Stride parameters in endurance runners

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ABSTRACT

It is commonly thought that athletes automatically adapt to a simple, natural and cyclical action, such as running, and that any increases in performance level are almost entirely due to improvements of the conditional capacity and metabolic systems. The importance of mechanical and co-ordinative attributes and the possibilities for conserving movement and re-utilising elastic energy deriving from the eccentric contraction movements have rarely been explored and have never been a focal point of research in endurance sports. This study included 61 male and female long-distance runners, 31 of whom performed at a national/international level and 30 of whom were amateur level competitors. In periodic tests conducted for functional evaluations, video recordings were made of the athletes' running movements at different speeds. Several kinematic parameters were analysed. The statistical results, behavioural analysis and individual adaptations obtained are useful for elaborating and proposing methodological elements in training for correcting and perfecting distance running technique.

AUTHOR

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Introduction

Attempts to classify sports are countless. In the areas of science, technique and methodology, when we want to emphasise the physiological components and conditional capacities, we generally place the disciplines in three large groups (SAIBENE et al., 1986). The first group includes activities in which a maximum level of intensity is reached and exhausted in a few seconds (intensive sports); the second group comprises intermediate activities, with mixed metabolic implications; in the third group are activities that are characterised by the repetition of effort for protracted lengths of time (endurance sports with a strong metabolic component of aerobic origin).

The same school of thought places research with regards to the first group in the area of the study of biomechanics, neurophysiology, and endocrinology, while the others are assigned to the study of bioenergetics and the major organic functions. However, if co-ordination abilities are used as the criteria for distinguishing the disciplines, it becomes more difficult to isolate and define each specialty.

In the sports literature, endurance running is classified among the cyclical aerobic specialties with low co-ordination and technical content. VERCHOSSHANSKJ (2001), for example, stated: “the composition of cyclical movements (that require the development of endurance) seems to be simpler than that of acyclic locomotion”.

The opinions and studies published so far, for example McARDLE et al. (1996), reinforce the idea that each athlete automatically adapts to a simple, natural and repetitive movement, like that of running, and that improvements in performance are entirely related to the improvement of conditional abilities and metabolic implications:

“An exercise that can be performed for a prolonged period of time is relatively simple from a mechanical standpoint, since the gesture is repeated from the beginning to the end; the movements – some of which were learned in childhood - are completely automatic and racing strategy is relatively simple... it’s pretty evident that in these situations the nervous and psychological factors are much less important than the physical, physiological and biomechanical ones” (SAIBENE et al., 1986).

Although various studies have shown that mechanical efficiency is the component that differentiates elite athletes (among themselves) in endurance running, even these studies continue to hint that an individual athlete’s running technique cannot be effectively modified to produce a significant result and that, at any rate, adaptations are consequences of bio-structural and metabolic modifications that occur during training.

Furthermore, when biomechanical parameters were taken into consideration, the results and observations made by experts lead to conclusions that are diametrically opposed. FORTNER (2006), after a lengthy observation of the rhythmic behaviour of the first three finishers at the 1999 New York Marathon (Kagwe, Chebe and Bayo), noted that the winner “adopted a longer stride (at the same speed) as opposed to a greater frequency”. NOAKES (2001), citing other authors (MORGAN, 1995 and NELSON & GREGOR, 1976), states: ”through training, athletes lengthen their stride and reduce frequency. Some researchers maintain that this optimises running economy because the increased stride length is more economical than an increase in frequency”. On the other hand, McARDLE et al. (1996) claim that: “it generally costs more to lengthen one’s stride than it does to shorten it” and VITTORI (1997) states: “There is no doubt that the energetic cost required to maintain the same speed is greater for a long stride than it is for a shorter stride at a higher frequency... it costs more to create length than it does to create frequency”.

According to CAVANAGH & WILLIAMS (1982), athletes themselves automatically choose the best speed and any attempt at modifying the stride length or stride frequency “produces a negative effect on the mechanical efficiency”.

Within the study conducted in an attempt to establish the best individual energetic cost by way of a variation in stride frequency and stride length at a given speed there exists a conceptual error that excludes all results except those obtained: modifying a “spontaneous” movement by way of any voluntary intervention produces the effect of increasing energy expenditure.

The question that we might pose at this point is: are we absolutely certain that an athlete is able, always and in any circumstance, to match his/her motor potential to the technical and mechanical parameters of endurance running in an automatic and instinctive manner? More precisely, can the work of the middle- and long-distance coach (on a level with the trainers of any other specialty or discipline) be targeted towards modifying the characteristics and technical, rhythmical and mechanical running abilities of an individual athlete?[1]

This article is not meant to be a "scientific" study in the strict sense, nor does it mean to point to definite and certain conclusions. Instead, we have gathered, arranged and organised field data, applying the work methods usually employed by sports technicians. Accordingly, the instruments that have been used are the same ones that we commonly use.

Using the parameters given by the examination of stride length and stride frequency, we are investigating the possible development of a reference model. The ultimate aim is to find elements of analysis that help to provide field technicians with an additional interpretation of the methodological management of running technique, in order to optimise training programmes, especially for elite athletes. With such, coaches will be better equipped to identify the characteristics of their athletes and to assign the exercises that are most appropriate for improving performance.

Running: Stride frequency and stride length

In physics, frequency is defined as the number of times that a periodical phenomenon occurs in a unit of time. The unit of measure – the Hertz (Hz) -- is equivalent to one cycle per second. In running, stride frequency times stride length determines the speed of movement. An athlete who wants to improve his/her personal record at any distance has no choice: he/she must do something to improve the product of the two elements.

Coaches, especially those of middle-distance runners, generally record the time that their athlete takes to cover a given distance in training, in other words, the product of length and frequency. But if we want to disassemble the technical elements of running in order to study possible adjustments and corrections, it is a good idea to record both, given the fact that it isn't clear which strategy for improvement (increasing length or frequency) should be preferred and whether this generally applies to all types of runners.

One of the first studies on the rhythmic behaviour of endurance running was performed by a Danish researcher, BOJE (1944). He got an endurance runner to run on a treadmill at various speeds. He recorded a frequency of 2.66Hz at 9.3km/h (97cm stride length) and 2.93Hz at 17.8km/h (168cm stride length). A 91% increase in speed corresponded to an increase in stride length of 83% while the frequency increased by only 10%.

There are many ways to measure an athlete's stride frequency during a race or in training. You can count the number of strides over a set time or, more simply, record the time it takes to perform a certain number of strides. For example, you record the time it takes for the same foot to touch the ground 10 times. To determine the frequency, divide 20 by the time registered for 10 strides. If you want to calculate the strides per minute (Hz x 60), divide 1200 by the recorded time. For speed trials that are measured from a starting position, the calculation of the kinematic parameters of running is relatively more complex. For prolonged trials, on the other hand, the travelling speeds are much more uniform. It is for this reason that, when we know the speed that corresponds to the distance at which the frequency was measured, we can easily derive the average stride length by way of an indirect calculation.

Stride frequency and stride length are the results of a series of related forces that interact and create a succession of movements, which, in their entirety, we call running. An untrained eye that observes two people running, even if they are at different performance levels, will probably not be able to distinguish the differences.

1 It is important to emphasize the fact that the individual modifications that training can produce are difficult to detect with the naked eye. The units of measure are millimeters and hundredths of Hz. It must be remembered that, in order to cover the distance of a marathon, a top athlete takes from 25,000 to 30,000 steps, an amateur may take 40,000 or more. It's not difficult to imagine the repercussions that imperceptible technical variations might have on the result.

In reality, a person's anthropometric and bio-structural characteristics, his/her strength level, his/her available energy and – not least – his/her capability to perform the specific action, make an individual's way of running unique. Training effects each of the components cited and can have a big effect on raising the peak of sustainable maximum speed as well as on the possibility of prolonging work sessions at a certain speed. In endurance running, the latter is paramount: reducing the energy cost at a given intensity is crucial.

The adaptation process reaches highly tangible levels in the first cycle of organised training. For example, take a group of youths with little experience and scarce adaptation to prolonged exertion. Have them run a distance between 1km and 3km as fast as they can. In the three weeks following the test, let the subjects train regularly by running aerobically. In the fourth week, have them repeat the test they took on the first day. All coaches with experience in this field will agree that the resulting improvements (with rare exceptions) will be striking. The improvements registered for subjects who had relatively low starting values will be even more remarkable.

In such a short space of time (15-20 days) what are the transformations that act upon the group? Did their heart capacity increase? Did their capillaries widen? Did their muscles develop? Did their mitochondria double in number? Did the enzymes speed up their activity?

Maybe, to a certain extent. However, no combination of these is enough to explain average increases in speed of 10-20% over a 2km distance.

It is more probable that the rate of increase in performance is due to two factors:

1) A better distribution of effort (strategy): For inexpert athletes (and not only!), it is difficult to choose the optimal speed. An overly prudent approach and (worse yet) an excessively fast start can weigh heavily on the final result. Learning to better calibrate one's speed based on the resources available is an objective that can be reached even in a short time;
2) An increase in mechanical output: In short, it is the start of learning process aimed at perfecting a running style thanks to which the athlete will be able cover the same distance at ever faster speeds. Alternatively, he/she will be running longer distances while keeping the same average speed. Useless movements and the abnormal contractions of some muscular groups diminish, the kinetic chains will be activated more effectively in the direction of movement, breathing will become deeper and the arms will be synchronised with the movements of the lower limbs.

In other words, one is able to use the resources he/she already possesses in a more effective manner towards the accomplishment of the task at hand.

Mechanical output can be defined as the ratio between useful energy (motion) and the effort spent in transforming energy. The human system is regulated in such a way that all of its sub-systems adapt themselves in order to function in the most effective manner. It remains to be seen whether the ability to run (especially at submaximal speeds) pertains to the instinctive adaptation/perfecting process (that is, if running must be considered an activity requiring a low degree of co-ordination) or whether it can be coached and improved through a teaching/learning process.

Mechanical output in running may vary from person to person and at different speeds, from 25 to 40-45%[2], a huge difference. The two main elements that affect the output in running are:

a) Preservation of the quantity of motion;
b) Re-utilisation of elastic energy.[3]

Objective a) is pursued by reducing braking, or negative work, to a minimum (from the beginning of the phase in which the

Table 1:

	Elite male	Elite women	Non-elite male	Non-elite women	Σ
Partcipants n.	21	10	22	8	61
Age (average) SD (years)	28.4 5.4	27.1 6.0	45.0 5.6	40.9 10.0	35.9 10.3
MAS (km/h) average SD (km/h)	21.6 1.0	19.1 0.9	15.2 1.5	13.1 1.6	17.7 3.4
Height (cm) average SD (cm)	176.2 5.5	166.3 6.6	177.4 6.0	169.6 9.1	174.3 7.6
Entries n.	200	160	100	40	500

foot makes contact with the ground until the passage of the centre of mass beyond the projection of the point at which the force was applied. Objective b) comes about during positive work following the exploitation of energy accumulated in the deformation of elastic elements during the same running phase.

The paradox of mechanical output lies in the need to reduce negative work to a minimum in order to preserve the quantity of motion (first principle of dynamics) and, at the same time, increase the "loading of the springs" that supply free energy in the positive phase.

This reflection alone would be sufficient to substantiate the conviction that it is extremely difficult (if not impossible) to try to standardise all of the possible variables and formulate an unequivocal reference model. Deductions, reasoning and possible hypotheses lead to an individual analysis of the subject and not so much to the comparison of the behaviour of various individuals. It is possible to come to the same result by "mixing the ingredients" in a different way. Nevertheless, the comparative study of different individuals' behaviour and the statistical analysis of the data can provide us with ideas for pointing out reference models and parameters to apply during individualised evaluations.

Methods

The participants in this study were 61 athletes of various qualifications that were then divided into four groups based on their performance level (Table 1). The data (500 entries in all) were gathered during the period of March 2005 to September 2006. The table specifies average and standard deviation for age, VO_2max and height. The specifics of the sample include:

- Elite Male Runners (n=21): middle-distance, long-distance and marathon runners from the Italian national team, all have an MAS (maximum aerobic speed) higher than 20km/h, they train on a daily basis (generally two sessions per day) with an average volume of 120-220km/week
- Elite Women Runners (n=10): middle-distance, long distance and marathon runners from the Italian national team, all have an MAS higher than 18km/h, they train on a daily basis (generally two sessions per day) with an averaging volume of 100-200km/week

2 Amount of chemical energy transformed into mechanical energy. The rest (80-95%) is dispersed in the form of heat. In research methodology the net output is also identified, that is, it subtracts the amount of energy necessary to maintain the person in an erect position. See CAVAGNA (1988).

3 Although the factors that make up for the reduction or increase in output are different, I preferred to focus on these two dynamics upon which almost all of the other components converge.

- Non-Elite Male Runners (n=22): running is a hobby and they train from three to six times a week with an average volume of 40-80km/week, all have an MAS lower than 17km/h
- Non-Elite Women Runners (n=8): running is a hobby and they train from three to six times a week with an average volume of 30-60km/week, they all have an MAS lower than 15km/h

The surveys on average stride frequency/ stride length at various running speeds were made during routine evaluation tests on standard athletic tracks during team meetings or organised gatherings.

Two types of evaluation test were used:

1. Continuous speed progression following the Conconi protocol (heart rate progression as a function of running speed).
2. 5-6 incremental fractions of 2km, at constant speed within each single step following the Fiorella-Gigliotti protocol (lactic acid progression as a function of running speed).

Only the first test was used with the non-elite runners. Around 40% of the total survey was also filmed with a Panasonic FZ30 30 frame/s digital camera.

The measurement of the stride frequency/ stride length was performed on the straight part of the track, recording the time it took to take 20 steps (frequency): every 200m in the first test and every 400m in the second test. Afterwards, the stride frequency values were linked to the time it took the athletes to cover the corresponding 100m distance.

Comparison of stride length and stride frequency

Men

Figure 1 represents the parameters of stride length (in red) and stride frequency (in blue) at various running speeds relative to the group of top male athletes.

Around 200 surveys were performed on the 21 elite middle and long distance athletes. The correlation rate is markedly high for the stride length parameter (R=0.878/P=0.000)[4] as well as for that of stride frequency (R=0.7333/P=0.000) in relation to the running speed. Figure 2 shows the same co-ordinates referred to the group of non-elite runners with around 100 surveys on 22 athletes.

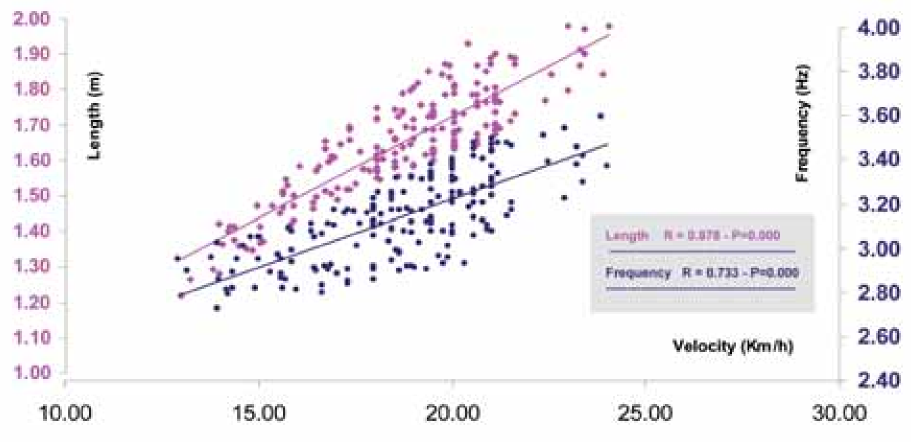


Figure 1: Stride length and stride frequency at different velocities in elite male runners

4 R = correlation coefficient between two variables, P = correlation significance index

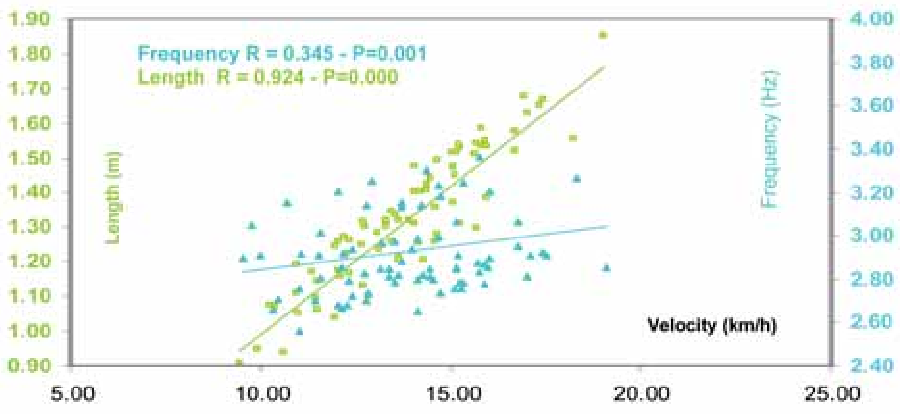


Figure 2: Stride length and stride frequency at different velocities in non-elite male runners

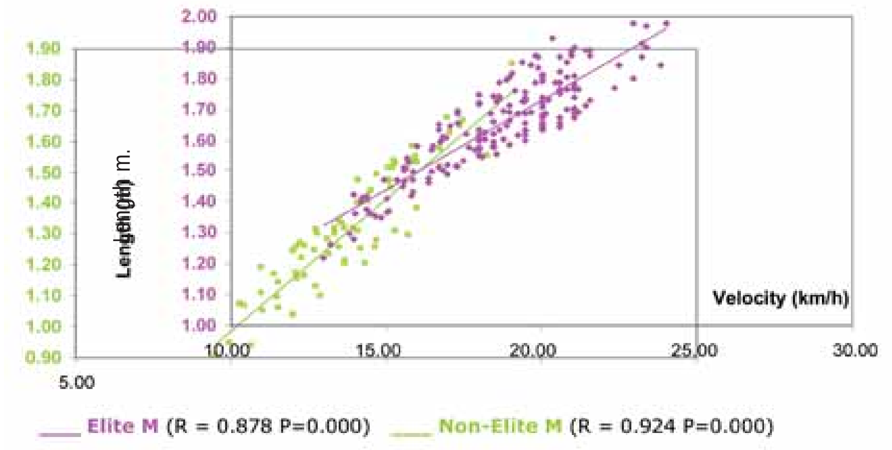


Figure 3: Stride length at different velocities in elite and non-elite male runners

The consistency of the length parameter is evident in the group of elite athletes (R=0.924/P=0.000) while the frequency (R=0.345/P=0.001) is not. In both cases, the parameters are highly significant.

If we use the same graph, superimposing the progress of the two reference groups and separating stride length (Figure 3) and frequency (Figure 4), the earlier observations appear even more evident.

The comparison of stride length in the two reference groups emphasises a fundamental and significant correlation with alterations in velocity. This fact leads us to suppose that the stride length is a relatively "stable" parameter with a restricted range of variability. On the other hand, if we compare the data referring to turnover rate (Figure 4), we can see a clear distinction between the behaviour of the two groups: the dots on the chart relating to the elite runners remain correlated

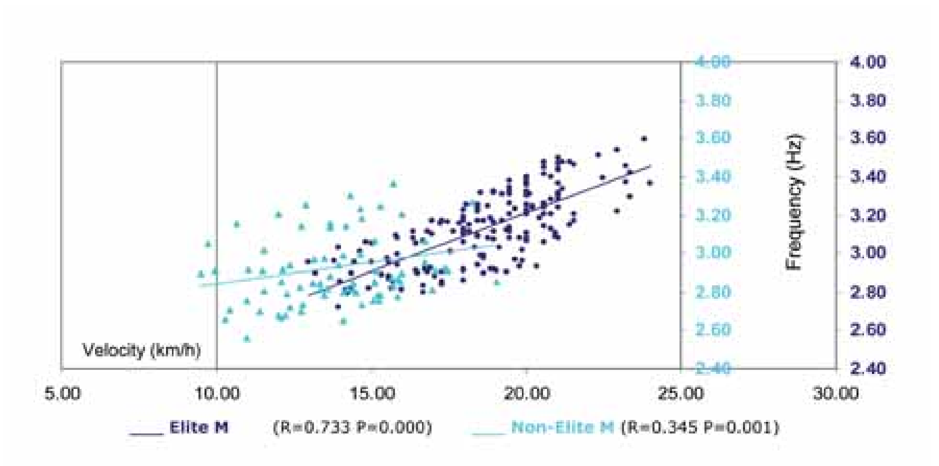


Figure 4: Stride frequency at different velocities in elite and non-elite male runners

while those of the non-elites show a marked scattering. This evidence brings us to presume that the frequency of movement is the discriminating element in the technical evolution of the mechanics of endurance running. This adaptation, however, remains linked to that of stride length, which is the parameter that varies most in relation to speed variation.

Women

The same analysis procedures were used to study the behaviour of the two female groups. Bear in mind, however, that the data gathered in this study was lower in number than that available for the two male groups. It is reasonable nevertheless to assert that the statistical data that emerged from the two female groups substantially confirms what emerged from the two male groups:

a) stride length follows a stable and homogenous correlation at all levels of performance;
b) stride frequency shows levels of correlation that are proportionate to performance level.

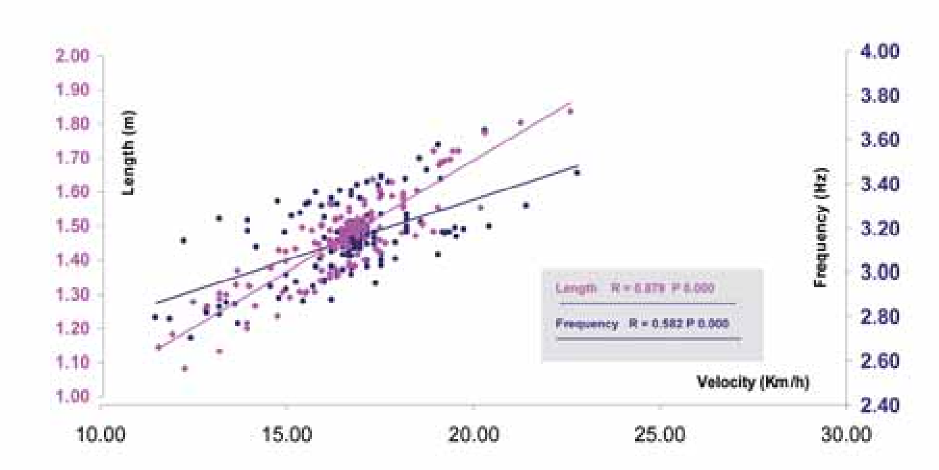


Figure 5: Stride length and stride frequency at different velocities in elite female runners

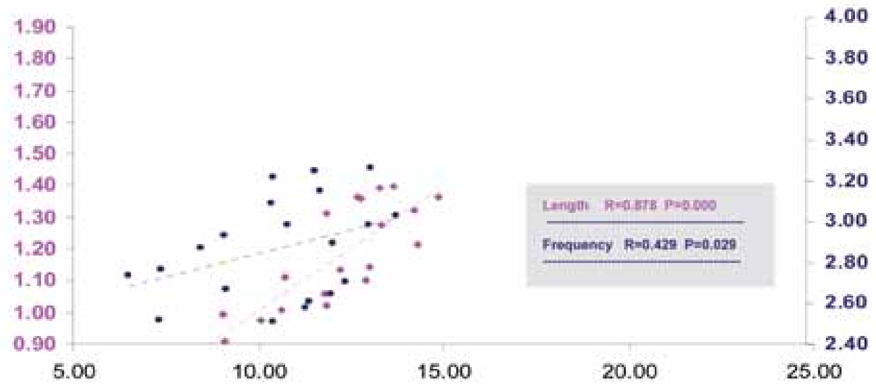


Figure 6: Stride length and stride frequency at different velocities in non-elite female runners

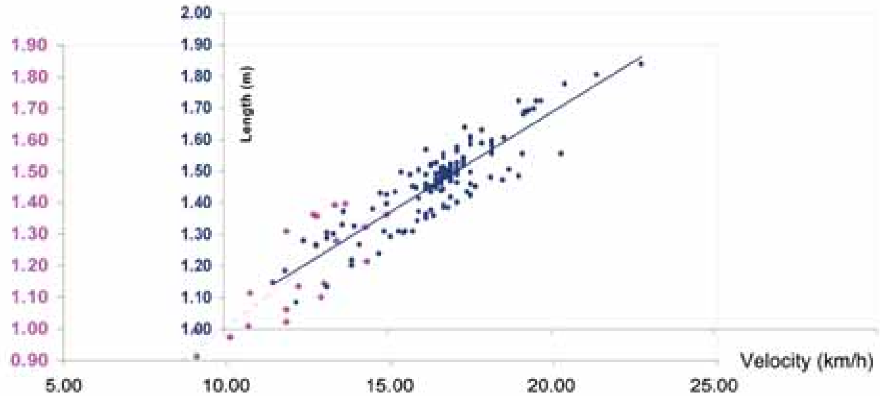


Figure 7: Stride length at different velocities in elite and non-elite female runners

To provide more detail, 160 surveys of stride frequency/stride length were made on 20 athletes from the Italian middle- and long-distance teams (or, at any rate, top national runners) (Figure 5). The correlation of the stride length in relation to the various speeds is practically identical to that of the male group (R=0.879 vs. 0.878); that of frequency is less (R=0.582 vs. 0.733). This deviation could be partly ascribed to different international qualification between the male group (which we could define as excellent) and the female group. This fact would confirm the hypothesis that the higher the athlete's performance level, the greater is the degree of correlation between speed variation and turnover. The resulting data is highly significant for both parameters.

The non-elite female group was the smallest, composed of only eight athletes, and 40 surveys on frequency and stride length at different running speeds (7<15km/h) were made. As in the other group, this one showed a high correlation in the stride length parameter (R=0.878 – P=000) and a lower one

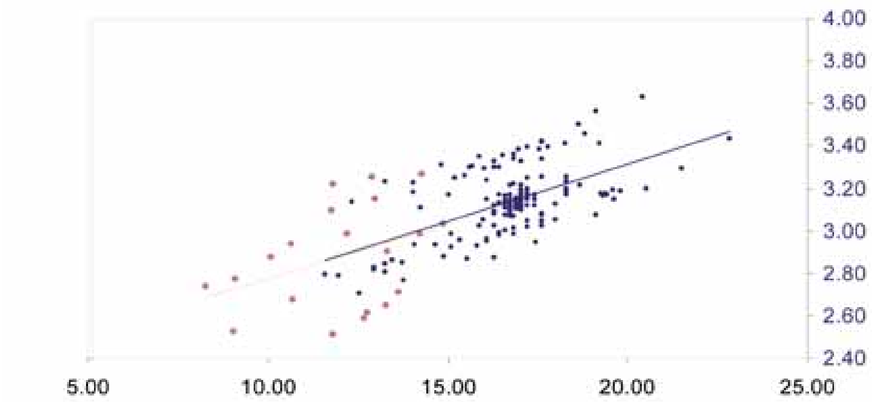


Figure 8: Stride frequency at different velocities in elite and non-elite female runners

(R=0.429 – P=0.029) (Figure 6) in the stride frequency parameter.

Figures 7 and 8 compare the data of the two female groups, separating stride length (Figure 7) from stride frequency (Figure 8). Compared to the same data from the male groups, we note a closer relationship in turnover behaviour. In this case, too, we can propose the hypothesis of a less marked difference in the qualification of the female group with respect to the male group.

All Groups

Figures 9 and 10 show the scattergram referring to all four groups in their respective expressions of frequency and stride length. Whilst we must not overlook the overall correlation of frequency (R=0.681, P=0.000), we have to emphasise the significance of the stride length data (R=0.939, P=0.000) gathered from the test groups. This evidence would support, among other things, the hypothesis that considers the subject's height to be of little relevance in stride length variation when related to speed of movement[5].

Figure 11 shows the values of the two parameters (stride frequency/length) in an attempt to find an internal correlation profile. The meaning that we can give to this correlation is that less-trained (or less efficient) athletes tend to uphold only one of the two parameters, fundamentally because of a limited (or imbalanced) gradient of muscular strength (the correlation among the dots is negative). On the contrary, the data on highly efficient athletes shows a progressive line, which leads us to presume a greater control and a greater balance[6] in the use of strength between the negative and positive phases of the running stride.

Correlation rates in the various groups and their significance:

Non-elite Males:	R= -0,034	P= 0.733
Non-elite Females:	R= -0.017	P= 0.936
Elite Males:	R= 0.320	P= 0.000
Elite Females:	R= 0.128	P= 0.100

5 Some studies had hypothesized an important height incidence (more specifically on the length of the inferior limbs) on the stride length (FORTNER, 2006). In the context of the aerobic speeds this element would statistically seem not very important since both the men and women (average height difference of 10cm) have shown a similar behaviour in the variation of stride length at equal speed.

6 VITTORI (1997) summarises the activity of the muscular groups that are involved in the frequency and length of a step. In the first case (frequency) the force of the anti-gravitational muscles that improves the stiffness and decreases the "collapsing" of the knee at the moment of the foot's impact with the ground. Stride length, on the other hand, is regulated by the strength of the flexor muscles. As we'll see further on (note 8), we propose the hypothesis that, at least in the case of long distance runners, the anti-gravitational muscles are also involved in the regulation of stride length.

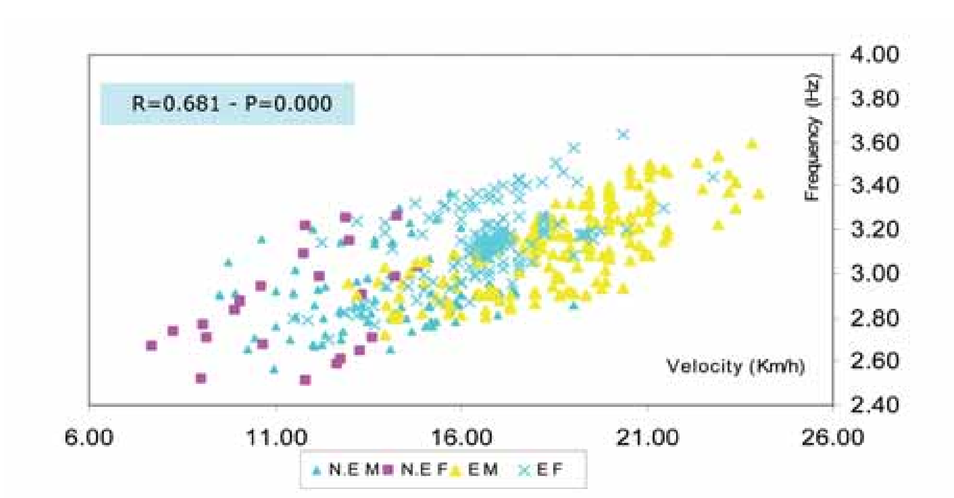


Figure 9: Scattergram of stride frequency at different velocities for all groups

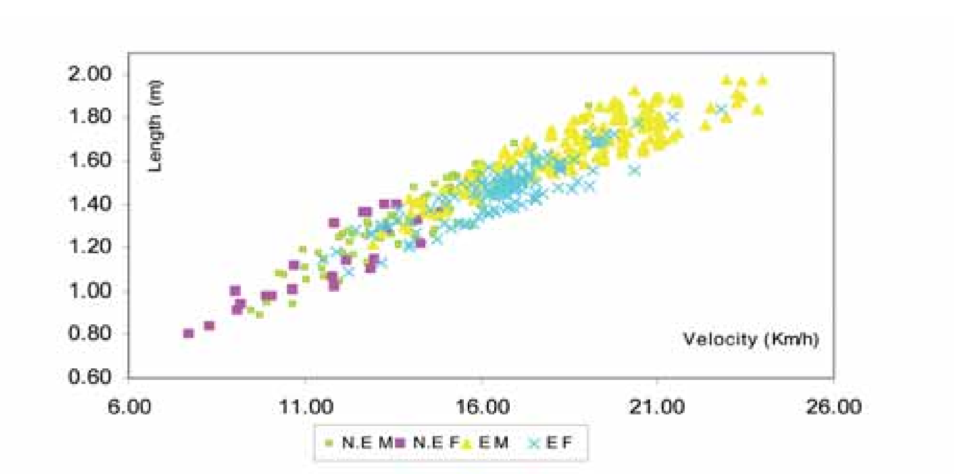


Figure 10: Scattergram of stride length at different velocities for all groups

The statistical analysis emphasises the significance of the data as a whole and for the elite male group. The correlation of the other groups, on the other hand, is less significant.

Individual behaviour: Analysis and observations

The underlying theme of this study springs from the conviction that, at the basis of animal movement (in our case, human), there are electro-mechanical characteristics and that energetic metabolism is "in tow". These mechanisms act in such a way as to satisfy and support what is requested of them in the best possible way. In other words, it's not the anaerobic metabolism's activity that brings about the increase in muscular force but, on the contrary, it is the recruitment of a greater number of motor units that draws more energy in order to keep the movement "alive". In order to understand the range of motor

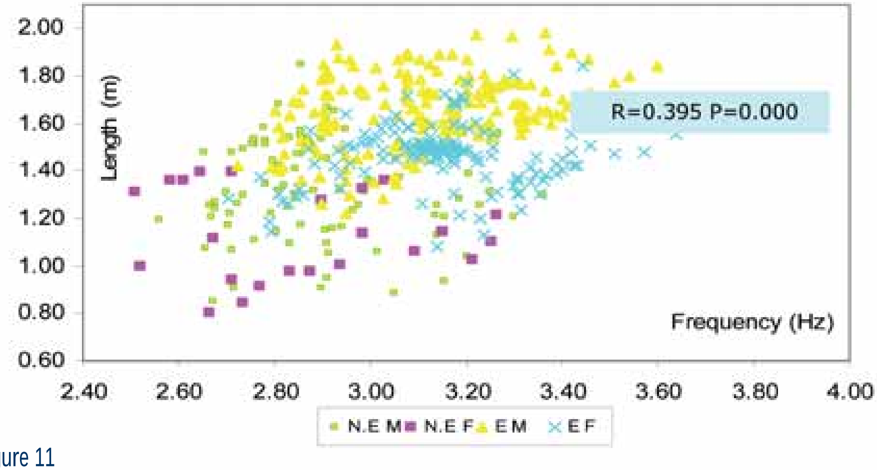


Figure 11

expressions, it is necessary to examine and measure the physiological parameters, keeping in mind that minimal variations in intensity can produce enormous differences in the duration of the effort.

A second concept that we should clarify refers to the condition by which all of the deductions brought forth from the analysis of the statistical data allow us to formulate a general idea and trace lines of tendency for the proposal of a reference model. They do not provide us, in any case, with mathematical formulas that can be applied to every single athlete.

In this, a critical examination by the coach (or training expert) is still essential in order to provide guidelines useful for perfecting the technical action.

"All humans who are able to run possess a range of velocity in which their mechanical output reaches a peak" (CAVAGNA, 2006). A runner becomes a specialist in a particular distance when his innate characteristics and those that he has acquired (through training) bring him to a technical level that, within a group of his peers, gives him an optimal combination between average speed and distance covered. Obviously, the limit is represented by maximum mechanical power. Output, however, distinguishes athletes within the same potential range[7]. In general, elite athletes have a greater range of velocity in which they are efficient. The modulation of the propulsive impulses (kinesthetic differentiation and the proper succession of stimulus frequencies of the locomotive plates) combined with a rhythm that is appropriate for the variation in speed, yield optimal use of total metabolic energy as well as of the energy that comes from the elastic response of the structures of the locomotive apparatus.

The following are examples of how it is possible to gather elements for evaluation by monitoring the kinematic parameters of running in an isolated fashion or together with information drawn from metabolic indicators.

Stride length and stride frequency obtained from the same athlete in various situations

Figures 12 and 13 superimpose the data collected on a marathon runner during a test

7 A study performed by MORGAN & CRAIB (1992) on runners of the same aerobic potential over 10,000m revealed that, statistically, at least 64% of the variation in performance is due to running economy.

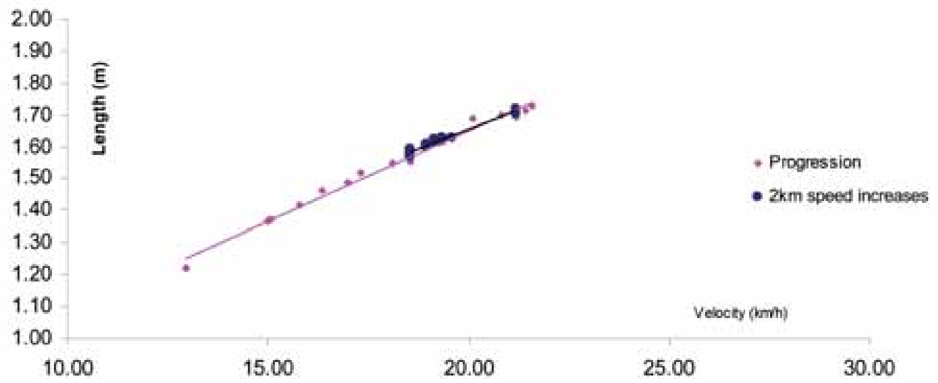
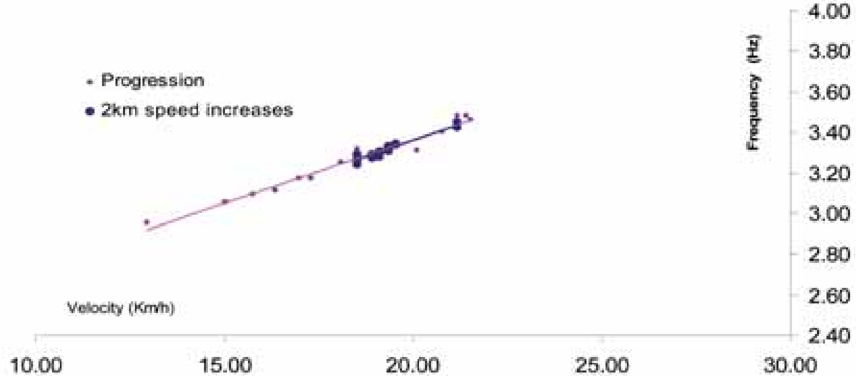


Figure 12



Figures 12 and 13: Changes in stride length and frequency with increasing velocity (purple) and work load (blue) for Athlete A

of continuous progression from 13 to 23km/h (purple) and at increasing work loads (blue) represented by six steps of 2km (increase in speed of 0.2km/h from 19 to 22km/h). The length of the stride as well as the stride frequency at equal speed remained stable in both conditions (the dots correspond perfectly with each other).

The data of a second athlete of equivalent technical level in the same conditions is shown in Figures 14 and 15. There is a marked technical variation between the test in progression and that at constant speed. The latter shows that the frequency had a sharper increase than the stride length in comparison with the test of continuous progression. This analysis refers to the stabilisation of running technique and rhythmic abilities in various work situations.

Stride Length and Heart Rate

In Figures 16 to 20, the relationship between running speed, stride length and heart rate variation is shown. All studied

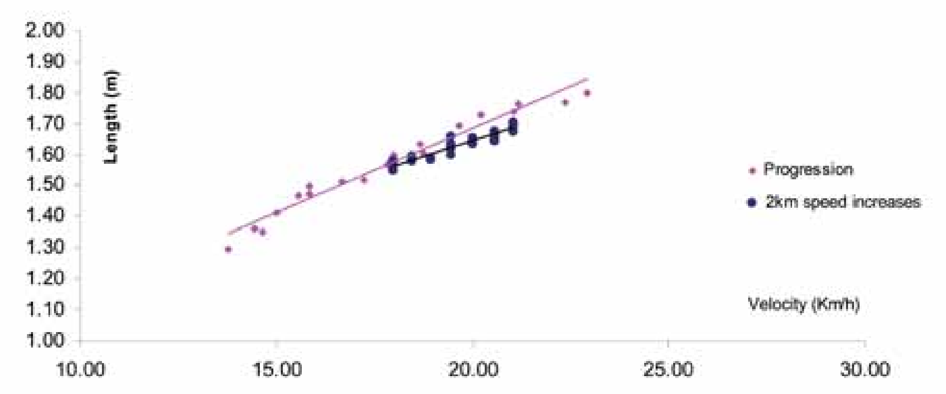
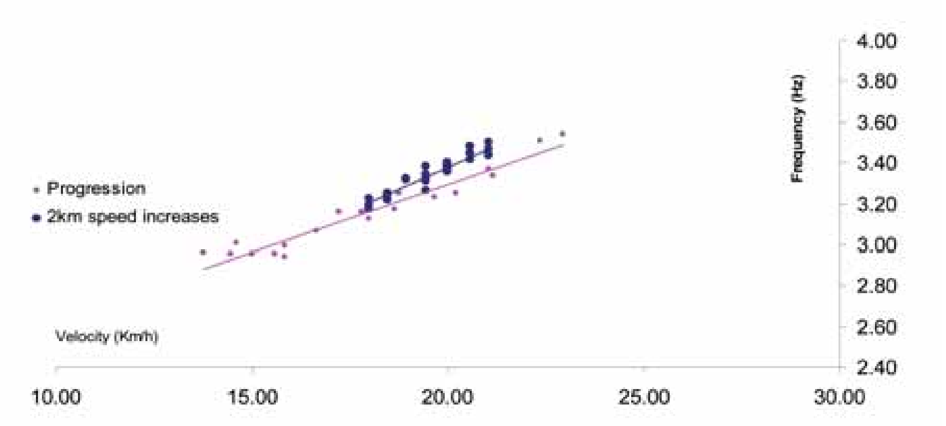


Figure 14



Figures 14 and 15: Changes in stride length and frequency with increasing velocity (purple) and work load (blue) for Athlete B

groups are included and for elite runners we also specified the type of race (middle-distance or marathon). Almost all subjects in the study showed a very similar behavior. Stride length as a function of speed follows the same path as heart rate:

a) linear relationship up until the anaerobic threshold;
b) curve deflection at higher speeds.

In other words, above a certain level, an increase in speed can be attributed more to an increase in stride frequency than to stride length[8]. This seems to show that correlation between running speed and stride length – high in all groups of runner – is, in fact, even higher if we only take the aerobic intensity area into account.

8 One of the hypotheses that could explain this behavior is that long-distance runners – because of the great amount of medium/low intensity work) train their flexor muscles little while their antigravity muscles are always under tension. At higher speeds they try to compensate this “mechanical limitation” by increasing stride frequency. This obviously results in a higher energy cost. In short we could say – thus contradicting VITTORI’s statement (note 6) only in part – that in prolonged running, athletes use the strength of their antigravity muscles even to control stride length, when speed is relatively low.

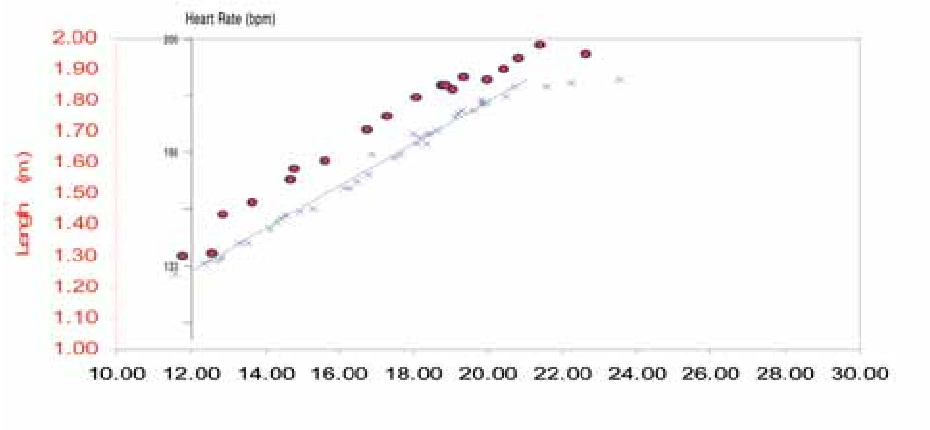


Figure 16: Stride length and heart rate in elite male middle-distance runners

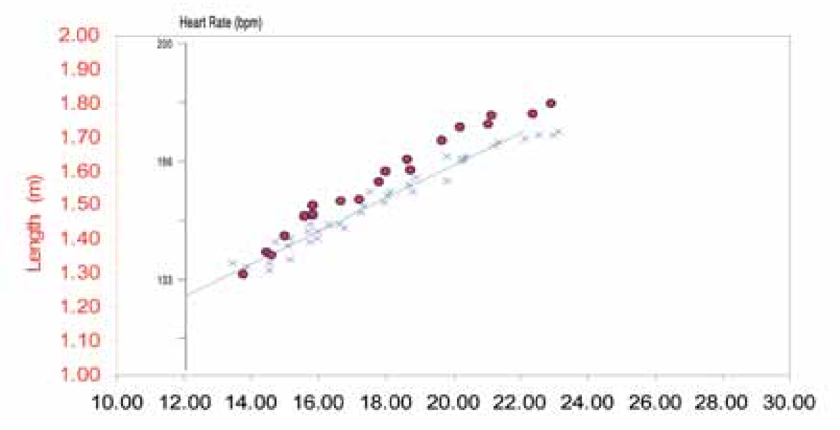


Figure 17: Stride length and heart rate in elite male marathon runners

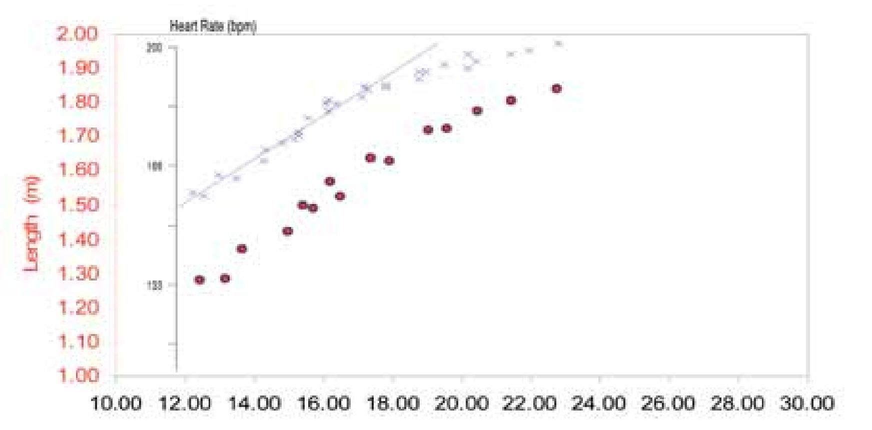


Figure 18: Stride length and heart rate in elite female middle-distance runners

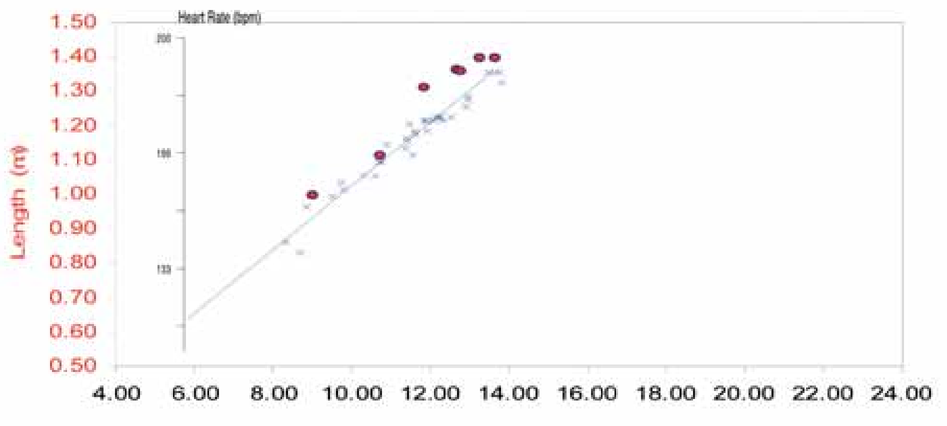


Figure 19: Stride length and heart rate in non-elite female distance runners

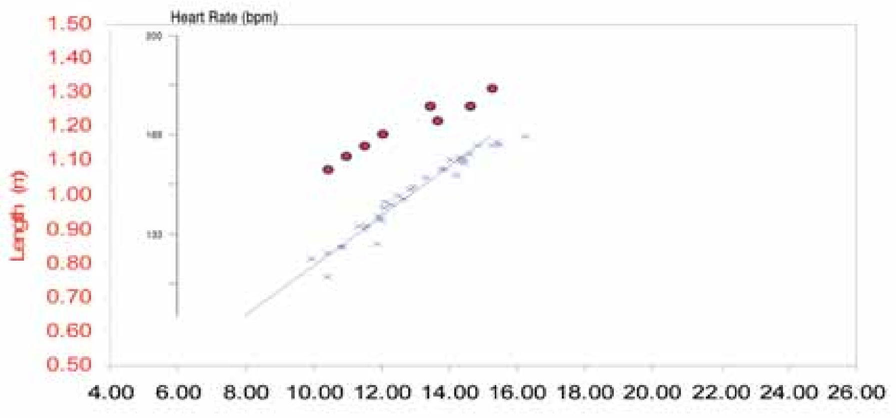


Figure 20: Stride length and heart rate in non-elite male distance runners

Stride Frequency and Heart Rate

Figures 21 and 22 show the behaviour of a male elite middle-distance (under 23) in reference to stride length and frequency. It is clear that, up to 19km/h, the athlete's stride frequency is more or less constant (under 3Hz), which means that an increase in speed is almost entirely a function of stride length. Between 19 and 21.5km/h, stride frequency changes, adapting itself to the change in speed. At the same time, heart rate changes pattern: while it seems to show a deflection (as if it had passed the anaerobic threshold), what actually happens is that it follows a new straight line to the right of the first one and is therefore more efficient (red arrow).

Figure 23 shows the example of an athlete from the male elite short middle-distance group (800m and 1500m). Unlike most of his colleagues, he originally specialised in longer distances and unlike non-elite runners, the correlation between his stride length and running speed remains high (0.994 is the overall correlation) even for speeds that are higher than anaerobic threshold and VO_2max speed.

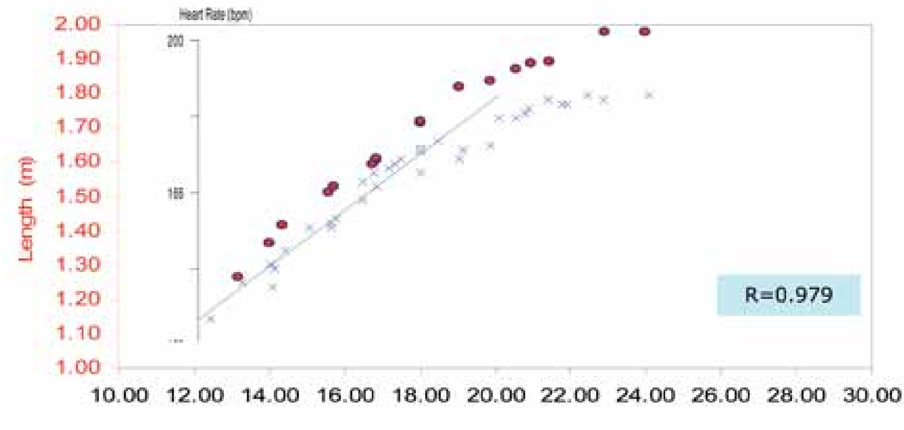


Figure 21: Stride length and heart rate in an elite male U23 middle-distance runner

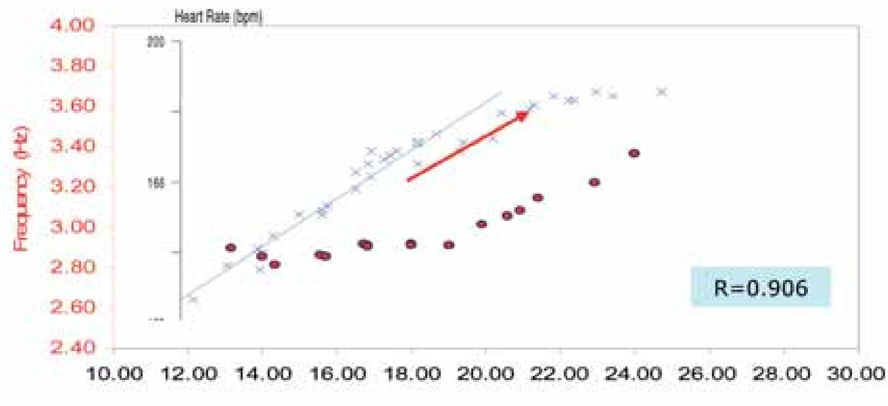


Figure 22: Stride frequency and heart rate in an elite male U23 middle-distance runner

This example is consistent with the hypothesis (note number 8) that athletes who are trained to reach and maintain higher speeds are more capable of activating their flexor muscles, thus increasing stride length even at typically anaerobic speeds.

Methodological implications, techniques and field practice

Far from offering solutions for every circumstance, our results show the need, in any case, for the coach or technical specialist of endurance runners to pay special attention to the development of the motor potential of the athlete as far as co-ordination, technique and tactics are concerned. Action to improve the biomechanical parameters of stride frequency/stride length can be:

a) Direct: Through input during the global execution of motion (at all rates of speed and, particularly, close to race speed);
b) Indirect: Through all the training means likely to improve performance: development and balancing of speed, intra and inter-muscular synchronisation, supple-

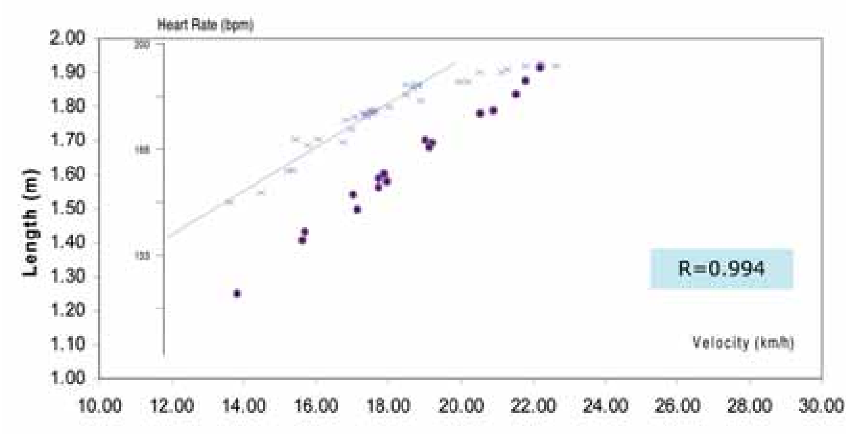


Figure 23: Stride length and heart rate in an elite male middle-distance runner

ness/muscle relaxation, sense of rhythm, kinesthetic perception and differentiation.

In any case, the longer-lasting and deeper modifications and adaptations occur as an effect of extensive exercising related as closely as possible to the specific action. A few studies[9] and, most of all, direct experience of the methods used by top elite endurance runners, show it is more productive to give the athlete feedback during specific exercise. With these premises, exercising speed and stride[10] for a few dozen metres must be considered instructive and/or complementary but not specific.

Conclusion

Running is the fastest means of unaided human locomotion. Machines of all kinds have cut the need for running in normal endeavours to zero, thereby confining it to the exclusive world of sports and fitness. The growing phenomenon of more and more sedentary people becoming “marathoners” is in a sense Nature’s call after being overpowered and abused. Furthermore, mankind is interested in discovering its limits through records.

The world of research can address both of these expectations.

The analysis of two elementary parameters performed with unsophisticated instruments (compared with those in a laboratory) led to few certainties and many doubts on a series of issues that can be addressed when dealing with prolonged running. Hopefully, therefore, further and more detailed studies will follow, with the goal of confirming or refuting the hypotheses we put forth in this paper.

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I would like to thank the athletes, technicians, and doctors of the Italian national middle-distance and marathon team with whom I have worked in the past ten years; all of the other enthusiasts and running buffs who were willing to be “measured” for this study and, not last, Prof. Alberto Madella for “guiding” me through every phase of the drafting of this document.

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9 CONLEY proved that a long period of training at prolonged running leads to an improvement in running economy. On the contrary, short training bouts directed at fine-tuning specific aspects of running have negligible effects on performance (KRAHENBUHL & PANGRASI, 1983).

10 A school of thought maintains that brief exercises on technique have a direct effect on prolonged running and must therefore be considered a specific training means.

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