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TITLE: A prospective, randomised, cross-over study to determine the effect of different airflow rates from a hand-held fan on breathlessness recovery from submaximal exercise in healthy adults.

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Abstract

Objectives: Facial airflow from a hand-held fan may reduce breathlessness severity and hasten post-exertion recovery. Data from randomised controlled trials are limited and the optimal airflow speed remains unknown. We aimed to determine the effect of different airflow speeds on recovery from exercise-induced breathlessness.

Methods: A prospective, randomised, cross-over design. Ten healthy participants (7 male; mean age 29 ± 4 yrs; height 175 ± 9 cm; body mass 76.9 ± 14.1 kg) completed six bouts of four minutes of exercise. During the first five minutes of a 20-minute recovery phase, participants received one of five airflow speeds by holding a fan ~15 cm from their face, or no fan control, administered in random order. Fan A had an internal blade, and fan B had an external blade. Breathlessness was measured using a numerical rating scale (NRS) at minute intervals for the first 10 minutes, and facial skin temperature recorded using a thermal imaging camera (immediately post-exertion and 5 minutes' recovery).

Results: Nine participants completed the trial. A significant main effect for airflow speed ($p=0.016$, $\eta p^2=0.285$) and interaction effect for airflow speed over time ($p=0.008$, $\eta p^2=0.167$) suggest that the airflow speed modifies breathlessness during recovery from exercise. Fan speeds of 1.7m/s or greater increased the speed of recovery from breathlessness compared to control ($P<0.05$) with the highest airflow speeds (2.5 m/s and 3.3 m/s) giving greatest facial cooling.

Conclusion: Higher airflow rates (1.7 m/s or greater) reduced self-reported recovery times from exercise-induced breathlessness and reduced facial temperature .

KEY MESSAGES

What is already known on this topic?

- Facial airflow from a hand-held fan may reduce breathlessness severity and hasten post-exertion recovery, however optimal airflow for symptom relief remains unknown.

What this study adds?

- We identified higher airflow rates from a handheld fan reduced both facial temperature and self-reported recovery from exercise-induced.
- Fan speeds of 1.7m/s or greater increased the speed of recovery from breathlessness with the highest airflow speeds (2.5m/s and 3.3 m/s) giving greatest facial skin cooling.

How this study might affect research, practice, or policy?

- We identified a minimum handheld fan airflow speed to improve recovery from exertional breathlessness, which will inform patient fan selection and be used to inform future clinical trials.

INTRODUCTION

Regular exercise is essential for good physical and mental well-being for everyone. However, a 2016 National Statistics survey of physical activity estimated only 66% of men and 58% of women aged 16 and over meet weekly aerobic exercise guidance (1). Overcoming barriers to exercise is of great health and economic importance, with physical inactivity forecast to be "the biggest public health problem of the 21st century" (2). Therefore, ways to increase exercise endurance and help recovery from exertion, would encourage a virtuous cycle of increasing physical activity.

In healthy individuals, cool airflow from a fan during exercise in a hot environment increases endurance time and reduces perceived exertion ratings (3). In a normothermic environment, cool facial airflow e.g., from a fan, reduces self-reported breathlessness induced by increased inspiratory load (4) and when fan-airflow is used to provide cooling after exercise, heart rate recovery is quicker (5).

In those living with medical conditions - a group less likely to achieve recommended physical activity levels (6) due to avoidance of exertion-related breathlessness (7) - cool facial airflow from a hand-held fan (fan) reduces breathlessness severity (8-9), improves exercise capacity (10) and hastens recovery from exercise (11-12). The mechanisms for these effects are not completely understood. Emerging work in people with chronic obstructive pulmonary disease (COPD) and chronic breathlessness reports a reduction in dynamic hyperinflation (10), and suggest a "neural respiratory gate" (13).

Although we know that, from a range of commercially available fans, patients prefer higher airflow (1.9 m/s) (14), we do not know the airflow speed or fan design for optimum recovery from exertion-related breathlessness. We therefore conducted a study in healthy volunteers aiming to; i) determine the effect of different constant fan airflow speeds on breathlessness and facial skin temperature during recovery from exercise, and ii) explore airflow speed and fan appearance preference.

METHODS

Design

This study was a prospective, randomised, cross-over design (complete in-person, or multiple n-of-1 design). During a single visit participants completed six 4-minute exercise bouts (five with intervention for recovery; one with control) and recovered whilst seated in a chair, with study measures taken for the first 10 minutes. During the first five minutes of recovery participants received one of five fan airflow speeds by holding a fan ~15 cm from their face, or no fan (control) (Figure 1). The order of the airflow rate, including control, was randomised by a blinded remote investigator using an online randomiser (numbergenerator.org/randomnumbergenerator/1-10).

Study participants

A convenience sample of 10 healthy volunteers was recruited from our research team's existing networks and snowballing. Eligible participants were healthy adults aged > 18 years and participated in regular physical activity. Exclusion criteria were known cardiovascular disease, respiratory disease, current musculoskeletal injury and GP advice not to exercise. All participants provided written informed consent. The study was approved by the University of Hull, Faculty of Health Sciences, Research Ethics Committee prior to the start of data collection (REF FHS315).

Baseline data collection

Age, sex, height and weight were recorded. Lung function was measured using standard spirometry (Jeager Oxycon Pro, Hoechberg, Germany). Three technically acceptable forced vital capacity (FVC) manoeuvres were performed (15), with a minimum of two reproducible recordings (difference ≤ 150 ml for forced expiratory volume in 1 s [FEV_1] and FVC). The highest FEV_1 and FVC readings were recorded and predicted values and lower limits of normal were calculated (16).

Exercise

The Yo-Yo incremental exercise test (17) was performed up to level 13.4 (~4 min) to induce breathlessness.

Fan intervention

Two commercially available fans; Fan A (blades enclosed, [Fan U, StressNoMore, UK]) and Fan B (blades external, [VORCOOL Mini Handheld Fan, model YGH365B, Tinksky]), (Figure 2) were modified with a pulse width modulator motor speed control switch, so the fan speed was adjustable. Two fans were selected to facilitate a broader range of airflow rates and to allow for participant preference on fan design to be determined. Both were fitted with a 12V external motor to ensure a stable power supply and constant fan speed. Airflow generated by five speed control switch settings was measured with a Testo 405i Smart Probe (Testo, Ltd, United Kingdom) using a volume flow (duct) test. The mean airflow speed at each speed control setting was calculated from a minimum of 6 measurements (range 6 – 15). Five airflow speeds were then selected from the two fan models;

- Fan A; Speed 1=0.7 m/s (SD = ±0.02), Speed 2=1.0 m/s (SD = ±0.07),
- Fan B; Speed 3=1.7 m/s (SD = ±0.03), Speed 4=2.5 m/s (SD = ±0.07) and Speed 5=3.3 m/s (SD = ±0.04)

Outcome measures

Primary outcome: Breathlessness rated with the Numerical Rating Scale (NRS) (0 = no breathlessness and 10 = worst possible breathlessness) (18-19) at baseline and every minute during 10 minutes recovery.

Secondary outcomes: Heart rate and oxygen saturation were measured at baseline and every 30 seconds during 10 minutes recovery using a pulse-oximeter (Nonin Onyx II, Nonin Medical Inc, Plymouth, USA). A thermal image of the face centred on the left cheek was recorded at 0- and 5-minutes recovery using a FLIR C3 (Teledyne FLIR, United States) thermal camera. Participants were asked their preference regarding recalled pre-set airflow speed, self-adjusted (taken following recovery) airflow speed and fan appearance.

Statistical analysis

Sample size: Based on prior research (12) and a minimal important difference of 1 for NRS breathlessness scales (20) we assumed a partial eta² of 0.20 as the effect size for the interaction effect of fan speed (n=6) x time (n=10) with an SD = 1, power = 90% and alpha = 5% which would give a target sample size of *n* = 10 participants.

Primary outcome: Differences in breathlessness during recovery across the fan speeds were assessed using a P(6 x 10, fan speed x time, respectively) repeated measures ANOVA with replication on all experimental factors (complete within-subject/cross-over design). Polynomial contrast analysis was utilised to assess for a linear relationship between fan speeds and breathlessness recovery and a simple contrast analysis, corrected for False Discovery Rate (21), determined differences between each fan speed and the control. A repeated measures ANOVA, with simple contrast analysis, was conducted for each minute of recovery.

Secondary outcomes: Differences in facial skin temperature were assessed across fan speeds using a 6 x 2 repeated measures ANOVA. Polynomial and simple contrast analysis (comparing each fan to control) were conducted. Paired t-tests determined differences in facial skin temperature for each fan immediately and at 5 minutes following recovery. Differences in heart rate during recovery across the fan speeds were assessed using a repeated measures ANOVA with post-hoc polynomial and simple contrast analysis. Oxygen saturation are presented categorically as a number that displayed exercise-induced arterial hypoxaemia (i.e., SpO_2 less than 95% (22), over two time points). Preferences are reported as frequency analysis. Effect sizes are presented as partial eta² or Cohen's d, as appropriate. Data analysis was supported by JASP (JASP, Version 0.14.1).

RESULTS

Participant characteristics

Ten healthy/active participants were enrolled [7 male; mean age 29 ± 4 yrs; mean height 175 ± 9 cm; body mass 76.9 ± 14.1 kg; BMI 24.9 ± 2.8 (healthy for an active/athletic population)]. All participants were healthy for ≥2 weeks prior to the study and spirometry was above the lower limit of normal (16) (FEV_1 100 ± 4.6 % predicted; FVC 102 ± 7 % predicted; FEV_1/FVC 80 ± 6%). Due to a technical failure with one of the fans on the day of testing, data presented below are from nine participants only.

Breathlessness recovery from exercise

We found a significant main effect for airflow speed ($F(5,40)=3.190$, $p=0.016$, $\eta_p^2=0.285$) and interaction effect for airflow speed over time ($F(50,400)=1.608$, $p=0.008$, $\eta_p^2=0.167$) (Figure 3). Polynomial contrast analysis identified a linear relationship across fan speeds ($T(40)=-3.114$, $P=0.003$) and the simple contrast analysis (FDR corrected) identified a difference between control and Fan Speed 3 ($T(40)=-3.412$, $P=0.005$) and Fan Speed 5 ($T(40)=-2.827$, $P=0.018$) (Figure 3). Simple contrast analysis at each minute of recovery suggests no difference in breathlessness immediately after exercise; however, breathlessness differed from control at one minute of recovery with Fan Speed 3 ($T(40)=-2.537$,$P=0.015$), at two minutes of recovery with Fan Speed 3 ($T(40)=-2.598$ $P=0.013$) and Fan Speed 5 ($T(40)=-2.165$,$P=0.036$) and at three minutes of recovery with Fan Speed 3 ($T(40)=-2.669$, $P=0.011$)), Fan Speed 4 ($T(40)=-2.335$, $P=0.025$) and Fan Speed 5 ($T(40)=-2.669$, $P=0.011$) (Figure 3). Group mean NRS breathlessness reached moderate clinical significance (a 1 point change in NRS) between 1 and 2 minutes of recovery with Fan Speed 3, and at 2 minutes of recovery with Fan Speed 5. Fan Speed 4 differed from control by 0.8 and 0.7 units at 2 and 3 minutes of recovery, however did not reach clinical significance (Figure 3, Supplementary table). Breathlessness had returned to baseline for all participants by 5 minutes.

Heart Rate and oxygen saturation

Heart rate showed no main effect for airflow speeds ($F(5,40)=1.722$, $p=0.152$) nor an interaction effect ($F(50,500)=0.889$, $p=0.687$). No participant showed signs of even mild exercise-induced arterial hypoxemia (SpO_2 of 93-95%).

Facial skin Temperature

A significant main effect for airflow speed ($F(5,40)=15.258$, $P<0.001$, $\eta_p^2=0.656$) and interaction effect was noted across airflow speed over time ($F(5,40)=18.494$, $P<0.001$), $\eta_p^2=0.698$). Polynomial contrast analysis identified a linear relationship across fan speeds ($T(40) =-8.143$,$P<0.001$), and the simple contrast analysis (FDR corrected) identified a difference between control and each fan speed (Figure 4). Post-hoc pairwise comparisons results suggest that facial skin temperature continued to increase over the first five minutes of recovery under control (29.5 ± 1.1°C to 31.6 ± 1.6 °C, $T(8)=-8.288$,$P<0.001$, $d=-2.763$), in contrast to all other fan speeds where either no differences in facial skin temperature was observed (Speed 1, Speed 2, Speed 3, $P>0.05$) or skin temperature decreased (28.9 ± 1.1°C to 27.8 ± 1.4 °C, $T(8)=4.260$,$P=0.003$, $d=1.420$, with Fan Speed 4 and 28.9 ± 1.4°C to 27.3 ± 1.6 °C, $T(8)=5.862$,$P<0.001$, $d=1.954$, with Fan Speed 5), Figure 4.

Fan preferences

Eight out of nine participants preferred the enclosed style of fan and 7/9 preferred fan Speed 3 (1.7m/s) or higher (two preferred Speed 3, three preferred Speed 4 and two preferred Speed 5).

DISCUSSION

Main findings

We found a reduction in recovery time for exercise-induced breathlessness and facial temperature in healthy individuals using a handheld fan during recovery from exertional breathlessness. Fan speeds of 1.7m/s or greater increased the speed of recovery from breathlessness with the highest airflow speeds (2.5m/s and 3.3 m/s) giving greatest facial skin cooling. All participants returned to baseline breathlessness by five minutes. Heart rate and oxygen saturation recovery rates were unaffected by airflow. Most participants preferred an enclosed blade fan design and a pre-set airflow speed of at least 1.7 m/s.

Airflow speeds

Our data complement the literature in showing that patients prefer higher airflow speeds, and here we identify accelerated recovery from exertional breathlessness as a potential mechanism. A study of healthy volunteers in a cycle exercise test found that as metabolic requirements and ambient temperature increased, so preference for airflow and a cooler environment increased (23). Participants preferred the highest airflow available (2.3 m/s), although satisfaction from a ceiling fan directly over their heads was greater than a small handlebar-mounted fan. Subjective breathlessness was not measured.

In people living with chronic breathlessness, Smith and colleagues (14) tested a range of commercially-available fans with 33 participants with COPD. The fan with the highest flow-rate (1.9 m/s, 30 cm from the face) was preferred, but no measures of breathlessness at rest, on exertion or during recovery were taken.

Reductions in recovery time

In healthy volunteers, cool airflow from an industrial fan placed in front (~1 metre) of the participant's face during recovery following 30 minutes cycling exercise reduced heart rate recovery time (in contrast to our findings) but breathlessness measures were not taken (5), and airflow rate and direction were not reported.

In line with our findings in a healthy population, preliminary data from studies of people living with chronic breathlessness suggest shortened recovery time from exercise-induced breathlessness with commercially available fans (12,24). A pilot trial of 14 people with COPD with/without a fan during a 6-minute walk test and during recovery showed greater endurance and faster breathlessness recovery with the fan (24). In a mixed-methods study, although only an improvement of around 25 seconds, qualitative data showed participants valued this reduction (12). A pooled data analysis found over half of participants with chronic breathlessness reported increased physical activity with the fan (11). Although confirmation in larger studies is required, more confident self-management of exertion-related breathlessness may encourage physical activity and reverse/prevent the deconditioning cycle (8). Our data highlight, for the first time, the importance of sufficient airflow speed to elicit the beneficial improvements seen in breathlessness recovery exertion.

Mechanisms of perceived breathlessness

Our data support the direct relationship between facial cooling and increasing airflow speed. Stimulation of areas innervated by trigeminal nerve (4) or of oral mucosal stimulation (25) by airflow and/or cooling have been previously proposed to mediate observed reductions in breathlessness. Self-reported breathlessness during nasal administration of airflow with/without oxygenation is increased with lidocaine anaesthesia of the nasal mucosae (26). Facial airflow may activate the insular cortex, anterior cingulate cortex and the amygdala, a common pathway for the perception of pain and anxiety, which are relevant in breathlessness for healthy subjects and patients (27). Marchetti et al. (10) suggested that the resulting altered perception of breathlessness allowed people with COPD to alter breathing patterns thereby reducing dynamic hyperinflation.

Thermal comfort may influence the perception of breathlessness (23), and heat-induced hyperventilation is recognised. Facial thermal comfort may play a role in breathlessness perception; breathlessness was perceived as more severe by facemask users in the Covid-19 pandemic (28).

Acceptability/preference of fans

In the current study, most participants preferred an enclosed blade fan design and a pre-set airflow speed of at least 1.7 m/s. In the current study however, the enclosed fan had a maximum airflow speed of 1.0 m/s, suggesting that alternative fan designs are required to match patient preference in both fan appearance and airflow. In addition to preferred airflow rate, patients prefer fans that are quiet (14). In general, patients find the fan acceptable (9,24) but reported barriers relate to scepticism regarding benefit and their appearance (29).

Practical Implications

We show that high airflow speeds give recovery benefit with regard to subjective breathlessness. In addition to providing useful information for commercial gymnasiums, the use of a fan could encourage sedentary adults, with or without medical conditions, to increase their physical activity.

For recovery benefit, fan with speeds of at least 1.7 m/s should be used, held approximately 15 cm distant. Further, fans with enclosed blades may have a more acceptable appearance.

Implications for future research

Our findings regarding fan speeds are consistent with uncalibrated fans in people with chronic medical conditions and are therefore likely to be applicable to this group. However, our subjects were fit young adults, capable of exerting to a level where cooling was important. Those limited by breathlessness or fatigue or both, may not be able to exert to this degree and our proposed mechanism of facial cooling may be less relevant. Individuals living with chronic breathlessness are those most likely to benefit from a reduction in exertion-induced breathlessness. Indeed, our findings are consistent with work in people with disease-related breathlessness, where even modest improvements in recovery time from exertional breathlessness were perceived as beneficial, may increase physical activity levels and maintain better control over breathlessness self-management (9, 11-12). Therefore, this study should be repeated on people living with chronic breathlessness due to medical conditions. Further work to produce a fan design for optimal flow rate and appearance is needed.

Strengths and limitations

To our knowledge, this is the first study to explore the effect of the handheld fan with different calibrated and constant airflow speeds under controlled conditions. Although we did not quite reach our target sample size, (9/10), the high correlation between measurement points, the high number of repeated measures and the comparably small within-subject variance further point towards adequate power of 89% to detect effects, despite the slightly smaller interaction effect size found in this trial. However, results will need to be confirmed in future studies. The fan models we used do not represent all options possible. The same person collected the data and provided the intervention, and the Yo-Yo exercise test was conducted on the flat with a simple 180-degree turn and may not represent other types of physical exertion. We did not assess effects of any fatigue on repeat runs, however envisage fatigue to have minimal effect on our results as; i) each bout of exercise was sub-maximal and matched for intensity and duration, ii) breathlessness was similar immediately after exercise across all fan speeds, iii) breathlessness recovered to baseline within 5 minutes of the 20 minutes recovery period, and iv) any potential effect due to fatigue would be minimised/negated by randomisation. Similarly, we consider carry-over effects from the fan to be minimal as improvements in breathlessness due to the fan are shown to be diminished on the commencement of additional physical exertion (30). Further, we did not observe any differences in breathlessness immediately post-exercise and any theoretical carry-over effect would, again, be minimised/negated by adopting a randomisation sequence. We did not monitor respiratory rate which could help further point to other mechanisms of breathlessness recovery.

Conclusion

We found higher airflow rates from a handheld fan reduced both facial temperature and self-reported recovery from exercise-induced breathlessness. The most participant-acceptable design was an enclosed blade model. Although applicable, findings should be replicated in people with breathlessness due to disease.

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CONFLICTS OF INTEREST

A Brew has nothing to disclose. S O'Beirne has nothing to disclose. F Swan has nothing to disclose. M Johnson has nothing to disclose. C Ramsenthaler has nothing to disclose. P Watson has nothing to disclose. P Rubini has nothing to disclose. M Fagan has nothing to disclose. A Simpson has nothing to disclose.

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CONTRIBUTOR STATEMENT

Planning: FS, MJ, AS, PR, PW, MF, MF, AB, SO'B, CR. Conduct: PW, AB, SO'B, FS, AS. Analysis: AS, CR. Interpretation: FS, MJ, AS, PR, PW, MF, MF, AB, SO'B, CR. Manuscript: first draft AB, S'OB, AS. Revisions and approval of final manuscript: FS, MJ, AS, PR, PW, MF, MF, AB, SO'B, CR.

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Figure Captions

Figure 1. Study plan

Figure 2. Fan A, Left, (blades enclosed, [Fan U, StressNoMore, UK]) and Fan B, Right, (blades external, [VORCOOL Mini Handheld Fan, model YGH365B, Tinksky]).

Figure 3. Mean (95% CI) breathlessness measured on a numerical rating scale (0-10) for 5 minutes of recovery from intermittent exercise with administration of a hand-held fan at different airflow speeds or control (no fan).

Figure 4. Mean (95% CI) facial skin temperature (^{o}C) immediately and following five minutes of recovery from intermittent exercise with administration of a hand-held fan at different airflow speeds or control (no fan).