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Examining the physiological strain with electric fans during high indoor heat stress

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ABSTRACT

Fans have been positioned as a low-cost, sustainable, and accessible heat resilience solution during extreme heat. Many health agencies caution against fan use when air temperature exceeds skin temperature (e.g. ≥35°C) suggesting they will accelerate body heating compared to still air. However, the increased evaporative efficiency with a fan likely mitigates greater rises in core temperature and cardiovascular strain compared to still air when the air temperature is >35°C. The present study evaluated the physiological responses with and without fans when indoor air temperature exceeded skin temperature to elucidate the safe upper limit. In a randomized crossover design, 10 healthy adults (4 females, 24±4 y, 1.8±0.1 m, 75.8±10.1 kg) were exposed to a simulated indoor overheating scenario whereby air temperature increased linearly from 38°C to 47°C over 3 hours, with a fan (~5.5 m/s) or still air (<0.2 m/s). Heart rate and core temperature were significantly greater with a fan compared to still air when air temperature was ≥44°C and ≥45°C, respectively. Mean skin temperature and skin blood flow were statistically higher with a fan. While a fan increased whole-body sweat rate, the additional sweating can be counterbalanced with increased fluid intake (~250 mL/h at 43°C) to mitigate dehydration. In conclusion, fans result in a higher heart rate or core temperature compared to still air in healthy adults when indoor air temperature >43°C; ~3-11°C greater than guidance from various health agencies globally. Future work in other age groups and heat-vulnerable populations is needed, including field-based evaluation.

1. Introduction

Evidence-based interventions for protecting individuals during extreme heat are critical for developing effective heat health action plans. One of the best protective approaches to mitigate heat-related complications is to cool the local environment with air conditioners. While air conditioners address current needs, they embody a maladaptation strategy to extreme heat[1] by contributing to global warming through greenhouse gas emissions via operational energy use, refrigerant leakage and embodied carbon[2]. Further, air conditioners are inaccessible to billions globally[3,4] warranting the evaluation of safe alternative solutions to protect individuals from the negative consequences of extreme heat.

Electric fans have been proposed as a low-cost, market-ready, scalable heat-stress mitigation strategy during extreme heat events[5] with a significantly lower carbon footprint relative to air conditioners[6,7]. Fans do not cool the surrounding environment, but rather they cool an individual through i) convection if the air temperature is lower than skin temperature; and ii) enhance evaporative efficiency of sweat from the skin surface. However, fans will be harmful to all individuals at high indoor temperatures, irrespective of heat-vulnerability, when the increased convective heat gained cannot be fully counterbalanced by the cooling provided by the evaporation of sweat. Heat-health guidelines from various agencies continue to advise against fans when ambient temperature exceeds skin temperature (e.g., >32.2°C, See Table 1). More recent guidance from the World Health Organization has defined the temperature threshold for fan use at ≤40°C[8]. Concerns have been raised that the updated temperature limit has been promoted too hastily

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Table 1
Current proposed indoor temperature limits for safe fan use by various public health agencies.

Organization	Safe fan use threshold
Centre for Disease Control[42]	32.2°C/90F
Red Cross[43]	32.2°C/90F
US EPA[44]	32.2°C/90F
South Africa: Health Department[45]	35.0°C/95F
UK Health Security Agency[46]	35.0°C/95F
Health Canada[47]	35.0°C/95F
World Health Organization[8]	40.0°C/104F

without sufficient empirical evidence in humans confirming safety as the limit is largely based on biophysical modeling[9]. Where the true indoor temperature threshold for fan use resides is further obfuscated as independent biophysical modeling efforts using different methods and approaches have proposed different limits that: i) do not exceed 35°C when predicting the change in core temperature using heat balance equations assuming a static skin temperature[9], ii) around 39°C with biophysical modelling predicting compensability assuming static skin and core temperatures[10], iii) or up to 43°C using the Gagge model which accounts for body heat exchanges in core and skin with the surrounding environment[11].

While relatively fast and easy to execute, biophysical modeling is limited by the predefined parameters warranting the need for an *in vivo* validation. Notably, the most conservative models fixed skin temperature[9,10] which may not truly represent the changes in skin temperature when exposed to high air temperatures with or without a fan[12]. Further, biophysical modeling to date do not predict the cardiovascular strain experienced which is a likely precipitating mechanism for increased cardiac-related morbidity and mortality during prolonged extreme heat exposure[13,14]. Lastly, these aforementioned biophysical models apply static environmental conditions, which do not emulate the transient rise in indoor air temperatures that may be experienced during an extreme heat event[15]. The extent of indoor overheating experienced during an extreme heat event is dependent on occupant behaviour and dwelling characteristics. Practically, electric fan use indoors during extreme heat events will likely be in combination with progressive indoor overheating and not simply a static air temperature.

Thus, the purpose of the present study was to evaluate the heart rate and core temperature responses with and without a fan when indoor temperature exceeds skin temperature in healthy adults using a simulated indoor overheating model. Although limited, data suggest an electric fan may be beneficial in mitigating rises in heart rate and core temperature during prolonged heat exposure in healthy young adults up to 42°C[12,16,17], but detrimental at 47°C[16] suggesting that the indoor temperature threshold may likely reside above skin temperature (e.g. ~35°C). Based on current evidence using prolonged static heat exposure, it was hypothesized that a fan will continue to be beneficial or safe (e.g. causing no clinically meaningful differences in heart rate or core temperature compared to still air [<0.2m/s]) at indoor air temperatures exceeding 40°C, but become harmful when indoor air temperature exceeds the highest proposed threshold from biophysical modeling (43°C[11]).

2. Methods

2.1. Ethics approval and participants

Using G*Power (Version 3.1.9.7), a minimum sample size of 8 participants was determined *a priori* using published data[12] powered to detect a within subject difference in heart rate between fan and still air conditions (effect size = 1.2, α = 0.05, and β = 0.80). Following ethical approval from Lakehead University, participants were recruited from the Thunder Bay region between January and April 2024 to minimize the potential influence of heat acclimatization. Participants were eligible if they were between 19 to 39 years of age, and did not present with, or have any history of, any respiratory, metabolic, or cardiovascular disease, and were not currently on any medication. The study was registered retrospectively (ClinicalTrials.gov: NCT06584903) as it was not determined a clinical trial during initial review.

2.2. Experimental trials

Participants completed two 180-minute temperature ramp protocols in a counterbalanced random order (generated by EM) separated by at least 48 h. All participants provided a urine sample on arrival to confirm the absence of dehydration (<1.02) using a digital refractometer (PAL-10S, Atago) and changed into standardized t-shirts and shorts (for a total clothing of ~0.20 clo, including underwear). Afterward, participants were instrumented and sat on a chair on a balance scale (GFK 330aH, Adams Equipment) for a 45-minute baseline at ~37°C in still air to equilibrate with the environment. Next, the indoor temperature in the climate-controlled room increased linearly to 47°C over 180 mins at ~0.06°C/min (relative humidity 26±4%) while participants either sat i) facing a 46 cm 3-blade fan positioned 1.2 m anterior (5.3±0.9 m/s); or ii) in still air (0.1±0.0 m/s). The high fan speed was selected to represent the worst-case scenario of heat gain where ambient temperatures exceed skin temperature.

2.3. Instrumentation and data analysis

A retort stand was positioned ~0.4 m anterior to the participant and suspended a hot wire anemometer (Testo 405i) and a temperature and humidity probe (HMP100, Vaisala) ~1.0 m above the floor sampling at 0.2 Hz and 1.0 Hz, respectively, and was averaged each minute. Minute averaged rectal temperature was measured ~12 cm past the anal sphincter using a general purpose thermistor probe (DeRoyal) and expressed as the change from baseline. Minute averaged skin temperature was measured at 4 sites using wireless sensors (DS1922L-F5# iButton, Maxim Integrated) and computed as a weighted average[18]. Skin blood flow of the forearm was measured using laser doppler flowmetry (Periflux 5000, Perimed) and expressed in absolute perfusion units. A continuously recording 3-lead electrocardiogram was used to calculate minute-averaged heart rate (BioAmp, AD Instruments). Electrocardiogram-gated brachial blood pressure (Tango M2, SunTech), thermal comfort, thermal sensation, and changes in body mass, were recorded every 10 minutes. Rate pressure product, an index of cardiovascular strain, was computed as the product of heart rate and systolic blood pressure. All data were analyzed as the mean response during each 1°C rise in indoor temperature (e.g. 38.00°C – 38.99°C).

2.4. Statistical analysis and interpretation

All physiological and perceptual parameters were independently compared between fan and still air using separate two-way repeated measures mixed-model ANOVA with the repeating factor of temperature (10 levels: 38 – 47°C) and the non-repeated factor of airflow (2 levels: fan vs still air). Where an interaction was observed, post-hoc comparisons were analyzed with Holm-Sidak correction factor as it reduces the risk of type II errors with increasing multiple comparisons. All statistical analysis was conducted using GraphPad Prism version 10.3. For primary outcome variables, statistical differences were complemented with minimal clinically meaningful differences between fan and still air conditions for a given indoor air temperature using previously reported thresholds for heart rate (≥5 BPM[19]) and rectal temperature (≥0.2°C [20]) to confirm physiologically meaningful differences in cardiac and thermal strain experienced, respectively.

3. Results

3.1. Data overview

Ten healthy young adults (4 females, 24±4 y, 1.8±0.1 m, 75.8±10.1 kg) provided written and verbal consent, and participated in all experimental trials. Two participants (2 females) did not complete the still air (n = 1) or fan (n = 1) condition (feeling unwell noted), thus only data up to the maximum temperature experienced (46°C) was analyzed. Complete data sets were collected for all outcome parameters except for skin blood flow as one participant demonstrated excessive movement artifacts, and thus their data was excluded from analysis. All physiological and perceptual data (mean and standard deviation) for fan and still air conditions are presented in Table 2. All data supporting the findings are freely available on the Open Science Framework https://doi.org/10.17605/OSF.IO/36K7C.

3.2. Cardiovascular responses

Heart rate was similar at baseline (P = 0.998). A main effect of temperature (P<0.001), and airflow (P = 0.04), and an interaction (<0.001) was observed for heart rate between fan and still air conditions. A clinically meaningful difference in heart rate was observed between fan and still air from 44°C onwards (P<0.05, Fig. 1). A main effect of fan (higher with fan, P = 0.001) but not temperature (P = 0.71) was observed for systolic blood pressure without an interaction (P = 0.55). A trend for a main effect of fan (P = 0.07), but no effect of temperature (P = 0.78), and no interaction (P = 0.55) was observed for diastolic blood pressure. A main effect of fan (P = 0.001) and temperature (p<0.001), and an interaction (P<0.001) was observed for rate pressure product. Rate pressure product was higher with a fan when the indoor temperature exceeded 43°C (P<0.01). A main effect of fan (<0.001) and temperature (P = 0.009), and an interaction (P = 0.04) was observed for skin blood flow. Skin blood flow was similar at baseline (P = 0.76); however, skin blood flow was higher with a fan compared to still air for all indoor temperatures assessed (P<0.001).

3.3. Thermoregulatory responses

Baseline rectal temperature was similar between conditions (fan: 37.10±0.18°C, still air: 37.06±0.19°C, P = 0.97). A main effect of fan (P = 0.05) and temperature (P<0.001) with an interaction (P<0.001) was observed for the change in rectal temperature. The change in rectal temperature was greater with a fan when indoor temperature was ≥45°C (P<0.002, Fig. 1). A clinically meaningful difference between rectal temperature with and without a fan was observed when the indoor temperature was ≥46°C. A main effect of fan (P<0.001) and temperature (P<0.001), and an interaction (P<0.001) was observed for mean skin temperature. Mean skin temperature was higher with a fan throughout the protocol (P<0.05). Similarly, a main effect of fan (P<0.001) and temperature (P<0.001), and an interaction (P<0.001) was observed for whole-body sweat rate whereby whole-body sweat rate was higher with a fan at each temperature assessed (P<0.02).

3.4. Perceptual responses

No main effect of fan (P = 0.20), but a main effect of temperature (P<0.001) and interaction (P = 0.003) was observed for thermal comfort. Greater thermal discomfort with a fan was experienced when the indoor temperature was ≥46°C. A main effect of temperature (P≤0.001), but no main effect of fan (P = 0.64) and no interaction (p = 0.95) was observed for thermal sensation.

4. Discussion

When indoor air temperature was equal to or below 43°C (3-11°C

Table 2
Outcome parameters observed at baseline and during each 1°C rise in indoor temperature with and without a fan.

	Baseline	38°C	39°C	40°C	41°C	42°C	43°C	44°C	45°C	46°C	47°C**
Heart Rate (BPM)											
No Fan	82±13	81±12	82±12	84±14	85±13	87±15	90±15	91±15	94±17	96±18	95±17
Fan	80±13	81±13	82±13	84±14	87±17	90±17	94±19	**99±22**#	**106±24**#	**112±26**#	**115±28**#
Systolic Blood Pressure (mmHg)											
No Fan	123±9	121±7	122±7	121±7	123±6	122±8	122±6	122±7	123±7	123±7	122±9
Fan	124±6	125±6	125±6	124±6	125±7	125±6	125±6	125±8	125±5	125±7	128±8
Diastolic Blood Pressure (mmHg)											
No Fan	76±7	75±7	75±7	74±8	76±6	76±7	76±7	76±7	75±8	76±10	74±9
Fan	77±7	79±6	78±7	78±5	77±9	78±5	78±5	77±7	77±7	76±8	79±9
Rate Pressure Product (mmHg x BPM x 10^3)											
No Fan	10±1.6	9.9±1.6	10±1.5	10.1±1.6	10.5±1.7	10.5±1.7	10.9±1.7	11.1±1.6	11.5±2	11.4±1.8	11.5±1.9
Fan	9.9±1.7	10.2±1.6	10.2±1.6	10.4±1.9	10.8±2.1	11.2±2.1	11.7±2.2	**12.3±2.6**	**13.2±2.9**	**13.9±2.9**	**14.6±3.3**
Skin Blood Flow (AU)**											
No Fan	26±17	26±12	27±16	29±15	29±17	31±19	35±23	39±28	42±30	44±29	50±28
Fan	36±16	**53±23**	**57±22**	**59±29**	**58±34**	**62±40**	**68±46**	**77±48**	**82±53**	**86±41**	**85±23**
Δ Rectal Temperature (°C)											
No Fan	0.0±0.1	0.0±0.1	-0.1±0.1	0.0±0.1	0.0±0.2	0.1±0.2	0.1±0.2	0.1±0.2	0.2±0.2	0.2±0.2	0.2±0.2
Fan	0.0±0.1	0.0±0.1	-0.1±0.1	0.0±0.1	0.0±0.1	0.1±0.2	0.1±0.2	0.2±0.2	**0.3±0.2**	**0.4±0.2**#	**0.4±0.3**#
Skin Temperature (°C)											
No Fan	36.7±0.2	36.8±0.3	36.8±0.3	36.9±0.3	36.9±0.3	37.0±0.3	37.1±0.3	37.2±0.3	37.2±0.3	37.3±0.3	37.4±0.3
Fan	36.8±0.2	**36.9±0.2**	**37.0±0.2**	**37.1±0.2**	**37.2±0.3**	**37.3±0.3**	**37.4±0.3**	**37.6±0.3**	**37.7±0.3**	**37.9±0.3**	**38.0±0.4**
Whole-Body Sweat Rate (g/min)											
No Fan	2.8±1.0	2.7±0.6	3.1±1.4	3.1±1.2	3.9±1.7	3.6±1.7	3.8±1.5	4.9±1.5	4.7±0.8	5.0±0.9	5.6±1.5
Fan	3.8±1.3	**4.6±1.4**	**5.1±1.7**	**4.7±2.2**	**5.8±2.1**	**6.6±2.2**	**7.5±2.5**	**7.9±1.8**	**7.6±1.5**	**8.5±2.3**	**10.8±2.4**
Thermal Comfort (mm)											
No Fan	22±9	31±17	39±19	46±21	54±25	62±25	68±30	76±35	80±36	84±34	86±32
Fan	29±14	36±21	45±22	52±27	58±28	63±29	68±32	82±28	92±23	**106±14**	**111±11**
Thermal Sensation (mm)											
No Fan	103±13	108±13	115±11	120±13	123±13	130±15	134±16	140±17	140±16	142±16	142±16
Fan	106±14	106±31	116±19	120±17	124±17	129±17	134±18	140±16	146±14	143±19	150±13

Notes: Data presented as Mean±SD. Bold text denotes significantly greater than no fan (P<0.05).
** Analysis includes a maximum of 9 participants.
# Clinically meaningful difference. BPM: Beats per minute.

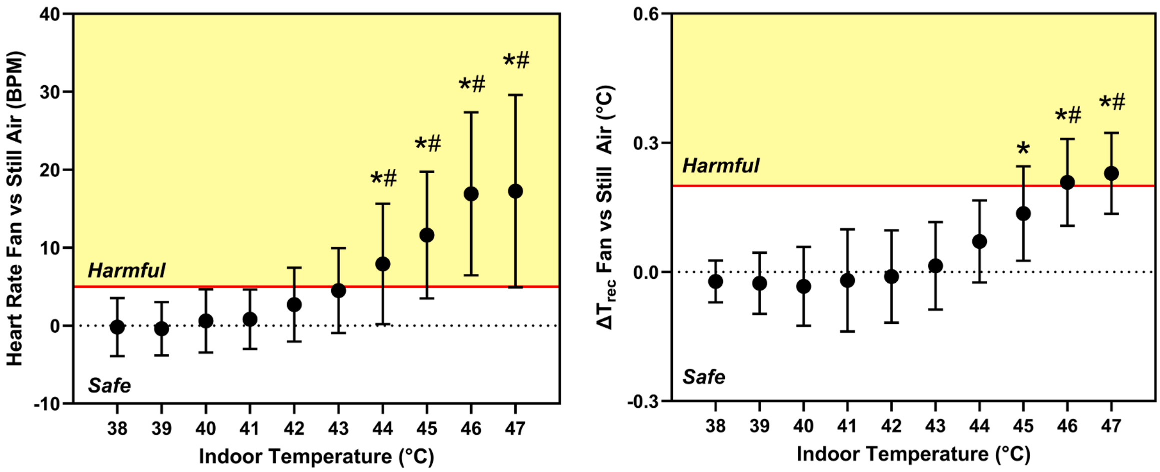

Fig. 1. Mean difference (95% confidence intervals) for heart rate (HR, left) and the change in rectal temperature (ΔT_{rec}, right) between fan and still air. The solid red line identifies the thresholds for clinically meaningful differences between fan and still air to be either safe (below) or harmful (above). Note: Only 8/10 participants are included in the mean difference data at 47°C. *Significantly higher with a fan ($P<0.05$). #Clinically meaningful mean difference. BPM: Beats per minute.

above current guidance, Table 1) a fan did not cause a higher heart rate or core temperature in comparison to still air in resting healthy adults. This threshold for fans to incur physiological strain exceeds the recent guideline update by the World Health Organization[8]. Above this threshold, a fan likely becomes harmful, irrespective of humidity, due to the added convective heat gain which cannot be fully counterbalanced with evaporation and must therefore be complemented with (e.g. skin wetting[21], wet clothing[22]) or substituted for (e.g. air conditioning, evaporative coolers[23]) other cooling strategies to mitigate potentially fatal physiological strain. These findings have the potential to sustainably protect over 500 million people globally from the fatal consequence of extreme heat[11].

For a heat intervention to be defined as safe, it must not incur additional harm. The World Health Organization defines a heat intervention as one that maintains core body temperature within a healthy range and reduces the risk of negative health consequences[24]. While occupational guidance for a safe working environment states the objective is to maintain body core temperature below 38°C, this is likely impossible for individuals experiencing prolonged indoor heat stress – even when doing intermittent work at 36°C with still air[20]. Thus, we suggest that a heat intervention during heat waves should be based on the definition of patient safety, "…the absence of preventable harm to a patient and reduction of the risk of unnecessary harm associated with health care to an acceptable minimum."[25] As demonstrated in Fig. 1, the change in core temperature becomes significantly greater with a fan when indoor air temperature is ≥45°C, with a clinically meaningful difference occurring at ≥46°C. In support, Morris et al. [16] observed a greater change in core temperature with a fan relative to still air in young adults at 47°C, and benefits of a fan have been reported during prolonged exposure in indoor temperatures at or below 42°C (See Fig. 2). We do, however, recommend that the safe indoor temperature threshold for fan use should be less than 45°C as rises in cardiovascular strain, a potentially more life-threatening physiological response to heat stress[13], preceded rises in core temperature (Table 2 and Fig. 1).

One of the pathophysiological mechanisms suggested to increase the risk of cardiac events during extreme heat is myocardial ischemia[13]. As observed (Table 2), increases in cutaneous vasodilation and sweating occur during heat stress to facilitate heat dissipation from the core to the periphery. The decreased peripheral resistance and redistribution of central blood volume to support increased skin blood flow results in an increase in heart rate and contractility, and thus cardiac output, to maintain blood pressure[26]. Heart rate and contractility are factors determining myocardial oxygen consumption[27]. Increases in myocardial blood flow during heat stress support the increased myocardial oxygen demand[28]. In persons with compromised coronary blood flow, the increased myocardial oxygen demand may increase the risk of myocardial ischemia[29]. Increases in cardiovascular strain precede rises in core temperature in young[30] and older[31] adults during simulated extreme heat exposure. Recognizing that cardiovascular comorbidities are one of the leading causes of hospital admissions during extreme heat events[14], it stands to reason that the safe thresholds for a heat intervention, like an electric fan, should be determined based on cardiovascular strain. As observed, a fan resulted in increased cardiovascular strain (assessed with rate pressure product) in

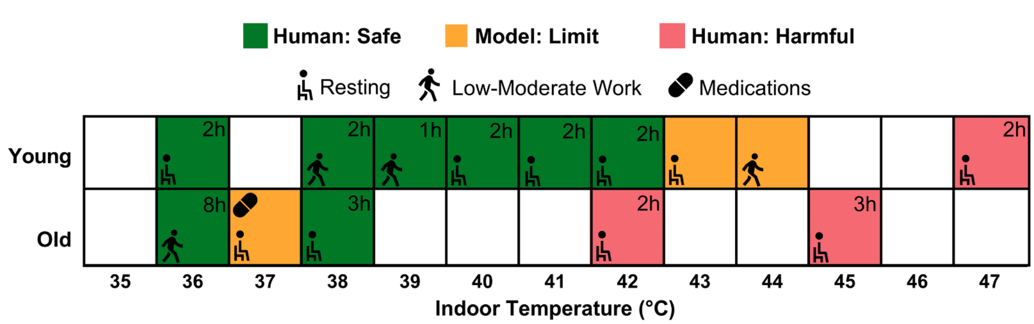

Fig. 2. The current evidence on fan use in temperatures exceeding public health guidance in young (top) and older (bottom) adults. Colors represent where a fan has been proven to be safe and/or beneficial in humans (green), proposed to be safe based on modelling (orange), or has been proven to be harmful at this temperature (red), irrespective of humidity. The time (in hours) in each top right corner represents the tested duration of use, and the activity (resting or low/moderate exercise) is reflected in the bottom left corner. The supporting evidence for each temperature and group are as follows; Young: 36°C & 42°C[30], 38°C[39], 39°C[34], 40°C[40], 40°C & 47°C[16], 41°C[17], 43°C[11], 44°C[41]; Old: 36°C[20], 37°C[10], 38°C & 45°C[21], 42°C[31].

young adults when indoor air temperature was equal to or greater than 44°C, ~2°C lower than the meaningful clinical difference observed with the change in core temperature (See Table 2). Although only healthy young adults were assessed, rate pressure product exceeded a proposed clinical threshold for silent ischemia (>12,000[32,33]) with a fan when indoor air temperature was ≥44°C. Additionally, a clinical trial examining fans in hot and dry conditions (45°C, 15%) terminated testing healthy older adults without coronary artery disease early due to a 3-fold increase in rate pressure product relative to controls, of which 43% did not complete the entire condition due to feeling unwell[21]. Similarly, the two participants who felt unwell and did not complete the current protocol experienced an increase in rate pressure product of 46% (14,280 mmHg*BPM, no fan) and 76% (15,120 mmHg*BPM, fan) at 46°C. Collectively, we propose that the safe limit for fans should be determined by cardiovascular strain and not core temperature.

The primary objective of this study was to evaluate at what indoor air temperature will a fan be more harmful than still air during a simulated indoor overheating scenario, likely due to the inability to counterbalance heat gain with sufficient evaporative heat loss. At higher indoor temperatures, a fan can prove to be harmful at low humidity while being beneficial at a higher humidity[34]. Thus, a low indoor humidity was selected *a priori* to ensure that the air temperature at which a fan would become harmful would be most appropriately identified. In hot and humid climates (e.g., tropical climates), when the indoor temperature is high, the humidity is also high and lab-based evidence has proven a fan will attenuate cardiovascular strain in younger[30] and older[21] adults under these conditions. Furthermore, vapor indoor sources like showering/bathing, cooking and occupants tend to increase indoor humidity compared to outside, making it increasingly unlikely to experience hot and dry indoor environments[35]. Whether a fan is harmful at an even lower humidity (<20%) combined with 43°C remains unknown. Although in hot and dry climates, it is easy and affordable to decrease the indoor temperature and increase the humidity with evaporative coolers[23]. In highly humid conditions where evaporative coolers are less effective, an electric fan will be beneficial below the safe air temperature threshold in young adults[30], with more work needed in older populations. Fans are particularly useful in hot and humid climates because they increase evaporative efficiency, however, in hot and dry climates evaporative efficiency is already high and thus the use of a fan could be harmful[16,21].

In 2012, A Cochrane review concluded that insufficient evidence existed to support or refute the health effects of electric fans during heat waves[36]. Over the last decade, work from independent research units (See Fig. 2) have demonstrated the benefits of a fan for mitigating negative health effects in indoor temperatures exceeding previous, and current, thresholds (Table 1). However, a potential problem in relaying when a fan is beneficial for mitigating strain when indoor temperature exceeds 35°C is that one must also be cognizant of their surrounding humidity. Unfortunately, describing the humidity and temperature combinations in which a fan will only prove beneficial when indoor temperatures exceed 35°C may complicate public health messaging. Even alternative metrics such as Heat Index which integrate both ambient humidity and temperature are not appropriate for defining the indoor threshold for fans[16]. Thus, simplifying the messaging to only include the temperature threshold where fans are safe or beneficial, irrespective of humidity, is likely the best approach, and in line with current messaging from public health agencies (Table 1). Past and present findings support that fans are likely safe up to 43°C in resting young healthy adults. Future work is needed to confirm the indoor temperature threshold in older adults and those with pre-existing medical conditions, especially considering they have an increased risk of experiencing indoor overheating[37].

A high fan speed (5.5 m/s) was used to generate the worst-case scenario critical threshold. This was purposeful to ensure high dry heat gain at each rise in indoor air temperature. This high airflow is not commonly achievable by many commercially available fans[38]. It remains unknown whether slower speeds (e.g. <1.0 m/s), which are more representative of typical indoor conditions, will extend the range of safe indoor temperatures for fan use due to the improved evaporative efficiency with concomitant reductions in heat gain and evaporative requirements. Unique to this study was the utilization of an indoor overheating model akin to what may be experienced during a heat wave [15]. As highlighted in Fig. 2, the indoor temperature threshold observed aligns with various biophysical modeling and static condition human studies where air temperature ≥35°C. However, more work is needed to confirm the benefit, safety, or harm, of a fan during prolonged exposure (>2h) to static and dynamic environmental conditions mimicking indoor heat wave conditions in young and older adults. Whether heat acclimation or acclimatization will increase the safe air temperature for fan use remains unexplored. While our study was sufficiently powered *a priori*, the small sample size which included two participants that did not complete the entire protocol may limit generalizability of the results. Lastly, our findings are only applicable to resting individuals, warranting future work incorporating tasks of daily living.

5. Conclusion

Electric fans resulted in an increased heart rate and greater rise in core temperature relative to still air when indoor air temperature exceeded 43°C with low relative humidity. Our simulated overheating scenario complements current evidence examining longer duration exposure in static conditions (Fig. 2), and suggests that the recent guidance updates by World Health Organization[8] may be conservative for young healthy adults. More work is needed in older adults and other heat-vulnerable groups, in addition to ecologically valid assessments of electric fan use in naturally occurring extreme heat.

Ethics approval and consent to participate

Ethical approval was granted by the Lakehead University Research Ethics Board (#1469041). All participants provided written and approve

Data sharing statement

All data supporting the findings are freely available at the Open Science Framework Repository under the CC0 1.0 Universal License https://doi.org/10.17605/OSF.IO/36K7C.

Competing interests

The authors declare they have no competing interest related to this work to disclose.

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CRediT authorship contribution statement

Emily Mihalcin: Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Stefano Schiavon:** Writing – review & editing, Writing – original draft, Investigation, Formal analysis. **Nicholas Ravanelli:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Nicholas Ravanelli reports financial support was provided by Natural Sciences and Engineering Research Council of Canada. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

All data supporting the findings are freely available at the Open Science Framework Repository under the CC0 1.0 Universal License.

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