Heat Exhaustion and Dehydration as Causes of Marathon Collapse

R.W. Kenefick, M.N. Sawka

Thermal and Mountain Medicine Division
U.S. Army Research Institute of Environmental Medicine
Natick, MA 01760-5007

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This article reviews causes of marathon collapse related to physical exhaustion, heat exhaustion and dehydration. During severe exercise-heat stress (high skin and core temperatures), cardiac output can decrease below levels observed during exercise in temperate conditions. This reduced cardiac output and vasodilated skin and muscle can make it difficult to sustain blood pressure and perhaps cerebral blood flow. Dehydration can accentuate this cardiovascular strain. In contrast, excessive heat loss to the environment during cold weather may result in hypothermic collapse. Other factors contributing to post-race collapse might include reduced skeletal muscle pump activity and dehydration and prior heat stress mediated changes in cerebrovascular responses to orthostatic challenges.
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Robert W. Kenefick and Michael N. Sawka

US Army Research Institute of Environmental Medicine, Natick, Massachusetts, USA

Abstract

This article reviews causes of marathon collapse related to physical exhaustion, heat exhaustion and dehydration. During severe exercise-heat stress (high skin and core temperatures), cardiac output can decrease below levels observed during exercise in temperate conditions. This reduced cardiac output and vasodilated skin and muscle can make it difficult to sustain blood pressure and perhaps cerebral blood flow. Dehydration can accentuate this cardiovascular strain. In contrast, excessive heat loss to the environment during cold weather may result in hypothermic collapse. Other factors contributing to post-race collapse might include reduced skeletal muscle pump activity and dehydration and prior heat stress mediated changes in cerebrovascular responses to orthostatic challenges.

Marathon running is a reasonably safe endeavor with only one reported death per 50 000 participants.\(^1\) Despite this relatively low rate of catastrophic injury, physical collapse during the marathon can occur either during the race itself or immediately following completion of the event. Roberts\(^2\) has reported an exercise-associated collapse incidence rate of 1.13\% of race entrants over 12 Twin Cities Marathon races and rates of collapse of 0.2–3.7\% have been reported for other distance running events.\(^3\) Collapse during the marathon may be caused by any number of factors, including cardiac arrest, hypoglycaemia, hyponatraemia, dehydration, hyperthermia and hypothermia. Collapse following the event is typically caused by postural hypotension, a result of the cessation of exercise and/or heat strain and/or dehydration. Although various pathologies or other medical conditions may lead to collapse, the purpose of this review is to provide an overview of causes of marathon collapse related to exhaustion, heat exhaustion and dehydration.

1. Physical Exhaustion

Exhaustion during marathon competition may be the result of several factors, individually or in combination. Factors related to collapse from exhaustion during the event may include hypoglycaemia, from inadequate carbohydrate intake, insufficient training for the event or use of a strategy during the race for which runners were not properly trained. As noted by Roberts\(^7\) and Holtzhausen et al.,\(^3\) there is an increase in the rate of collapse at 3.5 hours after the start of the race, likely among runners attempting to achieve qualifying times for other marathons. Their intense efforts may be greater than the current fitness level or heat acclimatisation status of the athlete and may further result in either glycogen depletion or hyperthermia. Any of these factors, alone or in combination, may contribute to collapse.

2. Hyperthermia and Dehydration

During exercise-heat stress, the primary mechanisms for heat loss are increased skin blood flow and sweat secretion. Maintaining high skin blood flow
can impose a substantial burden on the cardiovascular system. High skin blood flow is associated with reduced cardiac filling, reduced right atrial pressure and reduced stroke volume, which require a higher heart rate to maintain cardiac output. This reduction in cardiac filling occurs because the cutaneous venous bed is large and compliant, and dilates during heat stress. In addition, sweat secretion can result in a net body water loss (dehydration), thereby reducing blood volume. Therefore, heat stress can reduce cardiac filling both through pooling of blood in the skin and through reduced blood volume. During severe exercise-heat stress (high skin and core temperatures), cardiac output can decrease below levels observed during exercise in temperate conditions. This reduced cardiac output and vasodilated skin and muscle can make it difficult to sustain blood pressure and perhaps cerebral blood flow.\(^4\)

3. Exhaustion from Heat Strain

Core temperature and skin temperatures provide indices to predict the incidence rate for exhaustion from heat strain.\(^5\) Figure 1 illustrates some relationships between core temperature and incidence of exhaustion from heat strain for heat-acclimated persons exercising in uncompensable (most likely very hot skin) and compensable (most likely cool skin) heat stress. During uncompensable heat stress (UCHS), evaporative heat loss is insufficient to dissipate body heat and skin temperatures are relatively high. During compensable heat stress (CHS), heat loss is sufficient to dissipate body heat and skin temperatures are relatively low.

Fig. 1. Relationships between core temperature and incidence of exhaustion from heat strain for heat-acclimated persons exercising in uncompensable (hot skin) and compensable (cool skin) heat stress. During uncompensable heat stress (UCHS), evaporative heat loss is insufficient to dissipate body heat and skin temperatures are relatively high. During compensable heat stress (CHS), heat loss is sufficient to dissipate body heat and skin temperatures are relatively low.

In the marathon and ultramarathon distances,\(^6\) core temperatures in runners who have collapsed during or after the race were reported to be between 38 and 40°C. This suggests that skin temperatures may have been high and perhaps in combination with some degree of dehydration. Despite the relatively low body core temperatures in collapsed runners, environment does appear to play a role in collapse. It is also important to note that there may be a time period between the collapse of the athlete and the measurement of body core temperature. During this period of time individuals are exposed to varying environments and may gain or lose heat to the environment, thus changing body core temperature from that at the time of collapse. Using a linear regression model, which included collapse due to dehydration, vasovagal syncope, orthostatic syncope, exhaustion and hyperthermia, Roberts\(^2\) reported a general trend towards increased collapse rate with higher dew points. If evaporation is limited as a result of high dew-point temperature or running in a pack where evaporative heat loss can be reduced as a result of lower air flow, skin temperatures would become elevated.

If skin temperature is low, some runners can tolerate remarkably high core temperatures. Core temperatures ranging from 38.0-41.1°C in runners successfully completing half-marathon and mara-
thon distances[7] have been observed. Pugh et al.[7]
reported a core temperature of 41.1°C for the winner
of a marathon run and suggested that tolerance of a
high body temperature was necessary for success in
the marathon. Maron et al.[8] reported one marathon
runner maintained a core temperature between 41.6
and 41.9°C for the last 44 minutes of a race when
skin temperatures were 24°C.

4. Hypothermia

It is not surprising that during warm weather
marathon events there is a greater incidence of col-
lapse as a result of hyperthermia; however, hy-
perthermia (rectal temperature ≤35°C) has often been
reported during marathons held in cool and compen-
sable environments. A 12-year profile of exercise-
associated collapse casualties for the Twin Cities
Marathon reported 3% of the male and 3% of the
females runners were classified as hypothermic.[9] In
general, runners competing at or below 12°C or in
cool, wet weather may be at a greater risk of hy-
perthermia.[9] However, Maughan[10] has reported rec-
tal temperatures classified as hyperthermic (35.6°C)
to hyperthermic (39.8°C) among runners during the
same race, in cool conditions (10–12°C). In addition,
Roberts[5] has observed a rectal temperature of 33°C
during one of the ‘hottest’ (16°C) Twin Cities Mar-
athons in 1983. Incidences of hypothermia in various
environments during marathon competition may be
due to a number of factors. Inexperienced runners
may start the race at a pace that is too fast, slowing
down or even walking as a result of fatigue later in
the event, while being exposed to cool and/or wet
weather. As a result, there will be a decline in
exercise intensity and heat loss to the environment
can exceed heat production leading to declines in
core temperature.[4]

Environmental conditions can also change
throughout the day of the event, air temperature
changes of up to 17°C have been reported[10] and
rain, sleet, wind or cloud cover, which may occur
later in the event, would have a greater impact on
slower runners who are likely to be on the course for
a longer period of time. Risk for hypothermia may
be further exacerbated by insufficient clothing, as
clothing worn at the start of the race may not be
appropriate for changes in weather conditions oc-
curring later in day.

5. Postural Hypotension

The most commonly encountered collapse asso-
ciated with the marathon is postural hypotension,
which typically occurs following the event or could
occur if an athlete were to stop running for a period
of time during the race. Athletes who finish the
marathon and collapse are typically fully conscious
but are unable to stand without support. This type of
collapse is likely due to one factor or a combina-
tion of factors. One factor contributing to this hypotens-
ion is the large fall in total peripheral resistance
which occurs upon the cessation of exercise, where
there is a large fall in central blood volume and atrial
filling pressure due to the pooling of blood in the
dilated capacitance veins of the lower limbs (no
muscle pump and dilated skin). In addition, the
ability to withstand an orthostatic challenge may be
compromised by the combination of heat stress and
dehydration. Recent findings[10] have demonstrated
that hypohydration and prior heat stress lower cere-
bral blood flow velocity, which may contribute to
cyascope observed upon completion of marathon
competition.

6. Conclusion

Physical collapse by marathon participants can
be related to a number of factors including exhaus-
tion, hypoglycaemia, hyperthermia, hypothermia,
dehydration and hyponatraemia. This collapse may
be mediated by insufficient training or heat accli-
misation, inappropriate race strategy or inap-
propriate nutritional (water, electrolytes, carbohydrate)
replacement. Collapse due to hyperthermia and de-
hydation may be the result of cardiovascular strain
and an inability to sustain blood pressure. In addi-
tion, inadequate evaporative cooling will increase
skin temperatures, thus augmenting cardiovascular
strain. Excessive heat loss to the environment during
cold-wet weather may result in hypothermic col-
lapse. Lastly, collapse related to postural hypotens-
ion, occurring after the race, may be the result of
venous pooling in the periphery or alterations in cerebral blood flow velocity from hyperthermia and/or dehydration.

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References

Correspondence: Dr Robert W. Kenefick, Thermal and Mountain Medicine Division, US Army Research Institute of Environmental Medicine, Kansas Street, Natick, MA 01760, USA.
E-mail: Robert.Kenefick@us.army.mil

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