The Effect of Trait Self-Control on Dyspnoea and Tolerance to a CO_2 Rebreathing Challenge in Healthy Males and Females

Brown, J.C.[a], Boat, R.[a], Williams, N.C.[a], Johnson, M.A.[a], & Sharpe, G.R.[a]

[a]Department of Sport Science, Clifton Campus, Nottingham Trent University, Nottingham UK

Address for correspondence: Mr James Brown, Academic Associate in Sport Science, Erasmus Darwin, Clifton Campus, Nottingham Trent University, Nottingham NG11 8NS, United Kingdom

Email: james.brown02@ntu.ac.uk

Emails of co-authors: ruth.boat@ntu.ac.uk, neil.williams@ntu.ac.uk, michael.johnson@ntu.ac.uk, graham.sharpe@ntu.ac.uk

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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 (CO_2) gradually increased over a period of 6 minutes or until an intolerable level of dyspnoea. Air hunger (AH) intensity – a distinctive quality of dyspnoea, was measured every 30 seconds. 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 ± 42s), tolerated the rebreathing challenge for longer than males low in self-control (SCLOW) (252 ± 66s, $P = 0.021$), experienced slower increases in AH intensity during the rebreathing challenge (0.03 ± 0.01 $cm \cdot s^{-1}$ vs. 0.04 ± 0.01 $cm \cdot s^{-1}$, $P = 0.045$) 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 SCLOW females for challenge duration. However, SCHIGH females (9.29 ± 0.66 cm) reported greater air hunger at the end of the challenge than SCLOW females (7.75 ± 1.75 cm, $P = 0.003$). It is possible that SCLOW 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 CO_2 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.

Key Words: Dyspnoea, Self-control, Air Hunger, Multi-dimensional Dyspnoea Profile, CO_2 Rebreathing, Tolerance.

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 (Baumeister, Vohs, & Tice, 2007). The ability to exert self-control is influenced by disposition (trait self-control) and the situation (state self-control) (Taylor, Boat & Murphy, 2018). Dispositional self-control is a relatively stable trait, associated with many positive life outcomes across multiple domains (Galla & Duckworth, 2015; de Ridder et al. 2018). High levels of dispositional self-control are also associated with effective regulation strategies when dealing with aversive/challenging activities (Nielsen et al. 2020). 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) (Shmueli & Prochaska, 2009; Crescioni et al. 2011).

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 (Kurzban, 2016; Nielsen et al. 2020). Physical exercise commonly generates such sensations and overriding the urge to quit to achieve a specific goal is considered an act of self-control (Taylor, Boat & Murphy, 2018; Boat & Cooper, 2019). 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 (Rosembaum, 1980; Schmeichel & Zell, 2007; Stork et al, 2017; Finne et al, 2018; Wolff et al, 2019a; Ahm, Kim & Kwon, 2021). 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 (Taylor, Boat & Murphy, 2018; Finne et al. 2018; Boat & Cooper, 2019).

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 (Smoliga et al. 2016). 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 (Scano et al, 2009; Nishino et al, 2011; O'Donnell et al. 2020). Pain and dyspnoea share many commonalities, with much of our recent progress into the understanding of dyspnoea originating from pain research (Von Leupoldt et al, 2009; Banzett et al. 2015). Like pain, dyspnoea is multi-dimensional in nature, having sensory-perceptual and affective dimensions (Lansing, Gracely & Banzett, 2009; Banzett et al. 2015). These aversive sensations associated with dyspnoea and pain appear to be processed by the same brain areas (Von Leupoldt et al, 2009), which may partly explain why dyspnoea and pain appear to occur, develop, and resolve together in clinical populations (Liotti et al, 2001; Clark et al. 2014; Chen et al. 2018). As pain and dyspnoea share these commonalities, it could also be the case that individuals with low self-control are less tolerant of dyspnoea (Rosembaum, 1980; Schmeichel & Zell, 2007; Wolff et al, 2019).

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 breathing challenge rather than exercise to eliminate the possibility of participants confusing perceptual dyspnoea ratings with overall discomfort. The CO_2 rebreathing challenge, administered in the present study, has previously been employed to invoke dyspnoea (Wan et al, 2006; Wan et al, 2008; Sainju et al. 2018). 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 PCO_2 (Wan et al. 2008). We hypothesized that individuals with high trait self-control would tolerate the rebreathing challenge for longer, thereby reaching higher end tidal PCO_2, whilst rating lower air hunger intensity than low trait self-control individuals.

Although hypercapnia 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 (Banzett et al. 2015).

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 (Cory et al. 2015; Molgat-Seon et al. 2018; Ferentzi et al. 2021) and report greater symptom severity in clinical trials (Ekman et al. 2005; Katsura et al. 2007; Scoczynski et al. 2019). Sex moderates the effect of dispositional traits, such as anxiety on perceptions of pain (Keogh and Birkby, 1999; Jones, Zachariae & Arendt-Nielsen, 2002). Therefore, our secondary aim was to investigate whether sex moderated our hypotheses.

Methods

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 hours, and food and caffeine for 3 hours. 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.

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 possible 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 CO_2 rebreathing (Wan et al. 2006; Wan et al., 2008).

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 FEV_1/FVC ratio was <70%. Participants then completed a 6-minute rebreathing challenge. The CO_2 rebreathing challenge was a version of the standardised rebreathing test (Read, 1967) where 5 Litres of an oxygen-rich gas mixture (95% O_2, 5% CO_2) was breathed from a 6-litre reservoir (P3 Medical, Bristol, UK). Expired air was returned to the reservoir so that inspired CO_2 concentration increased over time, thereby increasing minute ventilation ($\dot{V}_E$). This method induces dyspnoea whilst preventing hypoxia (Wan et al, 2006; Wan et al. 2008). 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 CO_2 rebreathing challenge for as long as possible. The CO_2 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.

Self-report measures

Self-Control

To assess trait self-control, participants completed the 13-item brief self-control scale (BSCS, Tangney et al. 2004) (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 (Maloney, Grawitch, & Barber, 2012).

Dyspnoea measurements

Air Hunger Intensity

Before undertaking the CO_2 rebreathing challenge, a script, previously used by Wan et al. (2008), 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 (Gift, 1998; Isumizaki et al. 2011) 10-cm visual analogue scale (VAS). To conceal previous ratings a new scale was used on each occasion. Baseline (AH_{BASE}) and final air hunger (AH_{END}) 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 (AH_{SLOPE}) was calculated by calculating the unit change (cm) per second. This was done using the slope function in Microsoft Excel (Microsoft Office, 2016).

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; “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 (Banzett et al, 2011; Meek et al, 2012; Banzett et al. 2015).

Respiratory Variables

Ventilatory and pulmonary gas exchange variables were measured breath by breath using a metabolic cart (JAEGER™ Vyntus™ CPX incorporating SentrySuite CPET BxB software, Version 2.21.1; Vyaire Medical Products Ltd, Chineham, Basingstoke). Participants breathed through a mouthpiece connected to a low-resistance (<1.0 cm $H_2O \cdot L^{-1} \cdot s^{-1}$ at <15 $L \cdot s^{-1}$) 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 O_2 sensor based on an electrochemical principle, and a fast response digital CO_2 sensor based on the principle of infrared absorption. These were calibrated using ambient air and gases of known concentration (5% CO_2, 15% O_2, balance N_2; BOC, Guilford, UK). End-tidal partial pressure of CO_2 ($P_{ET}CO_2$) and $\dot{V}_E$ were reduced to 10 s averages. Baseline values were taken as the average during room air breathing ($P_{ET}CO_{2BASE}$, $\dot{V}_{EBASE}$). End-test values were taken as the average over the final ten seconds of rebreathing. As both $P_{ET}CO_2$ and $\dot{V}_E$ varied considerably between individuals, the absolute increase in these variables from baseline to the end of rebreathing ($\Delta P_{ET}CO_2$, $\Delta\dot{V}_E$) was calculated. The rate of change ($P_{ET}CO_{2\ SLOPE}$, $\dot{V}_{ESLOPE}$) was calculated as unit change per second after a linear trendline was fitted.

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, $P_{ET}CO_{2BASE}$, $P_{ET}CO_{2\ SLOPE}$, $\dot{V}_{EBASE}$, $\dot{V}_{ESLOPE}$, AH_{BASE}, AH_{END}, AH_{SLOPE}, 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 AH_{BASE} 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 (Blanca et al. 2017), 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 (Liao, Li & Brooks, 2016). 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 (η_p^2) and interpretated as small (0.01), medium (0.06) and large (0.14). For some analyses ($\Delta P_{ET}CO_2$, $\Delta\dot{V}_E$), 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.

Results

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).

Table 1. Participant characteristics

	SCHIGH Males	SCLOW Males	SCHIGH Females	SCLOW Females
Age (years)	**24 ± 5**	**22 ± 2**	**23 ± 2**	**22 ± 3**
Height (m)	**1.81 ± 0.07**	**1.80 ± 0.06**	**1.67 ± 0.07**$^{*\#}$	**1.62 ± 0.05**$^{*\#}$
Mass (kg)	**79 ± 7**	**80 ± 11**	**66 ± 11**$^{*\#}$	**61 ± 7**$^{*\#}$
BMI (kg/m^2)	**23.9 ± 1.9**	**24.7 ± 3.4**	**23.8 ± 3.6**	**23.2 ± 2.4**
Self-control (BSCS Score)	**52 ± 4**	**38 ± 4***†	**50 ± 4**	**36 ± 5***†
Exercise sessions per week	**4.59 ± 1.08**	**3.91 ± 1.27**	**3.38 ± 1.44***	**3.43 ± 1.53**

Notes: * denotes significant difference to SCHIGH Males (P < 0.05), † denotes significant difference to SCHIGH Females (P < 0.05), $^{\#}$ denotes significant difference to SCLOW Males (P < 0.05)

Challenge Duration

For challenge duration, there was a significant self-control*sex interaction (F (1, 62) = 6.743, P = 0.012, η_p^2 = 0.098). Follow up comparisons showed SCHIGH males (302 ± 42 s) tolerated the challenge for longer than SCLOW males (252 ± 66 s) (mean difference, 49s, 95%CI [8, 91 s], F (1, 62) = 5.651, P = 0.021, η_p^2 = 0.084). However, there was no difference in challenge duration between SCHIGH females (259 ± 62 s) and SCLOW females (287 ± 70s, mean difference, -28s, 95%CI [-71, 15 s], F (1, 61) = 1.723, P = 0.194, η_p^2 = 0.027). SCHIGH males also tolerated the challenge for longer than SCHIGH females (mean difference, 43s, 95%CI [1, 84 s], F (1, 62) = 4.199, P = 0.045, η_p^2 = 0.063). Challenge duration was not different between SCLOW males and SCLOW females (P = 0.108).

End Tidal CO_2 Responses

For $P_{ET}CO_{2BASE}$ 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, η_p^2 = 0.137) with males (36.64 ± 2.79 mmHg) having higher $P_{ET}CO_{2BASE}$ than females (34.23 ± 3.34 mmHg) (mean difference, 2.38 mmHg, 95%CI [0.86, 3.89 mmHg]).

$P_{ET}CO_2$ increased linearly throughout the rebreathing challenge. For $P_{ET}CO_{2SLOPE}$, 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 for $P_{ET}CO_{2SLOPE}$ (F (1, 62) = 17.632, P < 0.001, η_p^2 = 0.221), which was steeper in males (0.09 ± 0.01 $mmHg \cdot s^{-1}$), than females (0.08 ± 0.01 $mmHg \cdot s^{-1}$) (mean difference, 0.14 $mmHg \cdot s^{-1}$, 95%CI [0.07, 0.20 $mmHg \cdot s^{-1}$]).

As $P_{ET}CO_2$ increased quicker in males than females, separate independent samples t-tests for each sex were conducted for $\Delta P_{ET}CO_2$. $\Delta P_{ET}CO_2$ was greater in SCHIGH males than SCLOW males (mean difference, 3.80 mmHg, 95%CI [0.43, 7.17 mmHg], t (32) = 2.295, P = 0.028, d = 0.787) (*Fig.1*). $\Delta P_{ET}CO_2$ was not significantly different between SCHIGH females and SCLOW females (*P* = 0.590) (*Fig. 1*).

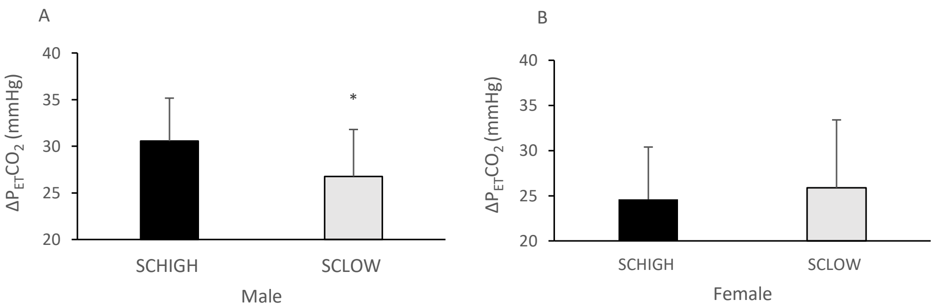

Fig. 1. $P_{ET}CO_2$ increase from baseline at the end of the rebreathing challenge in males (A) and females (B). *Different from SCHIGH group (P < 0.05). Values are mean ± standard deviation.

Ventilatory Response

For $\dot{V}_{EBASE}$, 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, η_p^2 = 0.083), with males (16.78 ± 5.29 $L \cdot min^{-1}$) having higher $\dot{V}_E$ at baseline than females (14.15 ± 3.54 $L \cdot min^{-1}$) (mean difference, 2.67 $L \cdot min^{-1}$, 95%CI [0.42, 4.93 $L \cdot min^{-1}$]).

$\dot{V}_E$ 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 $\dot{V}_{ESLOPE}$. There was a main effect of sex (*F* (1, 62) = 10.371, *P* = 0.002, η_p^2 = 0.143), with $\dot{V}_{ESLOPE}$ 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 $\dot{V}_E$ increased quicker in males than females, separate independent samples t-tests for each sex were conducted for $\Delta\dot{V}_E$. There was no significant difference between SCHIGH males and SCLOW males (*P* = 0.357), or SCHIGH females and SCLOW females (*P* = 0.095).

Dyspnoea

Air Hunger Intensity – Visual Analogue Scale (cm)

For AH_{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_{BASE} (*F* (1, 62) = 4.592, *P* = 0.036, η_p^2 = 0.069), with SCHIGH participants (0.27 ± 0.42 cm) rating lower AH_{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_{SLOPE} (*F* (1, 62) = 4.210, *P* = 0.044, η_p^2 = 0.064). Follow up comparisons showed that AH_{SLOPE} was lower in SCHIGH males (0.03 ± 0.01 $cm \cdot s^{-1}$) than in SCLOW males (0.04 ± 0.01 $cm \cdot s^{-1}$) (mean difference, - 0.01 $cm \cdot s^{-1}$, 95%CI [- 0.02, 0.00 cm] *P* = 0.045). There was no difference in AH_{SLOPE} between SCHIGH females (0.03 ± 0.02 $cm \cdot s^{-1}$) and SCLOW females (0.03 ± 0.01 $cm \cdot s^{-1}$, *P* = 0.385). There was also no difference in AH_{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_{END} (*F* (1, 59) = 7.347, *P* = 0.009, η_p^2 = 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_{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, η_p^2 = 0.141). There was no difference between SCHIGH males and SCHIGH females (*P* = 0.050, η_p^2 = 0.063), or SCLOW males and SCLOW females (*P* = 0.071, η_p^2 = 0.054).

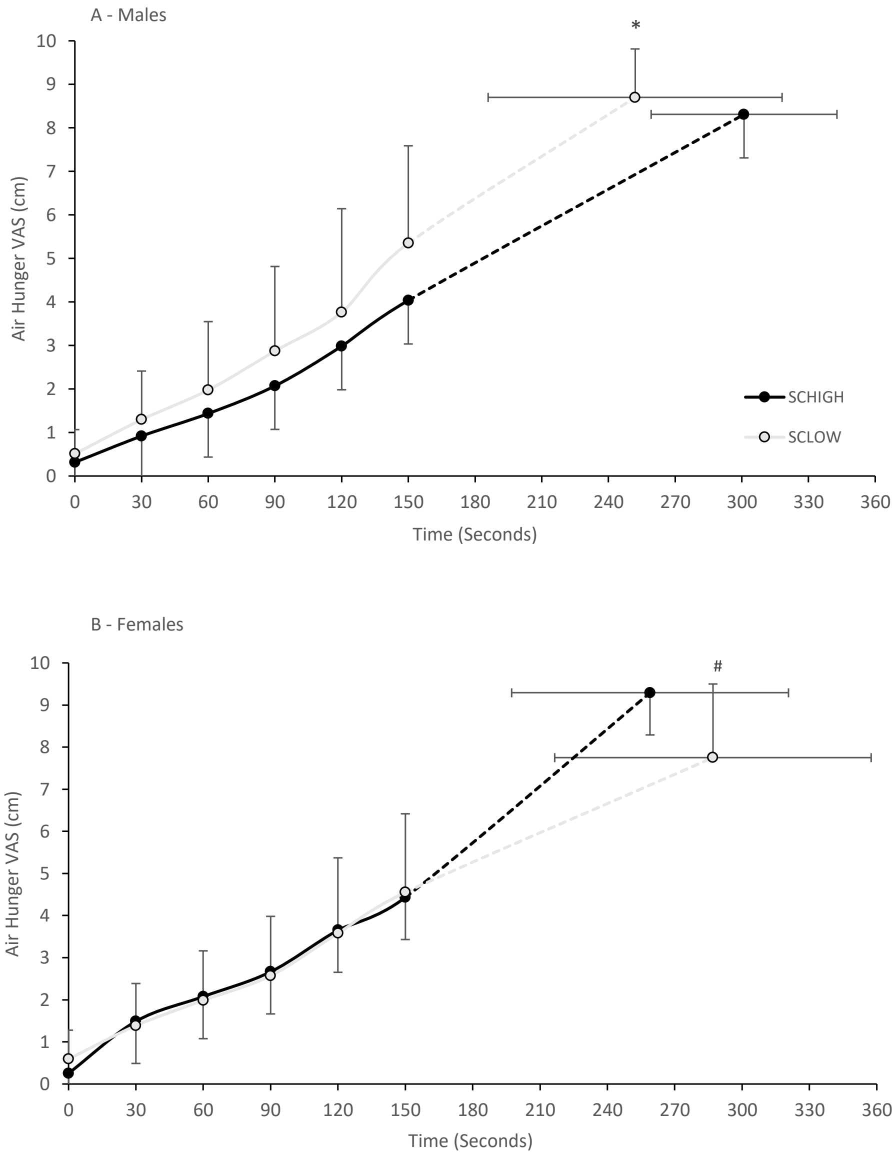

Fig 2. Air hunger (AH) responses over time in males (A) and females (B). All participants completed at least 150 seconds of the rebreathing challenge. Average AH values at each 30s interval were plotted until this time-point. The final plot displayed at the end of the dashed line represents the group average AH_{END} plotted against the average task duration for each group. * Denotes significant difference in challenge duration between SC groups of the same sex ($P < 0.05$). # Denotes significant difference in AH_{END} ratings between SC groups of the same sex ($P < 0.05$).

Multidimensional Dyspnoea Profile

Immediate Perception Score

There was a significant self-control*sex interaction for immediate perception score (*F* (1, 60) = 7.111, *P* = 0.010, η_p^2 = 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, η_p^2 = 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* = 0.036, η_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 SCLOW males 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 SCLOW males and SCLOW females at the level of each individual descriptor.

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).

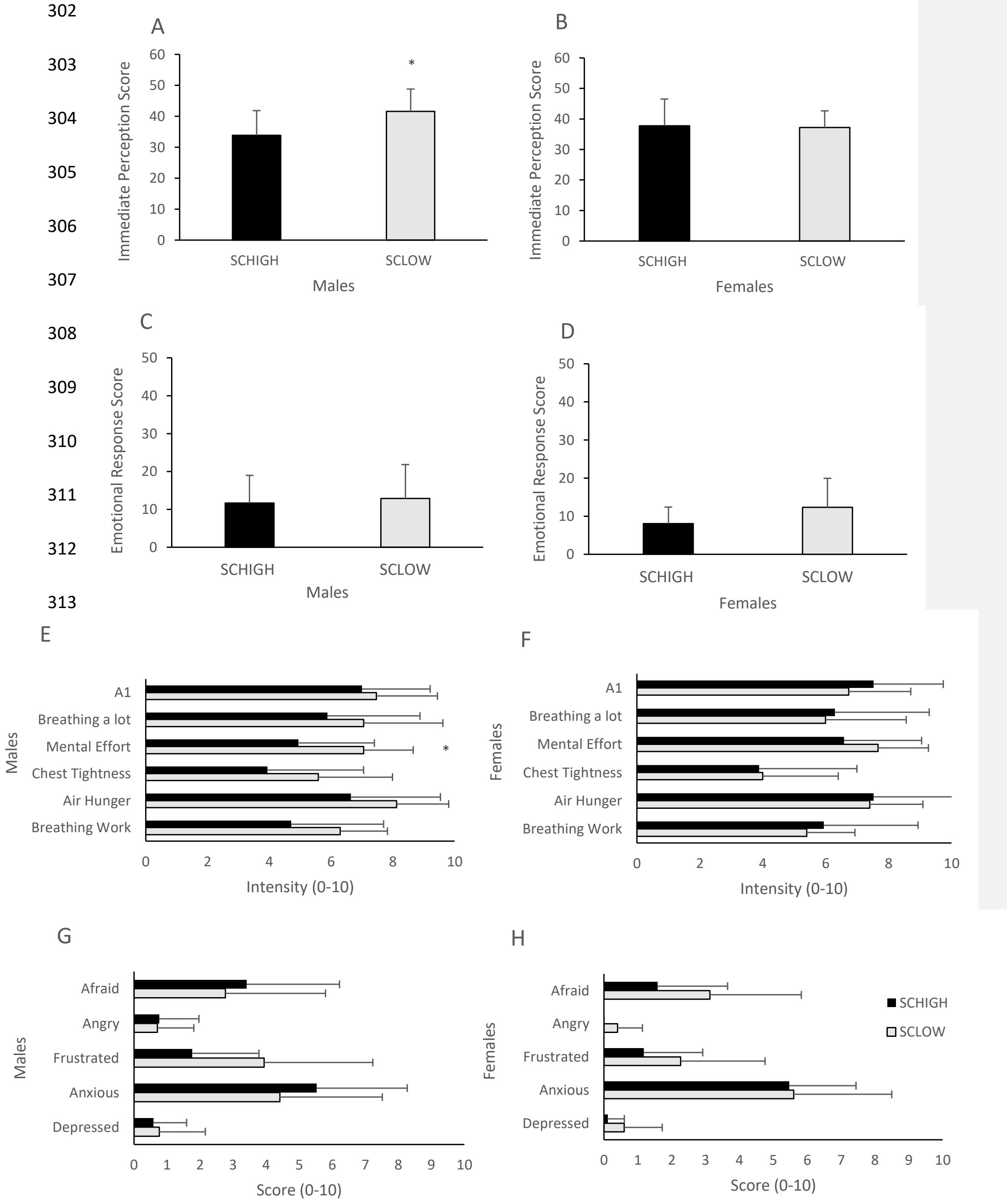
A
Immediate Perception Score
SCHIGH
SCLOW
Males
*
B
Immediate Perception Score
SCHIGH
SCLOW
Females
C
Emotional Response Score
SCHIGH
SCLOW
Males
D
Emotional Response Score
SCHIGH
SCLOW
Females
E
Males
A1
Breathing a lot
Mental Effort
Chest Tightness
Air Hunger
Breathing Work
Intensity (0-10)
F
Females
A1
Breathing a lot
Mental Effort
Chest Tightness
Air Hunger
Breathing Work
Intensity (0-10)
G
Males
Afraid
Angry
Frustrated
Anxious
Depressed
Score (0-10)
H
Females
Afraid
Angry
Frustrated
Anxious
Depressed
Score (0-10)
SCHIGH
SCLOW

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.

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 $P_{ET}CO_2$ concentration. There was no difference between SCHIGH and SCLOW females for challenge duration or for absolute increases in $P_{ET}CO_2$ 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 (Schmeichel & Zell, 2007; Goldberg et al, 2017; Wolff et al, 2019b). In a painful handgrip task, inferior task tolerance in low-self-control individuals was reflected by more rapid increases in ratings of perceived exertion (Wolff et al. 2019b). 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 (Taylor, Boat & Murphy, 2018). 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 (Inzlicht, Schmeichel and Macrae, 2014; Boat & Taylor, 2017).

Interestingly, Wolff et al. (2019b) 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 (O'Brien et al. 2020), 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 (de Ridder, Kroese & Gillebaart, 2018). Trait self-control has a strong effect on automatic behaviours and only a small-to-medium effect on behaviours requiring effortful control (de Ridder et al. 2012). 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 (Schmeichel & Zell, 2007; Wolff et al, 2019b; Ahm, Kim & Kwon, 2021). 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 (Jones et al, 2002; Thompson, Keogh & French, 2011; Speed et al. 2017). This effect may be due to trait anxiety being lower in males than females (Kaczkurkin et al. 2016). Females consistently score higher than males on measures of self-control, inferring a similar phenomenon when participants are grouped based on self-control (Chapple, Vaske & Hope, 2010; Gibson et al. 2010; Achtziger & Bayer, 2020). 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 supress sensations of pain, whilst females are expected to express sensations of pain (Rollman, 1995; Samulowitz et al. 2017; Walters & Williams, 2019).

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 (Ekstrom et al, 2017; Skoczyński et al. 2019). 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 (Harms, 2006; Schaeffer et al. 2014; Cory et al. 2015). In females, this places greater mechanical constraint on V_T expansion during submaximal exercise, leading to a more rapid, shallow breathing pattern and increased diaphragm activation at a given $\dot{V}_E$ (Schaeffer et al. 2014; Cory et al. 2015). The conscious awareness of a greater neural respiratory drive required to achieve a given $\dot{V}_E$ may therefore contribute to the higher ratings of exertional dyspnoea experienced by healthy, young females compared to males (Schaeffer et al. 2014). 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 (Schmeichel & Zell, 2007; Wolff et al, 2019b; Ahm, Kim & Kwon, 2021).

Self-control failure occurs when a proximal desire conflicts with a distal goal (Boat & Cooper, 2019). Individuals with high trait self-control adhere to exercise programmes and lose more weight than individuals with low self-control (Crescioni et al. 2011; Englert & Rummel, 2016; Finne et al. 2018). 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 (Biederman & Schefft, 1994; Ferrandis et al, 2017; Heydarian et al. 2018). 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 (Thomas, Decramer & O'Donnell, 2013; Gea et al, 2015; O'Donnell et al. 2020).

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 (Wan et al, 2006; Wan et al, 2008; Zhang et al, 2019; Powers et al. 2020). 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 CO_2 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.

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