Quantitative Comparison of Locomotor Performance in Different Race Walkers

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INTRODUCTION

Biomechanics of track and field activities has been investigated by many authors. A literature overview on race walking points out various analyses on: supporting energy (Zarrough et al. 1974), mechanical energy variations (Marchetti et al. 1983), potential versus kinetic energy variations (Ralston and Lukin, 1969), muscular work efficiency (Marchetti et al. 1983).

Payne (1979) reported the ground reaction components measured during race walking while some aspects of the related biomechanics were discussed by Boccardi et al. (1978) by displaying a vectorial representation of the ground reaction evolution.

As the trainers know well, the primary needs of the race walkers involve something more than a general description of the basic executive mechanism. The athletes have to solve a very complex problem: walk under restrictive rules for a time varying from 18 to more than 200 minutes at a speed that is usually more than two times higher the threshold at which a man begins running naturally (Cavagna et al., 1977). Such goal is obtained through a proper modification of the normal motor-patterns aimed to the best use of the endurance qualities. By the way, the critical importance of optimal motor efficiency to reduce any possible noisy factor is evident.

The aim of this study is to quantify locomotor performances of two homogeneous groups of differently ranked walkers. The vectorial representation of the ground reaction force is used to identify and compare typical biomechanical features associating with the athletic level. A further data processing, including normalization and statistical estimation of the differences between the results from the two groups, leads to a practical and powerful tool for the investigation of motor-coordination and asymmetry in race walking.

SUBJECTS

Six competitive race walkers were the subjects of this study. Three of them formed the high level group (HLG); this choice was made by considering the level of performance they provided during the last year on 10 km track races (mean time = 40′ 41″; s.d. = 10″). The homogeneity of the group was also strengthened by similar values of the athletes' body parameters (Table 1). The other three walkers were arranged into the low level group (LLG) which was identified by the same parameter used before (mean time = 51′ 30″; s.d. = 74″). In this group, body weight and height of the athletes were not similar.

TABLE 1

	TIME ON 10 km	BODY W. (kg)	HEIGHT (m)	Δ STEADY (%)	VELOCITY (m/s)	CADENCE (step/min)	STANCE DURATION (ms)	Δ R-L STANCE (ms)
H.	40′ 30″	67.0	1.82	8.5	3.45	176	339	−2
L.	40′ 44″	66.5	1.79	3.6	3.60	190	315	−12
G.	40′ 50″	66.0	1.77	4.0	3.22	193	310	−5
L.	50′ 16″	65.0	1.71	5.3	3.04	171	348	−4
L.	51′ 30″	55.5	1.72	3.5	3.08	164	363	−4
G.	52′ 45″	69.0	1.87	5.4	3.38	183	324	−6

METHODS AND EQUIPMENT

The experimental technique adopted for measurement of locomotor performances provided by differently ranked race walkers is the so called Vector Diagram Technique (VDT). The VDT allows the on-line monitoring, in vectorial form, of the ground reaction force evolution during the stance-phase of a step (Pedotti, 1977; Cova et al., 1980; Pedotti et al., 1983). The ground reaction force during walking is essentially due to the action of two different components: body weight and inertial forces produced by cyclic acceleration and deceleration of all the body segments. Since locomotion is the final result of a very complex motor-coordination of a great number of muscles, the study of the ground reaction force evolution provides synthetic information about the efficiency of the whole musculoskeletal system.

A scheme of the instrumentation adopted for this study is illustrated in Figure 1. The athletes were asked to walk, at about 80% of their own race standard, along a pathway about 18 meters long. At two thirds of the pathway, where they usually reached a steady-state progression speed, a force plate was fixed flush with the floor. Just aside the platform, two units of photocells featured by a special circuit for selective triggering (avoiding arm crossing detection) were also placed to measure the time the pelvis takes to cover the distance of one meter.

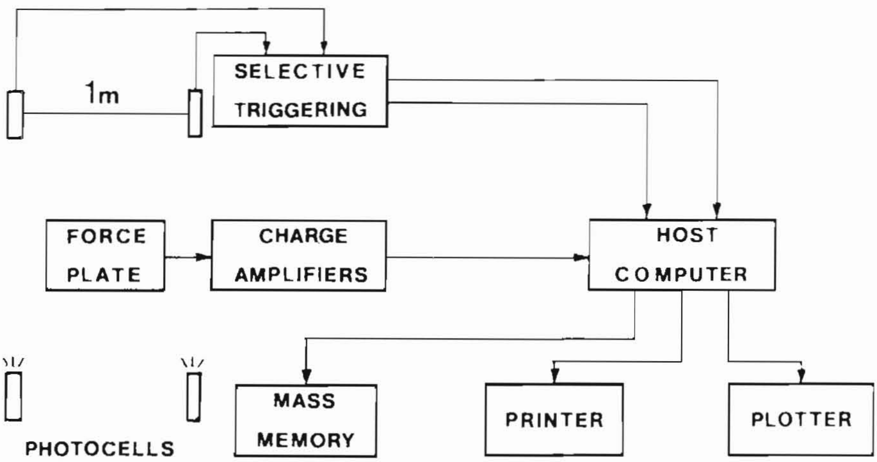


Fig. 1 Scheme of the equipment.

When the foot made contact with the force plate, analog signals proportional to the force exerted on it were generated and sent to the A/D unit of a host computer which allows the computation of the amplitude, inclination and application point of the instantaneous ground reaction vector and the representation of its evolution, commonly named vectogram, along the sagittal, frontal and floor plane. Jointly with the platform outputs, the signals from the photocells were also acquired and the mean velocity of progression was computed.

Although the crude vectogram usually illustrated in literature is very useful for obtaining information on locomotion, this study needed a further mathematical analysis to compare the results from the walkers and to quantify the coming out differences. Such analysis was composed by three main phases starting after the force plate data acquisition performed at a sampling rate of 1 KHz. This sampling rate is more than adequate to assure a good reproduction of the original signals and to render negligible those errors caused by discete convertion in the subsequent statistical process.

The first phase was concerned with the control of steady-state on the advancing speed. This steady-state feature, which allowed for the regular recurrance of measurements conditions, can be simply verified by integrating the horizontal component of force along the direction of progression. During steady-state walking this integral should be equal to zero but, in practice, a suitable range around the null value can be tolerated. Then steady-state was accepted when

$$1-p < \frac{\sum_{i=1}^{h} H_i^{+}}{\sum_{i=1}^{h} |H|_i^{-}} < 1+p$$

where H^+ and H^- are the positive and negative contribution to progression, h is the number of detected vectors and p defines the tolerance range of the trial.

The second phase was devoted to data normalization. For each vectogram the vertical (V) and horizontal (H) components and the displacements of the application point (D) were normalized as follows

$$Vn(tn) = V(tn) / W$$
$$Hn(tn) = H(tm) / W$$
$$Dn(tn) = [D(tn) - Dmin] / (Dmax - Dmin)$$

where $tn = t/T$ is the normalized time (in this study time normalization was driven to obtain 256 vectors each trial) and W is the athlete's weight.

Normalization of variables H and D was made both along the sagittal and frontal plane giving a complete 3-D description.

The last phase was regarding the statistical estimation of the differences between groups of data. Such groups were arranged «ad hoc» both to verify the asymmetry of walking in each athlete and to perform inter-individual or inter-ranking comparisons. For each group of data a typical evolution formed of 256 normalized vectors was then estimated by computing the mean values and the related standard deviations of the i-th vectors (i = 1, ..., 256). Since variables Vn, Hn and Dn of all the i-th normalized vectors were normally distributed around their own mean value, the differences between two groups of data were estimated through a two-tailed t-test by verifying the null hypothesis at 1% and 5% level of significance.

RESULTS

Talbe 1 shows, together with the athletes' best time on 10 km race and some anthropometric parameters, the mean values of some kinetic variables computed over the nine experimental trials.

The mean shift from perfect steady state progression ($\triangle$steady) do not exceed a tolerance p = 8.5% of the ratio between positive and negative acceleration along the advancing direction. Such value, if compared with that provided from healthy subjects during normal walking (Divieti and Santambrogio, 1986), points out a very good capability of the athletes to reach and easily hold steady-state feature.

The mean values of the advancing velocity confirm that the athletes were walking at about 80% respect their own best performance on 10 km race. Although the tolerance p is quite similar among the walkers, the mean advancing velocity referring to the H.L.G. is significantly faster than in the L.L.G.; this proves the presence of a more efficient motor-coordination in the high level athletes who are able, within the same run up length, to provide a better and controlled performance. The measured step cadences are less than the ones which can be computed through velocity and stance-phase duration thus confirming that the athletes were walking correctly with a foot always contacting the ground.

It is also interesting to note the occurrance of a longer left stance duration with respect to the right. Maybe this fact is connected with the habit to walk on track for race or training where about 60% of the distance is covered turning counter - clockwise.

Figure 2 illustrates the mean left and right vectograms referring to the walkers arranged in H.L.G.

From just a visual comparison of such results with those reported by Pedotti (1977) for normal walking and displayed on the sagittal plane, some interesting morphological differences may be pointed out. Vecto-

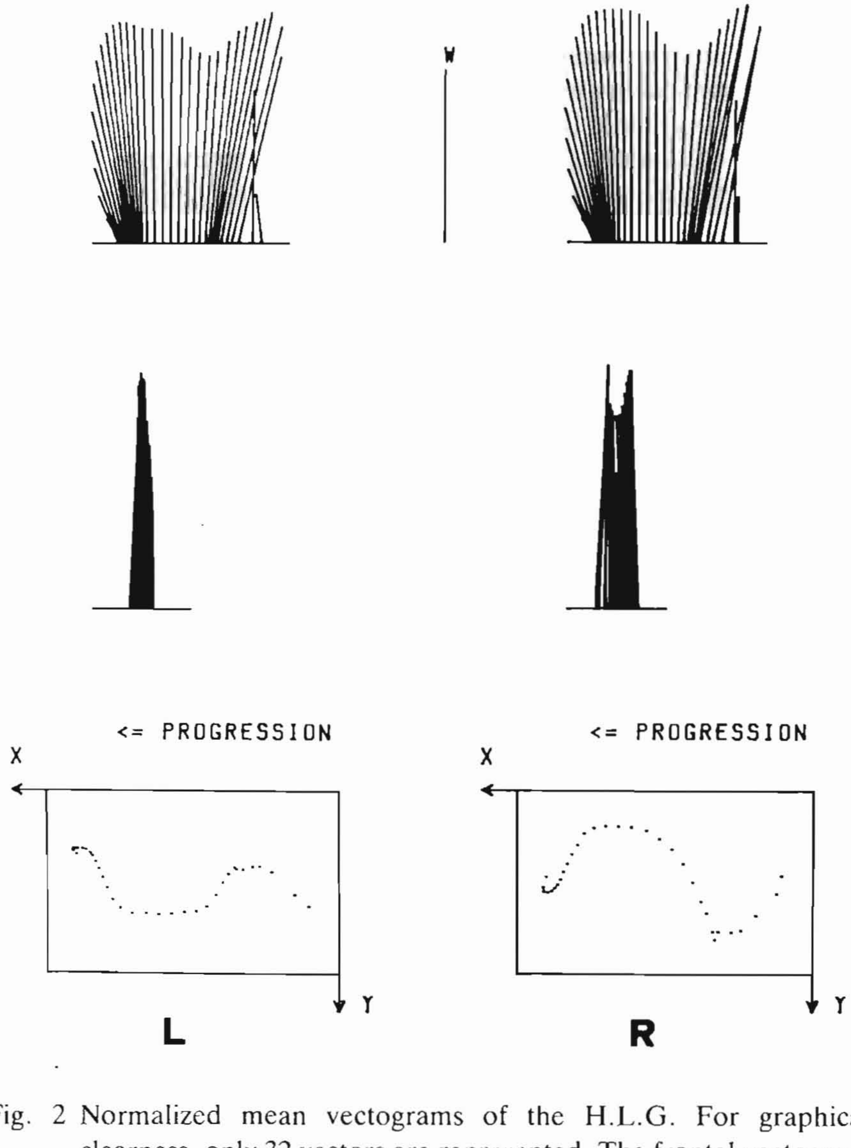
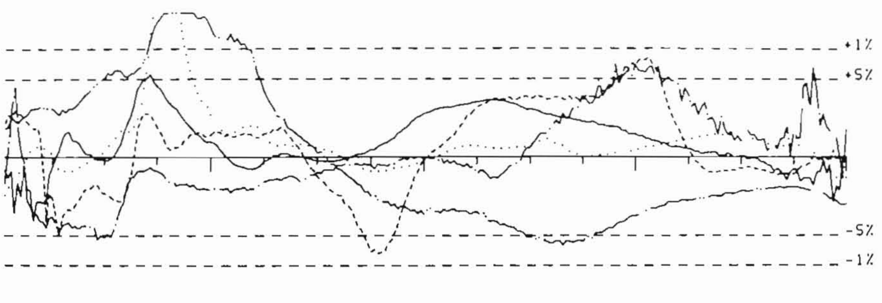


Fig. 2 Normalized mean vectograms of the H.L.G. For graphical clearness, only 32 vectors are represented. The frontal vectogram is to be read by viewing the subect from the back.

grams from race walking are characterized by higher values of both the two maxima and the minimum with respect to body weight; furthermore, a reduced difference between the value of the maxima and the minimum occurs thus underlining a limited vertical wasting of muscular work which is not useful to support movement. The vector distribution shows a closeness in the rearfoot followed by a fast forward displacement and a concentration in the forefoot. The frontal vectograms are more difficult to interpret just by visual inspection so that they will be discussed next by using the statistical approach. The application point evolution depicts an initial contact centered on the heel followed by a displacement towards the medial rearfoot that support the maximal impact force. After that the vectors quickly move on to the lateral side of the foot; the final thrust phase turns to be centered.

Figure 3 shows the t-test results obtained by comparing right and left vectograms of Figure 2. As the course of the statistical variable t demonstrates, significant asymmetries (at 0.05 level of significance) involve just 9.64% of the whole stance phase; the largest differences concern the frontal variables Py and Fy (see the t values at 0.01 level of significance) during the impact phase when the vector is located in the medial side of the foot. This result is probably related to different levels of the foot pronation and the control made by the shoe.



COMPONENT	SYMBOL	t-VALUES OUT OF THE CONFIDENCE INTERVAL			
		SIGNIFICANCE LEVEL 5%		SIGNIFICANCE LEVEL 1%	
FZ	______	3	1.17%	0	0.00%
FX	--------	23	8.98%	0	0.00%
FY	....	14	5.47%	11	4.30%
PX	____._	18	7.03%	0	0.00%
PY	______..	68	26.56%	29	11.33%
		tot. 126	9.84%	tot. 40	3.13%

Fig. 3 T-test graphs concerning the comparison between the right and left side vectograms from H.L.G.

Figure 4 illustrates the mean vectograms obtained by processing the data from L.L.G.

The general considerations coming out from the H.L.G. patterns are confirmed in spite of some differences concerning the vector amplitude at impact and the evolution of the application point. The asymmetry between the right and left vectograms involves 9.45% of the stance-phase at 0.05 level of significance; this result, which is comparable with that obtained from the H.L.G., suggests that the asymmetry is, in general term, a variable not dependent by the level of performance. The t-test

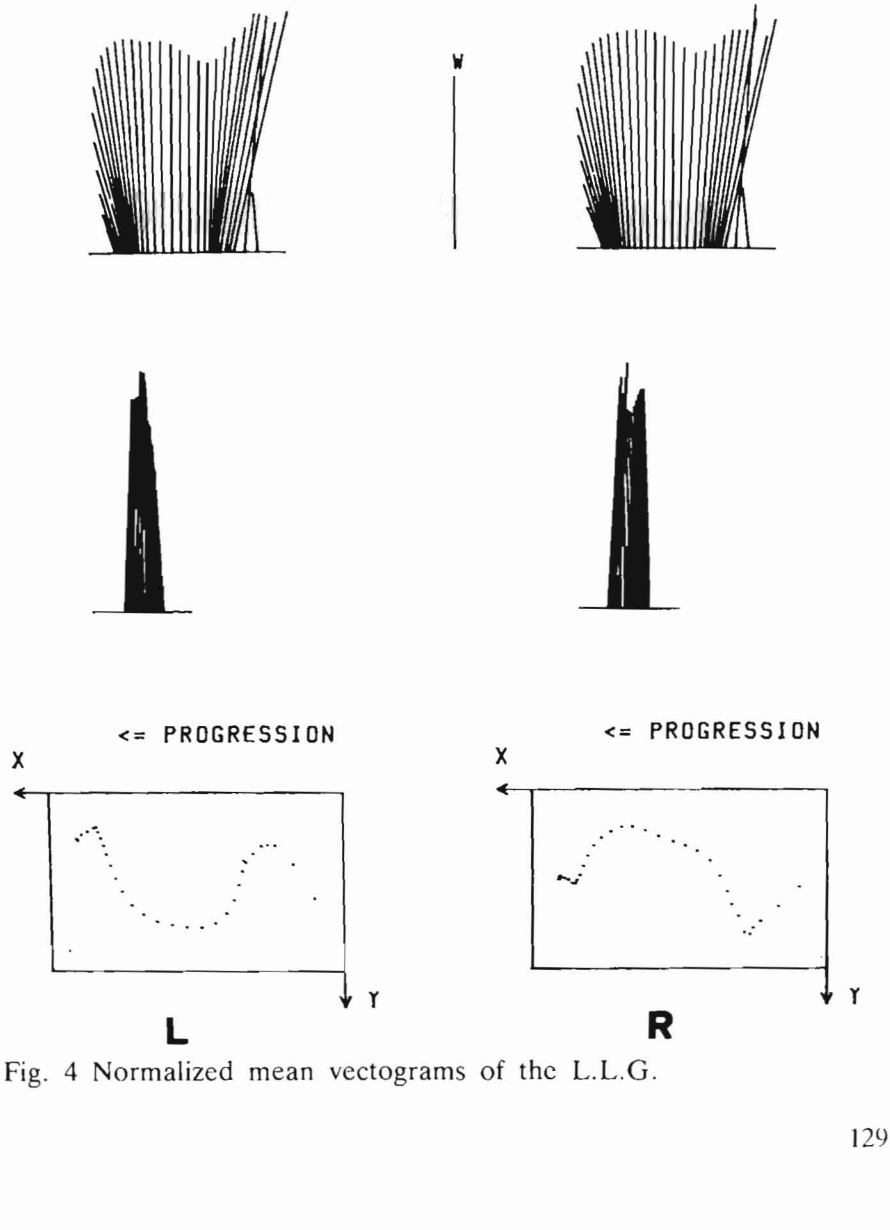
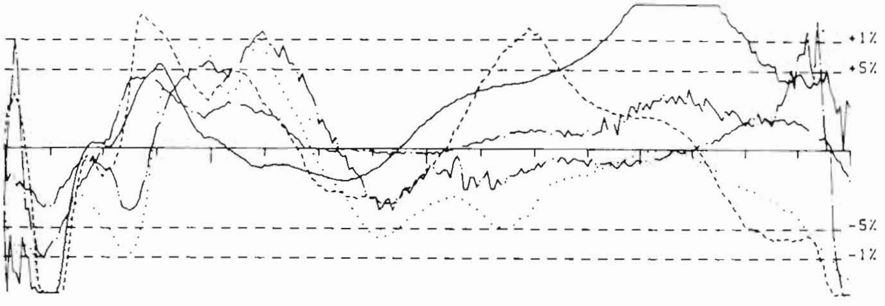


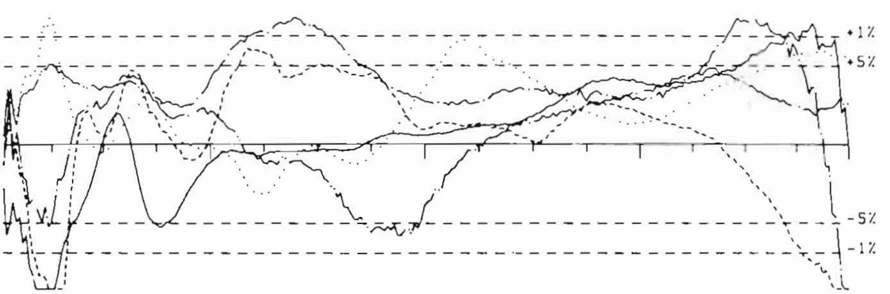
Fig. 4 Normalized mean vectograms of the L.L.G.

analysis applied to compare the results from H.L.G. and L.L.G. (see Figure 5 for right side comparison and Figure 6 for left side comparison) allows the estimation of significant differences involving, at 0.05 level, 23.13% of the right and 19.61% of the left stance-phase. Such differences mainly regard the three force components.



COMPONENT	SYMBOL	t-VALUES OUT OF THE CONFIDENCE INTERVAL			
		SIGNIFICANCE LEVEL 5%		SIGNIFICANCE LEVEL 1%	
FZ	———	90	35.16%	61	23.83%
FX	--------	78	30.47%	36	14.06%
FY	....	75	29.30%	19	7.42%
PX	——·—	26	10.16%	9	3.52%
PT	——..	27	10.55%	4	1.56%
		tot. 296	23.13%	tot. 129	10.08%

Fig. 5 T-test graphs concerning the comparison between the right vectograms from H.L.G. and L.L.G.



COMPONENT	SYMBOL	t-VALUES OUT OF THE CONFIDENCE INTERVAL			
		SIGNIFICANCE LEVEL 5%		SIGNIFICANCE LEVEL 1%	
FZ	———	52	20.31%	19	7.42%
FX	--------	47	18.36%	26	10.16%
FY	....	53	20.70%	5	1.95%
PX	——·—	79	30.86%	44	17.19%
PY	——..	20	7.81%	0	0.00%
		tot. 251	19.61%	tot. 94	7.34%

Fig. 6 T-test graphs concerning the comparison between the left vectograms from H.L.G. and L.L.G.

By analyzing the t-test graphs by a biomechanical point of view, interesting considerations on walking style may be obtained. Fz and Fx from L.L.G. exceed those from H.L.G. during the initial impact phase thus pointing out a stronger foot contact with the ground. This fact is influenced by the history of the previous step which may drive the L.L.G. athletes to higher velocity of the foot, less absorption of inertial forces, exaggerated step length, etc. In the last part of the stance-phase the H.L.G. shows a significant predominance of Fz (vertical oriented muscular action) while the L.L.G. presents greater Fx components (forward oriented muscular action). Both these results indicate that the H.L.G. walkers move reducing as much as possible localized horizontal accelerations in favour of a less step length and a better distributed support to locomotion.

Statistical comparison may also be usefully adopted to analyze characteristics of a single subject. In Figure 7 the vectograms of an athlete arranged into the L.L.G. are depicted. The main coming out features with respect to H.L.G. are: increasing of the impact vector amplitudes, central minimum lower than body weight, faster displacement of the vector from the rear to the forefoot, frontal vectors more inclined, faster medio-lateral displacement of the vector. Figure 8 and 9 show the t-test graphs concerning the comparison between the H.L.G. vectograms and those in Figure 7. The significant differences at 0.05 level reach 50.78% (right side) and 34.38% (left side) of the whole stance-phase mainly involving the three force components (Fz, Fx, Fy) and the application point displacement along the sagittal plane (Px).

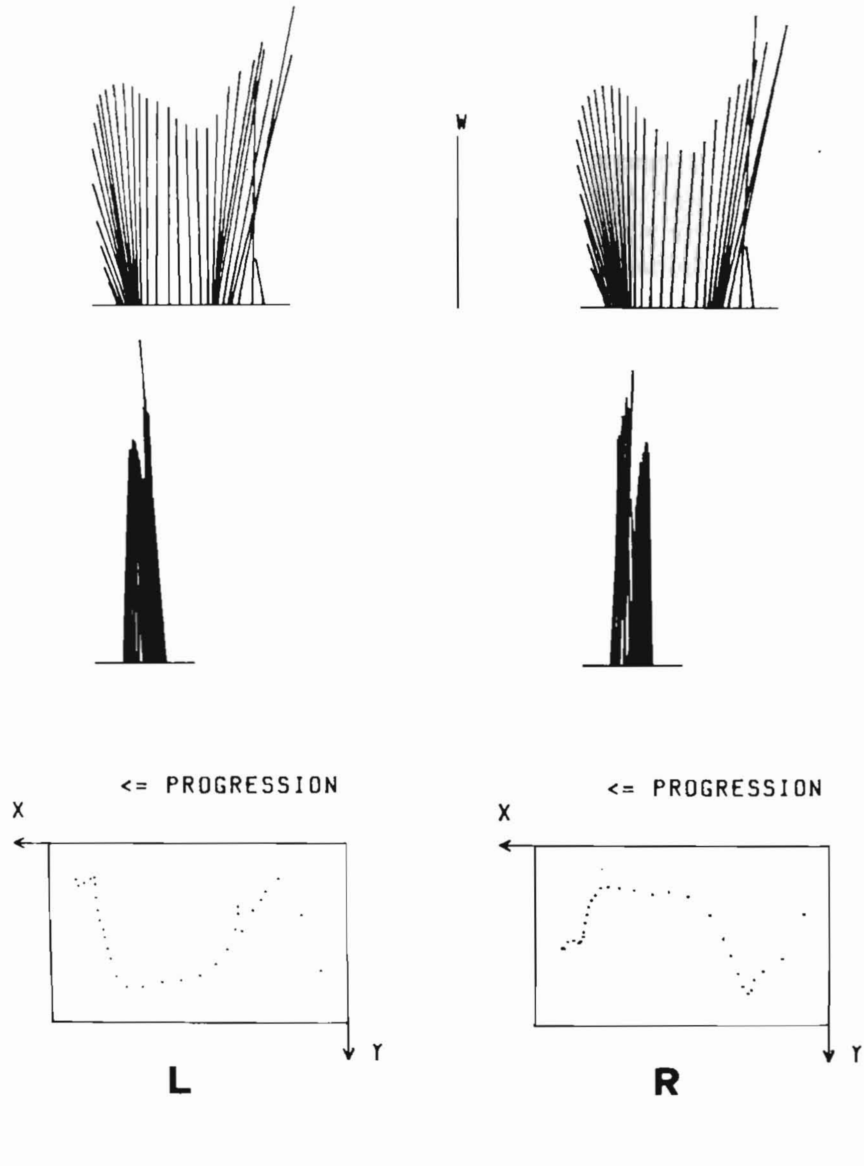
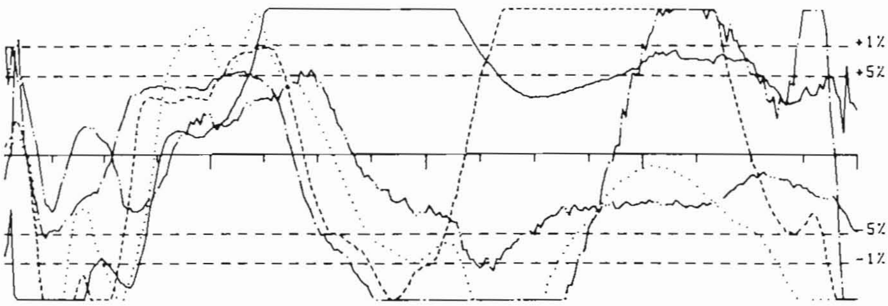
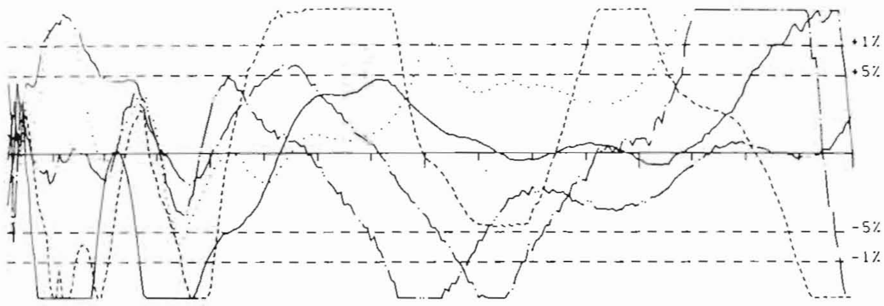


Fig. 7 Normalized mean vectograms of a single walker of the L.L.G. As for each other athlete, he performed nine trials.



COMPONENT	SYMBOL	t-VALUES OUT OF THE CONFIDENCE INTERVAL SIGNIFICANCE LEVEL 5%		t-VALUES OUT OF THE CONFIDENCE INTERVAL SIGNIFICANCE LEVEL 1%	
FZ	———	162	63.28%	101	39.45%
FX	-------	164	64.06%	120	46.88%
FY	....	154	60.16%	87	33.98%
PX	—.—	144	56.25%	109	42.58%
PY	—..	26	10.16%	6	2.34%
		tot. 650	50.78%	tot. 423	33.05%

Fig. 8 T-test graphs concerning the comparison between the right vectograms from H.L.G. and the single L.L.G. walker.



COMPONENT	SYMBOL	t-VALUES OUT OF THE CONFIDENCE INTERVAL SIGNIFICANCE LEVEL 5%		t-VALUES OUT OF THE CONFIDENCE INTERVAL SIGNIFICANCE LEVEL 1%	
FZ	———	78	30.47%	59	23.05%
FX	-------	127	49.61%	105	41.02%
FY	....	91	35.55%	72	28.13%
PX	—.—	89	34.77%	61	23.83%
PY	—..	55	21.48%	38	14.84%
		tot. 440	34.38%	tot. 335	26.17%

Fig. 9 T-test graphs concerning the comparison between the left vectograms from H.L.G. and the single L.L.G. walker.

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