The effect of trait self-control on dyspnoea and tolerance to a CO₂ rebreathing challenge in healthy males and females

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ABSTRACT

Background: High trait self-control is associated with greater tolerance of unpleasant sensations including effort and pain. Dyspnoea and pain have several commonalities and this study aimed to investigate for the first time whether trait self-control influences responses to a hypercapnic rebreathing challenge designed to induce dyspnoea. As sex also influences tolerance to dyspnoea, we also sought to investigate whether this moderated the role of trait self-control.

Methods: Participants (n = 65, 32 females) scoring high or low for trait self-control, performed a standardised rebreathing challenge, in which inspired carbon dioxide (CO₂) gradually increased over a period of 6 min or until an intolerable level of dyspnoea. Air hunger (AH) intensity – a distinctive quality of dyspnoea, was measured every 30 s. The multidimensional dyspnoea profile (MDP) was completed after the rebreathing challenge for a more complete overview of breathing discomfort.

Results: Males high in trait self-control (SCHIGH) (302 ± 42 s), tolerated the rebreathing challenge for longer than males low in self-control (SLOW) (252 ± 66 s, P = 0.021), experienced slower increases in AH intensity during the rebreathing challenge (0.03 ± 0.01 cm² s⁻¹ vs. 0.04 ± 0.01 cm² s⁻¹ P = 0.045) and reported lower perceived mental effort on the MDP (4.94 ± 2.46 vs. 7.06 ± 1.60, P = 0.007). There was no difference between SCHIGH and SLOW females for challenge duration. However, SCHIGH females (9.29 ± 0.66 cm) reported greater air hunger at the end of the challenge than SLOW females (7.75 ± 1.75 cm, P = 0.003). It is possible that SLOW females were unwilling to tolerate the same perceptual intensity of AH as the SCHIGH females.

Conclusions: These results indicate that individuals high in trait self-control are more tolerant of dyspnoea during a CO₂ rebreathing challenge than low self-control individuals. Tolerance of the stimulus was moderated by the sex of the participant, presenting an interesting opportunity for future research.

1. Introduction

Self-control can be defined as an individual’s capacity to control and override a predominant habitual tendency to achieve or protect a long-term goal [5]. The ability to exert self-control is influenced by disposition (trait self-control) and the situation (state self-control) [61]. Dispositional self-control is a relatively stable trait, associated with many positive life outcomes across multiple domains [15,22]. High levels of dispositional self-control are also associated with effective regulation strategies when dealing with aversive/challenging activities [42]. Indeed, self-control is linked to success at inhibiting proximal desires (e.g., smoking a cigarette, eating an unhealthy snack) to preserve long-term goals (e.g., quitting smoking, losing weight) [15,55].

Exerting self-control is challenging as it requires individuals to overcome tempting proximal desires in the face of uncomfortable sensations including effort, stress, and pain [35,42]. Physical exercise commonly generates such sensations and overriding the urge to quit to achieve a specific goal is considered an act of self-control [8,61]. Compared to individuals with low trait self-control, those with high trait self-control have greater tolerance of painful tasks, demonstrate superior performance during high-intensity exercise and adhere to exercise programmes more successfully [2,21,49,54,59,68]. It is suggested that individuals with low trait self-control are less successful in tolerating sensations of pain during exercise and that this increased perception of discomfort may lead to future exercise avoidance [8,21,61].

Another common sensation of discomfort during exercise is...
dyspnoea. Defined as a subjective experience of respiratory discomfort, dyspnoea commonly occurs in healthy individuals unaccustomed to the ventilatory demands of unfamiliar exercise [57]. Moreover, dyspnoea is more common in obese individuals and is consistently rated as one of the main reasons for exercise avoidance in clinical populations with pulmonary, neuromuscular, and cardiovascular diseases [43,45,52]. Pain and dyspnoea share many commonalities, with much of our recent progress into the understanding of dyspnoea originating from pain research [4,64]. Like pain, dyspnoea is multi-dimensional in nature, having sensory-perceptual and affective dimensions [4,36]. These aversive sensations associated with dyspnoea and pain appear to be processed by the same brain areas [64], which may partly explain why dyspnoea and pain appear to occur, develop, and resolve together in clinical populations [10,11,38]. As pain and dyspnoea share these commonalities, it could also be the case that individuals with low self-control are less tolerant of dyspnoea [49,54,69].

Therefore, the primary aim of the present study was to investigate whether trait self-control affects tolerance of dyspnoea. As we wanted breathing discomfort to be the participants focus of discomfort, we employed a rebreathing challenge rather than exercise to eliminate the possibility of participants confusing perceptual dyspnoea ratings with overall discomfort. The CO₂ rebreathing challenge, administered in the present study, has previously been employed to invoke dyspnoea [50,66,67]. Specifically, this challenge is used to evoke an aspect of dyspnoea called, ‘air hunger’. Described as an unpleasant urge to breathe, this aspect of dyspnoea is particularly sensitive to changes in blood PCO₂ [67]. We hypothesized that individuals with high trait self-control would tolerate the rebreathing challenge for longer, thereby reaching higher end tidal PCO₂, whilst rating lower air hunger intensity than low trait self-control individuals.

Although hyperventilation primarily elicits air hunger, dyspnoea is multidimensional and only measuring the intensity of air hunger would result in a relatively incomplete assessment of the influence of trait self-control. Therefore, we also measured the intensity of other sensory perceptual qualities such as, ‘chest tightness’ and ‘work of breathing’ as well as affective components including ‘unpleasantness’ and the emotional response [4].

Finally, as sex is an important consideration when investigating interoceptive sensations such as pain and dyspnoea, male and female responses to the rebreathing challenge were compared. Healthy females have consistently demonstrated reduced tolerance to pain and dyspnoea in experimental trials compared to males [12,20,41] and report greater symptom severity in clinical trials [17,29,56]. Sex moderates the effect of dispositional traits, such as anxiety on perceptions of pain [32,34]. Therefore, our secondary aim was to investigate whether sex moderated our hypotheses.

2. Methods

2.1. Participants

Sixty-six, non-smoking participants (32 females) (age: 22 ± 3 years, height: 173 ± 10 cm, body mass: 71 ± 12 kg) provided written informed consent to participate in the study. Prior to the laboratory visit, participants refrained from exercise and alcohol for 48 h, and food and caffeine for 3 h. The study was approved by the Nottingham Trent University Human Ethics Committee, and all procedures conformed to the standard set by the Declaration of Helsinki.

2.2. Experimental overview

Students (n = 396) at Nottingham Trent University were screened for trait self-control. A global score was calculated for each participant, with the lowest score being 13 and the highest being 65. 396 NTU students were screened for trait self-control using the BSCS. The median score (44) of all responses was calculated. The cohort was stratified according to sex and having a BSCS above or below 44. Students in each strata were then randomly sampled and invited to take part in the study. This sampling process continued until the target number (~15) for each group (SCHIGH male, SCLOW male, SCHIGH female and SCLOW female) was reached. Sample sizes for each group were based on previous studies that have explored the effects of trait anxiety during CO₂ rebreathing [66,67].

Participants attended the laboratory on one occasion. After assessment of height, body mass and baseline pulmonary function participants then completed a 6-minute rebreathing challenge during which air hunger intensity was measured. Immediately following this, participants completed a Multidimensional Dyspnoea Profile (MDP). Normal pulmonary function was assessed at baseline using a spirometer (Pneumotrac; Vitalograph, Buckingham, UK) according to published guidelines (ATS/ERS, 2019). Individuals were excluded from participating in the rebreathing challenge if their FEV₁/FVC ratio was <70%. Participants then completed a 6-minute rebreathing challenge. The CO₂ rebreathing challenge was a version of the standardised rebreathing test [47] where 5 Litres of an oxygen-rich gas mixture (95% O₂, 5% CO₂) was breathed from a 6-litre reservoir (P3 Medical, Bristol, UK). Expired air was returned to the reservoir so that inspired CO₂ concentration increased over time, thereby increasing minute ventilation (Ve). This method induces dyspnoea whilst preventing hypoxia [66,67]. Participants wore a nose clip and breathed through a mouthpiece. A 3 way-stopcock (Hans-Rudolph, 3 way-stopcock, 2100 Series) allowed the inspirate to switch between the reservoir and room air. A screen prevented participants seeing when inspirate switching occurred. Baseline values of air-hunger and respiratory variables were measured for 60 s. Participants were instructed to tolerate the CO₂ rebreathing challenge for as long as possible. The CO₂ rebreathing challenge was terminated either after 6 min or until they could no longer tolerate the challenge. In the latter case, the inspirate was switched to room air until the end of the sixth minute.

2.3. Self-report measures

2.3.1. Self-Control

To assess trait self-control, participants completed the 13-item brief self-control scale (BSCS, [60]) (e.g., “I am good at resisting temptation” and “I am able to work effectively towards long-term goals”). Participants indicated the extent to which each statement reflected their habitual behaviour on a five-point scale ranging from 1 (not at all) to 5 (very much). Nine items were reverse scored as they reflected a lack of self-control (e.g., “I wish I had more self-discipline” and “I am lazy”). The items have demonstrated acceptable internal consistency and predictive validity [39].

2.4. Dyspnoea measurements

2.4.1. Air hunger intensity

Before undertaking the CO₂ rebreathing challenge, a script, previously used by Wan et al. [67], was used to explain the sensation of air hunger. Participants rated air hunger intensity (measured to the nearest 0.1 cm) every 30 s using a validated [25,31] 10-cm visual analogue scale (VAS). To conceal previous ratings a new scale was used on each occasion. Baseline (AHBASE) and final air hunger (AHEND) scores were used in the analysis, with baseline taken as the average of two air-hunger ratings obtained during normal, quiet breathing. The rate of change in air hunger (AHGDP) was calculated by calculating the unit change (cm) per second. This was done using the slope function in Microsoft Excel (Microsoft Office, 2016).

2.4.2. Multidimensional dyspnoea profile (MDP)

The MDP was completed immediately after the rebreathing challenge and participants were asked to only refer to the final 30-seconds of
the rebreathing challenge.

The MDP measures dyspnoea across 3 separate components:

1. Overall breathing discomfort: Measured using the “A1 Scale”, Participants are asked to rate the unpleasantness of their breathing from 0 (“Neutral”) – 10 (“Unbearable”).

2. Sensory Quality of Dyspnoea: Participants are asked to provide details on 5 different qualities of dyspnoea experienced. Participants were asked if descriptors such as; “my breathing requires muscle work or effort”, and “My chest and lungs feel tight or constricted”, applied to how their breathing felt. Participants then rated which of the 5 qualities most accurately described how they felt, before rating the intensity of each descriptor from a scale of 0 (“None”) – 10 (“As intense as I can imagine”).

3. Emotional response to dyspnoea: Participants were asked to provide details on how their breathing sensations made them feel. The simple emotion scales used in the MDP asks participants to rate 5 commonly experienced emotions in the presence of dyspnoea on a scale from 0 (“None”) – 10 (“The most I can imagine”). Participants were asked whether their breathing made them feel emotions such as, “Anxious”, and “Frustrated”.

Two main components of the MDP were analysed, these being the “immediate perception domain”, comprising the unpleasantness (A1 rating) and the 5 sensory qualities (/60) and the “emotional response domain”, comprising the 5 emotional ratings (/50). The MDP has demonstrated acceptable validity and reliability in both laboratory and clinical studies [3,4,40].

2.4.3. Respiratory variables

Ventilatory and pulmonary gas exchange variables were measured breath by breath using a metabolic cart (JAEGER™ Vyntus™ CPX incorporating SentrySuite CPET Bx8 software, Version 2.21.1; Vyaire Medical Products Ltd, Chineham, Basingstoke). Participants breathed through a mouthpiece connected to a low-resistance (<1.0 cm H2O·L−1·S−1 at <15 L·S−1) digital volume transducer with a combined dead space of 53 mL. The flow sensor was calibrated automatically according to the manufacturer’s instructions using a built-in flow generator. Gas concentrations were sampled at the mouth via a 2.4 m sample line and analysed using a high speed digital O2 sensor based on an electro-chemical principle, and a fast response digital CO2 sensor based on the principle of infrared absorption. These were calibrated using ambient air and gases of known concentration (5% CO2, 15% O2, balance N2; BOC, Guilford, UK). End-tidal partial pressure of CO2 (PETO2CO2) and VE were reduced to 10 s averages. Baseline values were taken as the average during room air breathing (PETCO2BASE, VEBASE). End-test values were taken as the average over the final ten seconds of rebreathing. As both PETCO2 and VE varied considerably between individuals, the absolute increase in these variables from baseline to the end of rebreathing (ΔPETCO2, ΔVE) was calculated. The rate of change (PETCO2 SLOPE, VE SLOPE) was calculated as unit change per second after a linear trend-line was fitted.

2.4.4. Statistical analysis

All analysis was conducted using IBM SPSS (Version 26.0). A one-way ANOVA was used to examine participant characteristics for; age, height, mass, BMI, self-control score and training frequency between the following groups: SCHIGH Males, SCLOW Males, SCHIGH Females and SCLOW Females. A two-way ANOVA was used to examine the effects of self-control (High vs. Low) and sex (Male vs. Female) on the following variables: Challenge duration, PETCO2BASE, PETCO2 SLOPE, VBASE, V SLOPE, AHBASEx, AHENDx, AH SLOPEx, MDP immediate perception score and MDP emotional response score. Variance between groups was considered homogenous if Levene’s test was not significant (P > 0.05). Normality was assessed using z-scores calculated from skewness and kurtosis. If these assumptions were violated, a log transformation was applied. This was not successful in transforming AHBASE scores to fit a normal distribution. As there are no non-parametric alternatives to a two-way ANOVA and ANOVA is somewhat robust to deviations in normality [7], the analysis was run anyway and the violation for this variable reported. Significant outliers identified through box and whiskers plot as >3SD from the mean were removed from analysis [37]. Pairwise comparisons with Bonferroni corrections were used following a significant interaction/main effect. Significant self-control*sex interactions were followed up by interpreting the main effects between each level of self-control/sex. If there was no significant interaction, the main effects of self-control and sex were still interpreted. If statistical significance was reached, 95% confidence intervals were calculated for the difference. For ANOVA, effect sizes are given as partial eta-squared (ηp2) and interpreted as small (0.01), medium (0.06) and large (0.14). For some analyses (ΔPETCO2, ΔVE), it was more appropriate to use an independent samples t-test (for normally distributed data) or a Mann-Whitney U test (for non-normally distributed data) for each sex than a two-way ANOVA. On the occasions these analyses are used instead of a two-way ANOVA, the test, and the justification for its use instead of the two-way ANOVA is explained on each occasion in the results section. Effect sizes for independent samples t-tests were calculated using Cohen’s d, where 0.2, 0.5 and 0.8 represented small, medium, and large effect sizes. Statistical significance was set at P < 0.05. Results are presented as mean ± SD.

3. Results

3.1. Participant characteristics

Participant characteristics are shown in Table 1. As expected, male participants were taller and heavier than female participants (P < 0.05). There was no difference in height or weight between self-control groups of the same sex (P > 0.05). BMI was similar across all subsets. In the present study, the lowest score on the brief self-control scale (BSCS) was 29 and the highest was 61. Following the median split, as previously described, male and female participants in the SCHIGH groups had higher self-reported self-control scores than male and female participants in the SCLOW group (P < 0.05). There was no difference in self-control score between males and females in the same self-control subset. Unexpectedly, SCHIGH males participated in more exercise sessions per week than SCHIGH females (P = 0.044).

3.2. Challenge duration

For challenge duration, there was a significant self-control*sex interaction (F(1, 62) = 6.743, P = 0.012, ηp2 = 0.098). Follow up
comparisons showed SCHIGH males (302 ± 42 s) tolerated the challenge for longer than SCLOW males (252 ± 66 s) (mean difference, 49 s, 95%CI [8, 91 s], F (1, 62) = 5.651, p = 0.021, $\eta^2_p = 0.084$). However, there was no difference in challenge duration between SCHIGH females (259 ± 62 s) and SCLOW females (287 ± 70 s, mean difference, −28 s, 95%CI [−71, 15 s], F (1, 61) = 1.723, p = 0.194, $\eta^2_p = 0.027$). SCHIGH males also tolerated the challenge for longer than SCHIGH females (mean difference, 3.80 mmHg, 95%CI [0.43, 7.17 mmHg], p = 0.045, $\eta^2_p = 0.063$). Challenge duration was not different between SCLOW males and SCLOW females (p = 0.108).

### 3.3. End tidal CO$_2$ responses

For $P_{\text{ET}}$CO$_{2 \text{BASE}}$ there was no self-control*sex interaction (p = 0.480) or main effect of self-control (p = 0.262). There was a main effect of sex (F (1, 62) = 9.811, p = 0.003, $\eta^2_p = 0.137$) with males (36.64 ± 2.79 mmHg) having higher $P_{\text{ET}}$CO$_{2 \text{BASE}}$ than females (34.23 ± 3.34 mmHg) (mean difference, 2.38 mmHg, 95%CI [0.86, 3.89 mmHg]).

$P_{\text{ET}}$CO$_2$ increased linearly throughout the rebreathing challenge. For $P_{\text{ET}}$CO$_{2 \text{SLOPE}}$, there was no self-control*sex interaction (p = 0.573) or main effect of self-control (p = 0.116). There was a main effect of sex (F (1, 62) = 17.632, p < 0.001, $\eta^2_p = 0.221$), which was steeper in males (0.09 ± 0.01 mmHg s$^{-1}$), than females (0.08 ± 0.01 mmHg s$^{-1}$) (mean difference, 0.14 mmHg s$^{-1}$, 95%CI [0.07, 0.20 mmHg s$^{-1}$]).

As $P_{\text{ET}}$CO$_2$ increased quicker in males than females, separate independent samples t-tests for each sex were conducted for $\Delta P_{\text{ET}}$CO$_2$. $\Delta P_{\text{ET}}$CO$_2$ was greater in SCHIGH males than SCLOW males (mean difference, 0.53 ± 3.80 mmHg, 95%CI [0.43, 7.17 mmHg], $t$ (32) = 2.295, p = 0.028, d = 0.787) (Fig. 1). $\Delta P_{\text{ET}}$CO$_2$ was not significantly different between SCHIGH females and SCLOW females (p = 0.590) (Fig. 1).

### 3.4. Ventilatory response

For $\dot{V}_{\text{E BASE}}$ there was no self-control*sex interaction (p = 0.850) or main effect of self-control (p = 0.119). There was a main effect of sex (F (1, 62) = 5.582, p = 0.021, $\eta^2_p = 0.083$), with males (16.78 ± 5.29 L min$^{-1}$) having higher $V_{\text{E}}$ at baseline than females (14.15 ± 3.54 L min$^{-1}$) (mean difference, 2.67 L min$^{-1}$, 95%CI [0.42, 4.93 L min$^{-1}$]).

$\dot{V}_{\text{E}}$ increased throughout the rebreathing challenge. There was no self-control*sex interaction (p = 0.480) or main effect of self-control (p = 0.680) for $\dot{V}_{\text{E SLOPE}}$. There was a main effect of sex (F (1, 62) = 10.371, p = 0.002, $\eta^2_p = 0.143$), with $\dot{V}_{\text{E SLOPE}}$ being steeper in males (0.14 ± 0.05 L min$^{-1}$ s$^{-1}$) than females (0.10 ± 0.04 L min$^{-1}$ s$^{-1}$) (mean difference, 0.04, 95%CI [0.02, 0.06]).

As $\dot{V}_{\text{E}}$ increased quicker in males than females, separate independent samples t-tests for each sex were conducted for $\Delta \dot{V}_{\text{E}}$. There was no significant difference between SCHIGH males and SCLOW males (p = 0.357), or SCHIGH females and SCLOW females (p = 0.095).

### 3.5. Dyspnoea

#### 3.5.1. Air hunger intensity – visual analogue scale (cm)

For $AH_{\text{BASE}}$, there was no self-control*sex interaction or main effect of sex (p > 0.05). There was a main effect of self-control on $AH_{\text{BASE}}$ (F (1, 62) = 4.592, p = 0.036, $\eta^2_p = 0.069$), with SCHIGH participants (0.27 ± 0.42 cm) rating lower $AH_{\text{BASE}}$ than SCLOW participants (0.54 ± 0.60 cm, mean difference, −0.28 cm, 95%CI [−0.53, −0.02 cm]).

Air hunger increased throughout the challenge, and there was a self-control*sex interaction for $AH_{\text{SLOPE}}$ (F (1, 62) = 4.210, p = 0.044, $\eta^2_p = 0.064$). Follow up comparisons showed that $AH_{\text{SLOPE}}$ was lower in SCHIGH males (0.03 ± 0.01 cm s$^{-1}$) than in SCLOW males (0.04 ± 0.01 cm s$^{-1}$) (mean difference, −0.01 cm s$^{-1}$, 95%CI [−0.02, 0.00 cm]) (p = 0.045) Fig. 2(A). There was no difference in $AH_{\text{SLOPE}}$ between SCHIGH females (0.03 ± 0.02 cm s$^{-1}$) and SCLOW females (0.03 ± 0.01 cm s$^{-1}$, p = 0.385) Fig. 2(B). There was also no difference in $AH_{\text{SLOPE}}$ between SCHIGH males and females (p = 0.329) and SCLOW males and females (p = 0.062).

There was a self-control*sex interaction for $AH_{\text{END}}$ (F (1, 59) = 7.347, p = 0.009, $\eta^2_p = 0.111$). Follow-up comparisons showed there was no difference between SCHIGH males (8.31 ± 1.72 cm) and SCLOW males (8.70 ± 1.07 cm, p = 0.707). Conversely, $AH_{\text{END}}$ was higher in SCHIGH females (9.29 ± 0.66 cm) than SCLOW females (7.75 ± 1.75 cm) (mean difference, 1.54 cm, 95%CI [0.52, 2.57 cm], F (1, 59), p = 0.003, $\eta^2_p = 0.141$). There was no difference between SCHIGH males and SCHIGH females (p = 0.050, $\eta^2_p = 0.063$), or SCLOW males and SCLOW females (p = 0.071, $\eta^2_p = 0.054$).

#### 3.6. Multidimensional dyspnoea profile

##### 3.6.1. Immediate perception score

There was a significant self-control*sex interaction for immediate perception score (F (1, 60) = 7.111, p = 0.010, $\eta^2_p = 0.106$). Follow up comparisons showed SCHIGH males (33.87 ± 7.98) rated immediate perception scores lower than SCLOW males (41.59 ± 7.22) (mean difference, −7.99, 95%CI [−13.30, −2.68]) (F (1, 60) = 10.547, p = 0.002, $\eta^2_p = 0.150$) Fig. 3). There was no difference in immediate perception scores between SCHIGH females (37.76 ± 8.76) and SCLOW females (37.20 ± 5.65) (p = 0.602). There was also no difference between SCHIGH male and SCHIGH female participants (p = 0.110). However, SCLOW males rated immediate perception scores higher than SCLOW females (mean difference, 4.39, 95%CI [−0.93, 9.48], F (1, 60) = 4.627, p = 0.035).
\[ P = 0.036, \eta_p^2 = 0.072. \]

To investigate what was driving these differences in immediate perception scores, Mann-Whitney U tests were conducted at the level of each individual descriptor between SCHIGH and SCLOW males and between SCHIGH and SCLOW females. The differences in immediate perception scores between SCHIGH and SCLOW males was driven by significantly higher ratings of mental effort in SCLOW males (7.06 ± 1.60) compared to SCHIGH males (4.94 ± 2.46) (U = 221.50, Z = 2.706, \( P = 0.007 \)). There were no differences between SCHIGH males and SCLOW males for all other individual descriptors. There was no difference between SCHIGH males and SCLOW females at the level of each individual descriptor.

### 3.6.2. Emotional response score

For emotional response score, there was no significant self-control*sex interaction, or main effect of self-control/sex (all \( P > 0.05 \)).

## 4. Discussion

This study is the first to investigate the influence of trait self-control on dyspnoea. The main findings were that SCHIGH males tolerated the rebreathing challenge for longer than SCLOW males, thereby reaching greater absolute increases in \( P_{ETCO_2} \) concentration. There was no difference between SCHIGH and SCLOW females for challenge duration or for absolute increases in \( P_{ETCO_2} \) at the end of the challenge. Despite this, SCHIGH females reported greater air hunger at the end of the challenge than SCLOW females. Therefore, it is possible that SCLOW females were unwilling to tolerate the same perceptual intensity of air hunger as the SCHIGH females. Together, these results suggest that high trait self-control improves tolerance to air hunger but that this may manifest differently in males and females.

We report that, compared to SCLOW males, SCHIGH males experienced a slower increase in perceived air hunger and therefore superior tolerance to the rebreathing challenge. This aligns with previous reports of individuals with high trait self-control tolerating painful stimuli for longer than individuals with low trait self-control [26,54,69]. In a painful handgrip task, inferior task tolerance in low-self-control individuals was reflected by more rapid increases in ratings of perceived exertion [69]. Like pain, dyspnoea elicits a desire to alleviate the sensation, leading to shifts in motivation away from the specified task. Tolerance to, rather than alleviation of, pain and dyspnoea requires self-control [61]. The shifting priorities model of self-control suggests that aversive stimuli cause an attentional shift from a task-orientated goal, to feelings of discomfort associated with unpleasant sensations, such as pain and dyspnoea [30,71].

Interestingly, Wolff et al. [69] reported that during a hand-grip task faster increases in ratings of perceived exertion in low trait self-control individuals were mirrored by greater increases in pre-frontal cortex activation. The pre-frontal cortex is activated when self-control is required [44], indicating that individuals with lower trait self-control were having to employ greater cortical effort to persist with the hand-grip task than individuals with higher trait self-control. In the present study, SCLOW males reported that their work of breathing required greater mental effort than SCHIGH individuals, likely contributing to the shorter task duration in these participants. These data suggest that the inferior task tolerance in SCLOW males may be linked to the greater mental effort reported in this group compared with SCHIGH males. Indeed, meta-analytic evidence suggests that individuals with high trait self-control may have developed low effort, automatic, coping strategies that allow them to exert relatively less cognitive effort when faced with a task that causes discomfort [15]. Trait self-control has a strong effect on automatic behaviours and only a small-to-medium effect on behaviours requiring effortful control [14]. Since our participants were naïve to the rebreathing challenge, it is highly likely that they relied on automatic coping strategies to manage the sensations of dyspnoea. Therefore, it may be that individuals with high trait self-control experience slower increases in perceptual effort/discomfort due to reduced cortical demands through habitually ingrained coping strategies.

Unlike in male participants, trait self-control did not influence task duration in female participants. Extant literature reporting the influence of trait self-control on task duration in painful challenges does not consider the potentially moderating effect of sex [2,54,69]. Furthermore, all these studies had unbalanced numbers of male and female participants which may have disguised any modulating effects. Interestingly, in both experimental and clinical studies, trait anxiety influences pain in males but not females [32,58,63]. This effect may be due to trait anxiety being lower in males than females [33]. Females consistently score higher than males on measures of self-control, inferring a similar phenomenon when participants are grouped based on self-control [1,9,24]. However, as males and females in the present study scored similarly on the brief self-control scale, sex differences in trait self-control are unlikely to explain the contrasting results observed in male and female participants.

Our data show that SCHIGH females tolerated greater air hunger at the end of the rebreathing challenge (thereby demonstrating a superior capacity to persist with the task) than SCLOW females. Societal differences in how males and females are expected to react to aversive stimuli may help explain why trait self-control affected male and female subjects differently. Males are expected to suppress sensations of pain, whilst females are expected to express sensations of pain [48,51,65]. It is possible that this extends to expressing subjective dyspnoea, as females consistently report greater dyspnoea than males during exercise and when reporting symptoms of disease [18,56]. There are also key physiological differences between males and females that have been shown to affect exertional dyspnoea. Even after correcting for differences in height, females have relatively smaller lungs, weaker respiratory musculature, and narrower airways than age-matched males [12,27,53]. In females, this places greater mechanical constraint on \( V_t \) during submaximal exercise, leading to a more rapid, shallow breathing pattern and increased diaphragm activation at a given \( V_t \) [12,53]. The conscious awareness of a greater neural respiratory drive required to achieve a given \( V_t \) may therefore contribute to the higher ratings of exertional dyspnoea experienced by healthy, young females compared to males [53]. Sex differences are therefore an important consideration for future studies, as ignorance to sex differences in the processing of dyspnoea is likely to over-generalise findings and may prevent us from fully understanding sex specific mechanisms. As it was the primary aim of the present study to investigate the impact of trait self-control on perceptions of air hunger, with sex included as a potential modulator of this trait, investigating between sex differences was beyond the scope of the present study. However, sex is an important consideration for future studies, as ignorance to sex differences in the processing of dyspnoea is likely to over-generalise findings and may prevent us from fully understanding sex specific mechanisms.

The present study contributes to the growing body of literature surrounding self-control and exercise tolerance by showing that trait self-control affects tolerance of dyspnoea – a common source of discomfort during exercise. When considered alongside previous reports that high trait self-control confers greater tolerance of pain, it may be the case that these individuals exhibit superior performance during high intensity exercise due to greater tolerance of general discomfort [2,54,69].

Self-control failure occurs when a proximal desire conflicts with a distal goal [8]. Individuals with high trait self-control adhere to exercise programmes and lose more weight than individuals with low self-control [13,19,21]. This is possibly because the desire to achieve a distal weight loss goal outweighs the proximal desire to avoid any discomfort experienced with exercise. As self-control can be improved through training, training interventions that repeatedly expose individuals to
uncomfortable sensations may represent an interesting area of future study [6,16,28]. In clinical populations where dyspnoea is the primary reason for exercise avoidance, self-control training could possibly be utilised to combat the dyspnoea spiral associated with activity avoidance in these individuals [23,45,62].

There are several limitations in the present study. Measurement of motivation during the rebreathing challenge might have allowed fuller evaluation of the shifting priorities model of self-control. Furthermore, trait self-control is negatively associated with trait anxiety, which affects tolerance to dyspnoea [46,66,67,70]. This makes it difficult to discern the true effect of self-control from this study alone. Assessment of state self-control might have provided a more complete evaluation of this.

Finally, although CO₂ rebreathing invokes strong sensations of air hunger, it is less potent at invoking other dyspnoeic sensations such as respiratory muscle work/effort, thus whether trait self-control influences perceptual responses to, for example, flow-resistive loading warrants further study.

In conclusion, individuals with high trait self-control were more tolerant of a challenge designed to induce dyspnoea than individuals with low self-control. How trait self-control improves tolerance to
dyspnoea appears to be moderated by sex, representing an interesting area of future study. Similarly, investigating the state aspect of self-control on dyspnoea through ego-depletion may reveal a more complete picture of the role of self-control in tolerance to dyspnoea.

Fig 3. Scores from the Multidimensional dyspnoea profile (MDP) completed at the end of the rebreathing challenge. A) Male Immediate Perception scores, B) Female Immediate Perception scores, C) Male Emotional Response scores, D) Female Emotional Response scores, E) Male intensity scores for each individual descriptor of the immediate perception domain, F) Female intensity scores for each individual descriptor of the immediate perception domain, G) Male scores for each individual descriptor of the emotional response domain, H) Female scores for each individual descriptor of the emotional response domain. A1 = Unpleasantness of breathing sensations. *Different from SCHIGH group (\( P < 0.05 \)). Values are mean ± standard deviation.

**Declarations of Competing Interest**

None.
