factors. Dr. Ralph Mann of CompuSport (1992) defined one of these factors as the development of an athlete's potentials. These potentials include the strength, endurance, conditioning tolerance, mechanics ability, and mental concentration capacities of the individual athlete. The training of an athlete, however, is not as simple as realizing all these potentials. Attempting to maximize one variable

"When there is much desire to learn there, of necessity, will be much arguing, much writing and many opinions; for opinion in good men is but knowledge in the making."

— John Milton, 1608-1674

will often prove detrimental to another. For instance, "the muscle bulk required to maximize the strength potential serves to decrease the overall endurance potential of an athlete" (Mann, 1992). This intercorrelation must be carefully monitored, or else an athlete may find an "improvement" in one area adversely affecting their overall performance. For each athlete, the most valuable potentials must be selected for development even at the expense of the others; the athlete needs to "specialize." A long-distance runner would choose endurance and conditioning over raw strength, whereas a sprinter might put explosive power above all.

Development of the Sprinter

The development of an elite sprinter requires much more than knowledge of technique. As any coach could explain, instructing an athlete on how to compete requires knowledge of psychology, biochemistry, nutrition, physiology, and many other fields, including biomechanics. A coach must use all the information available in trying to weave together a plan for development. In the collection of this information, coaches look for assorted indicators that tend to predict the level of an athlete's performance.

The ability of an athlete to accelerate is certainly an important factor in any race. As the acceleration phase ends, however, the athlete enters a stage of constant maximal speed. Performance in this period of maximum speed is seen as one of the major predictors for top performance in sprint events (Brüggemann, 1988). Therefore,

this study focuses on the development of ideal biomechanics in the lower extremities for the maximum speed section of the short sprint.

Researchers have realized that in formulating a development plan it is advantageous to have a model of an ideal technique with which to compare an individual's performance. Unfortunately, the criteria for good running technique are controversial. The most widespread view is that there is no one "ideal" technique. It has been suggested that the ideal is specific to body type (leg length, natural stride length, etc.). Mann (1992) has compiled averages of female "elite" running parameters. His data, although limited in value as an optimal model, should serve as a useful benchmark.

The Elite Sprinter

All the parameters mentioned in this section are the results of a compilation of female elite sprinter characteristics while running at maximum speed. Mann (1992) used the terms good, average, and poor to categorize levels of importance for each parameter. The ranking of each parameter is based on the results of all the elite sprinters he analyzed up to 1992. For perspective, however, Mann points out that the "poor" rating would be considered good in many cases, even for a collegiate sprinter.

The "bottom line" in sprinting is horizontal velocity (HV). This HV, referring to the motion of the center of gravity (CG) of the athlete, is the product of stride rate or frequency (SR) and stride length (SL): $HV = SR \times SL$. The latter two quantities are somewhat inversely proportional; increasing the stride rate tends to decrease the

stride length and vice versa. Many researchers believe that key to overall improvement of performance is improving one while maintaining the other.

Horizontal velocity:	good = 35.8 feet/second average = 32.4 feet/second poor = 29.0 feet/second	(from Mann, 1992)
Stride length:	good = 7.83 feet average = 7.35 feet poor = 6.87 feet	(from Mann, 1992)
Stride rate:	good = 4.91 steps/second average = 4.42 steps/second poor = 3.92 steps/second	(from Mann, 1992)

Dr. Mann considers ground time and air time to be very valuable providers of insight into the elite performance. Ground time (GT) is defined as the average time any given athlete's foot is in contact with the ground during a single stride. GT regulates the athlete's ability to affect HV; a corresponding force over different time intervals produces different results. Air time (AT) is the average time between the takeoff of one foot and the touchdown of the other. AT dictates SL, and the combination of the two times determines SR (Mann, 1992).

Ground time:	good = 0.083 seconds average = 0.10 seconds poor = 0.12 seconds	(from Mann, 1992)
Air time:	good = 0.123 seconds average = 0.123 seconds poor = 0.113 or 0.133 seconds	(from Mann, 1992)

Sprinting at maximum speed is simply a repetitive cycle for each leg. The cycle discussed herein includes three phases: the supporting phase, the driving phase, and the restoring phase (Hay, 1978).

Phase I -- supporting (or amortization) phase:

This phase begins at "touchdown (TD)" when the foot lands in front of the athlete's CG, and ends at the "transition point (TP)" when the CG passes forward of the landing foot (Figure 1).

Mero et al. (1992)

claim the actions at the beginning of supporting phase are important in increasing explosive power and efficiency of movement in later phases.

Mann and Sprague (1980)

stress that the ground contact



Figure 1. Typical body position at (left) touchdown and (right) the transition point (Yakimovich and Tarasov, 1990).

is the most crucial factor in sprints. It is on the ground that the athlete provides the forces necessary to propel forward. The natural pull of gravity and any slowing of the forward motion due to air resistance should be rectified in this phase.

The CG's loss of altitude begins to correct immediately at touchdown, but the loss of HV is not immediately reversed. The key to achieving an effective touchdown in sprinting lies in a rapid curb of the velocity of the landing foot just before the touchdown (Li and Huang, 1987). In fact, to avoid *additional* braking action at touchdown the foot must be moving backwards at a speed equal to the current HV. To immediately begin rectifying the loss in HV during the restoring phase, the foot would have to be moving backwards with a speed in excess of the current HV.

At a low HV, this complication is not much of a problem. During an athlete's first few steps of a race, it is possible for her to obtain a backward horizontal foot speed at touchdown sufficient to result in a small or zero braking force (Payne et al., 1968). In the maximal speed region of sprint, however, the best that can be done is to minimize it.

Horizontal Foot Speed at Touchdown: (from Mann, 1992)	good = 24.2 feet/second average = 21.2 feet/second poor = 18.2 feet/second
Upper Leg Rotational Speed at Touchdown: (Extension) (from Mann, 1992)	good = 375°/second average = 291°/second poor = 208°/second
Lower Leg Rotational Speed at Touchdown: (Flexion) (from Mann, 1992)	good = 238°/second average = 120°/second poor = 3°/second

The foot exerts a great force on the ground at touchdown to combat the results of the air travel. The planting of the foot has drawn a significant amount of research attention. The placement distance relative to the CG, the horizontal foot distance at touchdown (FD), is an important factor in minimizing the braking force. The swing leg should be as close as possible to the support leg to "move" the CG forward, and the touchdown foot should not be too far forward, thus reducing the FD (Kunz and Kaufmann, 1983). Ozolin (1986) states that the sprinter should place the landing leg close to the vertical projection of the center of gravity. He claims this action, along with a good foot speed, loads the elastic energy of the calf muscles very well. Hay (1978) adds the point that the kneecap should be further forward than the touchdown

point allowing the athlete to "roll over" the point easier and enter the supporting phase earlier.

Bennett and his colleagues (1988) expand on the point of elastic loading. They observe that the Achilles tendon is a major storehouse of elastic energy, but they also note the importance of arch of the foot. Bennett and his colleagues assert the arch is about 50% as important as the Achilles itself. They go on to criticize the use of arch supports suggesting they "may be detrimental if they restrict flattening of the arch and so reduce strain energy storage."

Horizontal Foot Distance at Touchdown:
(from Mann, 1992)

good = 0.64 feet
average = 0.78 feet
poor = 0.92 feet

Nett (1964) found that top German sprinters commonly used an "active foot plant," landing on the outside edge and near the ball of the foot at touchdown, and concluded that longer distance runners used a more "passive" technique, landing more towards the heel, because the active plant is so energy-consuming (Figure 2). Mach (1982) claims not only is the active foot plant common in sprinters, but also that all athletes running the short sprint should use the active technique. Mach states later (1985), however, that a model technique includes the heel touching the ground during

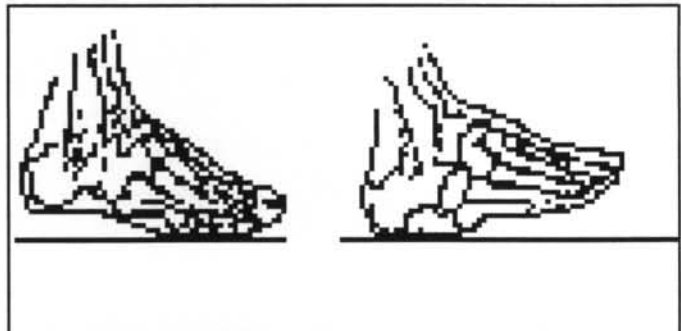


Figure 2. Foot plant techniques in running: (left) "active" and (right) "passive" techniques (Nett, 1964).

the supporting phase. Ecker et al. (1974) had long since warned "no effort should be made to prevent this [heel contact]," and Dyson (1970) points out that the contact is "light." Even though it saves energy for the heel to touch, it seems unadvisable for the short sprint. It is understandable only if the associated tissues (Achilles tendon, tissues in the arch of the foot, etc.) are first loaded to capacity with elastic energy.

Mann and Sprague (1980) listed the predominant muscle groups in this phase as follows (acting as noted): hip extensors (concentrically), knee extensors (eccentrically), and ankle plantar flexors (eccentrically). The end of this phase, the TP, marks the point at which the knee extensors and ankle plantar flexors switch to concentric activity.

Upper Leg Rotational Speed at Transition Point:	good = 490°/second
(Extension)	average = 435°/second
(from Mann, 1992)	poor = 380°/second

Another characteristic of the track athlete is the running "seat." An athlete can have a high seat (knee angle at TP is $141.7 \pm 2.9^\circ$) or a low seat (knee angle at TP is more acute) (Figure 3). The optimal height of the hip joint at TP during high-seat

running is 80-85% of the height of the hip when the athlete is standing with legs fully extended and ankles fully plantar flexed, "on tip-toes" (Tupa et al., 1991). Tupa and his colleagues advocated the high-seat running technique, claiming that "it becomes impossible to counteract [the

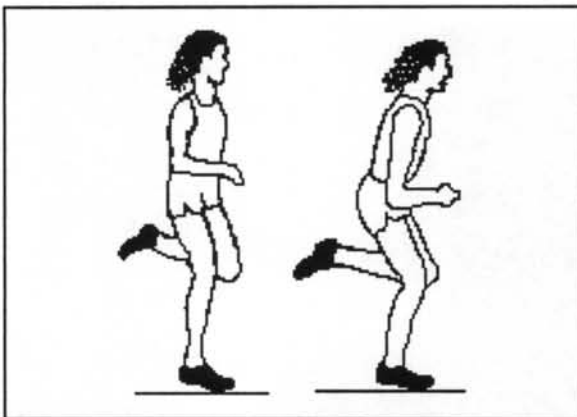


Figure 3. Examples of (left) high- and (right) low-seat running (Tupa et al, 1991).

body's inertial force at higher speeds] with a greatly bent support leg without distorting running technique." They attributed the success of several low-seat running athletes to extra strength development, which compensates for a distortion (such as increased time in the supporting phase) by increasing the push-off force at takeoff.

Phase II -- driving (or takeoff) phase:

This phase begins just after the TP and ends at takeoff, when the foot leaves the ground. The only key instant in this phase is takeoff (Figure 4). The push-off angle of the leg at takeoff relates closely to the flight angle of the CG. There is a connection between good technique and an acute push-off (Tupa et al., 1991). This correlation adds more support to the "low seat" running theory; an athlete running with a low seat would tend to have a smaller push-off angle than a high-seat runner.



Figure 4. Typical body position at takeoff [adapted from Tupa et al., 1991].

Upper Leg Motion* at Takeoff:
(from Mann, 1992)

good = 176°
average = 169°
poor = 162°

It is inadvisable to fully straighten the knee because that would require non-productive work. The extension of the knee joint from 164-168° to its full capacity is

* "Motion," when mentioned as in upper or lower leg motion at some key instant, is defined as angular position.

useless because it requires energy and the distance between the hip joint and the ankle actually decreases by an average of 8 mm (Tupa et al., 1984; Tupa et al., 1991).

Mann (1992) notes that the best sprinters tend to avoid maximum extension of the knee joint, but they minimize it to a certain degree, allowing for a shorter ground phase (I and II) and a faster SR.

Lower Leg Motion at Takeoff:
(from Mann, 1992)

good = 151°
average = 157°
poor = 163°

The predominant muscle groups in the driving phase (Figure 5) are as follows (acting as noted): hip flexors (eccentrically), knee flexors (eccentrically -- only in some cases), ankle plantar flexors (concentrically) (Mann and Sprague, 1980; Sinning and Forsyth, 1970).

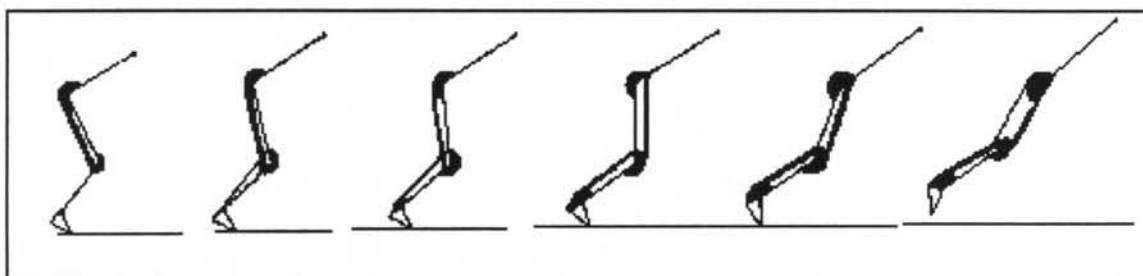


Figure 5. Stick figure in the driving phase, showing the actions of the leg muscles as takeoff approaches (Jacobs and Schenau, 1992).

Phase III -- restoring (or renewal) phase:

This phase begins just after takeoff and ends just before touchdown (to begin a new cycle). Fenn (1930) pioneered the kinetic description of the restoring phase movements by mathematically measuring the work done during running. This phase

may be broken down into two parts: (IIIa) reclamation subphase and (IIIb) preparation subphase.

Key instants in subphase IIIa are full leg extension and knee maximum flexion (Figure 6). Tupa et al. (1991) suggests the greatest angle between the thighs occurs immediately after takeoff. This

angle varies individually; no correlation was found between angle and success. When examining the history of an individual, however, the faster the speed, the greater the angle (Tupa et al., 1991).

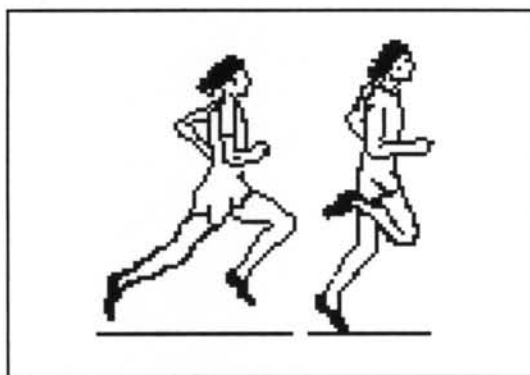


Figure 6. Typical body position at (left) full leg extension and (right) maximum knee flexion [adapted from Tupa et al., 1991].

Upper Leg Motion at Full Leg Extension:	good = 172°
(from Mann, 1992)	average = 166°
	poor = 160°

Kunz and Kaufmann (1983) emphasize the need to lift the knee as soon as possible. Yet Yakimovich (1990) claims that the impulse to accelerate the swing leg forward does not fire until knee maximum flexion and not just after takeoff as previously believed.

Lower Leg Motion at Maximum Knee Flexion:	good = 30°
(from Mann, 1992)	average = 35°
	poor = 41°

At knee maximum flexion, the hip position angle is of some importance insofar as it relates to the behind "whipping" of the shin (commonly called "butt-kicks"). The

extent of this motion varies widely, but it is generally agreed among sports scientists that a high whipping of the shin is good since it results in a decreased moment of inertia for the swing leg. Tupa et al.

(1991) suggested that for the foot to come up just below the buttock is ideal and that up near mid-buttock is too high (Figure 7). In the latter case, the motion is not smooth and indicates improper technique (e.g., excessive trunk lean, lumbar arching, or a late forward carry of the thigh).

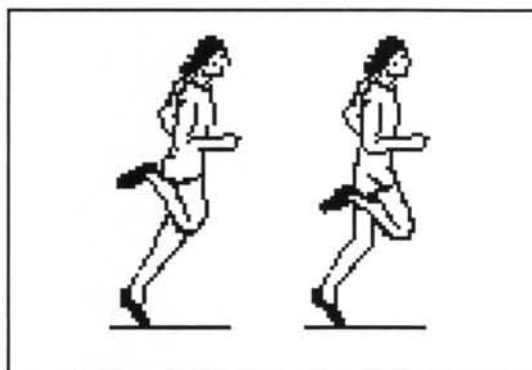


Figure 7. (Left) Excessively high and (right) optimal folding of the shin (Tupa et al., 1991).

Subphase IIIb begins at recovery (Figure 8). Key instants in this subphase are recovery, ankle cross, and full leg flexion.

Upper Leg Rotational Speed at Recovery: (Flexion) (from Mann, 1992)	good = 400°/second average = 368°/second poor = 336°/second
Lower Leg Motion at Ankle Cross: (from Mann, 1992)	good = 35° average = 45° poor = 54°
Lower Leg Rotational Speed at Ankle Cross: (Extension) (from Mann, 1992)	good = 40°/second average = 95°/second poor = 175°/second

One to three degrees before full leg flexion, an impulse fires in the hip extensors aimed at decelerating the swing leg; this swing leg motion is usually ballistic in sprinting (Yakimovich, 1990). The emphasis at this point in the stride should be

extending the fully flexed leg with an extended knee while flexing the lagging leg to its maximum (Ecker, 1974).

Upper Leg Motion at Full Leg Flexion:
(from Mann, 1992)

good = 176°
average = 169°
poor = 162°

Mann and Sprague (1980) listed the predominant muscle groups in this phase as follows (acting as noted):

hip flexors (concentrically)
until recovery, then hip
extensors (eccentrically).
Knee flexors and extensors
stay somewhat balanced, as
do the ankle dorsi and
plantar flexors. The reason

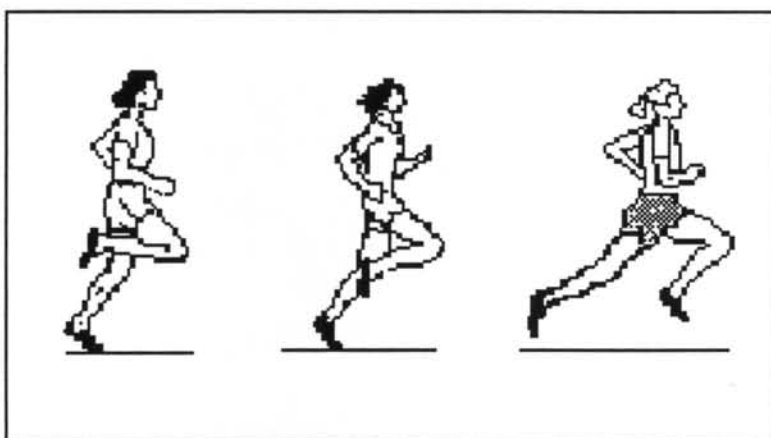


Figure 8. Typical body positioning at (left) recovery, (middle) ankle cross, and (right) full leg flexion [adapted from Tupa et al., 1991].

for the predominance of the hip articulating muscles is clear. It is somewhat expected that the muscles controlling the ankle are not predominant in this phase, but the fact the knee flexors and extensors are either not very active or well balanced is surprising. It is expected that the muscles across the knee act as follows: knee flexors (concentrically -- to lower the rotational moment of inertia) then knee extensors (eccentrically and then concentrically -- to reverse the flexion) followed by knee flexors (eccentrically -- to prepare for touchdown). Dyson (1970) gives a good explanation: "The reversal of the thigh movement . . . produces a transference of angular momentum and flail-like action in the fore leg." So, energy is saved by the

muscles of the knee, with the lower leg "riding" the momentum of the thigh. It is likely that all the knee muscles become more active nearing the end of the restoring phase; balanced muscular action stabilizes the knee joint at touchdown. Ozolin (1986) emphasizes the need for antagonist muscle balance. He stated the greatest activity of all muscle groups is at the moment just before touchdown and during the supporting and driving phases. The tenseness of corresponding antagonist muscles "strengthens" the joints for a firm landing, which leads to a high trajectory of the CG.

Although it is widely believed that an increased full leg flexion is beneficial to an athlete's speed, the benefit of increased leg lift tended to be offset by an increase in the CG to touchdown point distance (Mann and Sprague, 1980).

Method

A. Jalilov et al. (1991) report there is no significant difference between the most experienced coaches and first year track students in ability to evaluate a runner's technique with the naked eye alone. The human eye can only pick out the details of movement when a segment of the body stops instantaneously. Detailed patterns of movement in continual motion are not subject to visual perception. This limitation of evaluation explains the need for the use of analysis equipment for a full frame-by-frame evaluation of a runner's biomechanical technique.

The filming of twenty-two Lady Volunteer track runners (12 sprinters and 10 distance runners) took place outside on Tom Black Track on the University of Tennessee campus. A Photec 16-mm high-speed rotating prism camera system was set

up in the center area of the track. To contrast with the clothing and skin of the runners, reflective tape and paint were applied to key joints of the runners' bodies. They were then instructed to run at a full sprint through the 20.5-foot filming window in the far lane of the track with the camera running at 100 frames per second. The runners were allowed about 30 meters to accelerate to maximum speed. The black and white 200 ASA 16mm film used was sent to the Photographic Analysis Company in New Jersey for processing.

The digitizing setup involved the use of a frame-by-frame motion analysis projector, a Science Accessories Corporation GP-8 Sonic digitizer, and a Texas Instruments TI-BP computer with motion analysis software from Kansas State University (KSU). The sonic digitizer microphones were "squared" and secured to the frame of a translucent lucite board on which the film was projected. Before and throughout the digitizing process, care was taken to keep the projection orthogonal to the board.

As the data were being collected, frames were noted for the occurrence of certain key positions in a runner's stride. The two-dimensional digital coordinates in the sagittal plane were smoothed with a Butterworth-type low-pass digital filter as advocated by D. A. Winter (1979). The analysis of the data was performed with the aforementioned KSU system and subsequently with a spreadsheet on another IBM-compatible computer.

Data and Calculations

The processed data (see Appendix B) were converted into the form of Mann's averages (1992) through the use of a spreadsheet (refer to Appendix C for formula delineations).

General Performance Descriptors:

The general performance descriptors are defined as horizontal velocity (HV), stride rate (SR), stride length (SL), ground time (GT), and air time (AT). These data, specific to each athlete studied, are presented in Table 1, along with those for elite runners (Mann, 1992). These data are also graphically presented in Charts 1-5.

TABLE 1. GENERAL PERFORMANCE DESCRIPTORS

<i>CASE</i>	<i>HORIZONTAL VELOCITY</i>	<i>STRIDE RATE</i>	<i>STRIDE LENGTH</i>	<i>GROUND TIME</i>	<i>AIR TIME</i>
E1	35.8	4.91	7.83	0.083	0.123
E2	32.4	4.42	7.35	0.1	0.123
E3	29	3.92	6.87	0.12	0.113
E3					0.133
Ia	34.270851064	4.5454545455	7.7972	0.1	0.12
Ib	35.044166667	5	7.5169	0.11	0.09
Ic	36.425151515	5.2631578947	7.3864	0.1	0.1
Id	35.821219512	4.7619047619	8.1366	0.11	0.11
Ie	35.916486486	4.347826087	8.9827	0.1	0.13

<i>CASE</i>	<i>HORIZONTAL VELOCITY</i>	<i>STRIDE RATE</i>	<i>STRIDE LENGTH</i>	<i>GROUND TIME</i>	<i>AIR TIME</i>
If	31.350769231	4.5454545455	5.3393	0.09	0.12
Ig	38.925675676	4.5454545455	8.7334	0.08	0.13
Ih	39.103513514	5	8.6806	0.1	0.1
Ii	41.127297297	5	8.8002	0.08	0.11
Ij	40.417272727	5.2631578947	8.1949	0.09	0.1
Ik	37.85225	5	8.359	0.08	0.12
Il	38.759069767	4.5454545455	9.3058	0.1	0.11
Ila	29.826	4	7.417	0.12	0.12
Ilb	28.940697674	4	7.5527	0.15	0.1
Ilc	30.902452381	4.347826087	6.9435	0.13	0.1
Ild	32.52097561	4.5454545455	7.7227	0.12	0.12
Ile	31.496176471	5	6.6662	0.11	0.1
Ilf	32.093157895	4.347826087	9.3652	0.11	0.1
Ilg	30.413023256	3.7037037037	7.7391	0.13	0.1
Ilh	31.312307692	4.1666666667	7.3973	0.13	0.11
Ili	29.936	3.7037037037	8.3109	0.13	0.14
Ilj	29.935897436	4.347826087	7.0463	0.1	0.12

Chart 1. Horizontal Velocity.

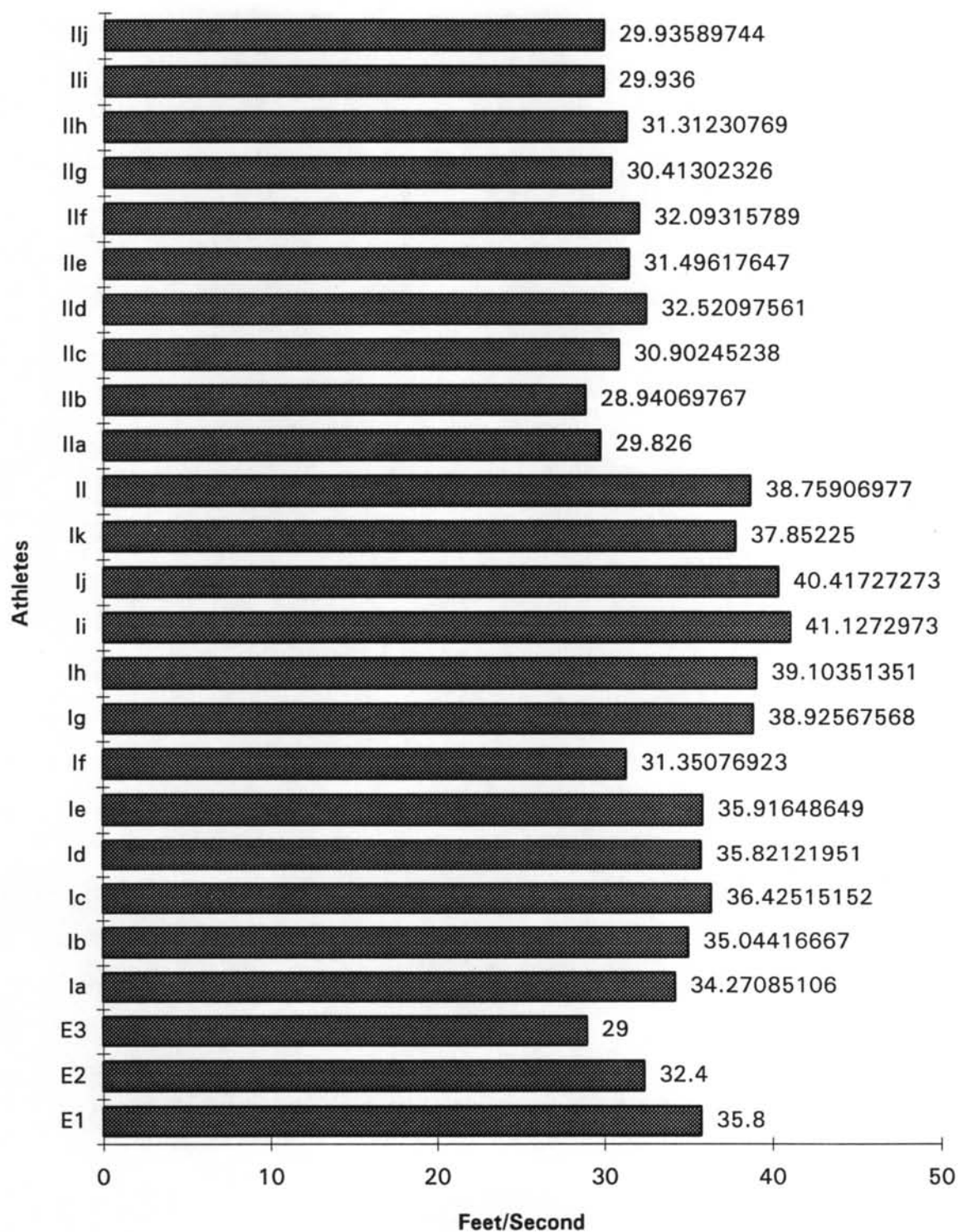


Chart 2. Stride Rate.

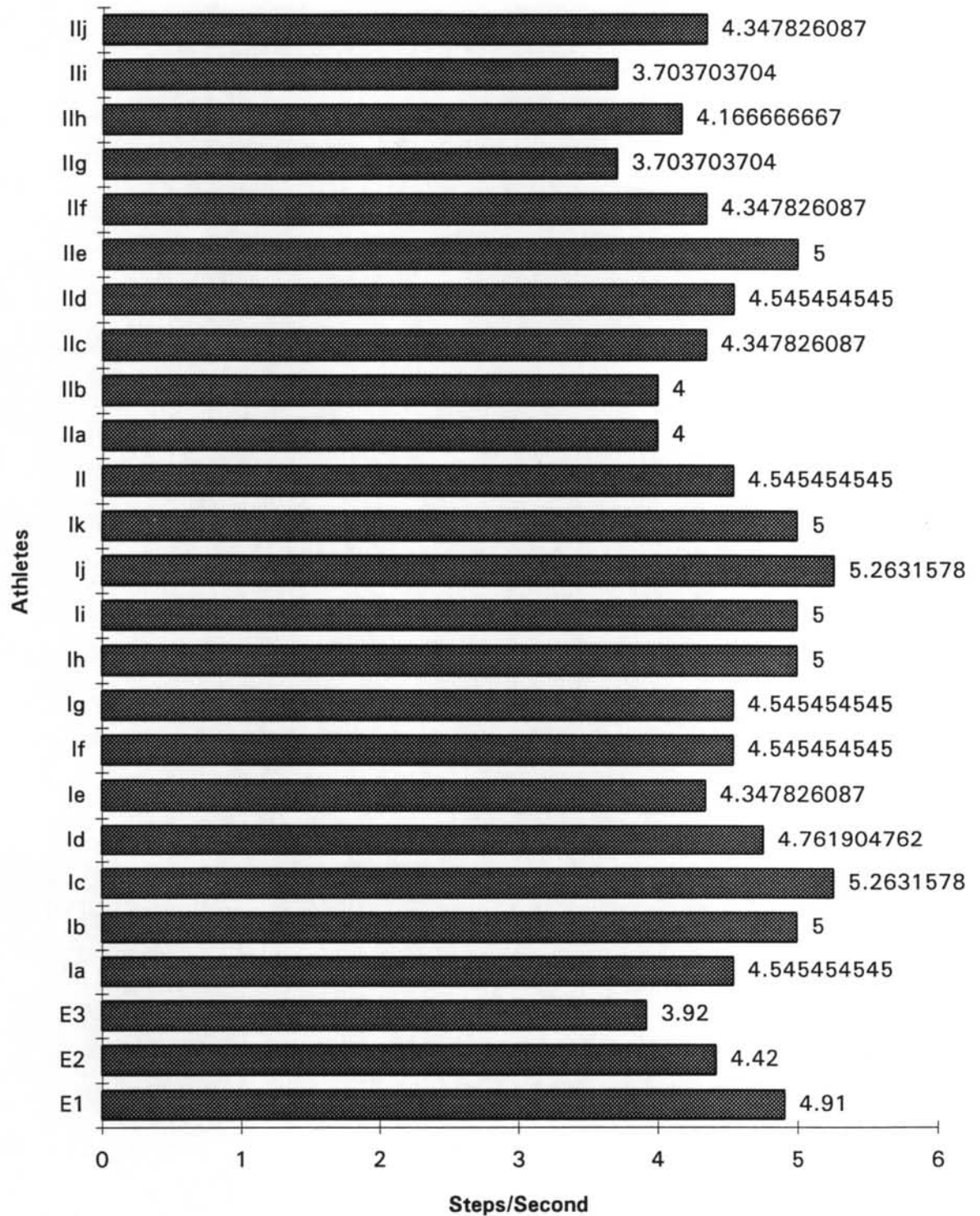


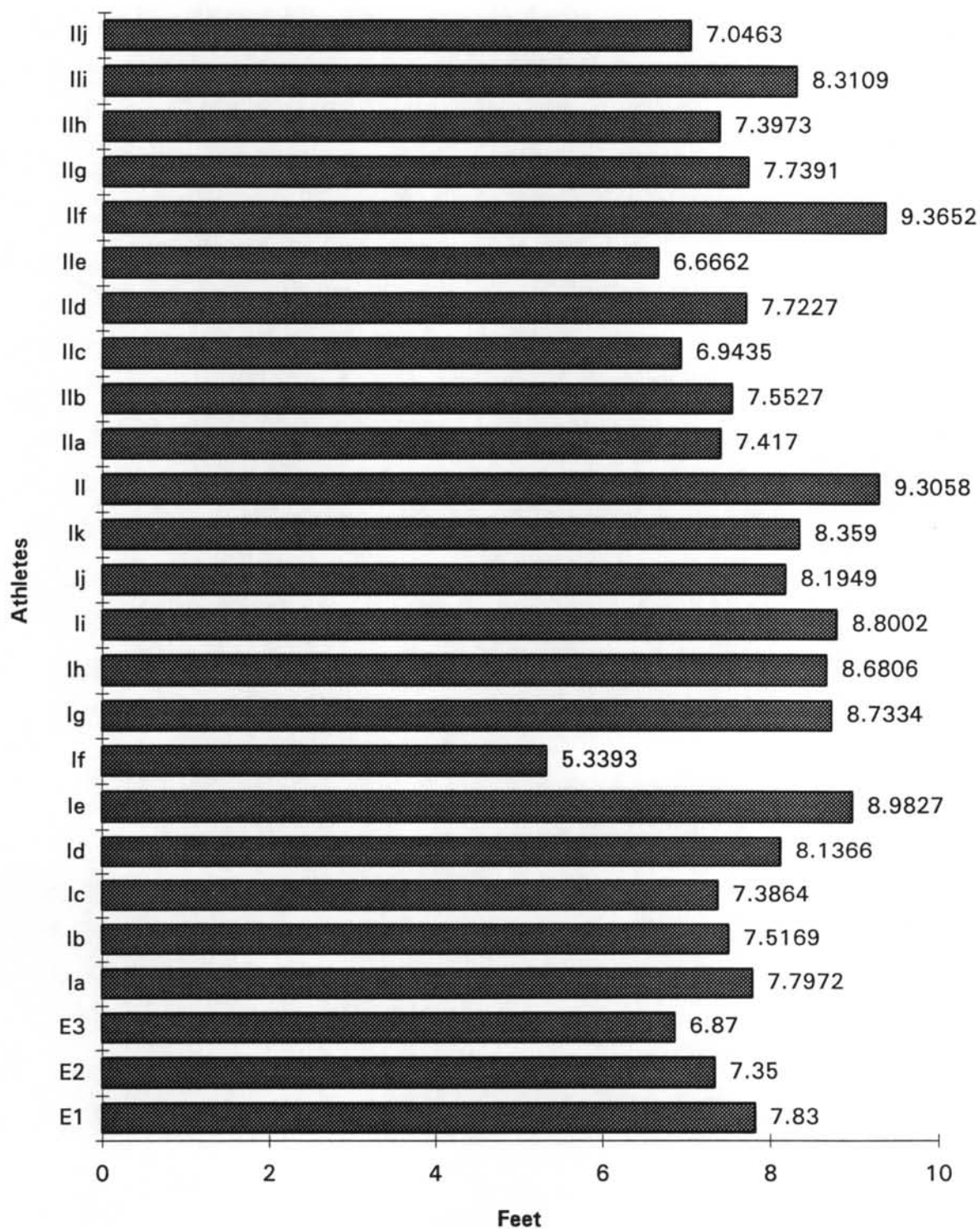
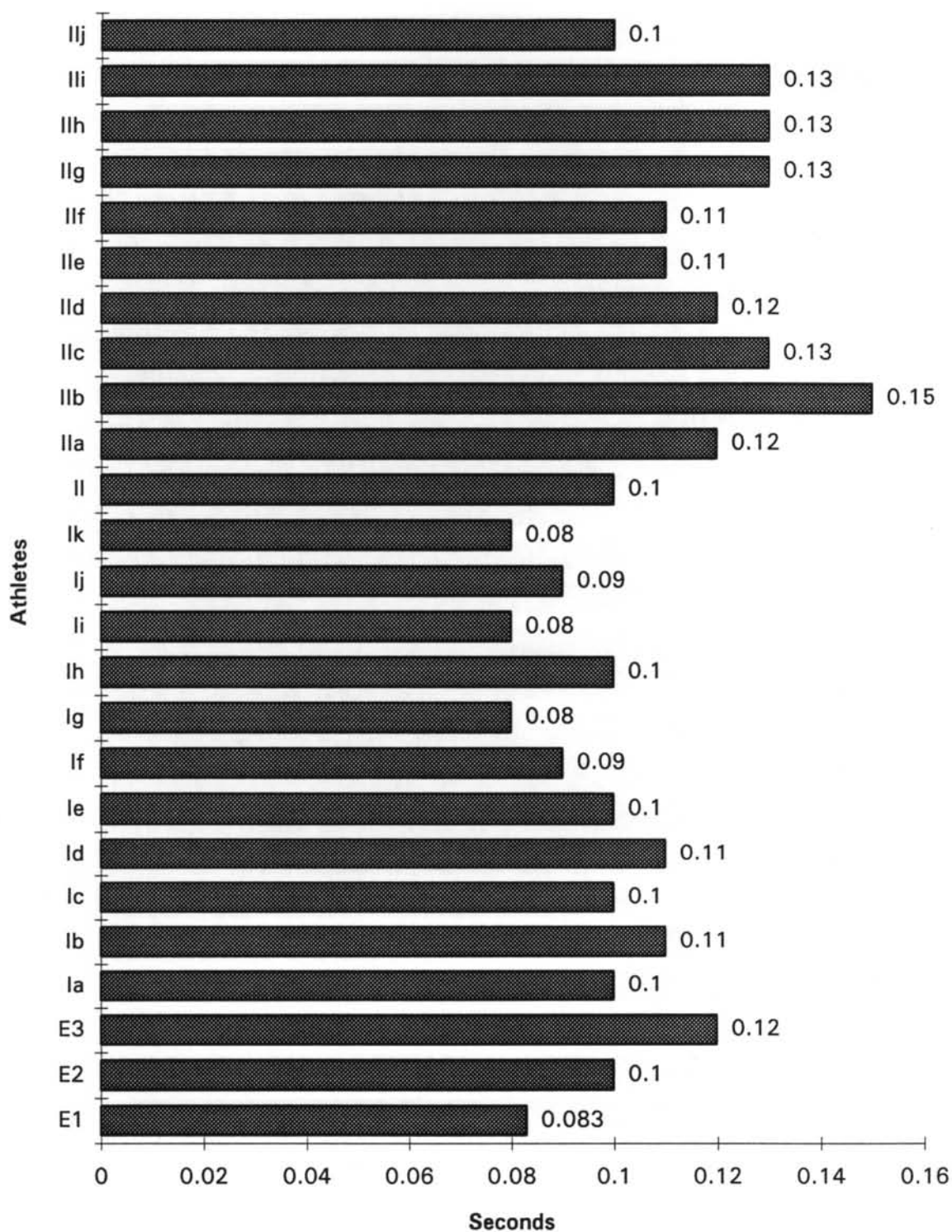
Chart 3. Stride Length.

Chart 4. Ground Time.



Supporting Phase Indicators:

The supporting phase indicators are defined as horizontal foot speed at touchdown (FS), horizontal foot distance at touchdown (FD), upper leg rotational speed at touchdown (UST), lower leg rotational speed at touchdown (LST), and upper leg rotational speed at the transition point (USP). These data, specific to each athlete studied, are presented in Table 2, along with those for elite runners (Mann, 1992). These data are also graphically presented in Charts 6-10.

TABLE 2. SUPPORTING PHASE INDICATORS

<i>CASE</i>	<i>HORIZONTAL FOOT SPEED AT TOUCHDOWN</i>	<i>HORIZONTAL FOOT DISTANCE AT TOUCHDOWN</i>	<i>UPPER LEG ROTATIONAL SPEED AT TOUCHDOWN</i>	<i>LOWER LEG ROTATIONAL SPEED AT TOUCHDOWN</i>	<i>UPPER LEG ROTATIONAL SPEED AT TRANSITION POINT</i>
E1	24.2	0.64	375	238	490
E2	21.2	0.78	291	120	435
E3	18.2	0.92	208	3	380
Ia	22.159951064	0.92115	345.98335	452.27465	406.3218
Ib	27.028866667	0.7343	300.34	329.7315	433.6256
Ic	29.854751515	0.5843	422.46245	406.36665	379.1019
Id	25.686719512	1.2999	407.04225	605.6196	541.0616
Ie	33.907586486	0.4655	338.3276	532.4373	346.4776
If	22.378219231	0.71905	404.29245	322.7344	616.31595

<i>CASE</i>	<i>HORIZONTAL FOOT SPEED AT TOUCHDOWN</i>	<i>HORIZONTAL FOOT DISTANCE AT TOUCHDOWN</i>	<i>UPPER LEG ROTATIONAL SPEED AT TOUCHDOWN</i>	<i>LOWER LEG ROTATIONAL SPEED AT TOUCHDOWN</i>	<i>UPPER LEG ROTATIONAL SPEED AT TRANSITION POINT</i>
Ig	35.203425676	0.70025	262.8412	565.1177	92.3763
Ih	26.995813514	1.07385	345.999	331.95145	442.4059
Ii	47.296697297	0.9816	468.2826	949.7477	605.5458
Ij	32.315672727	0.68715	376.51475	534.6752	413.816
Ik	34.11875	0.6426	475.23935	794.45095	627.7044
II	33.993519767	0.9656	350.9919	773.7386	647.6751
Ila	25.5383	0.80275	283.98	368.4113	504.0484
Ilb	21.344747674	1.16755	165.4601	270.2243	425.7858
Ilc	20.767752381	0.99935	235.37055	201.505	357.3475
Ild	16.39562561	1.1636	135.90525	229.18445	552.855
Ile	24.999976471	0.60915	269.0843	418.9528	113.2262
Ilf	16.055457895	0.9545	404.8625	119.43155	466.4281
Ilg	21.427773256	1.1787	249.92755	215.9301	344.2751
IIh	26.031707692	0.87205	284.3495	393.96795	408.2093
IIi	26.3954	0.5399	370.6921	599.7356	520.7315
IIj	23.848897436	0.73325	484.5629	369.0621	406.415

Chart 6. Horizontal Foot Speed at Touchdown.

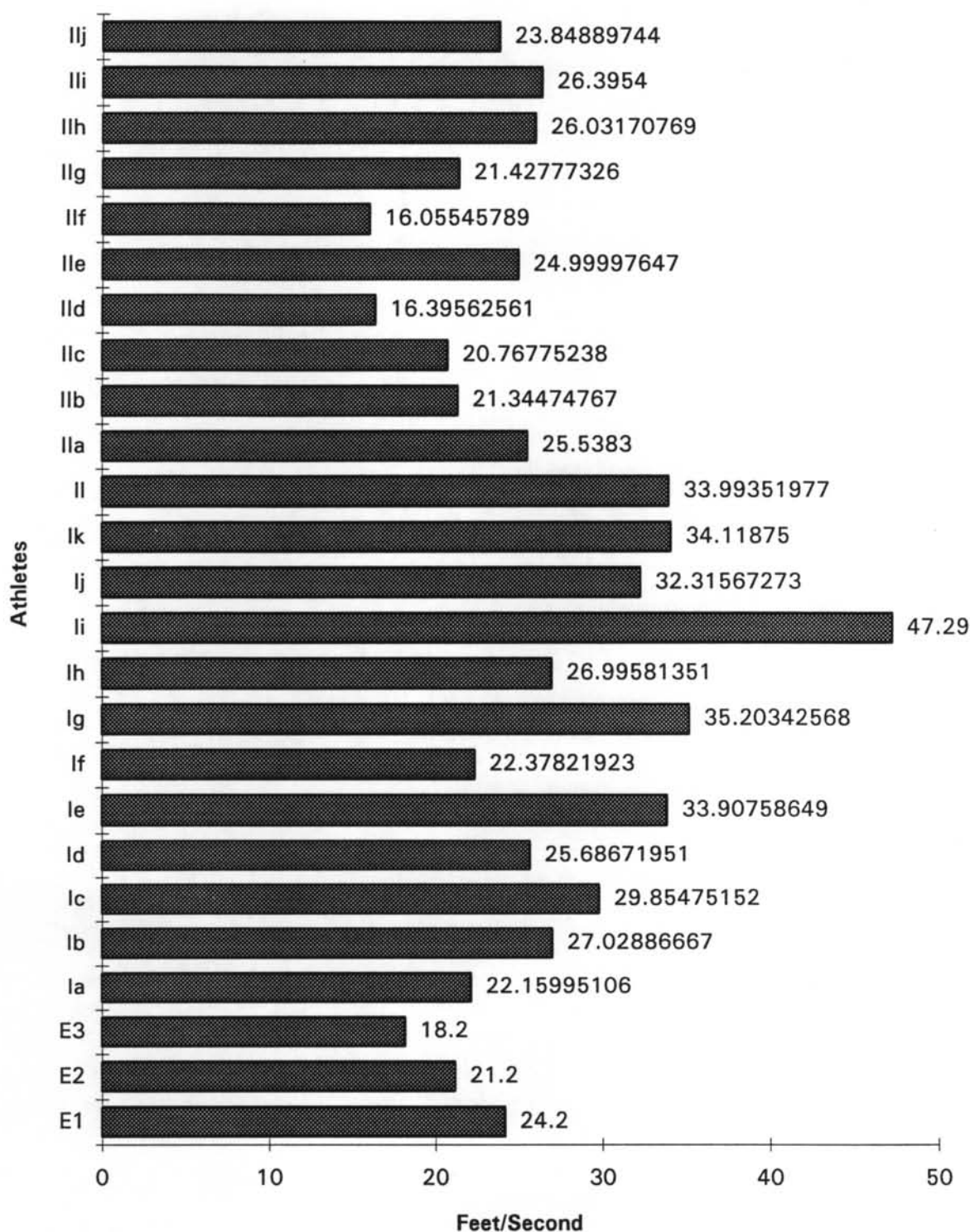


Chart 7. Horizontal Foot Distance at Touchdown.

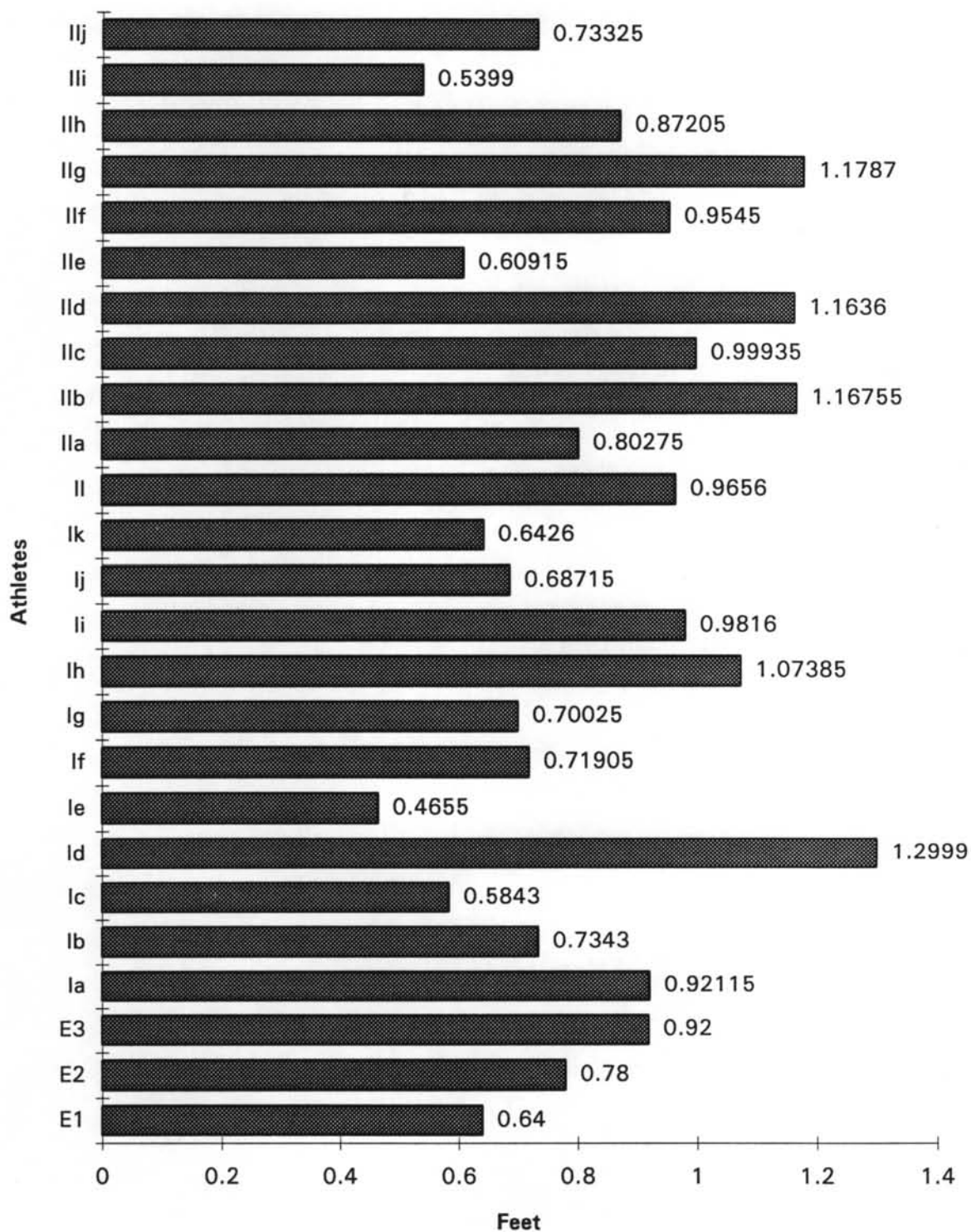


Chart 8. Upper Leg Rotational Speed at Touchdown.

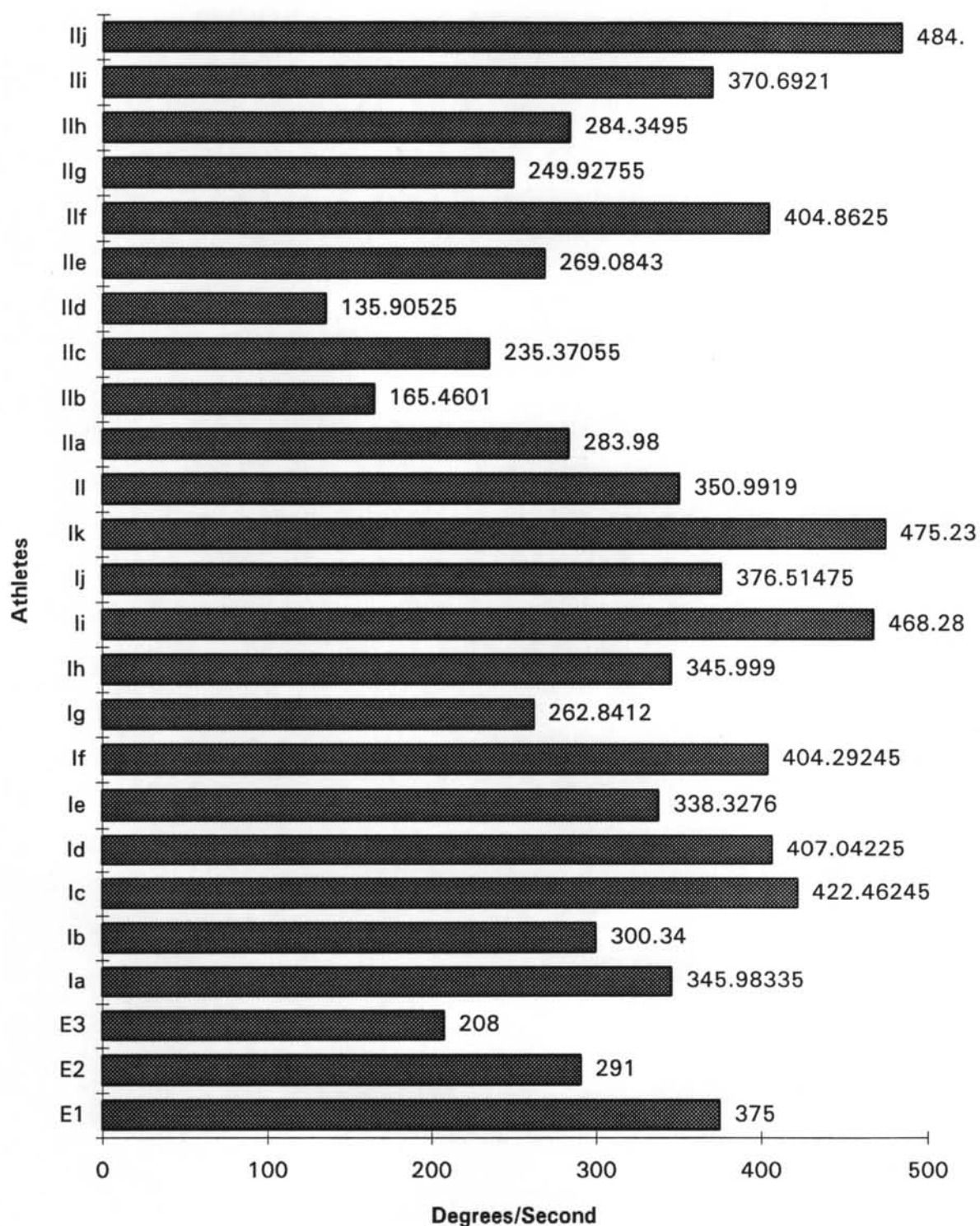


Chart 9. Lower Leg Rotational Speed at Touchdown.

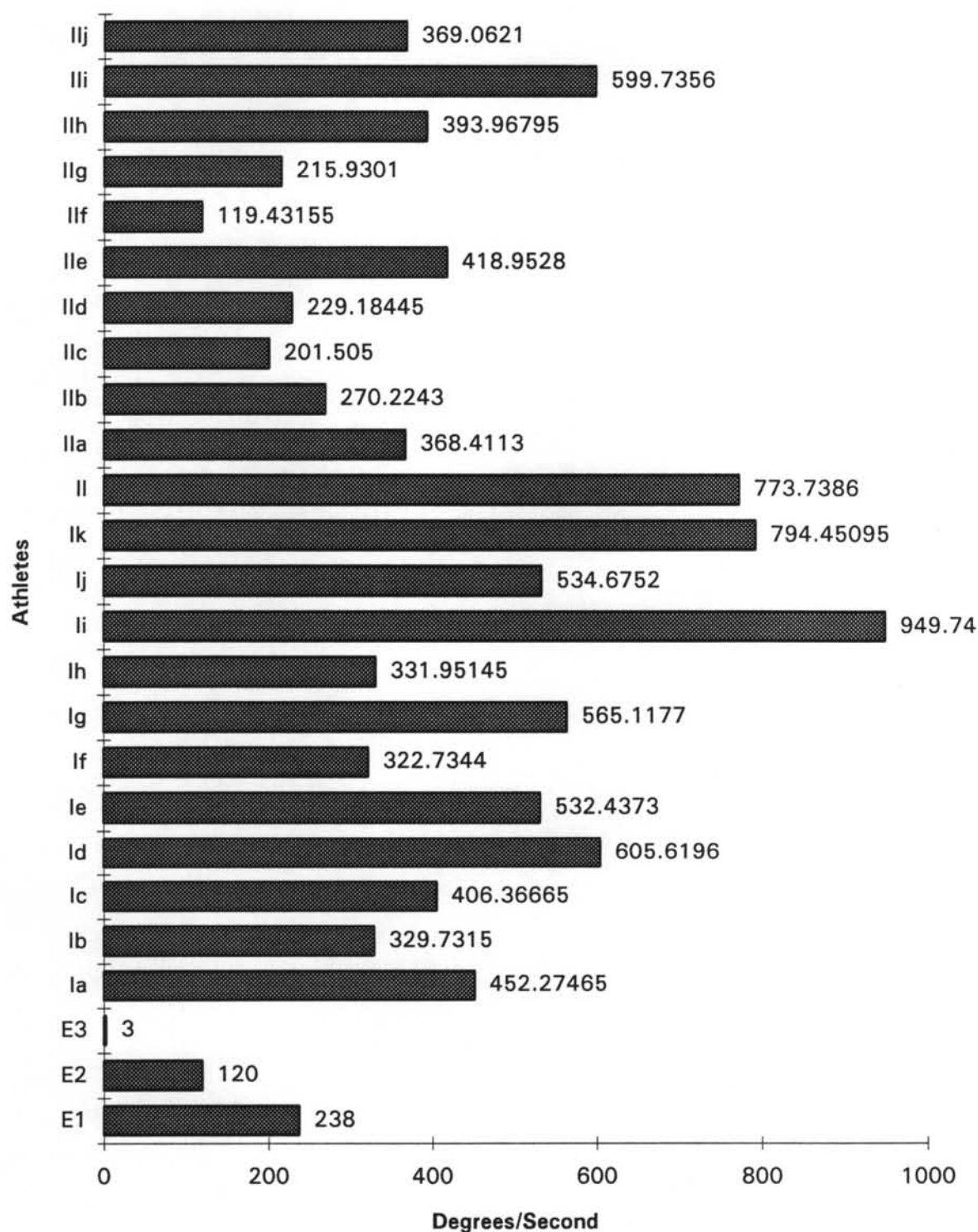
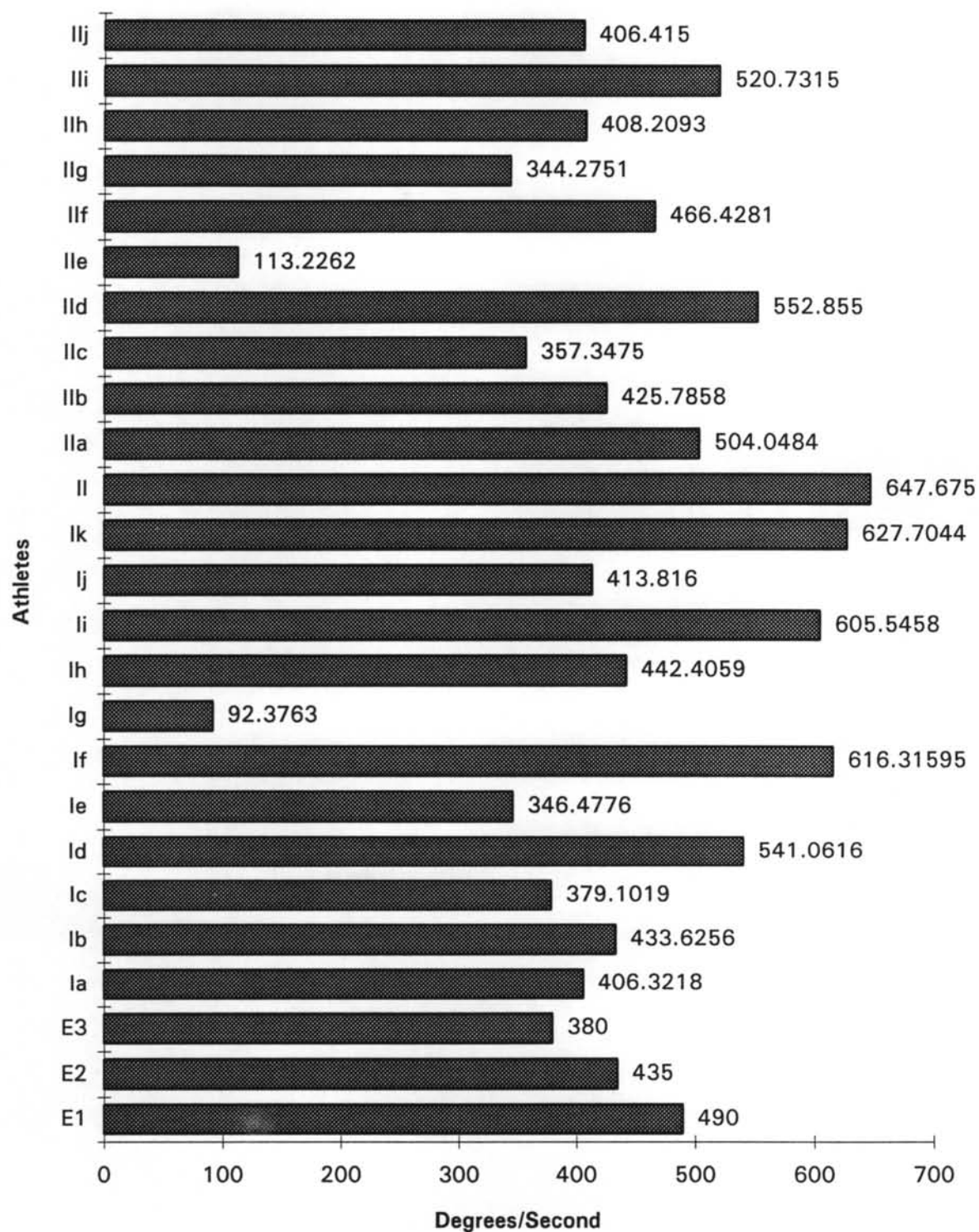


Chart 10. Upper Leg Rotational Speed at Transition Point.



Driving Phase Indicators:

The driving phase indicators are defined as upper leg motion at takeoff (UMT) and lower leg motion at takeoff (LMT). These data, specific to each athlete studied, are presented in Table 3, along with those for elite runners (Mann, 1992). These data are also graphically presented in Charts 11-12.

TABLE 3. DRIVING PHASE INDICATORS

<i>UPPER LEG MOTION AT TAKEOFF</i>	<i>LOWER LEG MOTION AT TAKEOFF</i>	<i>UPPER LEG MOTION AT FULL EXTENSION</i>	<i>LOWER LEG MOTION AT MAXIMUM KNEE FLEXION</i>	<i>UPPER LEG ROTATIONAL SPEED AT RECOVERY</i>
176	151	172	30	400
169	157	166	35	368
162	163	160	41	336
164.3218	160.918	164.16205	28.18625	734.09415
203.83535	162.6582	156.54275	30.9644	769.29595
168.42055	149.80075	166.46155	34.0958	658.10995
159.3202	158.03365	162.807	39.64385	702.7091
169.6085	156.68435	163.6331	34.7972	689.9323
184.65455	138.06135	174.2168	45.0009	572.463
165.59625	159.87065	169.80515	34.31115	811.98965
173.29775	155.8062	161.5489	43.9843	877.3385

161.98755	156.44145	157.4145	28.0868	551.903
163.57925	157.9544	160.7295	40.10775	687.50175
166.4871	155.5004	147.2471	34.946	641.33525
158.678	156.0545	157.9264	36.9678	561.2289
162.3693	162.79925	164.14635	47.43065	633.7831
163.68265	160.64785	160.7646	46.736165	619.3065
177.8838	160.8209	169.03675	37.3569	645.6693
164.10265	167.87035	163.9827	34.21235	526.099
170.4355	168.31685	169.60645	32.0867	680.7526
167.48825	152.23075	166.9487	41.3602	565.8721
158.1888	158.2901	158.3143	46.8393	626.98735
163.2764	150.29045	162.3721	34.5228	664.4412
151.63595	174.8187	152.16555	20.8544	639.9282
163.37365	161.83465	161.82345	51.8998	651.97635

Chart 11. Upper Leg Motion at Takeoff.

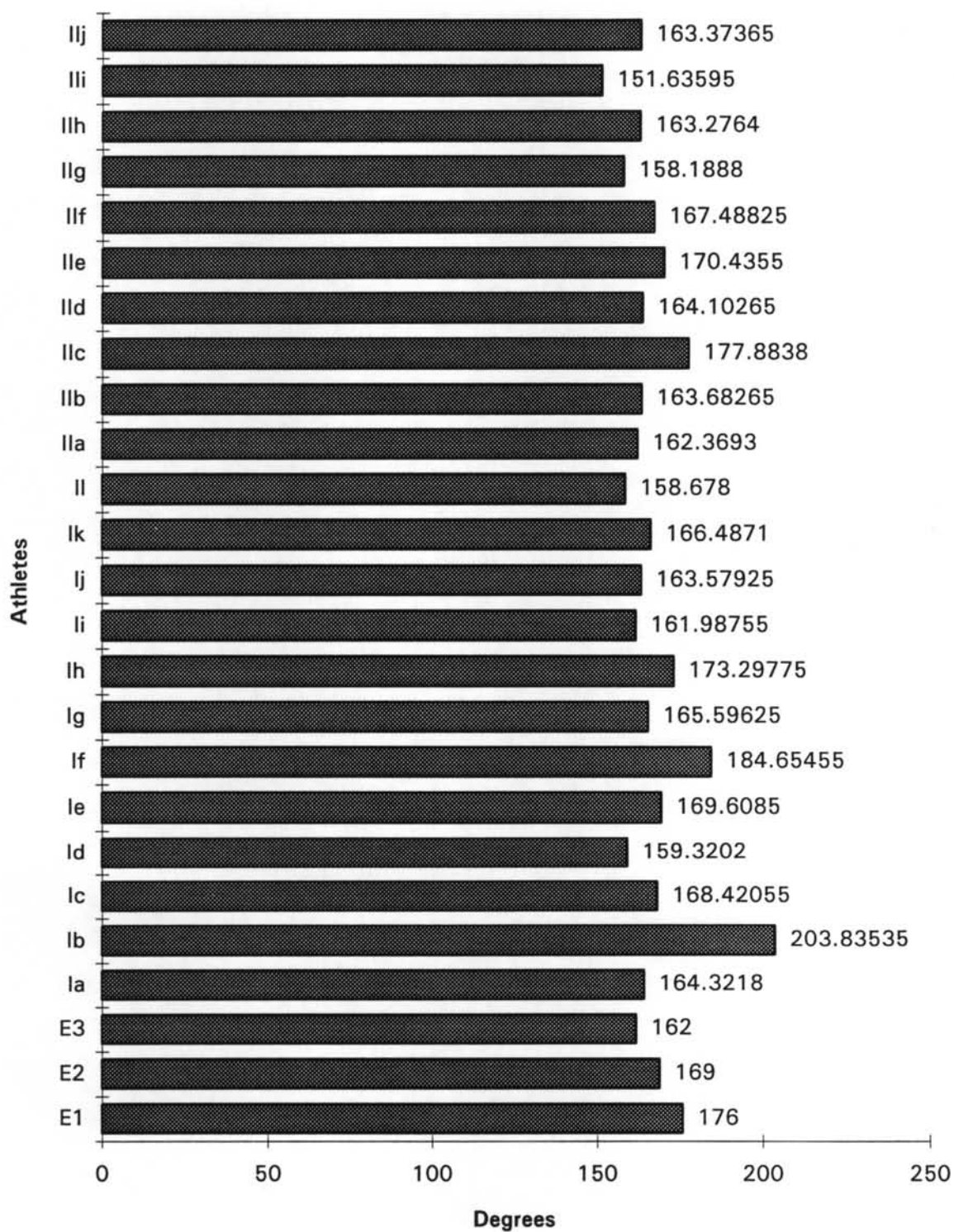
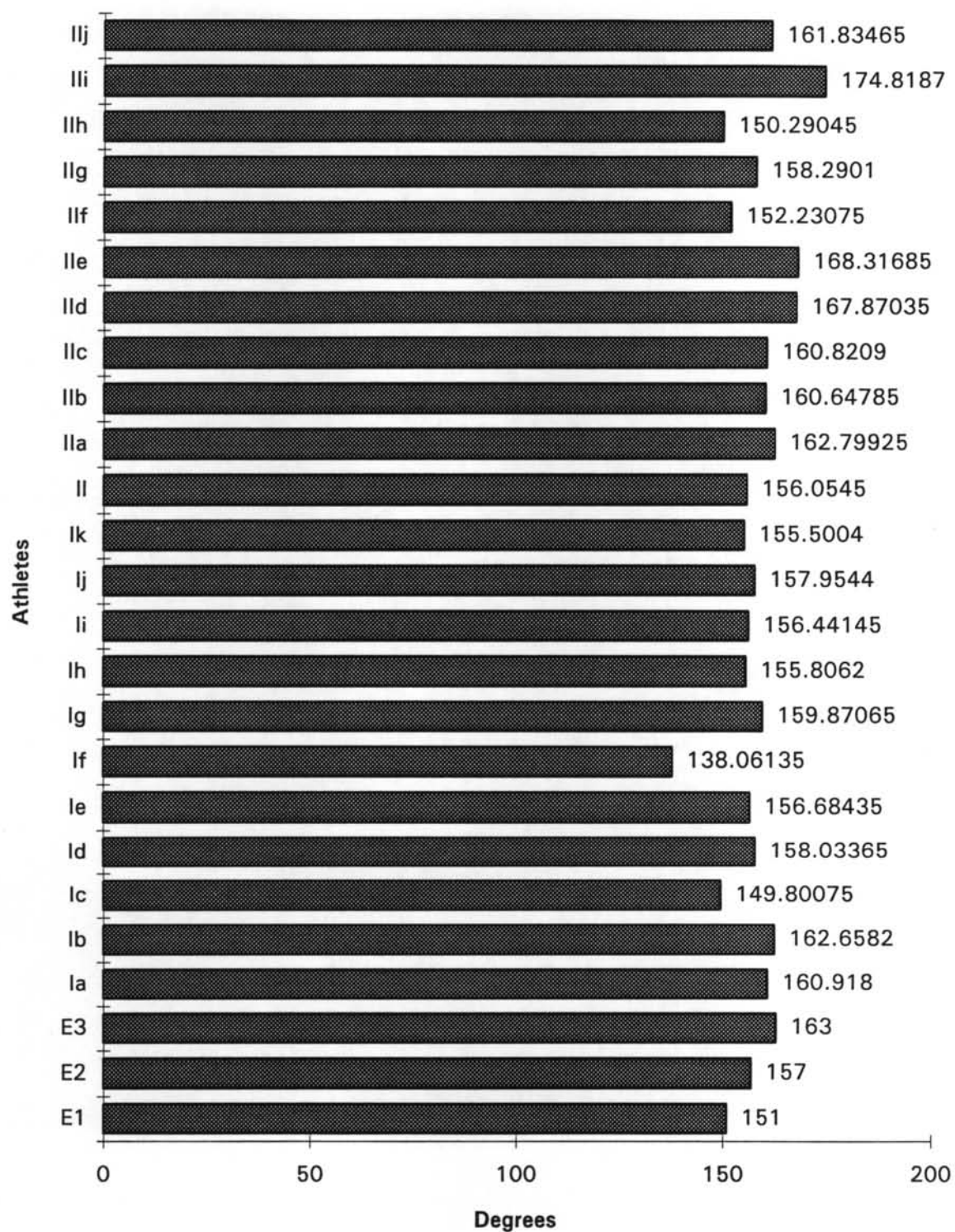


Chart 12. Lower Leg Motion at Takeoff.



Restoring Phase: Reclamation Indicators:

The reclamation subphase indicators are defined as upper leg motion at full extension (UME), lower leg motion at maximum knee flexion (LMF), and upper leg rotational speed at recovery (USR). These data, specific to each athlete studied, are presented in Table 4, along with those for elite runners (Mann, 1992). These data are also graphically presented in Charts 13-15.

TABLE 4. RESTORING PHASE: RECLAMATION INDICATORS

<i>CASE</i>	<i>UPPER LEG MOTION AT FULL EXTENSION</i>	<i>LOWER LEG MOTION AT MAXIMUM KNEE FLEXION</i>	<i>UPPER LEG ROTATIONAL SPEED AT RECOVERY</i>
E1	172	30	400
E2	166	35	368
E3	160	41	336
Ia	164.16205	28.18625	734.09415
Ib	156.54275	30.9644	769.29595
Ic	166.46155	34.0958	658.10995
Id	162.807	39.64385	702.7091
Ie	163.6331	34.7972	689.9323
If	174.2168	45.0009	572.463
Ig	169.80515	34.31115	811.98965
Ih	161.5489	43.9843	877.3385

<i>CASE</i>	<i>UPPER LEG MOTION AT FULL EXTENSION</i>	<i>LOWER LEG MOTION AT MAXIMUM KNEE FLEXION</i>	<i>UPPER LEG ROTATIONAL SPEED AT RECOVERY</i>
li	157.4145	28.0868	551.903
lj	160.7295	40.10775	687.50175
lk	147.2471	34.946	641.33525
ll	157.9264	36.9678	561.2289
IIa	164.14635	47.43065	633.7831
IIb	160.7646	46.736165	619.3065
IIc	169.03675	37.3569	645.6693
IId	163.9827	34.21235	526.099
IIe	169.60645	32.0867	680.7526
IIf	166.9487	41.3602	565.8721
IIg	158.3143	46.8393	626.98735
IIh	162.3721	34.5228	664.4412
IIi	152.16555	20.8544	639.9282
IIj	161.82345	51.8998	651.97635

Chart 13. Upper Leg Motion at Full Extension.

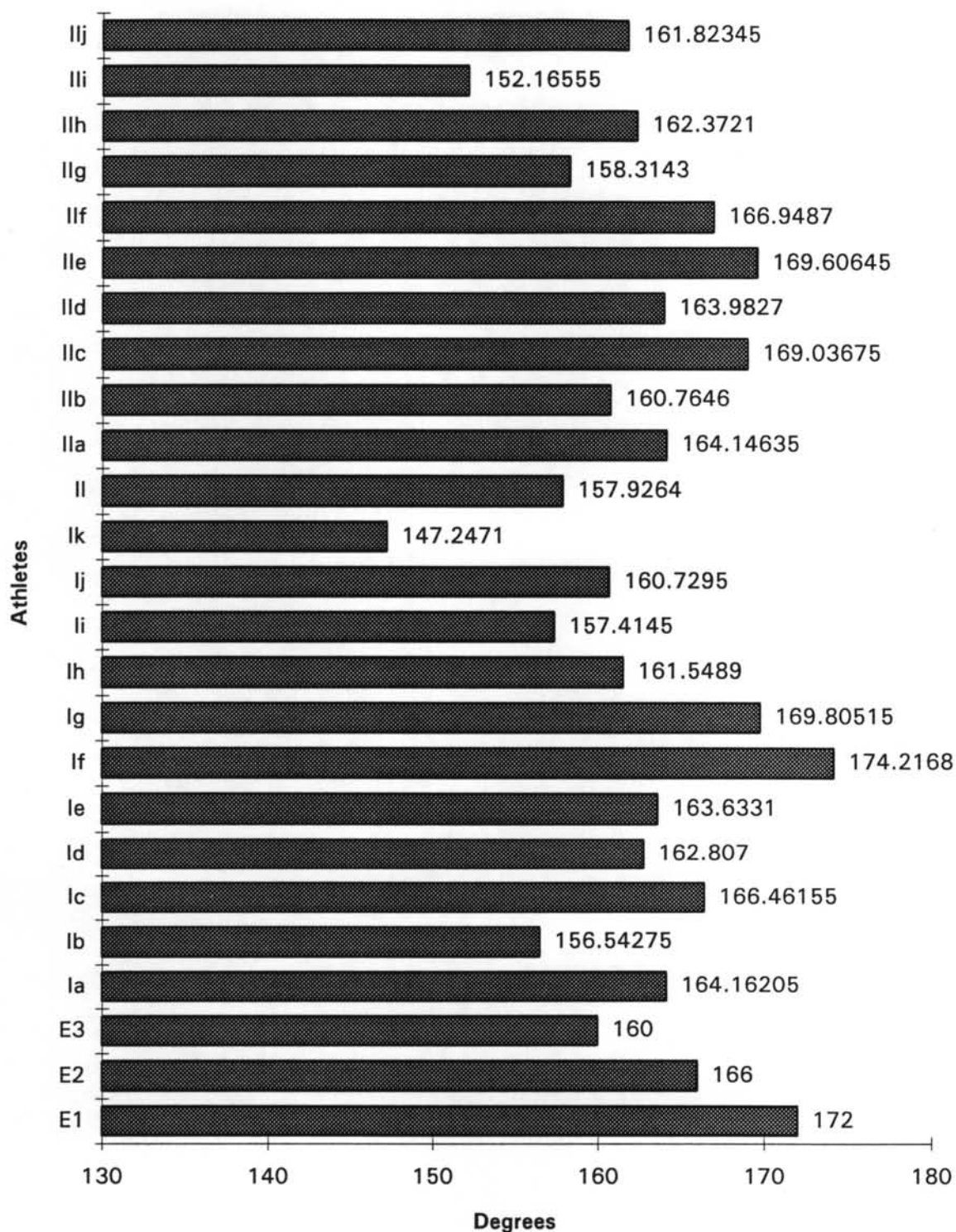


Chart 14. Lower Leg Motion at Maximum Knee Flexion.

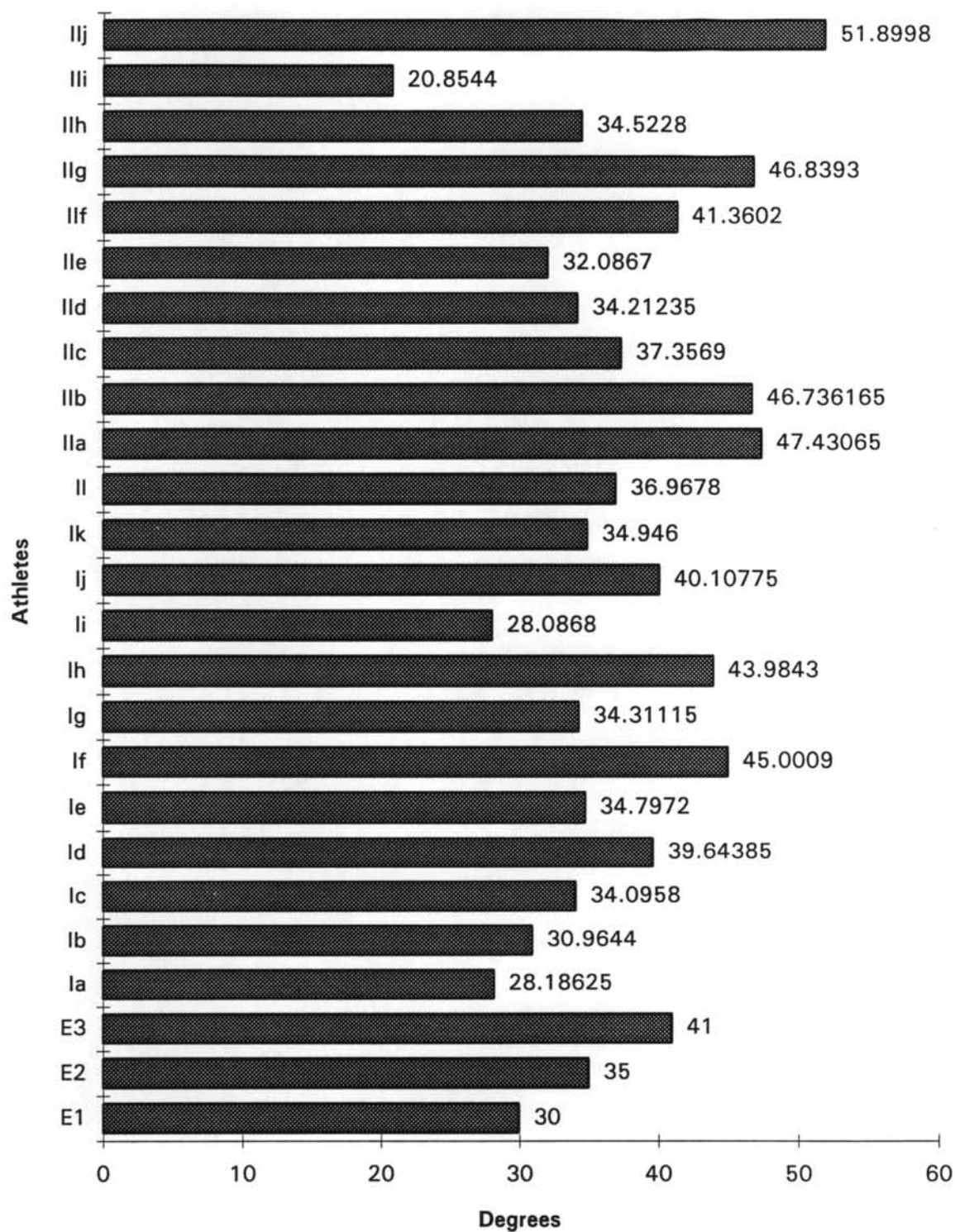
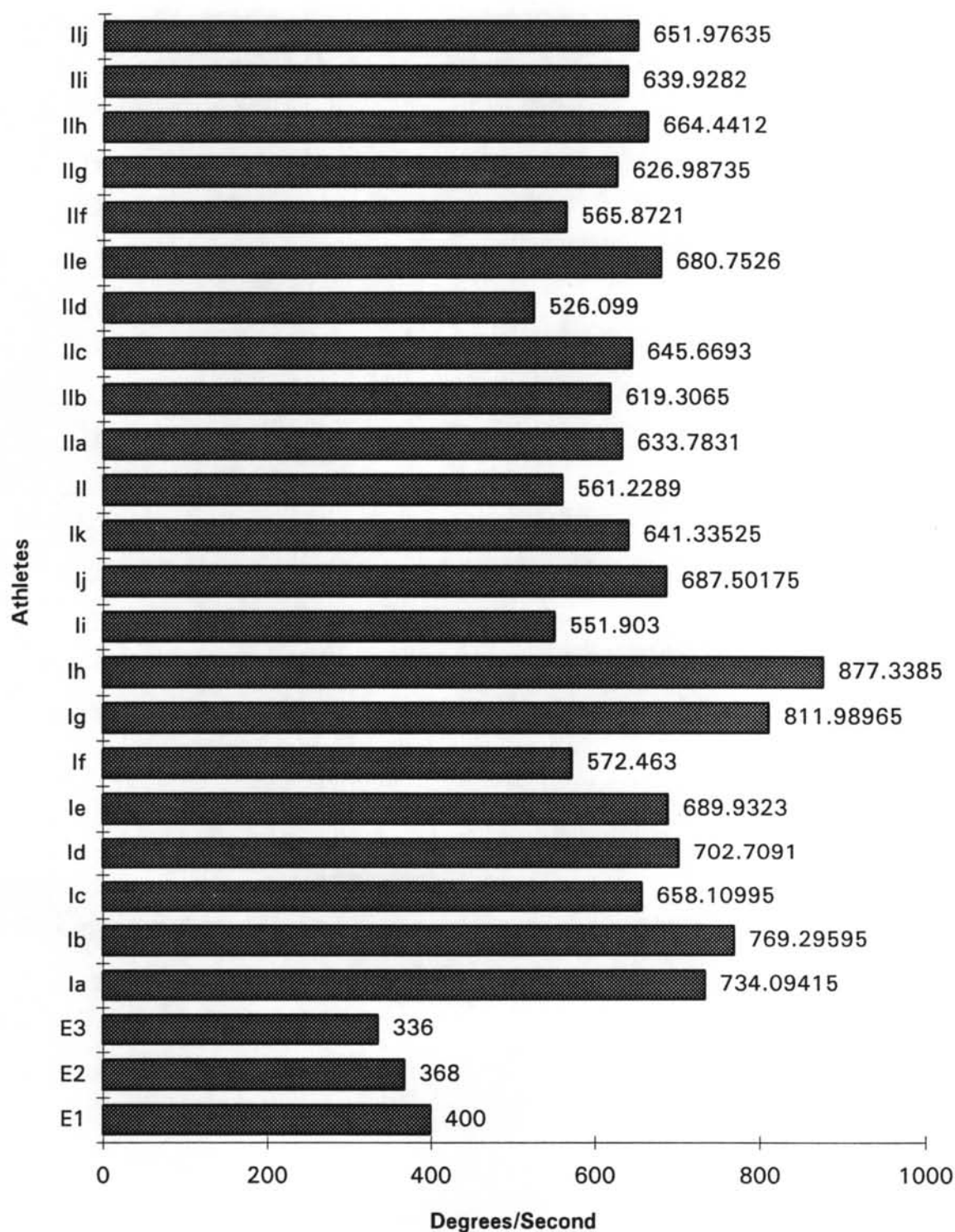


Chart 15. Upper Leg Rotational Speed at Recovery.



Restoring Phase: Preparation Indicators:

The preparation subphase indicators are defined as lower leg motion at ankle cross (LMA), lower leg rotational speed at ankle cross (LSA), and upper leg motion at full leg flexion (UMF). These data, specific to each athlete studied, are presented in Table 5, along with those for elite runners (Mann, 1992). These data are also graphically presented in Charts 16-18.

TABLE 5. RESTORING PHASE: PREPARATION INDICATORS

<i>CASE</i>	<i>LOWER LEG MOTION AT ANKLE CROSS</i>	<i>LOWER LEG ROTATIONAL SPEED AT ANKLE CROSS</i>	<i>UPPER LEG MOTION AT FULL LEG FLEXION</i>
E1	35	40	248
E2	45	95	241
E3	54	175	234
Ia	42.04515	999.9539	252.91015
Ib	45.28485	1404.5203	241.80125
Ic	52.62575	1228.3161	243.51425
Id	55.87955	891.09485	242.0032
Ie	51.4917	1248.53585	244.9062
If	59.3404	1251.73035	240.04565
Ig	44.63885	1341.8369	262.0534

<i>CASE</i>	<i>LOWER LEG MOTION AT ANKLE CROSS</i>	<i>LOWER LEG ROTATIONAL SPEED AT ANKLE CROSS</i>	<i>UPPER LEG MOTION AT FULL LEG FLEXION</i>
Ih	53.1609	1339.07165	243.674
Ii	52.6332	976.82625	241.2179
Ij	47.05955	1144.3874	243.1663
Ik	56.2795	1208.17265	231.11925
Il	56.59465	1095.8442	244.20245
Ila	53.29665	888.7249	239.8676
Ilb	52.6473	939.49635	242.1036
Ilc	46.33915	987.02895	252.08775
Ild	42.1606	1005.89065	239.98535
Ile	46.8715	1190.54055	241.33115
IIf	50.6081	913.4726	240.0715
Ilg	51.47355	942.6684	239.5906
IIh	46.706	1022.69165	240.5062
IIi	20.86065	1287.7787	240.01375
IIj	52.5186	806.05775	254.1098

Chart 17. Lower Leg Rotational Speed at Ankle Cross.

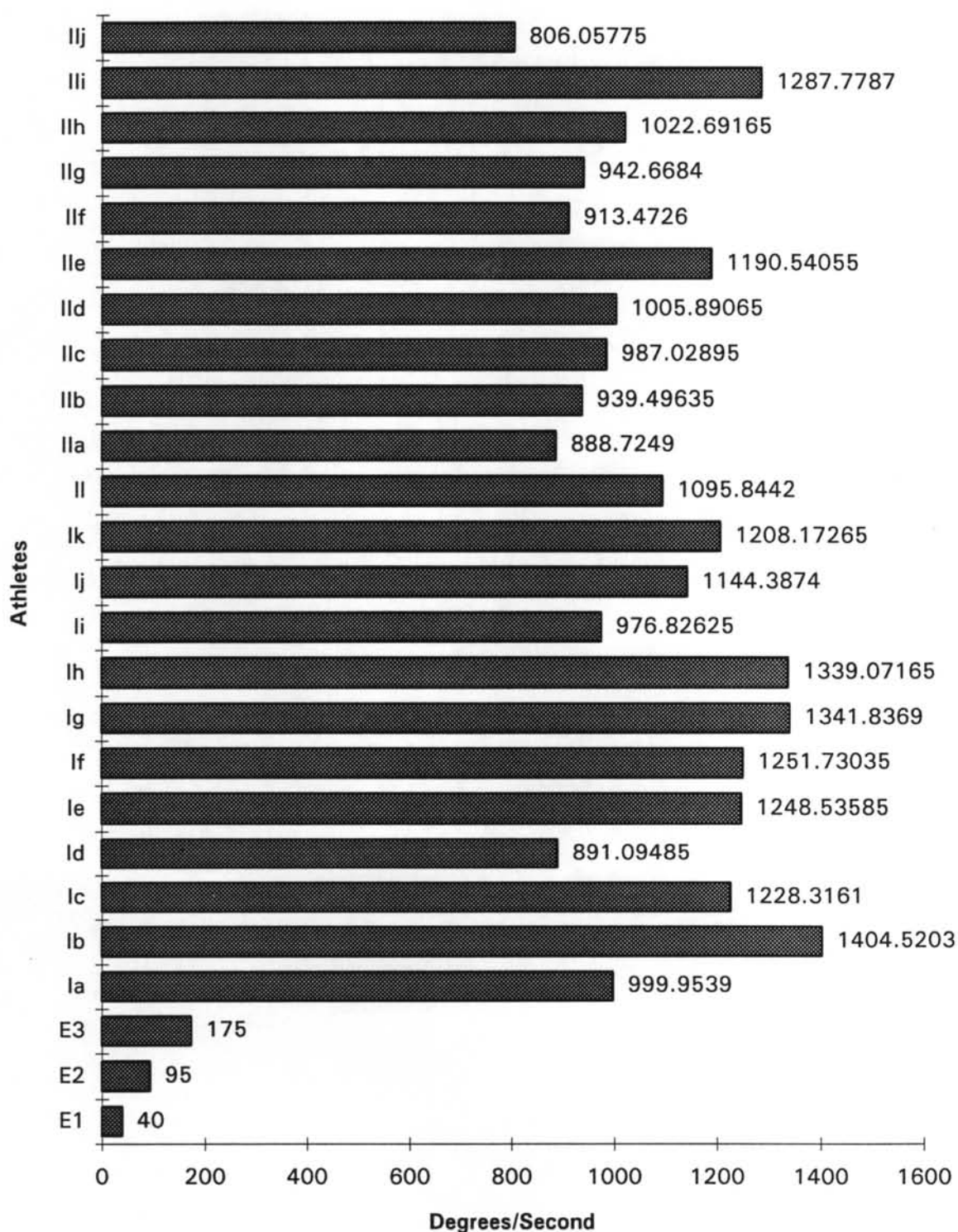
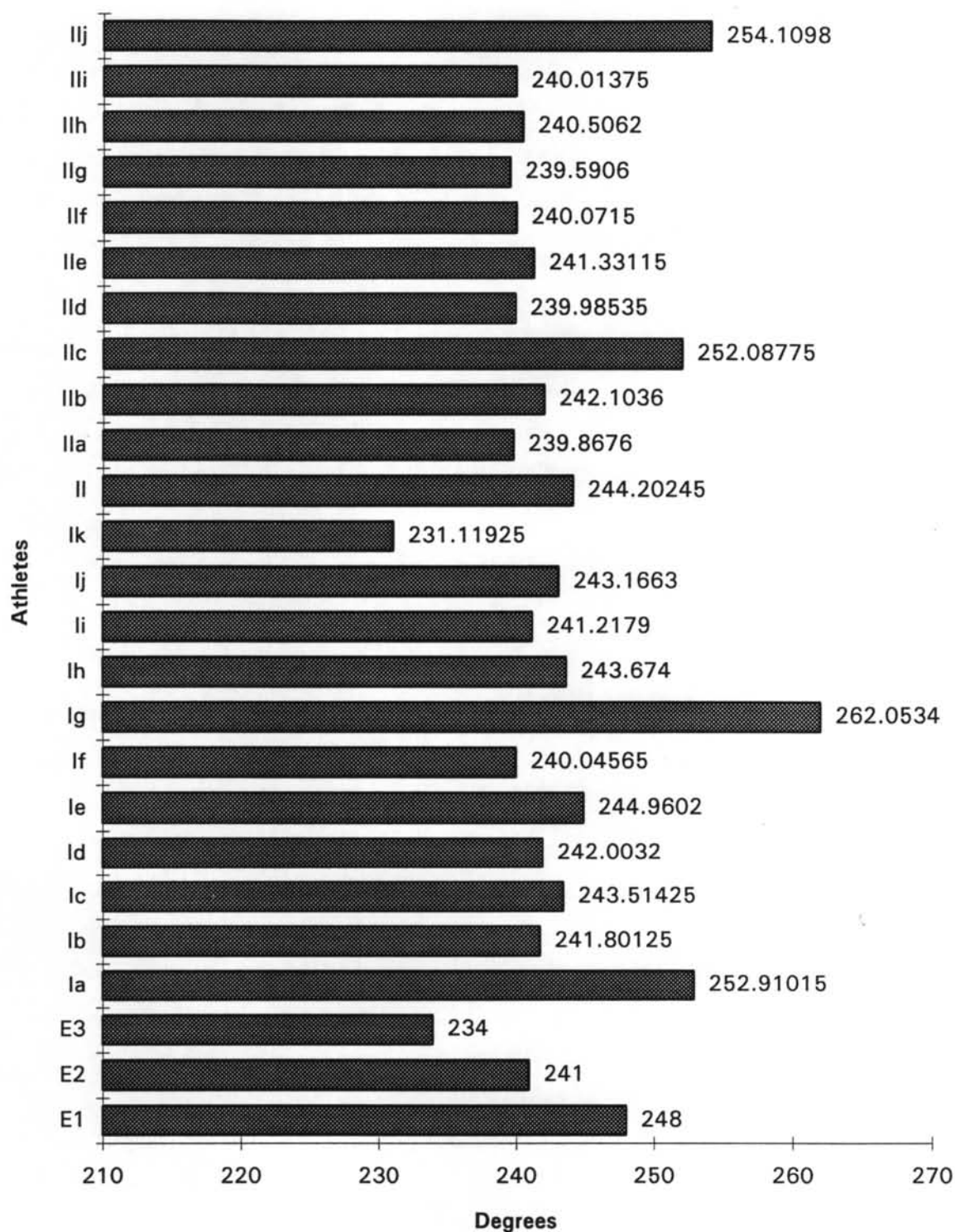


Chart 18. Upper Leg Motion at Full Leg Flexion.



Discussion

Limitations of Evaluations

It is important to note that Mann's elite data (1992) is not *directly* comparable with the results of another filming at the maximal speed section of a sprint. This limitation exists for several reasons. First, Mann's films were taken during actual races where environmental and other conditions are subject to change. Second, he films not at the beginning of the maximal speed phase, but later in that phase of the race. Third, it is not clear what analysis procedure Mann used in the preparation of his data (1992).

It would not necessarily be productive to take extraordinary measures to attempt to duplicate Mann's exact filming procedure. Even if the conditions were perfectly matched, the resulting information would not have significantly more value. Mann (1992) himself mentions his data should be used only as a descriptive tool (1992). Tupa et al. (1991) profess that taking averages of elite runners is only the "simplest solution to the problem of what is effective technique" (Tupa et al., 1991). It is, therefore, not advisable to assume that the elite averages are what is ideal for any one runner.

The applicability of Mann's work (1992) in a comparison with any specific filming of runners is contestable. If the nature of his data is kept in mind, however, some useful observations can result. These observations need to be circumspect. A drop in performance level of one indicator is not necessarily significant. Useful information is obtained by evaluating a number of parameters together.

In the case of the Lady Volunteer data, the LSA, LST, and USR were all "off the scale." It is possible that these occurrences are a sign of something radically different in the style of the Lady Vols and the "typical" elite runner. It is also, however, possibly a result of data collection technique, analysis procedure, or even technical error. Since the results of evaluating these parameters with respect to a radically dissimilar set of elite data would be problematic at best, it was decided to omit these factors in the overall evaluation. The remainder of the parameters still provide good technical insight.

Descriptors and Indicators

The general performance descriptors are not very helpful in pinpointing specific technique errors. They can, however, be valuable in identifying general areas that must be improved. The two most common signs seen here are a large imbalance in performance level of SR and SL and an imbalance in performance level of GT and

AT. Imbalances in SR and SL performance level do not necessarily show something is wrong; different runners use different techniques successfully. A relatively large imbalance, however, should at least be considered a warning sign. Excessive SL could mean that the athlete is overstriding, while excessive SR may mean that the athlete is inefficient in her striding technique. An imbalance in the rating of GT and AT is also a sign that something *may* be wrong. Low performance in one of these parameters suggests inefficiency of technique. An excessive GT could imply that a large braking action occurs at TD probably due to poor TD mechanics, or a large GT could demonstrate that there is a lack of power generation or maintenance. An excessive AT might suggest poor lower leg motion in phase III due to any number of factors, while a short AT could imply poor phase I and/or II mechanics. These descriptors, although their specific illustrative value is limited, aid in the overall comprehension of the sprinting motion.

Each phase or subphase contains information regarding mechanics and efficiency. Supporting phase indicators primarily suggest strengths and weaknesses in touchdown mechanics and power performance. A warning flag on GT will usually point to this phase. Driving phase indicators suggest strengths or weaknesses in body mechanics at takeoff and reflect strengths or weaknesses from phase I. Reclamation indicators suggest strengths or weaknesses in early restoring phase mechanics and

reflect strengths or weaknesses from previous phases. Preparation indicators suggest strengths or weaknesses in restoring mechanics as well as predict effectiveness of phase I mechanics.

The indicators in each phase should not carry much weight individually. Just because a runner's UST is high does not necessarily mean that the athlete's touchdown mechanics are a strength. Useful insight is gained only by combining observations from various phases and subphases to get an overall picture of what could be happening and how to improve it. Typical types of information collected from the assorted indicators are as follows: a sprinter's FS, FD, UMT, and LMT are all below the E3 performance level. The FS and FD ranking suggests a weakness in touchdown biomechanics. The UMT and LMT performance is possibly due to the athlete "rushing" through the driving phase in an attempt to compensate for lost time in the supporting phase. This athlete might have low ranking subphase IIIa mechanics as a result of the leg positioning at takeoff, etc. Each phase helps shed light on all the others.

Conclusions

The utilization of elite averages appears to be a useful tool in evaluating the biomechanical performance of the sprinter. The various descriptors and indicators give insight into the strengths and weaknesses of the athlete. The indicators in most of the cases in this study seem to point to the conclusion that a successful performance in the maximal speed section of the short sprint requires the athlete's ability to get through the supporting phase as quickly as possible. This is achieved through a high FS, a low FD, and the ability to generate great explosive power.

Deshon and Nelson (1964) bring up a significant point, however. It is entirely possible that the aforementioned characteristics of sprint running do not necessarily produce fast running by themselves; they are only indicators of an ideal technique. An athlete should not, in an effort to improve performance, simply be told to raise their knees higher or stride longer unless the coach first understands the underlying principles and weighs the consequences. Before action is taken in training, the observations obtained need to be carefully examined, for the evaluation of the athlete's technique by comparison to elite averages is not proven as a method for developing successful training strategy. A better model of ideal technique is needed; perhaps several, one for each body type and style of runner.

Recommendations for Further Research

This project has designed a pathway to be followed at the University of Tennessee in advising the Track and Field Department and to be used in developing models for optimal sprint performance specific to body type. Those following up on this project could film the track team several times throughout the year to provide feedback on current training techniques and their effectiveness while simultaneously identifying development tasks specific to the individual and tracking that individual's progress. Ideally, the program would have a system set up by which athletes get immediate data regarding their efforts. Such a program would keep drills at a sharper level because the athlete would hesitate to "slack off" on technique since the system could immediately offer feedback. The comparison of running parameters with elite averages does seem to be useful. If the benefit of direct comparison of biomechanical data is desired, however, a better model is needed. Realizing that it is important to distinguish characteristics indicative of the different body types when attempting to develop models of ideal technique, a more useful system could be made up of multiple models, each specific to a certain body type and style. A. Levchenko (1990) served as the inspiration for this system by suggesting the following guideline: tall women (170-180 cm) are better off with a long stride and relatively slow tempo

(height/SL>1.22); women 160-168 cm tall are better off utilizing "power running," a style with a shorter stride and faster tempo (height/SL=1.12-1.16).

Determining which model to emulate involves identifying each particular athlete's natural tendencies. Kunz and Kaufmann (1983) advise that the height of the athlete is an indication of their optimum running style, suggesting guidelines similar to Levchenko (1990). It is probably more accurate, however, to consider leg length rather than height. In either case, it is necessary to remember these values should serve as only one indication. Kunz and Kaufmann (1983) believe the optimal relationship of SL and SR depends on the athlete's crural index (calf length-thigh length ratio) and on their explosive power.

Just after full leg flexion, the "whipping out" of the shin occurs. Tupa et al. (1991) presents this action as a subject of a major controversy. The majority believes that extensive energy expended in the whipping out is to be avoided because too much energy is needed to stop the shin. Exaggerated whipping causes a stumbling at touchdown which relates to a loss of velocity of the CG. A minority holds, however, that extensive whipping is good since it stretches leg extensors, which allows better use of their elastic qualities approaching touchdown. This aspect of performance should be investigated further.

There are currently two philosophies regarding the short sprint. One is to reach maximum velocity as soon as possible and thus depend on speed endurance to carry the runner to victory. The other (as demonstrated by Florence Griffith-Joyner) is to delay acceleration and thus reach maximum velocity at a later stage, lessening the need for speed endurance (Jarver, 1990). The advantages of both techniques need to be examined further.

The principles behind the SL:SR ratio studies need to be examined and included in the evolution of development and training. Currently, Mann (1992) believes that the overall best performance is given by a high SR and moderate SL. Unfortunately, SR is not improved easily. Torim (1983) believes stride frequency is best improved between the ages of 7 and 11. After that, he claims it is practically impossible (Torim, 1983). But Levchenko (1990) holds that increasing one's stride rate is the most common way of increasing running speed. McFarlane (1985) speaks of improving stride length, however, by developing muscular power and proper running technique. A. J. Gibson (1983) suggests the need to investigate dynamic flexibility to increase SL. While static flexibility relates to the ease of movements at extremes of the range of motion, dynamic flexibility relates to the middle range. An increase in mobility could result in a longer stride with no reduction in stride rate.

Acknowledgements

"Everything that can be measured instrumentally should be compared with the opinions of experts and specialists, whose experience and intuition are often indispensable."

--Tupa et al., 1991

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Appendix A: Individual Case Evaluations

Note: In these case evaluations, the words "above" and "below" refer to performance level, **NOT** to the relation between numerical values.

Section I -- *Sprinters*

Case #Ia: Kim Townes

General Performance Descriptors

Ia ranks well in this category. HV, SR, SL, GT, and AT are all just at or above E2 levels. This could be an indication that Ia's technique is effective and that improvement is a matter of tinkering, perhaps with the SR:SL ratio rather than addressing a particular problem.

Supporting Phase Indicators

Ia has a weakness in this category. FS is below E3. FD is also low in ranking. These seem to suggest that Ia might have a problem with an excessive braking force. UST is above E2, however. USP is just below E2. These two results suggest that Ia attempts to compensate for poor performance in the FS and FD categories with a large UST. Since the performance level of this runner's rotational leg speed drops over this phase, the power of this athlete seems to be not quite enough to compensate for a poor performance of the foot at touchdown.

Driving Phase Indicators

Ia is not strong in this category. UMT and LMT are both below E2. This further strengthens the indication that Ia is not efficiently compensating for a poor FS and FD rating, and that this runner has difficulty regaining her leg rotation.

Restoring Phase: Reclamation Indicators

Ia is about average in this category. UME is below E2. LMF is above E1 level. The lower performance level shown for UME probably reflects residual effects from the rotational problems during phases I and II.

Restoring Phase: Preparation Indicators

LMA is above E2 level. UMF is above E1. These data seem good, but perhaps the exaggerated angle of leg flexion could partially cause the problems at touchdown discussed earlier.

Case #Ib: Tonya Lee

General Performance Descriptors

This athlete seems to be performing well. HV is above E2 level. SR is above E1. SL is above E2. However, it seems that Ib's timing is not on target. GT is below E2. AT is short of the E1-E2 range. AT being too short implies that SL is below optimum level for this athlete. Performance might improve with a slightly increased SL.

Supporting Phase Indicators

FS is above E1. FD is above E2. UST is just above E2. USP is just under E2 level. These data indicate that this athlete is not powerful enough to sustain a high level performance through this phase. Ib starts off well, but falls in performance level approaching TP.

Driving Phase Indicators

UMT is well above E1. LMT is just at E3 level. Ib seems to extend her takeoff leg too much, thereby doing non-productive work.

Restoring Phase: Reclamation Indicators

UME is below E3 level. LMF is above E2. Although this athlete compensates for the lower-level LMT performance, that compensation evidently adversely affects Ib's UME performance. Rectifying the lower leg positioning here seems to be possible only at the expense of other performance levels.

Restoring Phase: Preparation Indicators

LMA is at E2 level. UMF is just above E2 level. By this time, the runner recovers her level of performance, but perhaps at the cost of being inefficient.

Case #Ic: Leslie Henley

General Performance Descriptors

HV is above E1 level. SR is well above E1 level. SL is above E2 level. GT is at E2 level. AT is short of the E1-E2 range. Again, AT short of optimum indicates an increased SL is needed.

Supporting Phase Indicators

FS is well above E1 level. FD is above E1 level. UST is above E1 level. USP is just at E3 level. These data suggest that the athlete does not have sufficient power to maintain a high level of performance through this phase. Improving power would tend to improve GT level by shortening it.

Driving Phase Indicators

UMT is just below E2 level. LMT is just above E1 level. Ic has good lower leg performance in this phase. The upper leg performance also seems to be satisfactory, but would probably increase in ranking if the athlete became more powerful.

Restoring Phase: Reclamation Indicators

UME is just above E2 level. LMF is just above E2 level. Again, an increase in power might improve UME.

Restoring Phase: Preparation Indicators

LMA is just above E3 level. UMF is just above E2 level. Ic seems to kick out the shin too soon in the subphase. Delaying the extension should increase AT and therefore SL, and that change should effect overall improvement in performance.

Case #Id: Stehpanie Fields

General Performance Descriptors

HV is just at E1 level. SR is just under E1 level. SL is above E1 level. GT is above E3 level. AT is just short of optimum range. These data suggest good overall performance. GT might improve if power could be increased.

Supporting Phase Indicators

FS is above E1 level. FD is far below E3 level. UST is above E1 level. USP is above E1 level. These data are surprising; Id is able to maintain excellent rotational leg speed despite a significant braking action due to the

long FD. This suggests power is not the real problem, and simply shortening the FD would shorten GT and effectively increase performance.

Driving Phase Indicators

UMT is below E3 level. LMT is above E3 level. Perhaps this athlete sacrifices necessary GT in this phase to make up for lost time in phase I. Shortening FD should free up a little extra GT that could be used to obtain good leg extension and thus a more effective push-off in this phase.

Restoring Phase: Reclamation Indicators

UME is above E3 level. LMF is above E3 level. These data could be showing residual effects from the excessive power exerted during ground contact. Sufficient time is not allowed for UME to be optimized. The time freed up by shortening GT could allow for a supposedly beneficial lengthening of AT. Also, perhaps a tighter flexion at the knee could be beneficial.

Restoring Phase: Preparation Indicators

LMA is below E3 level. UMF is just above E2 level. Knee flexion still needs attention; perhaps if LMF were improved, LMA would improve as well.

Case #1e: Marvena Almond

General Performance Descriptors

HV is above E1 level. SR is just below E2 level. SL is well above E1 level. GT is at E2 level. AT is in range at upper E3 level. These data point to an effective performance. However, the following data suggest possible improvements.

Supporting Phase Indicators

FS is well above E1 level. FD is well above E1 level. UST is above E2 level. USP is below E3 level. These data suggest a lack of sufficient power to sustain a high level of performance through this phase.

Driving Phase Indicators

UMT is above E2 level. LMT is just below E2. This LMT suggests this athlete is doing non-productive work in over-extending the knee at takeoff. Increased power might improve UMT level.

Restoring Phase: Reclamation Indicators

UME is above E3. LMF is just below E2. The drop of performance level of the upper leg exhibited by the UME again suggests a relatively low power performance. Also, increased flexion at the knee could perhaps lower AT, allowing faster restoration of the swing leg due to a decreased moment of inertia about the hip.

Restoring Phase: Preparation Indicators

LMA is above E3 level. UMF is above E2. An improved LMF might improve LMA, but it still appears that he tries to extend the knee too early in this phase. Perhaps increasing UMF would allow for a higher power performance in phase I.

Case #If: Cheryl Finley

General Performance Descriptors

HV is above E3 level. SR is just above E2 level. SL is well below E3 level. GT is above E2 level. AT is in optimum range. These data show that there is probably a problem with the SL:SR relation.

Supporting Phase Indicators

FS is above E2 level. FD is above E2 level. UST is above E1 level. USP is well above E1 level. These data suggest good performance in this phase.

Driving Phase Indicators

UMT is above E1 level. LMT is above E1 level. These data suggest good performance in this phase.

Restoring Phase: Reclamation Indicators

UME is above E1 level. LMF is below E3 level. The small degree of lower leg flexion results in inefficient swing leg restoration.

Restoring Phase: Preparation Indicators

LMA is below E3 level. UMF is just below E2 level. Improving LMF and LMA performance could shorten AT, so perhaps an improvement in UMF (i.e., extra flexion) would counterbalance this effect and keep AT in the optimum range. This change would result in a longer SL, which could benefit overall performance.

Case #Ig: Dedra Davis

General Performance Descriptors

HV is above E1. SR is above E2. SL is well above E1. GT is at E1 level. AT is in range at upper E3 level. These data suggest good overall performance.

Supporting Phase Indicators

FS is well above E1. FD is above E2. UST is above E3. USP is well below E3. These data suggest a lack of power in the phase.

Driving Phase Indicators

UMT is above E3. LMT is above E3. The level of these data could be reflecting the relatively low power performance.

Restoring Phase: Reclamation Indicators

UME is above E2. LMF is just below E2. Increasing flexion at the knee might result in a beneficial shortening of AT.

Restoring Phase: Preparation Indicators

LMA is just above E2. UMF is well above E1. Perhaps, this UMF performance is too much. It might be a sign that the athlete is attempting to compensate for low power-generating ability. Lessening the extent of flexion coupled with an improvement in power could improve overall performance.

Case #Ih: Saidah Jones

General Performance Descriptors

HV is above E1. SR is above E1. SL is above E1. GT is at E2. AT is short of optimum range. These data suggest good overall performance.

Supporting Phase Indicators

FS is above E1. FD is well below E3. UST is above E2. USP is above E2. This athlete is able to sustain a relatively high level of performance through this phase despite a long FD. Shortening FD might show significant improvement through this phase.

Driving Phase Indicators

UMT is above E2. LMT is above E2. These data show relatively good performance.

Restoring Phase: Reclamation Indicators

UME is just above E3. LMF is below E3. The level of LMF performance would seem to lengthen AT. To compensate for this, it seems UME is not allowed to be optimized. Allowing full extension would increase AT and possibly allow a more beneficial push-off due to a longer "follow-through." AT could withstand a little lengthening; an increased LMF would tend to counteract this lengthening.

Restoring Phase: Preparation Indicators

LMA is just above E3. UMF is just below E2. The LMA suggests that this athlete is extending the knee too soon. The UMF also suggests a "rushing" to touchdown. Increasing the UMF would increase AT, perhaps into the optimum range. This change would result in a lengthened SL. This athlete, however, seems already to have an effective SL:SR ratio. Care must be taken in tampering with it.

Case #Ii: Michelle Bookman

General Performance Descriptors

HV is well above E1. SR is just above E1. SL is well above E1. GT is at E1. AT is just short of optimum range. These data suggest good overall performance.

Supporting Phase Indicators

FS is far above E1. FD is below E3. UST is far above E1. USP is far above E1. These data suggest this athlete is able to sustain a high level of performance throughout this phase despite a long FD.

Driving Phase Indicators

UMT is at E3. LMT is just below E2. These data suggest that the athlete is rushing through this phase. Decreasing FD might free up some time to allow for this phase to be optimized while maintaining the high level of the GT.

Restoring Phase: Reclamation Indicators

UME is below E3. LMF is above E1. The upper leg performance in this phase could be a result of the "rushing" of phase II. A good LMF is attained, though.

Restoring Phase: Preparation Indicators

LMA is above E3. UMF is at E2. These data suggest that this athlete extends the knee too soon. Correcting for this, however, might result in an increased AT and thus an increased SL. Care must be taken here not to overstride.

Case #Ij: Tisha Prather

General Performance Descriptors

HV is above E1. SR is well above E1. SL is above E1. GT is above E2. AT is short of optimum range. These data suggest good overall performance.

Supporting Phase Indicators

FS is above E1. FD is above E2. UST is just above E1. USP is above E3. These data suggest a lack of sufficient power to sustain a high level of performance throughout this phase. This was reflected also, perhaps, by the GT.

Driving Phase Indicators

UMT is above E3. LMT is just below E2. These data suggest a rushing of this phase, perhaps due to the trouble of sustainment in phase I.

Restoring Phase: Reclamation Indicators

UME is above E3. LMF is just above E3. Again, the relatively low level of performance in this phase could be the result of phase I trouble.

Restoring Phase: Preparation Indicators

LMA is above E2. UMF is above E2. These data show an improvement over the previous adverse effects. This athlete might need to increase UMF. This change would result in an increased AT, allowing it to approach optimum range. Also, the increase might result in more effective power application in phase I.

Case #Ik: Ruyika Foster

General Performance Descriptors

HV is above E1. SR is above E1. SL is above E1. GT is at E1. AT is in optimum range. These data suggest good overall performance.

Supporting Phase Indicators

FS is well above E1. FD is at E1. UST is well above E1. USP is well above E1. These data also suggest good overall performance.

Driving Phase Indicators

UMT is above E3. LMT is above E3. These data possibly show a weakness, rushing, in this phase.

Restoring Phase: Reclamation Indicators

UME is well below E3. LMF is at E2. The existence of the continued lower level of upper leg performance could indicate that phase II should be increased slightly to further improve efficiency of the push-off.

Restoring Phase: Preparation Indicators

LMA is just below E3. UMF is just below E3. These data suggest that the athlete extends the knee too soon. Perhaps increasing knee flexion throughout this phase and increasing the UMF to balance the change in AT would result in improved performance.

Case #II: Sue Walton

General Performance Descriptors

HV is above E1. SR is just above E1. SL is far above E1. GT is at E2. AT is just short of optimum range. These data suggest good overall performance. The excessive stride length needs to be examined, however.

Supporting Phase Indicators

FS is well above E1. FD is below E3. UST is above E2. USP is far above E1. These data suggest, surprisingly, that the runner can more than compensate for a poor FD.

Driving Phase Indicators

UMT is below E3. LMT is just below E2. These data suggest that the athlete rushes through this phase. Perhaps shortening FD could allow some extra time to fully optimize leg position at takeoff.

Restoring Phase: Reclamation Indicators

UME is below E3. LMF is above E3. These data are probably a result of rushing through phase II.

Restoring Phase: Preparation Indicators

LMA is below E3. UMF is above E2. These data indicate the runner extends the knee too soon. Perhaps an improved flexion at the knee could shorten AT and thus SL a bit. This change might result in a smaller FD and improved overall performance.

Section II -- Distance Runners

Case #IIa: Amanda Gillam

General Performance Descriptors

HV is above E3. SR is just above E3. SL is above E2. GT is at E3. AT is in optimum range. These data suggest an inefficient use of GT.

Supporting Phase Indicators

FS is just above E1. FD is just below E2. UST is above E3. USP is above E1. These data suggest that the athlete is able to compensate well for a low UST and slightly high FD. But since GT is rather long, it seems the compensation is inefficient.

Driving Phase Indicators

UMT is at E3. LMT is just above E3. These data suggest that IIa is rushing through this phase. Perhaps improving UST would allow time previously wasted in phase I to be used to optimize takeoff.

Restoring Phase: Reclamation Indicators

UME is just below E2. LMF is well below E3. The datum for the UME is possibly a result of an inefficient ground phase. The LMF is low, perhaps due to the fact that IIa is a distance runner. Increasing knee flexion in a distance runner's case is perhaps not advisable.

Restoring Phase: Preparation Indicators

LMA is just above E3. UMF is above E2. These data seem rather good considering the level of LMF.

Increased sprint performance might result from increased knee and leg flexion, but perhaps at an endurance cost that a distance runner might not want to pay.

Case #IIb: Celeste Susnis

General Performance Descriptors

HV is at E3. SR is just above E3. SL is above E2. GT is well below E3. AT is short of optimum range. This athlete also seems to use GT inefficiently.

Supporting Phase Indicators

FS is above E2. FD is well below E3. UST is well below E3. USP is above E3. FD and UST are clearly problem areas in this phase. Possibly, the obstacle here is low power exertion.

Driving Phase Indicators

UMT is above E3. LMT is above E3. The low level of performance shown by this data is probably because this athlete is rushing through this phase due to wasted time in the supporting phase.

Restoring Phase: Reclamation Indicators

UME is just above E3. LMF is well below E3. Again, this data might be an indirect result of poor phase I efficiency.

Restoring Phase: Preparation Indicators

LMA is just above E3. UMF is just above E2. Increasing UMF might increase the power applied in phase I, but it might also increase FD.

Probably the best thing for this athlete to do is to improve power to allow for more efficient use of GT.

Case #IIc: Laura Haynes

General Performance Descriptors

HV is above E3. SR is above E3. SL is above E3. GT is below E3. AT is short of optimum range. These data suggest an inefficient use of time.

Supporting Phase Indicators

FS is above E3. FD is just below E3. UST is above E3. USP is below E3. Possibly, more power is needed to keep this phase from being sluggish.

Driving Phase Indicators

UMT is just above E1. LMT is above E3. Perhaps more efficient use of power here could be realized here by not over-extending the knee.

Restoring Phase: Reclamation Indicators

UME is above E2. LMF is above E3. The UME could be improved by a more efficient phase I and II.

Restoring Phase: Preparation Indicators

LMA is above E3. UMF is above E1. These data indicate an acceptable performance for a distance runner. Perhaps knee extension could be delayed a bit longer.

Improving power generation ability is recommended for this athlete.

Case #IId: Sara Fieweger

General Performance Descriptors

HV is just above E2. SR is above E2. SL is just below E1. GT is at E3. AT is in optimum range. These data suggest an inefficient use of GT.

Supporting Phase Indicators

FS is below E3. FD is well below E3. UST is far below E3. USP is well above E1. This athlete can compensate well for poor foot performance at TD.

Driving Phase Indicators

UMT is above E3. LMT is below E3. These data suggest the athlete is rushing through this phase in an effort to compensate for time lost in phase I.

Restoring Phase: Reclamation Indicators

UME is above E3. LMF is just above E2. These data could indirectly result from an inefficient phase I performance.

Restoring Phase: Preparation Indicators

LMA is just above E2. UMF is just below E2. Perhaps increasing UMF could result in a more effective foot performance at TD.

It seems this athlete delays application of power in phase I. An increase in leg rotational speed prior to touchdown could alleviate some phase I inefficiency problems.

Case #IIe: Katrice Malcolm

General Performance Descriptors

HV is above E3. SR is above E1. SL is below E3. GT is above E3. AT is short of optimum range. These data suggest an inefficient use of time perhaps due to an SR/SL ratio.

Supporting Phase Indicators

FS is just above E1. FD is just above E1. UST is above E3. USP is far below E3. This athlete cannot compensate for slow UST. Accelerating the thigh earlier or faster seems to be indicated.

Driving Phase Indicators

UMT is just above E2. LMT is below E3. These data probably result from rushing this phase due to lost time in phase I.

Restoring Phase: Reclamation Indicators

UME is above E2. LMF is above E2. Again, these data might be improved with an improved phase I performance.

Restoring Phase: Preparation Indicators

LMA is just below E2. UMF is at E2. An increased UMF might allow for a more effective UST. This change would also increase AT, which would result in an increased SL and possibly in an improved SR/SL ratio.

Case #IIIf: Cindy O'Bryant

General Performance Descriptors

HV is just below E2. SR is just below E2. SL is far above E1. GT is above E3. AT is short of optimum range. These data suggest an inefficient use of GT. The possibility of overstriding must also be examined.

Restoring Phase: Reclamation Indicators

UME is just below E3. LMF is well below E3. Again, these data might be improved with an improved phase I performance.

Restoring Phase: Preparation Indicators

LMA is just above E3. UMF is just below E2. UMF should be increased to allow for more time for the landing leg to accelerate.

The best recommendation for this athlete to improve sprinting performance is to increase leg and foot speed at TD. Increasing power-generating ability could result in that change.

Case #IIh: Jennifer Brewer

General Performance Descriptors

HV is above E3. SR is above E3. SL is above E2. GT is below E3. AT is just short of optimum range. These data suggest inefficient use of time.

Supporting Phase Indicators

FS is above E1. FD is above E3. UST is just above E2. USP is above E3. The performance level of leg speed drops throughout this phase due to a long FD.

Driving Phase Indicators

UMT is above E3. LMT is just above E1. The low level of upper leg performance in this phase is possibly due to the rushing effect mentioned earlier.

Restoring Phase: Reclamation Indicators

UME is above E3. LMF is just below E2. Again, these data might be improved with an improved phase I performance.

Restoring Phase: Preparation Indicators

LMA is above E3. UMF is just below E2. As in the case of athlete IIg, the UMF should be increased to allow for more time for the landing leg to accelerate.

The best recommendation for this athlete to improve sprinting performance is to increase leg and foot speed at TD. Increasing power-generating ability could result in that change.

Case #Ili: Lynne Collazo

General Performance Descriptors

HV is above E3. SR is just below E3. SL is well above E3. GT is below E3. AT is longer than optimum range. These data suggest inefficient use of time, especially AT. It seems this athlete could be overstriding.

Supporting Phase Indicators

FS is above E1. FD is above E1. UST is just below E1. USP is above E1. These data suggest good performance in this phase.

Driving Phase Indicators

UMT is below E3. LMT is well below E3. These data suggest that the athlete is rushing this phase. Since GT is long, however, it is possible that Ili simply does not effectively apply leg power from phase I through phase II to takeoff.

Restoring Phase: Reclamation Indicators

UME is well below E3. LMF is well above E1. The low level performance of the upper leg here is a result of poor takeoff technique. The combination of a large UME and long AT suggests that the angle of takeoff is excessively steep.

Restoring Phase: Preparation Indicators

LMA is well above E1. UMF is just below E2. These data suggest good performance in this subphase.

This athlete needs to improve takeoff technique. This might be accomplished by practicing the timing of phase II. An improved takeoff might also result in a more efficient use of AT. Perhaps, then, this athlete's apparent problem of overstriding could be rectified.

Case #IIj: Michelle Reasor

General Performance Descriptors

HV is above E3. SR is just below E2. SL is above E3. GT is at E2. AT is in optimum range. These data suggest a small inefficiency in the use of GT.

Supporting Phase Indicators

FS is just below E1. FD is above E2. UST is far above E1. USP is above E3. It seems this athlete does not apply sufficient power to sustain a high level of performance throughout this phase.

Driving Phase Indicators

UMT is above E3. LMT is above E3. These data are probably a result of rushing due to an inefficient phase I.

Restoring Phase: Reclamation Indicators

UME is above E3. LMF is well below E3. Again, these data might be improved with an improved phase I performance.

Restoring Phase: Preparation Indicators

LMA is above E3. UMF is above E1. These data suggest good performance for a distance runner in this phase, although delayed knee flexion might give improved results.

This runner should concentrate on power development to improve sprinting performance.

Appendix B: Data Listing

Filtered Coordinate Data

Computer software such as the Center of Gravity Analysis, Segment Angle Analysis, and Joint Angle Analysis programs in the Kansas State University Film Analysis System were used to process the raw coordinate data to printouts as displayed below:

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*****
*****
***                                     ***
***      CENTER OF GRAVITY ANALYSIS      ***
***                                     ***
*****
*****
Data for RIGHT FOOT [for example]

      COORDINATE      VELOCITY      ACCELERATION
No.  TIME  HORIZONTAL  VERTICAL  HORIZONTAL  VERTICAL  HORIZONTAL  VERTICAL
1   0.00   -17.1890   -0.0943
2   0.01   -16.7606   -0.2317    45.4760   -13.8421
3   0.02   -16.2795   -0.3711    51.1392   -14.1931   460.1964   -34.3467
4   0.03   -15.7378   -0.5156    56.3200   -14.4296   542.1975   -29.3749
      .
      .
      .
45  0.44    -2.4768    0.3282    49.5701   -15.5534   -36.7710   -366.6062
46  0.45    -1.9499    0.1323    55.4236   -18.3805    86.7599   -315.3124
47  0.46    -1.3765   -0.0709    62.5528   -19.4589
48* 0.47    -0.6986   -0.2543

[* Number of frames of data varies person to person.]
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The CGA program was used to report rectangular data concerning the CG of the following body segments: left and right feet, left and right calves, left and right thighs, total body.

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*****
*****
***
***          SEGMENT ANGLE ANALYSIS          ***
***
*****
*****

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Data for LEFT THIGH (for example)

No.	TIME	ANGLE (POSITION)	ANGLE (FUNCTION)	ANGULAR VELOCITY	ANGULAR ACCELERATION
1	0.00	151.7282	151.7282		
2	0.01	154.5851	154.5851	253.8578	
3	0.02	156.8053	156.8053	186.0787	-7763.2430
4	0.03	158.3037	158.3037	98.5929	-10011.3831
		.			
		.			
		.			
45	0.44	147.7074	147.7074	643.5117	-13188.9725
46	0.45	153.5115	153.5115	482.3890	-20947.7497
47	0.46	157.3552	157.3552	224.5567	
48*	0.47	158.0026	158.0026		

[* Number of frames of data varies person to person.]

The SAA program was used to calculate and to report data concerning the following body segments: left and right calf, left and right thigh. The values related correspond to the dorsal angle between a given segment and the horizontal (i.e., the "back," not the "front").

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***          JOINT ANGLE ANALYSIS          ***
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Data for LEFT HIP (for example)

No.	TIME	ANGLE (POSITION)	ANGLE (FUNCTION)	ANGULAR VELOCITY	ANGULAR ACCELERATION
1	0.00	151.7282	151.7282		
2	0.01	154.5851	154.5851	253.8578	
3	0.02	156.8053	156.8053	186.0787	-7763.2430
4	0.03	158.3037	158.3037	98.5929	-10011.3831
		.			
		.			
		.			
45	0.44	147.7074	147.7074	643.5117	-13188.9725
46	0.45	153.5115	153.5115	482.3890	-20947.7497
47	0.46	157.3552	157.3552	224.5567	
48*	0.47	158.0026	158.0026		

[* Number of frames of data varies person to person.]

The Joint Angle Analysis program was used to calculate and to report data concerning the following joints of the body: left and right hip, left and right knee. The values related correspond to the dorsal angle between the two adjacent body segments (i.e., the "back," not the "front").

Worksheets

Immediately following is a listing of data points input into the spreadsheet for the direct purpose of calculating the performance indicators.

BODY CONSTANTS						
	CASE		COMPUTER			
	NO.	NAME	CODE	HEIGHT	WEIGHT	MASS
				(inches)	(pounds)	(kg)
<i>sprinters</i>						
	1a	Kim Townes	KIM	66.5	138	62.44343891
	1b	Tonya Lee	TONYA	70	140	63.34841629
	1c	Leslie Henley	LESLIE	63.5	121	54.75113122
	1d	Stephanie Fields	STEPH	62	119	53.84615385
	1e	Marvena Almond	MRVENA	67	129	58.37104072
	1f	Cheryl Finley	CHERYL	62.5	123	55.6561086
	1g	Dedra Davis	DEDRA	65	140	63.34841629
	1h	Saidah Jones	SAIDAH	66.5	123	55.6561086
	1i	Michelle Bookman	MICHB	64	127	57.46606335
	1j	Tisha Prather	TISHA	66	124	56.10859729
	1k	Ruyika Foster	RUYIKA	59	112	50.67873303
	1l	Sue Walton	SUE	65.5	116	52.48868778
<i>distance runners</i>						
	IIa	Amanda Gillam	AMANDA	67	129	58.37104072
	IIb	Celeste Susnis	CLESTE	66	116	52.48868778
	IIc	Laura Haynes	LAURA	64	113.5	51.35746606
	IId	Sara Fieweger	SARA	65.5	119	53.84615385
	IIe	Katrice Malcolm	KTRICE	60.25	104.5	47.28506787
	IIf	Cindy O'Bryant	CINDY	65	121.5	54.97737557
	IIg	Megan Thompson	MEGAN	68	136	61.53846154
	IIh	Jennifer Brewer	JENI	65	120	54.29864253
	IIi	Lynne Collazo	LYNNE	69	125	56.56108597
	IIj	Michelle Reasor	MICHR	65.5	123	55.6561086

TOUCHDOWN							
	CASE			RIGHT FOOT			
	NO.	NAME	CODE	TIME	CGA XCOORD	CGA YCOORD	CGA VEL
<i>sprinters</i>							
	Ia	Kim Townes	KIM	0.15	-11.0827	-1.9708	4.5923
	Ib	Tonya Lee	TONYA	0.01	-14.5041	-2.037	-0.0115
	Ic	Leslie Henley	LESLIE	0.21	-6.1066	-1.9469	11.2826
	Id	Stephanie Fields	STEPH	0.36	-2.5059	-1.9075	11.1642
	Ie	Marvena Almond	MRVENA	0.24	-4.3156	-2.0272	5.2357
	If	Cheryl Finley	CHERYL	0.25	-8.3141	-1.9479	17.6521
	Ig	Dedra Davis	DEDRA	0.25	-4.7683	-2.0919	4.5774
	Ih	Saidah Jones	SAIDAH	0.02	-14.8235	-2.2775	5.4414
	Ii	Michelle Bookman	MICHB	0.35	-2.4622	-3.6427	-17.6153
	Ij	Tisha Prather	TISHA	0.02	-15.0537	-2.03005	4.7209
	Ik	Ruyika Foster	RUYIKA	0.11	-12.3609	-2.1055	3.0502
	Il	Sue Walton	SUE	0.37	-1.5255	-2.0742	4.8513
<i>distance runners</i>							
	Ila	Amanda Gillam	AMANDA	0.26	-8.3668	-1.9445	5.7539
	Ilb	Celeste Susnis	CLESTE	0.01	-16.6159	-1.9595	4.058
	Ilc	Laura Haynes	LAURA	0.26	-4.6362	-1.9578	10.0985
	Ild	Sara Fieweger	SARA	0.4	-1.7826	-1.8517	21.4273
	Ile	Katrice Malcolm	KTRICE	0.21	-5.3299	-1.945	12.4533
	Ilf	Cindy O'Bryant	CINDY	0.24	-5.4341	2.8051	30.4171
	Ilg	Megan Thompson	MEGAN	0.28	-7.4237	-1.9742	8.2747
	Ilh	Jennifer Brewer	JENI	0.01	-15.7576	-1.9819	2.9906
	Ili	Lynne Collazo	LYNNE	0.16	-11.4093	-1.6023	3.5406
	Ilj	Michelle Reasor	MICHR	0.26	-8.0845	-1.6639	6.2625

TOUCHDOWN						
	CASE		LEFT FOOT			
	NO.	NAME	TIME	CGA XCOORD	CGA YCOORD	CGA VEL
<i>sprinters</i>						
	la	Kim Townes	0.37	-3.2855	-1.7061	19.6295
	lb	Tonya Lee	0.21	-6.9872	-1.8572	16.0421
	lc	Leslie Henley	0.02	-13.493	-1.9747	1.8582
	ld	Stephanie Fields	0.15	-10.6425	-1.8085	9.1048
	le	Marvena Almond	0.01	-13.2983	-1.9878	-1.2179
	lf	Cheryl Finley	0.03	-13.6534	-3.2821	0.293
	lg	Dedra Davis	0.03	-13.5017	-1.8005	2.8671
	lh	Saidah Jones	0.22	-6.1429	-2.013	18.774
	li	Michelle Bookman	0.15	-11.2624	-1.9968	5.2765
	lj	Tisha Prather	0.21	-6.8588	-1.8691	11.4823
	lk	Ruyika Foster	0.31	-4.0019	-1.9929	4.4168
	ll	Sue Walton	0.15	-10.8313	-1.9524	4.6798
<i>distance runners</i>						
	lla	Amanda Gillam	0.01	-15.7838	-2.002	2.8215
	llb	Celeste Susnis	0.26	-9.0632	-1.8455	11.1339
	llc	Laura Haynes	0.03	-11.5797	-1.9711	10.1709
	lld	Sara Fieweger	0.18	-9.5053	-1.8857	10.8234
	lle	Katrice Malcolm	0.01	-11.9961	-1.8881	0.5391
	llf	Cindy O'Bryant	0.01	-14.7993	-2.0416	1.6583
	llg	Megan Thompson	0.01	-15.1628	-1.7274	9.6958
	llh	Jennifer Brewer	0.25	-8.3603	-1.7717	7.5706
	lli	Lynne Collazo				
	llj	Michelle Reasor	0.03	-15.1308	-1.6097	5.9115

TOUCHDOWN				
	CASE		BODY @ right TD	BODY @ left TD
	NO.	NAME	CGA X COORD	CGA X COORD
<i>sprinters</i>				
	la	Kim Townes	-11.9781	-4.2324
	lb	Tonya Lee	-14.7753	-8.1846
	lc	Leslie Henley	-6.9723	-13.7959
	ld	Stephanie Fields	-3.9172	-11.831
	le	Marvena Almond	-5.2323	-13.284
	lf	Cheryl Finley	-8.7987	-14.6069
	lg	Dedra Davis	-5.5242	-14.1463
	lh	Saidah Jones	-15.4299	-7.6842
	li	Michelle Bookman	-3.5516	-12.1362
	lj	Tisha Prather	-15.4899	-7.7969
	lk	Ruyika Foster	-12.7827	-4.8653
	ll	Sue Walton	-2.527	-11.761
<i>distance runners</i>				
	lla	Amanda Gillam	-9.1901	-16.566
	llb	Celeste Susnis	-17.5108	-10.5034
	llc	Laura Haynes	-5.6593	-12.5553
	lld	Sara Fieweger	-3.0591	-10.556
	lle	Katrice Malcolm	-6.1684	-12.3759
	llf	Cindy O'Bryant	-6.5943	-15.5481
	llg	Megan Thompson	-8.4331	-16.5108
	llh	Jennifer Brewer	-16.6037	-9.2583
	lli	Lynne Collazo	-12.4891	-----
	llj	Michelle Reasor	-8.7468	-15.935

TOUCHDOWN						
	CASE		RIGHT THIGH	LEFT THIGH	RIGHT CALF	LEFT CALF
	NO.	NAME	SAA VEL	SAA VEL	SAA VEL	SAA VEL
<i>sprinters</i>						
	la	Kim Townes	-399.0308	-292.9359	-550.5513	-353.998
	lb	Tonya Lee	-277.0241	-323.6559	-371.95	-287.513
	lc	Leslie Henley	-451.3873	-393.5376	-564.8657	-247.8676
	ld	Stephanie Fields	-414.6103	-399.4742	-610.1301	-601.1091
	le	Marvena Almond	-347.5025	-329.1527	-679.0327	-385.8419
	lf	Cheryl Finley	-472.916	-335.6689	-312.5049	-332.9639
	lg	Dedra Davis	-533.4428	7.7604	-677.8866	-452.3488
	lh	Saidah Jones	-269.8546	-422.1434	-348.2485	-315.6544
	li	Michelle Bookman	-514.1036	-422.4616	-1095.6506	-803.8448
	lj	Tisha Prather	-351.9261	-401.1034	-373.9625	-695.3879
	lk	Ruyika Foster	-512.3643	-438.1144	-832.9757	-755.9262
	ll	Sue Walton	-182.4276	-519.5562	-912.6173	-634.8599
<i>distance runners</i>						
	lla	Amanda Gillem	-408.9259	-159.0341	-478.5418	-258.2808
	llb	Celeste Susnls	-76.7711	-254.1491	-215.1871	-325.2615
	llc	Laura Haynes	-305.133	-165.6081	-344.7006	-58.3094
	lld	Sara Fieweger	102.0907	-373.9012	-33.004	-425.3649
	lle	Katrice Malcolm	-329.7518	-208.4168	-424.0526	-413.853
	llf	Cindy O'Bryant	-486.2257	-323.4993	6.9302	-245.7933
	llg	Megan Thompson	-419.4726	-80.3825	-388.7101	-43.1501
	llh	Jennifer Brewer	-278.3027	-290.3963	-202.3488	-585.5871
	lli	Lynne Collazo	-370.6921	-370.6921	-599.7356	-599.7356 no left data - stride too long
	llj	Michelle Reasor	-681.149	-287.9768	-458.9997	-279.1245

TRANSITION POINT								
	CASE			RIGHT THIGH	LEFT THIGH	TIME OF	TOTAL BODY	TOTAL BODY
	NO.	NAME	CODE	SAA VEL	SAA VEL	LAST FRAME	CG XCOORD LAST	CG XCOORD 1ST
<i>sprinters</i>								
	1a	Kim Townes	KJM	-406.3218	-406.3218	0.47	-0.768	-16.8763 right thigh only
	1b	Tonya Lee	TONYA	-433.6256	-433.6256	0.36	-2.353	-14.9689 right thigh only
	1c	Leslie Henley	LESLIE	-379.1019	-379.1019	0.33	-2.1566	-14.1769 left thigh only
	1d	Stephanie Fields	STEPH	-541.0616	-541.0616	0.41	-1.8796	-16.5663 left thigh only
	1e	Marvena Almond	MARVENA	-346.4776	-346.4776	0.37	-0.1957	-13.4848 left thigh only
	1f	Cheryl Finley	CHERYL	-540.0616	-692.5703	0.39	-3.3059	-15.5327 left thigh only
	1g	Dedra Davis	DEDRA	92.3763	92.3763	0.37	-0.3725	-14.775 left thigh only
	1h	Saidah Jones	SAIDAH	-442.4059	-442.4059	0.37	-1.3587	-15.827 right thigh only
	1i	Michelle Bookman	MICHB	-605.5458	-605.5458	0.37	-2.8453	-17.8624 left thigh only
	1j	Tisha Prather	TISHA	-413.816	-413.816	0.33	-2.6508	-15.9885 right thigh only
	1k	Ruyka Foster	RUYKA	-627.7044	-627.7044	0.4	-1.0543	-16.1952 right thigh only
	1l	Sue Walton	SUE	-647.6751	-647.6751	0.43	-0.2287	-16.8951 left thigh only
<i>distance runners</i>								
	1la	Amanda Gillam	AMANDA	-504.0484	-504.0484	0.4	-4.7926	-16.723 right thigh only
	1lb	Celeste Susnis	CLESTE	-425.7858	-425.7858	0.43	-5.2138	-17.6583 left thigh only
	1lc	Laura Haynes	LAURA	-357.3475	-357.3475	0.42	-0.07887	-13.0579 left thigh only
	1ld	Sara Fieweger	SARA	-552.855	-552.855	0.41	-2.7149	-16.0485 left thigh only
	1le	Katrice Malcolm	KTRICE	-113.2262	-113.2262	0.34	-1.8407	-12.5494 left thigh only
	1lf	Cindy O'Bryant	CINDY	-466.4281	-466.4281	0.38	-3.5174	-15.7128 left thigh only
	1lg	Megan Thompson	MEGAN	-344.2751	-344.2751	0.43	-3.5869	-16.6645 left thigh only
	1lh	Jennifer Brewer	JENI	-408.2093	-408.2093	0.39	-4.5396	-16.7514 right thigh only
	1li	Lynne Collazo	LYNNE	-520.7315	-520.7315	0.35	-6.4083	-16.8858 right thigh only
	1lj	Michelle Reasor	MICHR	-406.415	-406.415	0.39	-4.7827	-16.4577 left thigh only

TAKEOFF						
	CASE			RIGHT FOOT	RIGHT HIP	RIGHT KNEE
	NO.	NAME	CODE	TIME	JAA PSN ANG	JAA PSN ANG
<i>sprinters</i>						
	Ia	Kim Townes	KIM	0.25	187.2138	157.9892
	Ib	Tonya Lee	TONYA	0.12	192.1098	157.8154
	Ic	Leslie Henley	LESLIE	0.31	194.2242	153.5275
	Id	Stephanie Fields	STEPH	0.04	216.7196	168.2989
	Ie	Marvena Almond	MRVENA	0.34	185.267	155.065
	If	Cheryl Finley	CHERYL	0.34	169.1552	134.3772
	Ig	Dedra Davis	DEDRA	0.33	189.7985	160.5033
	Ih	Saidah Jones	SAIDAH	0.12	190.3666	156.8807
	Ii	Michelle Bookman	MICHB	0.04	209.8972	162.2959
	Ij	Tisha Prather	TISHA	0.11	191.556	150.1865
	Ik	Ruyika Foster	RUYIKA	0.19	193.2574	153.5375
	Il	Sue Walton	SUE	0.04	206.254	157.624
<i>distance runners</i>						
	Ila	Amanda Gillam	AMANDA	0.38	194.2335	163.5911
	Ilb	Celeste Susnis	CLESTE	0.16	191.0975	155.3945
	Ilc	Laura Haynes	LAURA	0.39	173.9437	158.4937
	Ild	Sara Fieweger	SARA	0.06	198.9896	169.5794
	Ile	Katrice Malcolm	KTRICE	0.32	190.8811	173.567
	Ilf	Cindy O'Bryant	CINDY	0.35	193.6981	154.9211
	Ilg	Megan Thompson	MEGAN	0.41	203.956	161.8447
	Ilh	Jennifer Brewer	JENI	0.14	194.5935	148.7585
	Ili	Lynne Collazo	LYNNE	0.29	202.8295	164.2221
	Ilj	Michelle Reasor	MICHR	0.36	201.1134	165.9648

TAKEOFF						
	CASE			LEFT FOOT	LEFT HIP	LEFT KNEE
	NO.	NAME	CODE	TIME	JAA PSN ANG	JAA PSN ANG
<i>sprinters</i>						
	la	Kim Townes	KIM	0.02	204.1426	163.8468
	lb	Tonya Lee	TONYA	0.15	120.2195	167.501
	lc	Leslie Henley	LESLIE	0.11	188.9347	146.074
	ld	Stephanie Fields	STEPH	0.26	184.64	147.7684
	le	Marvena Almond	MRVENA	0.11	195.516	158.3037
	lf	Cheryl Finley	CHERYL	0.13	181.5357	141.7455
	lg	Dedra Davis	DEDRA	0.12	199.009	159.238
	lh	Saidah Jones	SAIDAH	0.33	183.0379	154.7317
	li	Michelle Bookman	MICHB	0.23	186.1277	150.587
	lj	Tisha Prather	TISHA	0.3	201.2855	165.7223
	lk	Ruyika Foster	RUYIKA	0.39	193.7684	157.4633
	ll	Sue Walton	SUE	0.25	196.39	154.485
<i>distance runners</i>						
	lla	Amanda Gillam	AMANDA	0.14	201.0279	162.0074
	llb	Celeste Susnis	CLESTE	0.41	201.5372	165.9012
	llc	Laura Haynes	LAURA	0.16	190.2887	163.1481
	lld	Sara Fieweger	SARA	0.3	192.8051	166.1613
	lle	Katrice Malcolm	KTRICE	0.11	188.2479	163.0667
	llf	Cindy O'Bryant	CINDY	0.14	191.3254	149.5404
	llg	Megan Thompson	MEGAN	0.18	199.6664	154.7355
	llh	Jennifer Brewer	JENI	0.36	198.8537	151.8224
	lli	Lynne Collazo	LYNNE	0.02	213.8986	185.4153
	llj	Michelle Reasor	MICHR	0.14	192.1393	157.7045

FULL LEG EXTENSION					
	CASE			RIGHT HIP	LEFT HIP
	NO.	NAME	CODE	JAA PSN ANG	JAA PSN ANG
	-----	-----	-----	-----	-----
<i>sprinters</i>					
	la	Kim Townes	KIM	187.2138	204.4621
	lb	Tonya Lee	TONYA	196.7418	210.1727
	lc	Leslie Henley	LESLIE	194.9591	192.1178
	ld	Stephanie Fields	STEPH	204.6494	189.7366
	le	Marvena Almond	MRVENA	195.8657	196.8681
	lf	Cheryl Finley	CHERYL	185.9453	185.6211
	lg	Dedra Davis	DEDRA	187.0701	193.3196
	lh	Saidah Jones	SAIDAH	196.8209	200.0813
	li	Michelle Bookman	MICHB	207.8021	197.3689
	lj	Tisha Prather	TISHA	193.0986	205.4424
	lk	Ruyika Foster	RUYIKA	202.4	223.1058
	ll	Sue Walton	SUE	203.9907	200.1565
<i>distance runners</i>					
	lla	Amanda Gillam	AMANDA	194.2335	197.4738
	llb	Celeste Susnis	CLESTE	191.0975	207.3733
	llc	Laura Haynes	LAURA	185.6029	196.3236
	lld	Sara Fieweger	SARA	195.4367	196.5979
	lle	Katrice Malcolm	KTRICE	192.1541	188.633
	llf	Cindy O'Bryant	CINDY	193.45	192.6526
	llg	Megan Thompson	MEGAN	203.705	199.6664
	llh	Jennifer Brewer	JENI	196.4021	198.8537
	lli	Lynne Collazo	LYNNE	202.9206	212.7483
	llj	Michelle Reasor	MICHR	201.5342	194.8189

KNEE MAX FLEXION					
	CASE			RIGHT KNEE	LEFT KNEE
	NO.	NAME	CODE	JAA PSN ANG	JAA PSN ANG
<i>sprinters</i>					
	Ia	Kim Townes	KIM	23.6097	32.7628
	Ib	Tonya Lee	TONYA	30.5009	31.4279
	Ic	Leslie Henley	LESLIE	31.729	36.4626
	Id	Stephanie Fields	STEPH	40.7076	38.5801
	Ie	Marvena Almond	MRVENA	32.1802	37.4142
	If	Cheryl Finley	CHERYL	37.4477	52.5541
	Ig	Dedra Davis	DEDRA	36.3351	32.2872
	Ih	Saidah Jones	SAIDAH	36.2286	51.74
	Ii	Michelle Bookman	MICHB	32.7612	23.4124
	Ij	Tisha Prather	TISHA	34.9432	45.2723
	Ik	Ruyika Foster	RUYIKA	36.5616	33.3304
	Il	Sue Walton	SUE	31.6192	42.3164
<i>distance runners</i>					
	Ila	Amanda Gillam	AMANDA	51.3758	43.4855
	Ilb	Celeste Susnis	CLESTE	43.3023	50.17003
	Ilc	Laura Haynes	LAURA	39.0547	35.6591
	Ild	Sara Fieweger	SARA	27.7336	40.6911
	Ile	Katrice Malcolm	KTRICE	28.4876	35.6858
	Ilf	Cindy O'Bryant	CINDY	39.6883	43.0321
	Ilg	Megan Thompson	MEGAN	38.2674	55.4112
	Ilh	Jennifer Brewer	JENI	34.5228	34.5228 left knee only
	Ili	Lynne Collazo	LYNNE	20.8544	20.8544 left knee only
	Ilj	Michelle Reasor	MICHR	46.953	56.8466

RECOVERY						
	CASE			RIGHT THIGH	LEFT THIGH	
	NO.	NAME	CODE	SAA VEL	SAA VEL	
<i>sprinters</i>						
	la	Kim Townes	KIM	797.1491	671.0392	
	lb	Tonya Lee	TONYA	843.2951	695.2968	
	lc	Leslie Henley	LESLIE	710.1522	606.0677	
	ld	Stephanie Fields	STEPH	702.7091	702.7091	right thigh only
	le	Marvena Almond	MRVENA	700.5414	679.3232	
	lf	Cheryl Finley	CHERYL	539.8053	605.1207	
	lg	Dedra Davis	DEDRA	995.5484	628.4309	
	lh	Saidah Jones	SAIDAH	668.5783	1086.0987	
	li	Michelle Bookman	MICHB	551.903	551.903	right thigh only
	lj	Tisha Prather	TISHA	685.6315	689.372	
	lk	Ruyika Foster	RUYIKA	662.1784	620.4921	
	ll	Sue Walton	SUE	611.5402	510.9176	
<i>distance runners</i>						
	lla	Amanda Gillam	AMANDA	645.7033	621.8629	
	llb	Celeste Susnis	CLESTE	601.2773	637.3357	
	llc	Laura Haynes	LAURA	584.4923	706.8463	
	lld	Sara Fieweger	SARA	633.3162	418.8818	
	lle	Katrice Malcolm	KTRICE	551.2228	810.2824	
	llf	Cindy O'Bryant	CINDY	514.6545	617.0897	
	llg	Megan Thompson	MEGAN	761.9903	491.9844	
	llh	Jennifer Brewer	JENI	664.4412	664.4412	left thigh only
	lli	Lynne Collazo	LYNNE	639.9282	639.9282	left thigh only
	llj	Michelle Reasor	MICHR	672.0009	631.9518	

ANKLE CROSS								
	CASE			RIGHT KNEE	LEFT KNEE	RIGHT CALF	LEFT CALF	
	NO.	NAME	CODE	JAA PSN ANG	JAA PSN ANG	SAA VEL	SAA VEL	
<i>sprinters</i>								
	la	Kim Townes	KIM	45.8048	38.2855	999.9539	999.9539	left calf only
	lb	Tonya Lee	TONYA	42.7431	47.8266	1535.3041	1273.7365	
	lc	Leslie Henley	LESLIE	44.1908	61.0607	1257.5779	1199.0543	
	ld	Stephanie Fields	STEPH	50.8586	60.9005	1116.112	666.0777	
	le	Mervena Almond	MRVENA	45.6023	57.3811	1159.1166	1337.9551	
	lf	Cheryl Finley	CHERYL	53.6703	65.0105	1300.8532	1202.6075	
	lg	Dedra Davis	DEDRA	42.0725	47.2052	1344.6015	1339.0723	
	lh	Saidah Jones	SAIDAH	50.0373	56.2845	1343.3705	1334.7728	
	li	Michelle Bookman	MICHB	55.1667	50.0997	1322.9757	630.6768	
	lj	Tisha Prather	TISHA	48.1044	46.0147	1296.1831	992.5917	
	lk	Ruyika Foster	RUYIKA	61.4434	51.1156	1284.1724	1132.1729	
	ll	Sue Walton	SUE	51.1385	62.0508	1095.8442	1095.8442	right calf only
<i>distance runners</i>								
	lla	Amanda Gillam	AMANDA	55.8862	50.7071	827.5356	949.9142	
	llb	Celeste Susnis	CLESTE	51.375	53.9196	1005.7766	873.2161	
	llc	Laura Haynes	LAURA	49.0525	43.6258	911.6172	1062.4407	
	lld	Sara Fleweger	SARA	36.5861	47.7351	955.9488	1055.8325	
	lle	Katrice Malcolm	KTRICE	48.7362	45.0068	1230.8889	1150.1922	
	llf	Cindy O'Bryant	CINDY	45.7173	55.4989	879.8388	947.1064	
	llg	Megan Thompson	MEGAN	43.7242	59.2229	967.9456	917.3912	
	llh	Jennifer Brewer	JENI	48.6493	44.7627	853.2235	1192.1598	
	lli	Lynne Collazo	LYNNE		41.7213	1287.7787	1287.7787	left calf only
	llj	Michelle Reasor	MICHR	46.8478	58.1894	749.1755	862.94	

FULL LEG FLEXION					
	CASE			RIGHT HIP	LEFT HIP
	NO.	NAME	CODE	JAA PSN ANG	JAA PSN ANG
	-----	-----	-----	-----	-----
<i>sprinters</i>					
	la	Kim Townes	KIM	100.7346	113.4451
	lb	Tonya Lee	TONYA	116.178	120.2195
	lc	Leslie Henley	LESLIE	112.3494	120.6221
	ld	Stephanie Fields	STEPH	107.6467	128.3469
	le	Marvena Almond	MRVENA	108.5677	121.5119
	lf	Cheryl Finley	CHERYL	118.1523	121.7564
	lg	Dedra Davis	DEDRA	100.0138	95.8794
	lh	Saidah Jones	SAIDAH	114.5321	118.1199
	li	Michelle Bookman	MICHB	113.8799	123.6843
	lj	Tisha Prather	TISHA	115.108	118.5594
	lk	Ruyika Foster	RUYIKA	141.48	116.2815
	ll	Sue Walton	SUE	114.4216	117.1735
<i>distance runners</i>					
	lla	Amanda Gillam	AMANDA	116.1797	124.0851
	llb	Celeste Susnis	CLESTE	115.8714	119.9214
	llc	Laura Haynes	LAURA	117.9169	97.9076
	lld	Sara Fieweger	SARA	117.3021	122.7272
	lle	Katrice Malcolm	KTRICE	120.5212	116.8165
	llf	Cindy O'Bryant	CINDY	121.7599	118.0971
	llg	Megan Thompson	MEGAN	115.0299	125.7889
	llh	Jennifer Brewer	JENI	111.2579	127.7297
	lli	Lynne Collazo	LYNNE	113.2053	126.7672
	llj	Michelle Reasor	MICHR	101.9536	109.8268

Appendix C: Formula Delineations

Determination of Horizontal Velocity:

$$\text{HV} = \frac{[(\text{CGA X-coordinate}^{**} \text{ of the total body CG for the first frame digitized}) - (\text{CGA X-coordinate of the total body CG for the last frame})]}{(\text{total time elapsed})}$$

Determination of Stride Rate:

$$\text{SR} = 1 \text{ step} / (\text{absolute value of the time differential between touchdowns})$$

{except in Ili's case, where liftoff data was used due to lack of sufficient touchdown data.}

Determination of Stride Length:

$$\text{SL} = \text{absolute value of } [(\text{CGA X-coordinate of right foot at right touchdown}) - (\text{CGA X-coordinate of left foot at left touchdown})]$$

{except in Ili's case, where liftoff data was used due to lack of sufficient touchdown data.}

Determination of Ground Time:

$$\text{GT} = (\text{time of right foot liftoff} - \text{time of right foot touchdown})$$

$$\text{OR } (\text{time of left foot liftoff} - \text{time of left foot touchdown})$$

$$\text{OR } (\text{right data} + \text{left data}) / 2$$

Determination of Air Time:

$$\text{AT} = (\text{time of right foot touchdown}) - (\text{time of left foot liftoff})$$

$$\text{OR } (\text{time of left foot touchdown}) - (\text{time of right foot liftoff})$$

{choice selected for combination that occurred in immediate sequence within sampling of frames.}

Determination of Horizontal Foot Speed at Touchdown:

$$\text{FS} = [\text{HV} - (\text{CGA right foot velocity at touchdown})]$$

$$\text{OR } [\text{HV} - (\text{CGA left foot velocity at touchdown})]$$

$$\text{OR } [\text{right data} + \text{left data}] / 2$$

** "X-coordinates" refer to horizontal coordinates and "Y-coordinates" refer to vertical coordinates.

Determination of Horizontal Foot Distance at Touchdown:

$$\begin{aligned} \text{FD} &= \{\text{absolute value of } [(\text{CGA X-coordinate of total body CG at touchdown}) \\ &\quad - (\text{CGA X-coordinate of right foot CG at touchdown})]\} \\ \text{OR } &\{\text{absolute value of } [(\text{CGA X-coordinate of total body CG at touchdown}) \\ &\quad - (\text{CGA X-coordinate of right foot CG at touchdown})]\} \\ \text{OR } &\{\text{right data} + \text{left data}\} / 2 \end{aligned}$$

Determination of Upper Leg Motion at Any Given Position:

$$\begin{aligned} \text{ULM} &= (360^\circ - \text{JAA right hip position angle at the given right leg position}) \\ \text{OR } &(360^\circ - \text{JAA left hip position angle at the given left leg position}) \\ \text{OR } &(\text{right data} + \text{left data}) / 2 \end{aligned}$$

Determination of Upper Leg Rotational Speed at Any Given Position:

$$\begin{aligned} \text{ULRS} &= (\text{SAA right thigh velocity at the given right leg position}) \\ \text{OR } &(\text{SAA left thigh velocity at the given left leg position}) \\ \text{OR } &(\text{right data} + \text{left data}) / 2 \end{aligned}$$

Determination of Lower Leg Motion at Any Given Position:

$$\begin{aligned} \text{LLM} &= (\text{JAA right knee position angle at the given position}) \\ \text{OR } &(\text{JAA left knee position angle at the given position}) \\ \text{OR } &(\text{right data} + \text{left data}) / 2 \end{aligned}$$

Determination of Lower Leg Rotational Speed at Any Given Position:

$$\begin{aligned} \text{ULRS} &= (\text{SAA right calf velocity at the given right leg position}) \\ \text{OR } &(\text{SAA left calf velocity at the given left leg position}) \\ \text{OR } &(\text{right data} + \text{left data}) / 2 \end{aligned}$$