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Effects of acute exercise on craving, mood and anxiety in non-treatment seeking adults with alcohol use disorder: An exploratory study

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ABSTRACT

Background: Exercise is increasingly being used in the treatment of alcohol use disorder (AUD). We examined the short-term effects of acute exercise on alcohol craving, mood states and state anxiety in physically inactive, non-treatment seeking adults with AUD.

Methods: Exploratory, single-arm study. In total, 140 adults with AUD (53.7 ± 11.8 years; 70 % female) were included in a randomized controlled trial (RCT) to study effects of physical activity on alcohol consumption. This acute exercise study was nested within the larger RCT. The intervention was a 12-minute sub-maximal fitness test performed on a cycle ergometer. Participants self-rated their desire for alcohol (DAQ) and completed mood (POMS-Brief) and state anxiety (STAI-Y1) questionnaires 30-minutes before exercise, immediately before, immediately after, and 30-minutes post. Ratings of perceived exertion (RPE) were collected. Effects of exercise were assessed using RM-ANOVA and dependent sample t-tests with effect sizes (Hedges *g*).

Results: In total, 70.6 % had mild or moderate AUD (DSM-5 criteria = 4.9 ± 2). The intervention was generally perceived as 'strenuous' (RPE = 16.1 ± 1.6). In the total sample, there was a main effect of time with reductions in alcohol craving [$F(3,411) = 27.33$, $p < 0.001$], mood disturbance [$F(3,411) = 53.44$, $p < 0.001$], and state anxiety [$F(3,411) = 3.83$, $p = 0.013$]. Between-group analyses indicated larger magnitude effects in those with severe compared to mild AUD, however, AUD severity did not significantly moderate the within-group improvements: group x time interaction for alcohol craving [$F(6,411) = 1.21$, $p = 0.305$]. Positive effects of exercise were maintained 30-minutes post-exercise.

Conclusion: A short bout of aerobic exercise reduced alcohol craving and improved mood states in adults with AUD.

1. Introduction

Alcohol use disorder (AUD) is associated with significant harms (Rehm and Shield, 2019), yet most people with AUD never seek professional support (Probst et al., 2015). Perceived stigma and dissatisfaction with conventional treatments are commonly cited reasons (Andreasson et al., 2013a). Physical activity is a non-stigmatizing intervention that could increase help-seeking and improve somatic and psychiatric health in those with AUD (Hallgren et al., 2017b). Several trials have evaluated the effects of structured exercise interventions for AUD (Giesen et al., 2016; Weinstock et al., 2020). Systematic reviews indicate that exercise-based interventions reduce depression and improve quality of life and somatic health (Gur and Gur, 2020; Hallgren et al., 2017a), but effects on drinking-related outcomes are less clear.

Craving for alcohol is considered a defining characteristic of AUD and related to the severity of alcohol dependence (Glautier and Drummond, 1994). Acute exercise could help to diminish alcohol cravings

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(Abrantes et al., 2013), while also reducing negative mood states that may 'trigger' drinking behavior (Greeley et al., 1992; Kushner et al., 2000) or increase the risk of relapse (Witkiewitz et al., 2011). Short bouts of moderate-intensity exercise could be undertaken when cravings for alcohol typically increase, for example, in the late afternoon or after work. Habitual drinking occasions could be substituted with brief exercise bouts that are healthy, mood enhancing and anxiolytic. When repeated, this pattern of behavior could potentially diminish the urge to drink, leading to lower consumption and fewer alcohol-related problems.

Two previous studies have examined the effects of acute exercise on alcohol craving and mood. In a cross-over trial, Ussher and colleagues randomized twenty men and women undergoing alcohol detoxification treatment to either 10-minutes of moderate intensity cycling (experimental) or 10-minutes of very light intensity cycling (control) (Ussher et al., 2004). Participants completed the Alcohol Urge Questionnaire before, during, immediately after, 5- and 10-minutes after exercise. Relative to baseline, there was a significant decline in alcohol urges in the experimental condition versus control, but only during exercise. Brown and colleagues explored the effects of acute exercise on craving, mood and anxiety over 12-weeks in 26 alcohol dependent outpatients (Brown et al., 2016). Improvements in mood and decreases in anxiety and craving were observed at every session. Over 12-weeks, the pre-post exercise changes in mood increased, anxiety remained stable, and craving diminished. These key studies indicate that short bouts of aerobic exercise have clinical utility, and could help to optimize treatment outcomes in adults with AUD.

Two key research questions remain unanswered. The first is whether these benefits are also seen in non-treatment seeking adults with AUD. These individuals comprise the majority of those with AUD (Andreasson et al., 2013a), and could also be appropriate targets for physical activity interventions (Hallgren et al., 2017b). Second, it is unclear whether AUD severity moderates the positive effects of acute exercise on these symptoms. Previous trials were small and included adults receiving (or recently discharged from) specialist's treatment, suggesting a high level of dependence. However, the majority (70–80 %) of adults with AUD have 'mild' dependence with only 2 or 3 diagnostic criteria fulfilled (Andreasson et al., 2013a). These individuals rarely seek treatment, but studies suggest they are interested in alternative treatment options (Andreasson et al., 2013b). These characteristics make non-treatment seeking adults with AUD an important population to investigate (Weinstock et al., 2020).

Within the context of a randomized controlled trial (RCT) (Hallgren et al., 2018), we conducted an exploratory study to assess the short-term effects of acute exercise on alcohol craving, mood states and state anxiety in non-treatment seeking adults with AUD. We focused primarily on changes within the total sample. A secondary aim was to identify potential differences in the response to exercise associated with AUD severity.

2. Material and methods

2.1. Study design

We conducted a single-arm trial that included four sequential assessments of alcohol craving, mood states and state anxiety. The assessments were taken 30 min before exercise ('baseline'), immediately before ('pre-exercise'), immediately after ('post-exercise'), and 30 min after exercise ('30-minutes'). With few exceptions (Ussher et al., 2004), previous acute exercise studies have included only two assessments taken immediately before and immediately after exercise. To assess how the timing of the pre-exercise assessment impacts pre- to post-exercise effect sizes, we included *two* pre-exercise assessments. We chose to compare pre-exercise levels to post exercise levels of the dependent variable, as has been tested in other studies (Brown et al., 2016; Ussher et al., 2004). Extending previous work, we included a follow-up assessment to determine whether the post-exercise changes persisted.

2.2. Participants

Between April 2018 and August 2019, advertisements were placed in a newspaper ('Mitt-i') distributed every Tuesday throughout Stockholm. The advertisement targeted adults aged 18–75 years who felt they 'exercised too little and drank a bit too much'. To avoid overlap with vacation periods, the ads were placed once in early March and again in August, allowing enough time for consecutive recruitment, enrolment, and follow-up (after 12-weeks) of 30–35 eligible participants. The neutral tone of the advertisement resulted in 150–200 enquiries (per advertisement). These were telephone screened (20−30 minute) by a research assistant to explain the purpose of the trial and determine eligibility. Full details of the RCT, including study aims, recruitment method and eligibility criteria are available in the published protocol (Hallgren et al., 2018). Briefly, the purpose of the RCT was to compare the effects of three 12-week interventions: aerobic exercise, yoga, and treatment as usual for AUD.

2.2.1. Inclusion and exclusion criteria

Potential participants were telephone screened (20−30 min). All participants were physically inactive (<150 min of moderate-to-vigorous physical activity/week), had no injuries or contraindications for engaging in exercise, and fulfilled the Diagnostic and Statistical Manual of Mental Disorders (DSM-5) criteria for AUD (that is, they scored positively on two or more items). In total, 140 eligible participants were enrolled. Those currently receiving treatment for AUD (specialist or non-specialist, e.g., general medical practitioner) were also excluded. Those indicating (at phone screening) the current use of any illicit drugs were also excluded. Findings from the RCT, including changes in alcohol consumption, will be reported in forthcoming papers.

2.3. Procedure

Eligible participants were invited to attend a baseline assessment within 1–3 weeks of the initial phone screening. Participants were advised to come hydrated and prepared to do a short bout of moderate-to-vigorous exercise. The purpose of this face-to-face assessment was two-fold: (1) to confirm trial eligibility as circumstances may have changed between the initial screening and the baseline assessment, and (2) perform a comprehensive baseline assessment consisting of: a submaximal cardiorespiratory fitness (CRF) test (see Intervention), multiple questionnaires (see Measures), and anthropometric assessments to calculate body mass index (BMI), blood pressure and resting heart rate. After explaining the purpose of the RCT, including potential risks (e.g. injury from exercise), written, informed consent was obtained and the baseline questionnaires were completed. Participants then completed the baseline CRF test, described below. Participants sat quietly in the testing room throughout the procedure. Interaction with the researcher was minimized during completion of the questionnaires. The procedure is illustrated in Fig. 1.

2.4. Measures

Socio-demographic information (age, sex, education, employment status) was collected during the baseline interview. Smoking status (cigarettes and smokeless tobacco) and living arrangements (lives alone, with partner, other) were also briefly assessed by interview. Average weekly physical activity levels were assessed by asking participants: During the past three months, how many times per week did you typically exercise? Examples of structured exercise were given which included brisk walking. If the person indicated having exercised, we then asked: how long was a typical exercise session? Those who exercised ≥ twice per week on average during the past three months (or ≥ 150 min per week) were excluded.

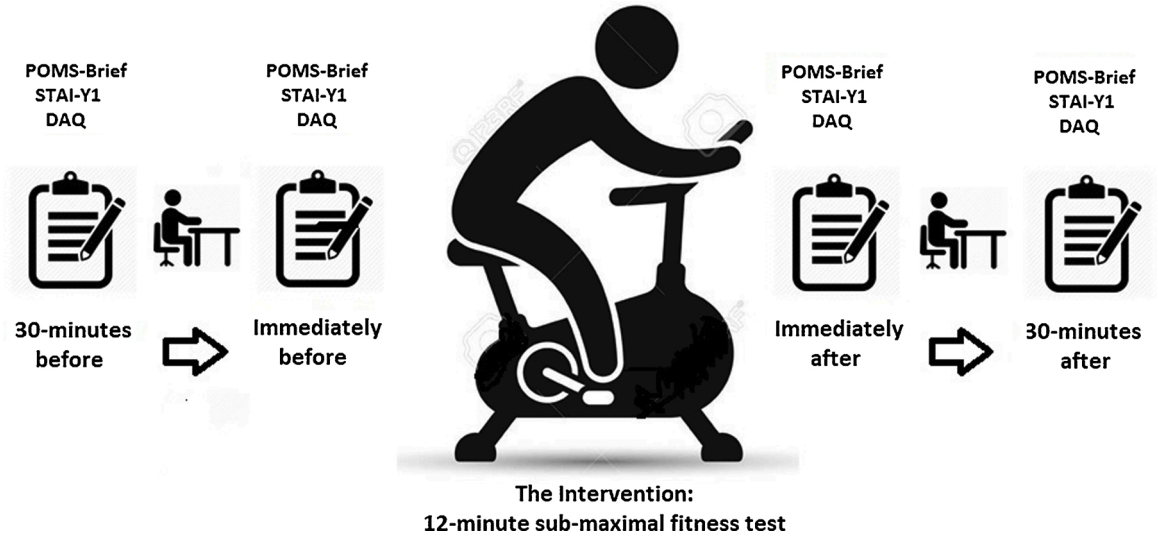

Fig. 1. Procedure for the acute exercise study.
Explanation: Participants completed a 12-minute sub-maximal cardiorespiratory fitness test on a Monarch cycle ergometer located in a quiet, well ventilated room. After explaining the procedure and obtaining informed consent, the participant's height, weight and waist-circumference were taken. Three identical questionnaires were completed on four separate occasions, as shown: The Profile of Mood States questionnaire (POMS-Brief), the State-Trait Anxiety Inventory (STAI-Y1) and the Desire for Alcohol Questionnaire (DAQ-short). Apart from the exercise test, participants sat quietly at a desk while completing the surveys, and again for 30 min between the first two and last two surveys, respectively. Drinking water was offered to all participants after the exercise test.

2.4.1. *Primary study outcomes*

To assess the effects of exercise on alcohol craving, mood states and state anxiety, the following three measures were included at all four time points:

2.4.1.1. Craving for alcohol. This was assessed using the validated eight-item version of the Desire for Alcohol Questionnaire (DAQ), Swedish version (Khemiri et al., 2017). All items are scored on a 7-point Likert scale, with higher scores indicting greater craving for alcohol. The DAQ includes four sub-scales: Desire to Drink, Negative Reinforcement, Positive Reinforcement, and Loss of Control (over drinking). The questionnaire has acceptable psychometric properties, and the short version was designed to assess changing in craving measured in experimental studies (Khemiri et al., 2017).

2.4.1.2. Mood disturbance. This was assessed using the 30-item Profile of Mood States questionnaire (POMS-Brief) (McNair et al., 1971). The POMS is a self-report inventory that has been used extensively to assess the acute effects of exercise on mood (Biddle et al., 2000; Herring et al., 2017; Hoffman and Hoffman, 2008). The questionnaire measures six dimensions of mood on a 5-point Likert scale. A total mood disturbance (TMD) index is derived by subtracting the Vigor-Activity score from the sum of the other five sub-scales (Tension-Anxiety, Depression-Dejection, Anger-Hostility, Fatigue-Inertia, and Confusion-Bewilderment). Higher scores on the POMS total and subscale scores indicate more negative mood states (except on the Vigor-Activity scale, where higher scores indicate stronger feelings of vigor).

2.4.1.3. State anxiety. This was assessed using the 20-item state subscale from the State-Trait Anxiety Inventory (STAI-Y1) (Speilberger et al., 1983). Participants indicate the extent to which each item describes them at that particular moment. Each item is scored on a 4-point Likert scale and provides an operational measure of anxiety at a particular moment. Higher scores indicate higher levels of anxiety. The STAI has been used extensively in previous acute exercise studies (Ensari et al., 2015).

2.5. *Intervention*

A sub-maximal exercise test was used to determine baseline CRF levels for the RCT (Bjorkman et al., 2016). The test also functioned as the exercise intervention for the acute exercise study. Assessments were performed in a laboratory-like environment with a normal ambient climate. After standard adjustment of the seat and handlebars, Borg's Rating of Perceived Exertion (RPE) scale was introduced to the participants (Borg et al., 1985). The RPE is a visually presented, single item scale, ranging from 6 (not strenuous at all) to 20 (maximally strenuous) that enables participants to rate how strenuous they perceive the exercise session to be at any moment. Participants then cycled on a calibrated mechanically braked cycle ergometer (model 828E, Monark, Varberg, Sweden) for a total of 12 min without stopping between increments. Pedal frequency throughout the test was 60 rpm. Cycling resistance started at 0.5 kilopond (kp) (equal to a rate of work of 32 W, where 1 W = 6.116 kpm/min and allowing for a 10 % efficiency loss in the drivetrain). After four minutes, the cycling resistance was increased to a higher work rate. This was individually determined to obtain an RPE of 14–16 (somewhat strenuous to strenuous). Participants continued cycling (without stopping) at the higher work rate for 4 min, with a 1-minute transition period between the lower and higher work rates (9 min in total). These two continuous cycling bouts were used to estimate VO_2max using heart rate (HR) data collected continuously during the test by relating the increase in heart rate to the increase in work rate. For the purpose of the acute exercise study, we extended the cycling session to 12-minutes (that is, 3 min past the end of the CRF test), as previous research suggests that acute exercise sessions may need to exceed 10 min to have significant effects on alcohol craving (Ussher et al., 2004). During the last 3 min, participants continued cycling at the same (higher) rate. Participants were offered drinking water about 30 min before the test, and again immediately after the exercise session. Details of the calculation used to estimate CRF are available as Supplementary material.

2.6. *Statistical analyses*

Descriptive data were calculated for all participant characteristics and the three main study outcomes at baseline. Means and standard

deviations were calculated for the primary study outcomes (alcohol craving, mood, state anxiety) measured at each time point (baseline, pre-exercise, post-exercise, 30-minutes post). Effects of the exercise intervention were assessed in two ways. First, we conducted repeated measures analysis of variance (RM-ANOVA) to determine the main effect of time (four time points included), group (AUD severity: mild, moderate, severe), and the group x time interaction (i.e., potential moderating effects). These analyses are complemented by group contrasts to determine the effect of AUD severity on the within group change over time. We calculated the mean group difference (mild versus severe, etc.) and the associated *p*-value and effect size (Hedges *g*), where: 0.2 = small, 0.5 = medium and 0.8 = large effect). Second, we conducted dependent samples t-tests with Bonferroni corrections to determine the magnitude of the within group change on each outcome. For these analyses, pre-exercise was used as the reference. The normality assumption was not violated for the primary study outcomes (Shapiro-Wilks test), and residuals were normally distributed (assessed using Q-Q plots). Where the assumption of sphericity was violated a Huynh-Feldt correction was used to adjust degrees of freedom and estimate *p*-value for RM-ANOVA. To explore potential sex differences, analyses were stratified by sex using the total sample only. Total and sub-scale scores were analyzed; however, given the exploratory nature of the study, we focus primarily on changes in the total scale scores. Missing data were minimal (<1 %). All data were analyzed using SPSS version 25 and STATA version 14.

Table 1
Participant characteristics.

Sex (Female); n (%)	98 (70)
Age; mean (SD), range	53.7 (11.8); 21–75
Highest Education; n (%)	
Primary	3 (2.1)
Secondary	40 (28.6)
Tertiary	97 (69.3)
Employment status; n (%)	
Employed	109 (77.9)
Pensioner	24 (17.1)
Studying	5 (3.6)
Unemployed	3 (2.1)
Other	6 (4.2)
Living arrangement; n (%)	
With partner	80 (57.1)
Alone	42 (30)
Other	31 (22.1)
Smoker (current); n (%)	14 (10)
Other tobacco ('snus'); n (%)	31 (22.1)
Body Mass Index (BMI); mean (SD)	27.8 (5.0)
BMI category; n (%)	
Obese (≥30)	44 (31.4)
Overweight (25–29.9)	55 (39.3)
Normal (18.5–24.9)	41 (29.3)
Cardiorespiratory fitness (ml/kg/min); mean (SD)	31.1 (6.3); 18.2–50.8
AUD severity (DSM5 criteria); mean (SD); range	4.9 (2.0); 2–11
AUD severity category; n (%)	
Mild (2–3)	41 (29.4)
Moderate (4–5)	53 (37.8)
Severe (≥6)	46 (32.8)
Alcohol craving (DAQ Total); mean (SD); range	20.8 (10.2); 8–47
Mood disturbance (POMS-TMD); mean (SD); range	21.3 (22.4); -18–89
State Anxiety (STAI-Y1); mean (SD); range	45.1 (3.6); 29–53

Notes:
Other employment includes: sickness benefit, disability support, income support, other (e.g. savings, inheretance).
Categories for employed exceed 100 % as some people selected more than one.
Other living arrangements include: with parents, with a child.
Snus is a form of chewable tobacco that is sold legally in Sweden.

3. Results

3.1. Participant characteristics

Participant characteristics are shown in Table 1. In total, 70 % were females (mean age = 53.7 years; SD = 11.8; range = 21–75 years). The majority (69.3 %) were tertiary educated, employed (77.9 %), and living with their partner (57.1 %). The proportion with mild, moderate, and severe AUD was 29.4 %, 37.8 % and 32.8 %, respectively (mean number of DSM-5 criteria = 4.9 (SD = 2.0; range = 2–11). Ten percent were current cigarette smokers and 22 % used smokeless tobacco. Combined overweight and obesity was higher (70.7 %) than in the general Swedish population (~50 %) (Marques et al., 2018). Consistent with previous studies, CRF was below the general population average (mean = 31.1, SD = 6.3; range = 18.2–50.8) (Ekblom-Bak et al., 2019).

3.1.1. Baseline differences in AUD severity

There were more males in the severe AUD group (37 %) compared to the moderate (24.5 %) and mild AUD groups (29.3 %), respectively ($p < 0.01$). Both cigarette smoking and other tobacco use ('snus') were more prevalent in those with severe AUD (19.6 %, 23.9 %), compared to mild AUD (9.8 %; 14.6 %; all *p*-values <0.01). Mood disturbance (POMS-TMD) was higher in severe AUD (mean = 28.7), compared to moderate AUD (mean = 19.9), and mild AUD (mean = 14.7) ($p < 0.001$). State anxiety, BMI and CRF did not differ significantly between AUD groups.

3.2. Exercise intensity

During the last minute (11–12) of the exercise intervention, most participants rated the exercise as 'somewhat strenuous' or 'strenuous' (Borg RPE mean = 16.2; SD = 1.6). Mean heart rate (HR) during the last minute of exercise was 131 beats/minute (SD = 16.3; range = 92–175). There were no differences in mean RPE or HR between those with mild, moderate, and severe AUD.

3.3. Changes in alcohol craving, mood disturbance, and state anxiety

Means and standard deviations for the three study outcomes measured at four time points are shown in Table 2. To illustrate the changes visually, mean scores for the total sample and stratified by AUD group are presented in Fig. 2. Group x time interaction effects are shown in Table 3. Adjusted within group comparisons (pre-exercise as reference) are shown in Table 4.

Table 2
Means and standard deviations on the primary study outcomes.

Outcome	Baseline	Pre-exercise	Post-exercise	30-minutes
Alcohol craving (DAQ)				
Desire to drink	5.1 (3.7)	4.8 (3.4)	3.8 (2.9)	4.1 (3.1)
Negative reinforcement	5.0 (3.1)	4.7 (3.1)	3.6 (2.6)	4.0 (2.9)
Positive reinforcement	4.5 (3.3)	4.3 (3.1)	3.4 (2.3)	3.9 (2.9)
Ability to control drinking	6.2 (3.8)	5.6 (3.8)	5.0 (3.6)	5.1 (3.9)
Total	20.9 (10.2)	19.4 (9.7)	15.8 (8.4)	17.2 (9.7)
Mood (POMS)				
Tension-anxiety	5.4 (4.1)	3.9 (3.7)	3.0 (3.2)	2.6 (3.1)
Depression	5.4 (4.7)	4.1 (4.3)	2.8 (3.4)	2.7 (3.4)
Anger-hostility	3.1 (4.1)	1.9 (3.2)	1.1 (2.1)	1.1 (2.2)
Fatigue	8.8 (5.1)	7.5 (5.2)	6.1 (4.7)	5.7 (4.8)
Confusion	6.4 (4.3)	5.4 (3.8)	4.4 (3.2)	4.5 (3.3)
Vigor	7.8 (4.5)	7.9 (4.9)	9.6 (4.5)	9.1 (4.4)
Total (TMD)	21.3 (22.5)	14.9 (20.3)	7.8 (16.9)	7.5 (17.2)
State anxiety (STAI-Y1)	45.1 (3.6)	44.8 (3.9)	44.3 (4.2)	44.2 (3.5)

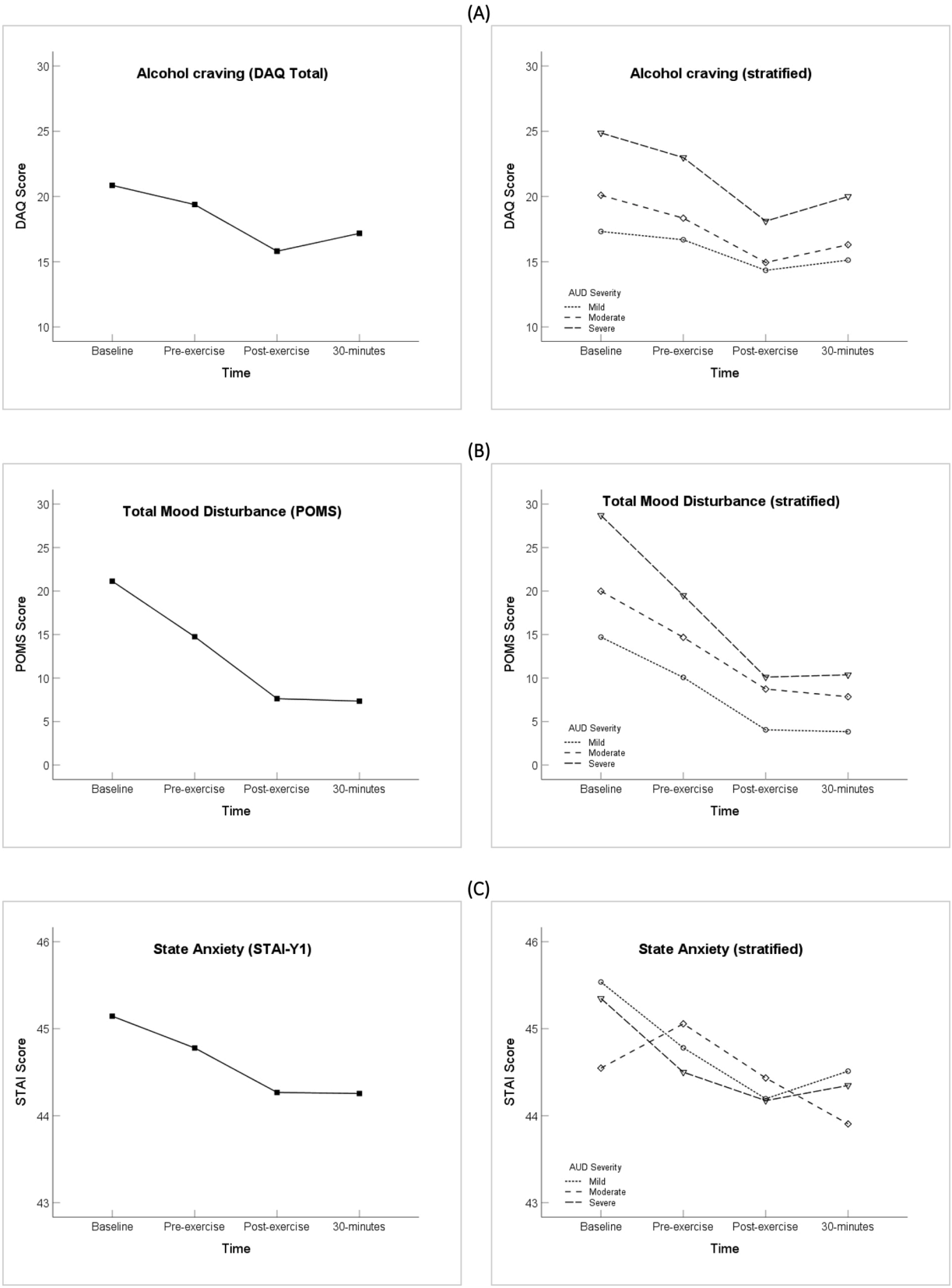

Fig. 2. Changes in alcohol craving (A), mood disturbance (B) and state anxiety (C). Totals and stratified by AUD severity (mild n = 41, moderate n = 53 and severe n = 46). Means are shown in all figures.

Table 3
Group by time interaction effects and AUD group contrasts.

Outcome	RM-ANOVA						Group contrasts								
	Time		Group		Group x Time		Mild vs Moderate			Mild vs Severe			Moderate vs Severe		
	F (3, 411)	*p*	F (2, 137)	*p*	F (6, 411)	*p*	Mean Difference	*p*	*g*	Mean Difference	*p*	*g*	Mean Difference	*p*	*g*
Alcohol craving (DAQ)															
Desire to drink	15,40	< 0.001	0,68	0,509	0,88	0,488	0,01	1,000	0,00	0,61	1,000	0,17	0,62	0,894	0,19
Negative reinforcement	25,50	< 0.001	3,67	0,028	2,14	0,069	0,13	1,000	0,05	1,32	0,054	0,42	1,18	0,069	0,40
Positive reinforcement	12,00	< 0.001	2,28	0,106	1,38	0,239	0,00	1,000	0,20	0,97	0,227	0,31	0,96	0,176	0,33
Ability to control drinking	8,07	< 0.001	9,18	< 0.001	0,89	0,494	1,43	0,092	0,40	2,73	< 0.001	0,77	1,30	0,125	0,34
Total	27,33	< 0.001	5,58	0,005	1,21	0,305	1,55	1,000	0,17	5,62	0,005	0,58	4,07	0,045	0,43
Mood (POMS)															
Tension-anxiety	41,97	< 0.001	2,63	0,076	1,26	0,286	0,47	1,000	0,13	1,40	0,082	0,37	0,94	0,346	0,25
Depression	52,64	< 0.001	2,22	0,112	2,38	0,054	0,88	0,703	0,23	1,60	0,111	0,38	0,72	0,939	0,17
Anger-hostility	35,42	< 0.001	1,49	0,229	2,20	0,079	0,06	1,000	0,02	0,74	0,513	0,22	0,81	0,340	0,25
Fatigue	42,44	< 0.001	1,25	0,290	1,44	0,218	1,01	0,823	0,20	1,47	0,369	0,29	0,46	1,000	0,09
Confusion	31,19	< 0.001	3,61	0,030	0,59	0,653	1,10	0,289	0,33	1,82	0,025	0,49	0,72	0,792	0,18
Vigor	18,13	< 0.001	2,65	0,074	0,93	0,460	1,26	0,407	0,28	1,97	0,072	0,43	0,72	1,000	0,15
Total (TMD)	53,44	< 0.001	3,12	0,047	1,63	0,174	4,65	0,555	0,25	9,00	0,041	0,44	4,36	0,599	0,21
State anxiety (STAI-Y1)	3,83	0,013	0,09	0,915	0,98	0,435	0,27	1,000	0,07	0,16	1,000	0,05	0,11	1,000	0,03

Notes: Main effect of time (baseline, pre-exercise, post-exercise, 30-minutes post); Main effect of AUD group (mild, moderate, severe: based on number of DSM criteria fulfilled); Group x time interaction (moderating effect of AUD severity across time); Hedges *g* effect sizes are shown.

3.3.1. Alcohol craving

Alcohol craving (DAQ total) reduced from pre-exercise (reference) to post-exercise ($p < 0.001$, $g = 0.53$), and 30-minutes ($p < 0.001$, $g = 0.33$), with small to moderate effect sizes. Similar magnitude improvements were obtained on all DAQ subscales (Table 4: Desire to drink, Negative reinforcement, and Positive reinforcement), except the Ability to control drinking, where the change at 30-minutes was not statistically significant ($p = 0.060$, $g = 0.16$). Results from RM-ANOVA showed a main effect of time [F(3,411) = 27.33, p=<0.001] and AUD group [F (2,137) = 5.58, $p = 0.005$] but the group x time interaction was not statistically significant. Group contrasts revealed that the reduction in alcohol craving over time was larger among those with severe AUD compared to mild AUD (MD=5.62, $p = 0.005$, $g = 0.58$).

Table 4
Within group changes in alcohol craving, mood state, and state anxiety.

Outcome	Pre to Post-exercise			Pre-exercise to 30-minutes		
	t (139)	*p*	*g*	*t* (139)	*p*	*g*
Alcohol craving (DAQ)						
Desire to drink	4,25	< 0.001	0,36	3,08	0,003	0,26
Negative reinforcement	5,95	< 0.001	0,50	3,93	< 0.001	0,33
Positive reinforcement	4,33	< 0.001	0,37	1,91	0,060	0,16
Ability to control drinking	2,47	0,015	0,21	1,90	0,060	0,16
Total	6,22	< 0.001	0,53	3,95	< 0.001	0,33
Mood (POMS)						
Tension-anxiety	3,67	< 0.001	0,31	5,50	< 0.001	0,47
Depression	5,77	< 0.001	0,49	6,08	< 0.001	0,51
Anger-hostility	4,82	< 0.001	0,41	4,82	< 0.001	0,41
Fatigue	5,00	< 0.001	0,42	7,00	< 0.001	0,59
Confusion	5,02	< 0.001	0,42	4,53	< 0.001	0,38
Vigor	6,22	< 0.001	0,53	4,52	< 0.001	0,38
Total (TMD)	6,80	< 0.001	0,57	7,34	< 0.001	0,62
State anxiety (STAI-Y1)	1,59	0,115	0,13	1,96	0,052	0,17

3.3.2. Mood disturbance

Mood disturbance (POMS-TMD) reduced from pre-exercise (reference) to post-exercise ($p < 0.001$, $d = 0.57$), and 30-minutes ($p < 0.001$, $d = 0.62$), with small to moderate effect sizes. Similar magnitude changes were obtained on all six POMS subscales (Table 2: Tension-anxiety, Depression, Anger-hostility, Fatigue, Confusion, and Vigor). These improvements were statistically significant at both time-points (all p-values <0.001). Results from RM-ANOVA showed a main effect of time [F(3,411) = 53.44, p=<0.001] and AUD group [F(2,137) = 3.12, $p = 0.047$] but the group x time interaction was not statistically significant. Group contrasts revealed that the reduction in mood disturbance over time was larger among those with severe AUD compared to mild AUD (MD=9.00, $p = 0.041$, $g = 0.44$).

3.3.3. State anxiety

State anxiety reduced from pre-exercise to 30-minutes only ($p = 0.052$, $d = 0.17$). Results from RM-ANOVA showed a significant main effect of time [F(3,411) = 3.83, $p = 0.013$], but the main effect of group was not statistically significant.

3.3.4. Sex differences

Results were materially the same for men and women (data not shown). Due to the low number of male participants, sex-differences within each level of AUD severity were not examined.

3.3.5. Supplementary analyses

Additional within-group analyses were performed stratified by AUD group (Supplementary Tables 1–3). These analyses were repeated using the baseline assessment as the reference for all post-hoc contrasts; changes over time are comparable to the main analyses but with marginally larger effect sizes (Supplementary Tables 4–6). Separately, we also examined within group changes from baseline to pre-exercise only. In the total sample, scores on the POMS-TMD reduced significantly ($t = 4.61(139)$, $p < 0.01$), but changes in craving and state anxiety between these two points were not statistically significant. To determine whether the pre-exercise levels of the dependent variables (alcohol craving, state anxiety and mood) were meaningfully related to participant's baseline drinking behavior, we ran a series of bivariate (Pearson) correlations using drinking frequency and quantity (the first two items of the AUDIT questionnaire) and the number of DSM-5 criteria fulfilled.

Pre-exercise alcohol craving was significantly correlated with the number of DSM-5 criteria ($r = .31$, $p < 0.001$), and the quantity of alcohol consumed ($r = .19$, $p = 0.021$). The association between pre-exercise mood (POMS-TMD) correlated significantly with the number of DSM-5 criteria fulfilled ($r = .27$, $p < 0.01$). The correlation between state anxiety and the quantity of alcohol consumed approached significance ($r = .14$, $p = 0.53$).

4. Discussion

This is the first trial to explore the effects of acute exercise on alcohol craving, mood state, and state anxiety in physically inactive, non-treatment seeking adults with AUD. The recruitment strategy was successful with 150–200 people responding to each advertisement, indicating a high level of interest in the exercise intervention. Findings indicate that a short (12-minute) bout of aerobic exercise may reduce cravings for alcohol in those with AUD; relative to mild AUD, the largest magnitude effects were observed in those with severe AUD. Across all levels of AUD severity, mood states improved following exercise, with the largest effects seen in those with moderate and severe AUD. Notably, in the total sample, the magnitude of exercise effects on craving ($d = 0.53$) and mood disturbance ($d = 0.57$) were potentially clinically meaningful based on a minimally important difference of 0.5 standard deviation units (Norman et al., 2003). As shown in Table 4, reduced craving were largely driven by potentially meaningful changes in negative reinforcement, while improved mood disturbance was largely driven by improved feelings of depressed mood and energy. Reduced craving and improved mood disturbance persisted 30-minutes post-exercise, suggesting that the benefits of acute exercise on these clinically relevant outcomes are not transitory (that is, disappearing immediately after exercise cessation). There were indications that acute exercise may lower state anxiety in some individuals, but most changes were not statistically significant. The lack of significant reductions in state anxiety were plausibly influenced by relatively favourable baseline state anxiety. Interaction tests revealed that AUD severity did not significantly moderate the positive effects of acute exercise on craving, mood state and state anxiety over time; all groups improved. However, there were indications that adults with severe AUD could benefit more than those with mild AUD. Lastly, these findings suggest that the timing of pre-exercise assessments of craving and mood states can have a marginal impact on pre- to post-exercise effect sizes. Small magnitude reductions in mood disturbance (POMS-TMD) between baseline and pre-exercise may have occurred as participants 'settled' into the novel testing environment.

These results extend two previous acute exercise studies. One trial (n = 20) involving men and women undergoing alcohol detoxification at a psychiatric hospital, compared 10-minutes of moderate cycling with 10-minutes of light cycling, and found a significant reduction in craving during but not immediately after exercise (Ussher et al., 2004). Another trial (n = 26) explored pre to post-exercise changes over 12-weeks and found consistent reductions in craving and improvements in mood and anxiety (Brown et al., 2016). Similar to the current study, effect size estimates were small to medium with some sessions reaching the large range. While important, both studies were limited by small samples, making investigation of exercise effects within different levels of AUD severity impossible.

Our findings have potential treatment implications. First, they suggest that even short bouts of aerobic exercise may help to reduce alcohol craving, including among those with moderate AUD; a population known to rarely seek treatment (Andreasson et al., 2013b). A strategy that could be used in clinical settings, therefore, is to recommend that patients exercise when alcohol cravings increase. This approach could temporarily diminish the 'urge' to drink alcohol and act as a distraction from salient alcohol-related cues (e.g., drinking establishments) that may otherwise be difficult to avoid. Second, previous research indicates that negative moods, including subjective feelings of tension, sadness and irritability, often precipitate heavy drinking occasions (Armeli et al., 2008). Individuals with AUD could be taught to recognize these symptoms, and to use exercise as a preventative or ameliorative self-treatment strategy. A practical method for clinicians without training in exercise prescription could be to recommend brisk walking of 10−15 min duration when craving increases, or when mood states worsen noticeably. Brisk walking is typically perceived as 'moderately intense' by physically inactive adults, and is feasible for most people, including those with mood disorders (Robertson et al., 2012).

Identifying physically inactive adults with mood-related symptoms could be a viable way to increase treatment rates. We have previously shown that the prevalence of depression is higher in those with AUD compared to the general population (Ahlin et al., 2015). In the current study, total mood disturbance scores were higher in severe AUD, compared to mild and moderate AUD. It has also been shown that physical activity levels are lower in adults with AUD compared to age-gender matched controls (Vancampfort et al., 2019). A recent experimental study involving young adults showed that those with AUD and comorbid mood symptoms were more likely to seek treatment for their 'emotional problems' compared to those with AUD alone (Capron et al., 2018). Thus, it might be possible to identify a proportion of non-treatment seeking adults with AUD by focusing initial attention on physical activity levels and mood-related symptoms, rather than alcohol consumption *per se*. This approach could be particularly effective in general health care settings, where people with mild AUD often present with comorbid symptoms. This idea relates to behavioral activation; a therapeutic strategy used to treat depression by scheduling behaviors that encourage positive reinforcement (Ekers et al., 2014). In the presence of negative affect, short-term exercise might function as a coping mechanism to relieve negative mood states though distraction, goal attainment, and (potentially) reinforcing social contacts that do not involve alcohol consumption. Beyond behavioral activation, acute exercise has known cognitive, neurophysiological, and neurochemical effects that could reduce the urge to drink and improve mood states synergistically (Basso and Suzuki, 2017; Hallgren et al., 2017b). Studies show that exercise can affect the mesolimbic and dopaminergic systems, which play a central role in the aetiology of substance use disorders, including AUD (Robison et al., 2018). These mechanisms require further investigation in human trials of acute exercise.

Strengths of the study include the large participant sample, which enabled stratification of these data by AUD severity. The assessment of change over four time-points is another notable strength, as it enabled change in symptoms over time to be observed, particularly during the largely unstudied pre-exercise time period. Previous studies have focused predominantly on immediately-pre exercise to post-exercise changes; mostly in adults with severe AUD. Some limitations are also acknowledged. This is a single-arm intervention study without a control group; consequently, we have been cautious in drawing conclusions about the 'effects' of exercise in this context. A cross-over trial, where participants act as their own controls, would be a stronger study design. Due to the length of the baseline RCT assessment (2.5−3 hours), which included the current nested exercise trial, it was not feasible to invite participants to return for additional baseline assessments; most were employed with work, family, and other commitments. The intervention used was a physical fitness test performed on a cycle ergometer. While cycling is a popular form of exercise, in most leisure contexts, it would rarely be performed under these laboratory-like circumstances, and this could limit the generalizability of our findings. Most of our participants were female, and it was not possible to conduct adequately powered analyses based on sex; thus, our findings could be more generalizable to women. Future studies should assess the effects of acute exercise in adults with AUD in naturalistic settings. Studies comparing the effects of different types of exercise, including resistance exercise are currently lacking, but could inform clinical practice and help to optimize treatment outcomes. Strength training is shown to reduce anxiety and depression (Gordon et al., 2018, 2017), and may have positive effects on

alcohol craving.

4.1. Conclusion

Many adults with AUD are interested in exercise-based interventions to help reduce alcohol consumption and increase physical activity levels. Our findings suggest that a short bout of aerobic exercise may reduce the urge to drink alcohol in adults with moderate and severe AUD, and may reduce negative mood states, including tension-anxiety, depression, anger-hostility, and fatigue – emotions known to frequently precipitate alcohol consumption in people with AUD. With minimal training requirements, there is potential to integrate brief exercise interventions into the routine treatment of AUD. Exercise based interventions could be used to augment conventional treatments in both specialist and general health care settings (Hallgren et al., 2017b).

Contributions

MH conceived the study, collected and analysed project data, and wrote the first draft. MPH was involved in the study design, selection of measures, interpretation of data, and co-wrote the manuscript. DV interpreted data and co-wrote the manuscript. MTH entered and analysed the data. ÖE provided expert advice on fitness testing, and co-wrote the manuscript. VA collected data and co-wrote the manuscript. SA (senior Professor) financially supported the project (with MH), provided expert advice on alcohol-related issues, and co-wrote the manuscript. All authors have read and approved the final article.

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Declaration of Competing Interest

The authors report no declarations of interest.

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Appendix A. Supplementary data

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