Take-off from the left foot during bounding.

Breaking contact with the ground, lowest position of centre of mass, first ground contact.

Figure 1: Take-off phases in the flop, scissor jump, pop-up jump and in bounding (foot, knee, hips, spinal column, which together form the extension loop). At the end of the take-off the swinging elements are in a favourable high position. In all the types of jumps examined, with the exception of the ankle jumps, the take-off duration (0.183-0.199 sec), the backward-forward straightening angle (22-30°) and finally the vertical force impulse are of a similar magnitude. All this taken together indicates a comparable stretch-shortening cycle. Therefore, all exercises examined are suitable for training the take-off and are very effective for the development of special jumping strength.

5.2 Confirmation of the order of rank

There are important differences between the individual types of jump with regard to take-off lean, the position of the upper body at take-off, the force values and the occurring rotations. According to the order of rank in Table 1: flop → scissor jump → pop-up jumps → multiple jumps → ankle jumps, there is a decrease in lean back at the moment of foot touchdown and analogously in the horizontal braking force (Tables 3 and 4). As the lowering of the centre of mass depends on the body lean at take-off, the centre of mass in the other jumping forms, with smaller take-off leans, is not so low and not so far behind the projection of the take-off foot as in the flop. Correspondingly, the lever effect of the take-off-leg-upper-body axis, as well as the loss of horizontal velocity or the horizontal braking impulse, is reduced in these exercises. However, this braking impulse has four important functions for the high jump:

> The braking impulse causes the straightening of the take-off-leg-upper-body axis from the backward and inward lean, and thus the conversion of the horizontal approach velocity into vertical take-off velocity. In the case of a pronounced take-off lean the braking impulse is higher and—in a successful jump—the conversion of horizontal into vertical velocity is also higher.

> The resulting take-off lean, the lowering of the centre of mass and the braking impulse lead to a reduction of horizontal velocity to the amount which is optimal for clearing the bar. According to our own measurements (e.g. KILLING/BÖTCHER 1996) this loss in velocity during the high jump take-off is, on average, 2.5 m/sec (range: 1.5-3.7).
Figure 2: The effective forces during the take-offs for the flop, unspecific pop-up jump and bounding

$F_x = \text{horizontal force parallel to the bar}$; $F_y = \text{horizontal force across the bar}$; $F_z = \text{vertical force}$

- Take-off lean and braking impulse prolong the take-off duration and thus enable the high jumper to get the body or individual parts of the body into a position facilitating bar clearance (arms and swinging leg high, hip in front, roll-in of the shoulder and pelvic axis).

- Finally the braking impulse contributes through the straightening movement (turning movement about the foot as the centre of rotation) to the introduction of the rotations which are necessary for an optimal bar clearance.

The factors mentioned, together with the explosive extension of the take-off leg, primarily create the prerequisites for a successful high jump and are therefore indispensable. From this point of view, identical straightening angles with a different take-off lean have quite a different effect. As the take-off lean increases, identical straightening angles lead to an increasing braking impulse or bracing effect. Therefore, if, in the types of jumps examined, the braking impulse during the take-off is steadily reduced, one can quite reasonably talk of a decreasing specificity of the exercises.

The laterally acting, braking forces, or the straightening-tilting movements, also change according to the order of rank shown. Only in the flop can one observe a lean away from the bar at the moment of foot touchdown and a lean towards the bar when breaking contact with the ground, and only in the flop are the force values in the lateral dimension so high. And it is only in the flop that the axes of the shoulder and pelvis turned towards the bar get close to one another. Without this straightening-tilting movement an optimal bar clearance would be impossible.

The other forms of jumping examined here reduce the effectiveness of the take-off brought about by the tilting movement. In the scissor and pop-up jumps in front of the bar a straightening to the vertical can be observed, and reduced lateral forces can be measured at the contact point between the take-off foot and the ground, because of the curved run-up. However, in both types of jump the rotations are rather neutralized than optimized towards the end of the take-off. In the other jumping forms both phenomena are completely missing because of the straight approach. Accordingly, the interaction of special jumping strength, rotational impulse and the stabilizing forces of the trunk is completely neglected in these jumping forms. Therefore, one cannot agree with Adamczewski/Dickwach (1991),
who state that, in the high and long jump, there is a high degree of correspondence between the dynamic and kinematic parameters and that largely identical training forms are possible. On the contrary, the high jump requires specific training exercises.

5.3 Specific features of individual forms of jumping

Apart from the different use of the swinging elements already mentioned, the more general jumping forms examined in this study showed some specific features, which deserve to be discussed separately. This concerns first of all the high force peaks in the multiple jumps. While the single leg take-offs for the flop, scissors and pop-ups specifically train the approach-take-off complex, in the multiple jumps the transition from the approach to the take-off is replaced by the transition from the depth jump to the following take-off. The jumping height of the previous jump creates a downward acceleration prior to the landing, which must be compensated for in the first part of the take-off, before there is a take-off extension. The greater the depth of fall, the higher is the load on the take-off leg (ADAMCZEWSKI/DICKWACH, 1991). The vertical force values at the beginning of the take-off, which are considerably higher than those in the flop, are an expression of this higher amortisation.

This gives rise to the hypothesis that the horizontal jumps also have a considerable plyometric character. BÜHRLE's (1985, 23) statement that, "For the development of the bouncing take-off, training forms could be used, in which the high kinetic energy of one's own body and/or of an exercise apparatus must be cushioned before the body and/or apparatus are again directly accelerated concentrically," also applies to the horizontal jumps. In the latter the depth of fall (of the depth jumps) is replaced by the combination of depth of fall, take-off lean and approach velocity. The passive landing impact to be determined this way can only be an approximate value for the real amount of force applied during the take-off. This can be reduced by a yielding movement of the knee of the take-off leg, and considerably increased by the use of the swinging elements, the active pawing touchdown of the take-off leg and, especially, by the explosive contraction of the extension muscles, so that in the first part of the take-off total forces up to 10KN can occur (cf. PRAUSE 191).

In this way, contrary to the affect of normal foot take-offs (e.g. pop-up jumps), on the one hand a strong, plyometric training effect for the extension muscles can be achieved, while, on the other hand, the passive movement apparatus is extremely stressed or even overtaxed. This means that a corresponding training state is required, if these highly reactive jumps are to be effective.

The second special feature concerns the hop or one-legged bounds. Because of the clawing, beating foot touchdown they are supposed, in the special literature (e.g. TANCIC 1985, PRAUSE 1991), to be particularly specific or effective. Correspondingly they have been put between the pop-up jumps and bounding runs in the order of rank in Table 1. However, our evaluations could not confirm this high estimation. Although the jumpers showed the highest vertical force values in the hop jumps, nevertheless take-off lean, take-off duration and take-off angle were less high-jump-specific than in the bounding runs.

Contrary to the straightening movement specific to the high jump, there was a bending of the upper body to the side of the take-off leg, which is the wrong direction from the point of view of the target technique and which impairs the extension of the whole body (see Figure 3).
As the athletes examined represented a high level of performance, the hypothesis suggests itself that hop jumps have the effects desired for the development of jumping strength only if the athlete shows an exceptionally high amount of physical and co-ordinative-technical ability. If these prerequisites are missing, faulty loads and injuries cannot be avoided, because of the high force peaks. Therefore, the bounding runs, which are less demanding from the point of view of technique, seem to be more suitable training means.

The third special feature concerns the ankle jumps, which seem to hold a special position in terms of take-off lean, long take-off contact, small straightening angle and low force peaks as compared with the multiple jumps. It is certainly correct that the ankle jumps are of a more general character because of these deviations. However, as far as specificity is concerned, their position in the order of rank is correct, except that they are placed a little too far from the multiple jumps. Here some interim forms with a more specific take-off are missing. In another publication, the so-called "medium jumps" were introduced between the distance-oriented bounding runs ("big" jumps) and the height-oriented ankle jumps ("small" jumps). Medium jumps are both distance and height-oriented (cf. Killing 1992). In these jumps the parameters of analysis would presumably be somewhere between the multiple and the ankle jumps, so that they would close the chain of specificity.

5.4 Development of specificity criteria

In Table 6 we have tried to set up an order of rank of the different jumping forms in terms of their specificity for the high jump, on the basis of the investigation results. In this context, 9 criteria have been chosen to examine the specificity of the exercises, taking the flop from a normal approach as the target technique. In this way, one can set up both quality grades of specificity (criterion fulfilled or not fulfilled), and also quantitative gradations within one criterion (far-reaching, partial or no agreement), or with regard to the sum total of criteria (4 criteria fulfilled, 5 criteria not fulfilled). Finally the criteria can also be ranked. As far as the criteria in the left half of Table 6 are concerned, only a few jumping forms correspond with the target technique, while almost all jumping forms fulfill the criteria in the right half of this table. Accordingly, the criteria in the left half of the table cannot be regarded as highly or strictly specific to the high jump.

Finally it should be noted that the specificity of the individual exercises can be varied through special conditions of execution. For example, the specificity of jumps will decrease if they are carried out uphill with additional weights or on soft ground (cf. Hutt 1992).

5.5 Practical implications

Although the observation that better jumpers have a longer upward flight is correct, this does not mean that poorer jumpers have only to achieve this to jump better or higher. Rather must they develop all performance-relevant factors in the correct relation to one another. The investigation showed that, in jumping exercises which have so far been called "special", the complexity of the flop jump is reduced by the lateral dimension or straightening-tilting movement. In all pop-up, horizontal and ankle jumps the rotations...
are suppressed in favour of a maximum extension impulse. Therefore, these exercises are not suitable to train the interaction of the different forces during the take-off for the flop. Although they do develop special jumping strength, they must be supplemented by additional and more specific exercises for the careful preparation of the target technique. These exercises are primarily jumps over the bar whose kinematic and dynamic values correspond much more closely with the target technique than other jumping exercises. Therefore, only jumps from a curved approach and over the bar can strictly be called specific means of training for the flop jump.

A similar view of technique-oriented jumping work was popular in the GDR. There, only jumps over the bar were called "special jumps" (BOTHMISCH/PRAUSE, 1989). Consequently, E. DRECHSLER (1987) developed the so-called "8 Exercises Test". The weakness of this multi-high-jump test, which has already been shown (predominance of jumping techniques with a focus on strength, risk of negative transfer to the flop take-off), have prompted us to develop simpler lead-up exercises and a multi-high-jump test suitable for the flop, the so-called "5+1 Test" (see KILLING 1997 and 1998).

Simplified exercises leading up to the flop are the side and the "sit" flop. These are used in training instead of the scissors jump or the flop from a straight approach, prior to the actual technique jumps, or they are used as an independent unit. These exercises can sometimes be observed when top level the jumpers are warming up: after a good take-off they clear the bar, which is rather low, without a hip extension and either completely without lateral airborne movements or in a sitting position (cf. KILLING 1993). With this sort of lead-up jumps it is easier for the jumper to change to the target technique without running the risk of a negative transfer during the take-off.

5.6 Implications for sport science

In spite of the use of only modest instruments, this examination of special jumping exercises for the high jump led to important results and conclusions, which suggest the need for further examination and discussion. It would certainly be useful to repeat the investigation with other athletes, using a three-dimensional analysis in order to

> confirm the angular values measured or to make them more precise,
> measure the horizontal velocities at the beginning and at the end of the take-off phase,
> determine the vertical take-off velocities or the flight heights.

In connection with the dynamometric measuring data, it would be possible not only to enrich, make precise and re-examine the measuring values and orders of rank presented here, but also to examine the hypothesis as to what extent, in the horizontal jumps, the combination of approach velocity and take-off lean can create plyometric effects which are similar those produced by drop jumps.

Going beyond these concrete questions, it is essential that biomechanical research should focus not so much on two-legged jumps but rather on the special jumping forms. If the single foot take-off is the target technique, increased specialisation implies that jumps with a single foot take-off should play a more dominant role in training. This would also be in accord with the results obtained by MÜLLER and KIEBELE (1995, 1998), which show that explosive strength for events which necessitate a single foot take-off can be developed best by exercises which require a single foot take-off.

The modelling of the single foot take-off is absolutely necessary for the detection of control mechanisms for the different performance-determining factors. Finally, the investigation on hand offers (qualitative) approaches to research into the connection between kinematic and dynamic parameters, which seem to make an integration of the latter into performance diagnosis possible. Here an extreme-group comparison appears to be useful, with the individual performance-determining parameters (weight, horizontal and vertical velocity at the beginning of the take-off, take-off lean, use of swinging elements) being changed in a target-oriented and extensive way.

2 WISCHMANN 1986 and HAMBURG/PLESS 1992, expressly demand high jump training exercises which are characterized by a vertical upper body during the jump, i.e. pop-up jumps and scissors jumps, in order to develop an effective take-off.
3 See KILLING 1989 and 1990; DAPENA (1994) refers to another form of apparent rotation in the flop, the so-called catting.
4 See e.g. RITZDORF/CONRAD 1987, DAPENA et al. 1992, KILLING/BÖTCHER 1996.
5 A positive exception are the studies by PRAUSE (1991), which have as yet hardly been recognized.
6 Because of the small deviations from the flop from a full approach, the flop from a half approach is neglected in the following. The well-known differences, e.g. low approach velocity, longer take-off contact and tendency to a powerful jump, could also be observed here.
The first part of the investigation was conducted in 1989 in co-operation with Schwitz and Schweizer from the Olympic Training Centre and University of Freiburg.

This previously customary form of force value determination offers the opportunity for comparisons with other investigations. However, as the touchdown of the take-off foot in the high jump (and in the other jumping forms examined in this study) takes place at an angle of 20 to 30° with the bar, in future measurements the co-ordinate system of the force values should be shifted correspondingly. In this way the horizontal forces in the direction of the foot touchdown could be clearly separated from those at an angle to the direction of the foot touchdown.

Because of the small size of the force platform and because the jumpers always had to jump one after the other, the force platform was not hit exactly in all jumps. However, for each jumping form several typical jumps could be measured.

The values for the flop correspond with the measurements of other studies (e.g., Rizzoli/Conrad 1987, Dapena 1992) and thus corroborate the investigation method and legitimize the corresponding results for the other jumping forms.

That lateral forces are measured at all can be explained by the arrangement of the co-ordinate system parallel to the bar, instead of parallel to the approach angle.

It should be noted that, in the high jump, the resulting velocity at the end of the take-off is only 1 m/sec slower than the velocity at the start of the take-off; there is primarily a change in the direction of movement.

In this context the decreasing average force values in the vertical dimension shown in Table 5 should also be noted.

Since the scissor, pop-up and multiple jumps do not necessarily require a different arm action, the deviations observed are primarily caused by technical shortcomings, compensatory movements or arbitrary changes. In the interest of a positive transfer with regard to the central functions of "creation of vertical impulse" and "control of rotations", it appears to be useful to use, or try to use, swinging elements which correspond with the target technique in all special jumps.

These effects occur to a somewhat lesser degree (because there is no new take-off) during the landing after pop-up jumps. This has not been examined in this study.

In this context the general use of the term "plyometrics" for almost all jumping forms by American as opposed to European sport scientists and practitioners is interesting (cf. recently Jacoby/Fraley).

A similar view can also be found in Gumbich and Adamczewski (in Dickwach 1991) as well as in Prause (1991).

In multiple jumps the vertical impact impulse is the result of mass (m), falling height (h) and angle of incidence factor (sin α) and the acceleration of gravity (g), while the horizontal impact impulse is the result of mass (m), horizontal velocity (v) and angle of incidence factor (cos α). Both can be added to the total impact impulse (cf. maximal values in Table 5).

Such a bending movement can be caused by lateral instability during the single foot take-off, or by an overloading which leads to inhibitory reflexes (cf. Schmidtbleicher 1994). In double foot jumps, landing stability is much greater, so that in the case of a slight inhibition the beating effect can develop to the full. This explains why jumps with a double foot take-off have a high training effect, in spite of the impact impulse being divided in half.

The swinging element impulse can only be determined indirectly. See Dapena (1992, 1994) and Prause (1991).

In the "8 Exercises Test" each athlete tries to jump as high as possible in 8 different exercises (flop, scissor jump, squat jump, straddle with the left and right leg) in a competition against himself or herself (and against others). The best heights achieved in all jumping forms are added together and result in a parameter for the athlete's special jumping ability. Using statistical evaluations of many athletes, standard orientation values were developed for individual age groups or performance categories.

A corresponding investigation on current top-level high jumpers is being prepared for the training and competition year 1997/98 in Berlin.

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Influence of elevated climatic heat stress on athletics competition in Atlanta, 1996

by David E. Martin

"Previous data regarding Atlanta's weather for the 1996 Olympic Games suggested that climatic heat stress would likely be high, perhaps even worse than for the 1992 Barcelona Games. As a result, details of climatic heat stress were documented at four major athletics competitions in Atlanta during 1996, including the U.S. Olympic team trials and Olympic Games. In addition, data were obtained regarding heat-related medical casualties among athletes at those competitions. Practical conclusions from these data should help athletes and coaches better identify 1) how to quantify climatic heat stress, 2) what occurs when athletes adapt to heat and humidity, 3) which groups of athletes are most likely to experience problems with heat stress and 4) what strategies might help in optimal preparation for similarly stressful competitions in the future.

Climatic heat stress and athletic performance

When highly fit athletes are asked whether they believe that heat and/or humidity will negatively affect their performance, two answers are typically obtained. Distance runners and race-walkers tend to dislike hot, sunny, humid days and expect race times to be slower under these conditions. The explanation is simple: a portion of the blood flow that ordinarily would be directed preferentially to working skeletal muscles now needs directing to the skin for convective and radiational cooling, and also for evaporative cooling from sweat production. Also, in the longer endurance events, unless fluid replenishment is obtained, blood volume will decrease from continual sweat loss, thereby slowing the maintainable pace in the final stages.

Realizing these heat stress limitations, endurance athletes typically take appropriate pre-race precautions: developing effective habits of hydration, daily weigh-ins to check on weight maintenance, and carefully planned inclusion of training blocks in warm/humid conditions, to enhance both physical and mental preparation for a successful competition. During the competition itself, they pay special attention to fluid intake and manageable pace, so as not to accumulate excessive heat.

On the other hand, field event athletes and short-distance runners seem to prefer hot, humid weather, saying that their warmer muscles have less tendency to cramp during their explosive-type activities. Whether their competition requires several hours to complete (e.g. pole vault or high jump), or a much shorter period (e.g. sprints), the short duration of their actual competition efforts permits them to acquire adequate energy-containing fluids (and even solid food) during their period of exposure to the elevated thermal load.

However, there are still no hard data to validate these two concepts or to determine whether men and women are equally affected. This was a primary reason for initiating this research.

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1.1 Earlier heat stress studies: Barcelona and Atlanta

Since it was anticipated that environmental heat problems would occur at the Barcelona Olympic Games, detailed climatic measurements were made during selected long distance running and walking competitions (VERDAGUER-CODINA et al. 1994). This study provided the first practical scientific perspective regarding the influence of climatic heat stress on athletic performance during a multi-day international competition.

Following those Games, and using a similar format, heat stress documentation studies were continued at the Atlanta Olympic stadium venue, from 1993 through 1995, on the same days as projected for the 1996 Atlanta Games competition schedule (MARTIN 1996). The most interesting conclusions from this research were that a) Atlanta's weather was unpredictable in terms of precipitation, temperature and humidity, and b) during 1993 and 1995 climatic heat stress was indeed even greater than that seen at the Barcelona Games.

In view of this potential climatic threat, a project, directed by the author and implemented under the auspices of the IOC Medical Committee's Subcommission on Biomechanics and Physiology, allowed continuation of these climatic heat stress studies during 1996 in an expanded format. First, three important athletics competitions were studied as pre-Games test events, to permit needed interaction with Games related personnel, policies and procedures. These events included

1) the IAAF Atlanta Grand Prix on 18 May,
2) the U.S. Olympic team selection trials from 14-23 June, and
3) the Peachtree 10km Road Race on 4 July.

Then, during the Olympic Games, four venues were studied: athletics, tennis, beach volleyball and modern pentathlon, because all had athletes competing for long periods outdoors in a stadium where radiant heating combines with ambient temperature and solar radiation to cause considerable thermal stress.

Collective consideration of data from the four Atlanta athletics competitions permits clearer answers than previously available for the questions posed earlier: 1) how do men and women compare in their response to high level competition in thermally stressful conditions, and 2) how do field event and short distance track event athletes compare to long distance runners in their response to competition in heat and humidity?

The primary aim of this research was to provide information and practical perspective to the coaching and scientific members of the athletics community. Such information will be useful for preparing future athletes to perform well in elevated climatic heat stress.

However, the information collected at the Games themselves was also used in a practical way to assist in day-to-day Games operations. Medical staff, stadium administrative staff and public-address announcing staff all found good use for the information regarding climatic conditions, which was recorded at 10 minute intervals during the entire period of competition. As increasing risk of thermal injury developed during each day, when pre-established climatic heat stress threshold values were exceeded, an increased output of resources provided an appropriate response. The kinds of response included 1) public address announcements to spectators urging them to drink fluids, 2) changing dress codes for officials to permit removal of jackets, 3) inclusion of overhead canopies to provide shade, and the addition of water-soaked towels to supplement electrolyte drinks for athletes on the field of competition, and 4) increased medical preparedness for mass-finish arrivals in the long distance competitions.

2 Measuring climatic heat stress

Climatic heat stress is defined as the combined effect of four environmental factors that interact with the body's ability to maintain its normal temperature: air temperature, relative humidity, wind and radiant heat. All four of these primary weather variables need to be quantified in order to determine the total influence of climate on exercise performance. Information reported by commercial weather sources, such as newspapers or television, does not completely describe cli-
matic heat stress, for several reasons. First, usually not all of the four factors mentioned above are reported. Second, if they are, they are provided separately, with no means provided for understanding their collective influence. Third, weather stations typically are located at airports, where conditions may be quite different from those in an athletic stadium.

Several commercially available instruments measure climatic heat stress. Usually all have three thermometers (Figure 1a), which together quantify the effects of wind, shade temperature, relative humidity and radiant energy. Figure 1b illustrates the Casella HSM 100 heat stress monitor (Regent House, Wolseley Road, Kempston, Bedford MK42 7YJ, England), used for the Atlanta climatic studies. As shown, the device was mounted on a tripod 1.5m (69") above the grass surface adjacent to the track, at the apex of the first turn. This provided: a) maximum exposure to the sun, b) optimum similarity to the conditions on the field of play, while not hindering competitive activities, c) no interference with accredited photographers, and d) no impairment of vision for television or for spectators (a small chair was provided for seating, in order not to block spectator viewing.

One thermometer measures the Dry Bulb Temperature (DBT). This is simply a standard thermometer, kept dry and out of the direct sunlight. It provides shade temperature, the value typically seen in newspaper and television weather summaries.

Another thermometer measures the so-called Block Globe Temperature (BGT). It is surrounded by a black globe, which absorbs the long-wave infrared energy from both sun and nearby heat-radiating surfaces, such as streets (or track) and buildings (or stadium). The greater the radiant energy, the higher the BGT and the more disparate this value is from DBT. Wind also influences BGT.

The third thermometer measures the so-called Wet Bulb Temperature (WBT). This thermometer is covered by a moistened cotton sleeve, and exposed to the sun and wind. As evaporation of water occurs, its conversion from the liquid state to water vapour requires energy. The greater the concentration gradient between water vapour at the thermometer surface and the surrounding air, the greater is the rate of evaporation and, with it, the potential cooling effect. Water vapour in the surrounding air, measured as relative humidity, can be determined from published tables based upon differences between DBT and WBT. As indicated above, the lower the relative humidity, the greater is the rate of evaporative cooling.

The collective influence of these three temperature readings is incorporated into the Heat Stress Index Temperature (HSI), calculated as follows: HSI = 70% WBT + 20% BGT + 10% DBT. Thus, humidity and wind are the most important climatic factors influencing performance. The combination of high humidity and high DBT produces what is often referred to as "wet heat," or "jungle heat," whereas a combination of high DBT and low relative humidity produces the so-called "dry heat" or "desert heat." Although a breeze will be beneficial in both instances, the rate of evaporative cooling will be greater in dry heat conditions.

2.1 Influence of climatic heat stress on exercise performance

In 1984 the American College of Sports Medicine (ACSM) published a "Position Stand on Prevention of Thermal Injuries During Distance Running", which was recently revised (Anonymous 1996). Included with those guidelines is a table of HSI temperature ranges (Table 1), together with descriptive terms indicating the increasing risk (low, moderate, high, etc.) of performing endurance exercise, such as distance running, for untrained, non-heat adapted, sedentary people, as climatic heat stress increases. Note that, in addition to the temperature ranges, a colour-coded "heat stress flag" is suggested for on-site viewing by medical staff or exercise participants, as an instant visual cue regarding existing heat stress conditions. Two additional columns of practical information for coaches and athletes, which do not appear in the ACSM guidelines, are also presented in Table 1. One is a series of single-word descriptions of comfort for exercise tolerance. The other provides suggestive phrases.
describing the extent to which sustained endurance exercise performance may be affected.

The original research which led to the relative weighing of the factors contributing to climatic heat stress was done by Constantin Yaglou (1957) and David Minard (1957, 1967). This was one facet of an ongoing effort to reduce the number of heat stress fatalities among military recruits undergoing basic stress training in subtropical environments. Their studies showed that the person most likely to become a heat stress casualty was overweight, sedentary, coming from a cooler region, and beginning basic training early in the summer before becoming heat-acclimatised. These factors, combined with the wearing of a military-style working uniform and a long day of hard endurance work, combined to increase the likelihood for developing heat injury. Yaglou and Minard proposed, as a guideline, that vigorous, endurance-orientated physical training be stopped when the HSI entered into the Extreme Risk region (>27.7°C; >82.0°F).

This Extreme Risk threshold of heat stress, (referred to hereafter as the Event Delay Threshold) was incorporated into the ACSM guidelines. Experience over the years, particularly for children and untrained adults, has shown it to be sensible. However, in the case of elite-level distance runners and walkers, heat acclimatised, with minimal body fat and minimally dressed, so that heat dissipation by evaporation, radiation, and convection is optimal, the question has often been asked whether the threshold for stopping their activity could be raised without compromising health.

Data acquired from the Barcelona Games do not clearly answer this question. There, the highest HSI recorded was on 7 August, in the Olympic Stadium in the sun, between 17:55hrs and 18:25hrs. During this period the HSI was 33°C (91.4°F) – slightly beyond the Dangerous Risk level. No competitions involving prolonged high-level endurance activity were occurring at this time, however. The men’s pole vault final was just starting. On 1 August, the women’s marathon started with a HSI at 27.7°C (82.0°F), and finished at 25.9°C (78.9°F). Also, on 7 August the men’s 50km race walk started with a HSI at 25°C (77°F) and finished at 28.9°C (84°F). Although 21% of the women and 7% of the men dropped out of these two endurance competitions, it is not known how many of these were bona fide medical heat

![Figure 2: Graphic summary of climatic heat stress measurements made during the IAAF Atlanta Grand Prix on 18 May 1996](image-url)
stress casualties or how many were simply athletes who opted out to optimize recovery for a post-Olympic competition.

The Atlanta experience, described below, provides insight on this and other questions posed earlier. For the historical record of athletics, a complete event-by-event summary of climatic heat stress data, as well as heat-related athlete medical casualties, for the 9 day Olympic athletics competition are presented here. A complete event by event summary of climatic heat stress values, as well as heat-related medical casualties for the IAAF Atlanta Grand Prix and the 8 day U.S. Trials, have already been published in the technical coaching journal of the USA Athletics Federation (Martín 1997a). Conclusions from these two competitions are summarised below, along with a more detailed analysis of the two Peachtree Road races of 1995 and 1996. A comparison of the various Atlanta Olympic venues for endurance events has also been published (Martín 1997b).

3 IAAF Atlanta Grand Prix

Unlike the multi-day U.S. Trials and the Olympic Games, with morning and evening periods of competition, this was a one-day competition, beginning mid-morning and concluding mid-afternoon. Athletes essentially flew in, competed, and flew out, leaving little time for acclimatization, either to time zones or climatic conditions.

3.1 Relevant weather summary

Atlanta was influenced by a large high-pressure weather system, positioned such that unseasonably warm air flowed from the west, i.e., over a dry land surface, rather than from the south, i.e., across the moist Gulf of Mexico. The result was a record day time high temperature of 33.3°C (91.9°F), with low humidity (below 40%). The normal high temperature for this date is 26.6°C (79.9°F). Brilliant sunshine prevailed throughout the daytime hours, with a cloudless sky.

3.2 Heat stress and athlete performance – Grand Prix

Figure 2 graphically summarises the four heat stress temperatures obtained at 10 minute intervals (°F and °C) during the entire competition period, which extended from 09:30hrs until 15:30hrs. The wide spacing of the four temperature values is characteristic of a hot dry day. BGT was high primarily because of solar radiation, WBT was low mainly due to cooling from a high evaporation rate, with DBT and HSI in between. During the morning hours, the difference between DBT and WBT was only 4.4°C (8°F), but as the relative humidity decreased steadily, this difference increased to 9.8°C (17.5°F) during the early afternoon hours. The minimal temperature deviations on a minute-to-minute basis are explained by the cloudless sky and only a slight breeze.

The highest shade temperature inside the stadium was 35.5°C (95°F) at 13:50hrs. This was 1.6°C (4°F) greater than the corresponding airport maximum, suggesting that the concrete surfaces within the stadium both absorbed and reflected heat. This so-called "crock-pot" heat-retaining effect shows clearly that airport climatic data may not accurately represent stadium data.

All except four events were held in Extreme Risk conditions (>29°C/88°F) – higher than the Event Delay Threshold. This included three middle-distance running events. One was the men's 3,000m, run at 14:30hrs and won by Paul Bitok in 7:47.80min. The highest temperature in the sun (BGT) for athletes and workers on the stadium floor had just occurred – 42.6°C (108.7°F) at 14:20hrs. However, this period also had the lowest humidity and greatest sweat evaporation rate. Another event was the women's 1,500m, run at 13:50hrs and won in 4:15.24min by Juli Henner (over Maria Mutola). The third event was the men's mile, run at 15:20hrs and won by Nourredine Morceli in 3:50.86min, a U.S. all comers' record. The highest HSI recorded was 30.5°C (86.9°F) at 15:20hrs, shortly after this men's mile run.

No events were delayed. No athletes in any event demonstrated signs of impending heat injury, either during or after their races. This suggests that healthy, highly fit, heat-acclimatised athletes have a considerably higher heat tolerance than healthy, non-acclimatised, sedentary people.

Although not shown in Figure 2, the track surface temperature was also measured intermittently, using infrared thermography (OTOTEMP 3000 K Exergen Corporation, Newton, Massachusetts, USA). The highest track surface temperature was 45.6°C (114.2°F) at 14:50hrs. Thus, it continually dissipated heat to the air by convection and radiation, and into the asphalt layer below by conduction.

4 U.S. Olympic team trials

A detailed, event by event record of all heat-related data for each day of the Trials has been published elsewhere (Martín 1997b); only a brief summary is presented here.

4.1 Relevant weather description

The first five days of this competition took place under sunny-to-partly-cloudy conditions,
along with warm humid weather and widely scattered showers and thunderstorms, often locally severe but short-lasting. During the final three days of the Trials sunny skies prevailed, with lower humidity but warmer temperatures. On all eight days the recorded daytime high temperature was higher than the expected normal high — by an average of 1.4°C (3°F) on the first five days, and by an average of 3.7°C (7.3°F) on the final three days. Also, the recorded low temperature was higher than the normal low — by an average of 2.2°C (3.6°F) for the first five days, and an average of 3.3°C (6°F) for the final three days.

4.2 Heat stress and athletic performance - trials

On the first day of competition, five of the 20 events were scheduled during Extreme Risk (Event Threshold Delay) conditions; these were sprints, field events and part of the heptathlon. All other events, including the rounds of three long distance running events (men's 10km, women's 5km and 10km), were held during High Risk conditions. During the long distance running events, the HSI ranged between 23°C (73.4°F) and 24°C (75.2°F), which was below the Event Delay Threshold.

During days 2 to 5, 49 events were all contested under High Risk conditions. The final 3 days were more thermally stressful, with 4 out of 17 events on Day 6, 11 out of 15 on Day 7, and all 10 on Day 8, held under Extreme Risk conditions.

The highest HSI reached was 30.9°C (87.5°F) on Day 8, during the men's 100 metres hurdles semi-final and women's 200 metres semi-final. At that time the track surface temperature was 44.5°C (112.1°F). The lowest HSI was 22°C (71.6°F) on Day 2, during the men's 100 metres final. The average HSI during the eight days of competition was 26.1°C (79°F). Twenty of the 111 events were held when the HSI was higher than the Event Delay Threshold, but no distance running or walking events were scheduled during this period. The average HSI during the trials and finals of the men's and women's 5km and 10km runs, and the women's 10km and men's 20km walks, was 24.5°C (76.1°F).

5 1995 and 1996 Peachtree road races

The Peachtree Road Race course covered part of the Olympic marathon course (roughly from kilometres 27 through 35), and started at a similar time (07:30hrs for the road race versus 07:05hrs for the marathons). With this in mind, Olympic marathon runners from many nations took the opportunity of participating in this event in both 1995 and 1996.

5.1 Relevant weather summary

The normal high and low temperatures for 4 July in Atlanta are 31.1°C (88°F) and 20.5°C (68.9°F), respectively. The road race begins an hour after sunrise, and if there is no cloud cover, nearly half of the course experiences sunshine.

In 1995 Atlanta was influenced by warm, moist air, with cloudy skies. There was a brief period of sunshine between 08:35 and 08:50hrs. From about 09:15hrs gradually disappearing clouds brought increasingly visible sunshine. On 4 July the maximum and minimum temperatures were 33.3°C (91.0°F) and 21.7°C (71.1°F).

In 1996 a large high pressure system, centred over the mid-western United States, brought cool, dry air flowing from north to south through the city. This advancing cool weather was fortuitous, as the day preceding had been hot and humid. On 4 July the maximum and minimum temperatures were 29.4°C (84.9°F) and 17.2°C (63°F). Accompanying the lower humidity and cooler temperatures, however, was a cloudless sky, with rapid and steady air warming soon after sunrise.

5.2 Heat stress and athletic performance - road races

Each race began at 07:30hrs and most finishers had completed the event by 09:30hrs. In 1995 initial cloud cover caused little increase in the HSI during the period when elite men and women were racing, but it did rise substantially for those "back in the pack". In 1996 the temperature at the start was substantially cooler, with much lower humidity. Figure 3 graphically summarises heat stress data collected from 06:55hrs through 09:50hrs for the 1996 race. Clear skies and sunshine started to raise the BGT rapidly, but the HSI was low enough at the start for this rise not to affect race performance adversely. Conditions were so good, in fact, that Hellen Kimaiyo set a new women's open course record (32:52) by 57 seconds! Joseph Kimani's 27:04 was not only an open men's course record (by 52 seconds) but also a new "aided world best" time for the 10km distance (the course is point-to-point [73% start/finish separation] with a net drop of 3.4m per km).

Table 2 summarises specific temperature and performance data during the 1995 and 1996 races. In Table 2a, note the more rapid rate of warming during 1996 compared to 1995, due to the cloudless skies (7°C/12.6°F versus 4.2°C/7.6°F over a two hour period). Also note the much higher humidity in 1995, as well as higher temperatures throughout the 2 hour period. The greater loss of metabolic heat energy produced by ath-