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Should electric fans be used during a heat wave?

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ABSTRACT

Heat waves continue to claim lives, with the elderly and poor at greatest risk. A simple and cost-effective intervention is an electric fan, but public health agencies warn against their use despite no evidence refuting their efficacy in heat waves. A conceptual human heat balance model can be used to estimate the evaporative requirement for heat balance, the potential for evaporative heat loss from the skin, and the predicted sweat rate, with and without an electrical fan during heat wave conditions. Using criteria defined by the literature, it is clear that fans increase the predicted critical environmental limits for both the physiological compensation of endogenous/exogenous heat, and the onset of cardiovascular strain by an air temperature of ~3–4 °C, irrespective of relative humidity (RH) for the young and elderly. Even above these critical limits, fans would apparently still provide marginal benefits at air temperatures as high as 51.1 °C at 10%RH for young adults and 48.1 °C at 10%RH for the elderly. Previous concerns that dehydration would be exacerbated with fan use do not seem likely, except under very hot (>40 °C) and dry (<10%RH) conditions, when predicted sweat losses are only greater with fans by a minor amount (~20–30 mL/h). Relative to the peak outdoor environmental conditions reported during ten of the most severe heat waves in recent history, fan use would be advisable in all of these situations, even when reducing the predicted maximum sweat output for the elderly. The protective benefit of fans appears to be underestimated by current guidelines.

1. Introduction

In the continental United States, the summer of 2012 was the hottest since records began. In 2013, record-breaking ambient temperatures were experienced across large parts of Eastern Australia (January) as well as the Western US (June). These heat waves continue to claim lives, with the elderly, poor and socially isolated at the greatest risk (Hajat et al., 2010). Public health recommendations for effective heat management strategies are absolutely essential to minimize heat-related mortality. A simple and cost-effective intervention is an electric fan. However, governmental public health messaging is often ambiguous and typically warns against their use. The suggested environmental limits for fan use has historically ranged from 32.3 °C (90 °F) (35% relative humidity (RH)) (Wolfe, 2003) to the “high 90s” (96–99 °F; 35.6–37.2 °C) with no RH stated (CDC, 2012). In contrast, a recent Cochrane review concluded that no evidence whatsoever currently exists in the literature supporting or refuting the use of electric fans during heat waves (Gupta et al., 2012). The authors did however suggest that the enhanced evaporation with fan use may lead to an increased risk of dehydration (Gupta et al., 2012).

In order to maintain a fixed core body temperature, the human body must balance the rate at which it produces heat, arising as a by-product of cellular metabolism (approximately 80–100 W at rest), with the rate at which heat is dissipated to the surrounding environment. Human heat dissipation occurs via dry (i.e. conduction and convection) and latent (i.e. evaporation) avenues of heat transfer. All dry heat transfer follows a temperature gradient, which in this case, is between ambient air and the skin surface. It follows that if air temperature exceeds skin temperature (approximately 35 °C; 95 °F) the gradient for dry heat loss is reversed and heat is added to the body instead of lost. Since the vast majority of dry heat exchange occurs via convection, this problem is compounded with additional air movement (such as with a fan). However, the human thermoregulatory system elicits the secretion of sweat on to the skin surface which subsequently evaporates, promoting latent heat

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loss; and the potential for evaporation (E_{max}) is increased substantially with increasing air movement. However, the elevation in E_{max} with additional air flow is diminished with increasing ambient humidity. Furthermore, a greater sweat production may be needed to facilitate the greater rate of evaporation required to maintain overall heat balance (E_{req}), and the elderly, who are considered a high risk group during heat waves, may be physiologically restricted (Kenney and Hodgson, 1987). The potentially greater requirement for sweat production with electric fans may also be elevated to the point of exacerbating physiological strain in terms of dehydration (Gupta et al., 2012) and cardiovascular strain.

Using a human heat balance approach and employing parameters defined by the literature, the following can be conceptually determined: i) the various combinations of air temperature and humidity at which an electric fan is counter-protective; ii) the predicted critical environmental limits for elevated cardiovascular strain and thermal strain, with and without an electric fan; and iii) the predicted sweat losses and therefore the risk of dehydration with and without an electric fan.

2. Methods

A conceptual human heat balance approach was used to derive the evaporative requirement for heat balance (E_{req}), the evaporative potential in the ambient environment (E_{max}), and the predicted rate of sweating, with and without an 18″ diameter electrical fan, set at maximum speed, placed at waist height, directly facing an individual at a distance of 1.0 m. The model simulated a younger adult (20–40 y), and an elderly adult (>75 y), who are lightly clothed, and seated indoors during a heat wave. Combinations of air temperature, (26–60 °C; 79–140 °F) and relative humidity (10%–100%) were used to represent a range of environmental conditions that extend beyond those historically arising during heat waves.

2.1. *Conceptual heat balance model – required evaporation*

The rate of evaporation required for heat balance (E_{req}) was calculated using Eq. (1) (Gagge and Gonzalez, 1996):

$$E_{req} = M - W - (C + R) - (C_{res} + E_{res}) \tag{1}$$

where M is metabolic energy expenditure; W is external work; C is convective heat loss; R is radiative heat loss; C_{res} is convective loss by respiration; E_{res} is evaporative heat loss by respiration. All units are in Wm^{-2}.

The rate of metabolic energy expenditure (M) was set at 65 Wm^{-2} which is equivalent to a person standing (Parsons, 2003). A typical value for M when seated could be as low as 58 Wm^{-2} (Parsons, 2003), however the highest potential value was selected to represent the worst-case scenario in terms of metabolic heat that must be dissipated to maintain a stable body temperature.

The rate of external work (W) was assumed to be 0 Wm^{-2} since any work on surrounding objects would be negligible (Parsons, 2003).

The combined rate of dry heat transfer by convection (C) and radiation (R) were calculated using Eq. (2) (Gagge and Gonzalez, 1996):

$$C + R = \frac{(t_{sk} - t_o)}{\left(R_{cl} + \frac{1}{f_{cl} h}\right)} \tag{2}$$

where t_{sk} is mean skin temperature in °C; t_o is operative temperature in °C which in this case was equal to ambient air temperature; R_{cl} is dry heat transfer resistance of clothing in $\text{m}^2\ \text{K}\ \text{W}^{-1}$; f_{cl} is clothing area factor (no units) estimated using Eq. (3) (McCullough and Jones, 1984):

$$f_{cl} = 1.0 + \frac{0.31 R_{cl}}{0.155} \tag{3}$$

where h is the sum of the convective heat transfer coefficient (h_c) in $\text{Wm}^{-2}\ \text{K}^{-1}$ and the radiative heat transfer coefficient (h_r) in $\text{Wm}^{-2}\text{K}^{-1}$. h_c is calculated using Eq. (4) (Mitchell, 1974), and h_r is calculated using Eq. (5) (de Dear et al., 1997; Parsons, 2003):

$$h_c = 8.3 v^{0.6} \tag{4}$$

where v is air velocity in ms^{-1}.

$$h_r = 4\varepsilon\sigma \frac{A_r}{\text{BSA}}\left[273.2 + \frac{(t_{sk} + t_r)}{2}\right]^3 \tag{5}$$

where ε is the area weighted emissivity of the clothing body surface (assumed to be 1.0); σ is the Stefan–Boltzmann constant, $5.67 \times 10^{-8}\ \text{Wm}^{-2}\ \text{K}^{-4}$; A_r/BSA is the effective radiative area of the body (assumed to be 0.70 for seated individuals (Fanger, 1967)); t_r is mean radiant temperature in °C.

A mean skin temperature (t_{sk}) of 35.5 °C (Drinkwater et al., 1982; Zahorska-Markiewicz, 1982) was employed for both young adult and elderly predictions. While the change in t_{sk} during a passive heat exposure may actually be 0.5 °C–1.0 °C higher in the elderly (Dufour and Candas, 2007) secondary to a lower evaporation from the skin, a higher t_{sk} would elevate the ambient air temperature at which the temperature gradient for dry heat loss would be reversed (i.e. to dry heat gain). The values employed in the present model therefore represented the worst-case scenario for estimating the environmental conditions at which a fan would become harmful.

For the “fan on” condition, a dry heat transfer resistance of clothing (R_{cl}) value of 0.0497 m^2KW^{-1} (front, facing fan; 50% of BSA) and 0.0844 m^2KW^{-1} (rear; 50% of BSA) was employed in the present model. This value was determined using ISO 9920 (2007) and was equivalent to a typical summer ensemble of underwear, a light cotton shirt (with sleeves rolled up to the elbow) and light cotton shorts, and included the insulative effect of air layers and alterations in insulation due to different levels of air flow. For the “fan off” condition, an R_{cl} value of 0.1291 m^2KW^{-1} was used across the whole body.

Air velocity (v) for the “fan on” condition was estimated by employing a free space air velocity of 4.5 ms^{-1}, which was determined using a hot-wire anemometer (VelociCalc 9535, TSI Inc, Shoreview MN, USA) during pilot testing of an 18″ diameter electrical fan (High velocity orbital air circulator, Whirlpool, Benton Harbor, MI, USA) at waist height set at maximum speed and at a distance of 1.0 m. The air flow profile around the body was then determined using a cylindrical model proposed by Kerslake (1972), and mean h_c values were then separately determined for the front (16.28 $\text{Wm}^{-2}\text{K}^{-1}$; 50% of BSA) and back (8.04 $\text{Wm}^{-2}\text{K}^{-1}$; 50% of BSA) halves of the body. For the “no fan” condition, an air velocity of 0.2 ms^{-1} was employed across the front and back of the body ($h_c = 3.16\ \text{Wm}^{-2}\text{K}^{-1}$) which accounted for any effects of natural convection.

A body surface area (BSA) of 1.8 m^2 was used for the present model. This BSA is equivalent to an individual with a body mass of 70 kg and a height of 1.73 m (DuBois and DuBois, 1916).

Mean radiant temperature (t_r) was assumed to be equal to ambient air temperature since the intent of the model was to assess electric fan use in an indoor environment; a uniform space with no sources of direct radiation (Parsons, 2003).