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The Efficacy of Vigorous-Intensity Exercise as an Aid to Smoking Cessation in Adults with High Anxiety Sensitivity: A Randomized Controlled Trial

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Abstract

Objective—High anxiety sensitivity predicts poor smoking cessation outcomes. Aerobic exercise reduces anxiety sensitivity and aspects of the risk conferred by anxiety sensitivity. In the current study, we examined whether exercise can aid smoking cessation in adults with high anxiety sensitivity.

Method—Participants were sedentary and low activity adult daily smokers (N = 136) with elevated prescreen anxiety sensitivity. Participants received 15 weeks of standard smoking cessation treatment (ST: cognitive behavioral therapy plus nicotine replacement therapy). Additionally, participants were simultaneously randomized to 15 weeks of either an exercise intervention (ST+EX; n = 72) or a wellness education control condition (ST+CTRL; n = 64). Self-

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reported smoking abstinence was assessed weekly during the intervention, at the end of treatment (10 weeks following the target quit date), and at 4 and 6 months following the target quit date. Abstinence was verified by expired carbon monoxide readings and saliva cotinine.

Results—Results indicated that point prevalence abstinence (PPA) and prolonged abstinence (PA) rates were significantly higher for ST+EX than for ST+CTRL at each of the major end points among persons with high anxiety sensitivity (PPA: b=−.91, SE=.393, t(1171)=−2.33, p=.020; PA: b=−.98, SE=.346, t(132)=−2.84, p=.005), but not among those with low anxiety sensitivity (PPA: b=−.23, SE=.218, t(1171)=−1.06, p=..29; PA: b=−.31, SE=.306, t(132)=−1.01, p=.32)

Conclusions—The present results suggest that exercise faciliates the odds of quit success for smokers with high levels of anxiety sensitivity, and therefore, may be a useful therapeutic tactic for this high-risk segment of the smoking population.

Keywords

Smoking; Smoking cessation; Intervention; Randomized controlled trial; Exercise; Aerobic exercise; Anxiety; Anxiety sensitivity

INTRODUCTION

Anxiety symptoms and disorders are associated with the maintenance and relapse of smoking (1). One promising means of elucidating the role of anxiety in smoking is to investigate the influence of transdiagnostic psychological vulnerability factors; factors that underpin the anxiety- smoking relation. Anxiety sensitivity, or the fear of anxiety-related sensations (2), is one such transdiagnostic factor (1). Anxiety sensitivity is a relatively stable (2), but malleable (3), cognitive-based individual difference variable (2) that is distinguishable empirically and theoretically from anxiety symptoms and other negative affect states (4).

There is strong evidence for the role of high anxiety sensitivity in the maintenance of smoking and in smoking cessation failure. Specifically, anxiety sensitivity is positively correlated with smoking motives to reduce negative affect (5) and beliefs that smoking will reduce negative affect (6). Similarly, higher levels of anxiety sensitivity are associated with increases in positive affect after smoking (7), and smoking reduces anxiety in high anxiety sensitivity smokers who smoked during stress exposure (8). Moreover, smokers higher in anxiety sensitivity, relative to those with lower anxiety sensitivity, perceive quitting as more difficult (9) and experience more intense nicotine withdrawal during early phases in quitting (10). Furthermore, anxiety sensitivity explains the relation between emotional disorders and nicotine dependence, barriers to cessation, and severity of problematic symptoms while quitting (11). Importantly, high anxiety sensitivity is related to greater odds of early smoking lapse (12) and relapse during quit attempts (13). These observed anxiety sensitivity-smoking relations are not better explained by smoking rate, sex, other concurrent substance use, panic attack history, or trait-like negative mood propensity (6,7).

Aerobic exercise has emerged as a promising intervention for aiding smoking cessation in individuals with high anxiety sensitivity. Indeed, a number of investigations have shown that exercise can effectively reduce anxiety sensitivity (14–16). In addition, exercise appears to

modulate the strength between anxiety sensitivity and psychopathological outcomes, such that these relations are weaker among those who exercise than among those who are inactive (17,18). Accordingly, by engaging in exercise, the vulnerable high anxiety sensitivity population may obtain better smoking cessation outcomes because they will experience reductions in anxiety sensitivity and will be less susceptible to negative outcomes (i.e., more likely to persist) when faced with a stressor (e.g., quit attempt, nicotine withdrawal, interpersonal stressors). Alternative therapeutic change mechanisms for the effects of exercise on smoking cessation are reductions in anxiety and depressive symptoms (19), nicotine withdrawal, craving (20,21), and weight gain (22).

The present study was designed to examine the efficacy of exercise as an aid to smoking cessation among high anxiety sensitivity smokers. Adults with elevated anxiety sensitivity received standard smoking cessation care and were randomly assigned to a 15-week exercise program (ST+EX) or 15-week wellness education control condition (ST+CTRL). We hypothesized that participants assigned to the ST+EX condition would evidence higher abstinence rates, both in the short term and long term, relative to those assigned to the ST +CTRL condition. Furthermore, we hypothesized that the efficacy of the exercise intervention would be specific to the high anxiety sensitivity sample targeted for intervention.

METHODS

Design

Sedentary and low activity adult smokers with elevated anxiety sensitivity were enrolled in a 30-week protocol. Participants received the intervention during weeks 1–15 and were asked to make a quit attempt at week 6. Primary outcome measures were point prevalence abstinence (PPA; no smoking in the 7 days prior to assessment) and prolonged abstinence (PA) at 10 (end of treatment; EOT), 16 (i.e., 4 months), and 24 weeks (i.e., 6 months) following the target quit date. Enrolled participants were randomly assigned to either a 15-week intervention combining standard care with exercise or a 15-week intervention combining standard care with wellness education. Cohorts (with up to 5 participants) were developed prior to beginning treatment based on availability. Randomization (variable size permuted block randomization) was generated by the study statistician and placed in sealed envelopes. At treatment inception, the therapist opened the envelope corresponding to the cohort number, and participants were randomly assigned to condition by cohort. Participants were compensated $25 for each of 7 selected assessment visits. In addition, participants who attended at least 90% of the sessions were compensated with an additional $125. The Institutional Review Board at Southern Methodist University approved the study procedures.

Participants

Between January 2010 and July 2014, 150 participants were recruited from the Dallas community and attended a baseline visit. Prior to enrollment, participants provided written informed consent and completed screening consisting of questionnaires, a diagnostic interview (using the Structured Clinical Interview for DSM-IV Diagnosis of Axis I Disorders Patient Version; SCID-NP(23)), and a medical examination comprising a physical

exam, laboratory work, and maximal exercise testing. Eligible participants met the following criteria at prescreen: (1) adult daily smokers (at least 1 year of smoking at least 10 cigarettes per day); (2) elevated anxiety sensitivity (prescreen score of ≥ 20 on the 16-item Anxiety Sensitivity Inventory; ASI-16); (3) sedentary (moderate-intensity exercise less than twice a week for 30 minutes or less); and (4) motivated to quit (reporting a motivation of at least 5 on a 10-point scale). A comprehensive list of exclusion criteria and screening procedures is provided in the study protocol (24).

Figure 1 depicts the participant flow for the trial. Of the 150 individuals that were enrolled in the study, 14 declined participation prior to the baseline session. Accordingly, 136 individuals were randomly assigned to ST+EX (n = 72) or ST+CTRL (n = 64). Table 1 describes demographic and baseline clinical characteristics of the sample. There were no significant between-group differences on any of these indices. Despite meeting the cut-off for elevated anxiety sensitivity at prescreen, there was wide variability of anxiety sensitivity at the baseline assessment (M=18.32; SD=11.62, range=0–53). Hence, our analyses included anxiety sensitivity as a moderator of treatment effects in order to investigate the original hypothesis that exercise would enhance smoking cessation only among those with high anxiety sensitivity.

Treatment Conditions

Extensive details on the interventions can be found in the study protocol (24). Participants received the standard treatment for smoking cessation (25,26) consisting of 7 weekly 60-minute sessions of cognitive behavioral therapy (CBT) for smoking cessation, wherein weeks 1–5 focused on preparing for a quit attempt, a quit attempt was scheduled for week 6, and weeks 6 and 7 focused on maintaining abstinence. At week 6 (target quit day), participants were also provided with optional nicotine replacement therapy (NRT) patches for up to 8 weeks. Participants received either an exercise or wellness education intervention alongside the CBT smoking cessation treatment. Both interventions were equivalent in time and duration, and consisted of thrice weekly, 35-minute sessions for 15 weeks.

Exercise Condition—Participants in the exercise condition were given the rationale that vigorous-intensity aerobic exercise aids smoking cessation because it provides an opportunity to reestablish a sense of safety around intense bodily sensations, which increases the likelihood of a successful quit attempt among smokers who are sensitive to bodily sensations. Exercise was completed on treadmills. Facilitators worked with each participant to progress their exercise intensity to a vigorous level (77% to 85% of their maximum heart rate as determined via maximal exercise testing at screening) by the end of week 4. At each session, participants completed a 5-minute warm-up and 25 minutes of exercise, followed by a 5-minute cool-down. Facilitators monitored heart rate during each session and adjusted treadmill speed and/or incline to ensure participants trained at the target heart rate (16,27).

Wellness Education Condition—Using a protocol adopted from previous smoking cessation studies (28,29), wellness education sessions included discussions of healthy lifestyle topics (e.g., healthy diet, sun protection, time management) alongside setting small weekly wellness goals. Participants were provided with the rationale that adopting healthy

lifestyle changes prior to quitting smoking might aid in smoking cessation, because achieving successes via small weekly wellness goals might bolster their self-efficacy.

Assessments

Abstinence—Self-reported smoking status was assessed in-person weekly from baseline through week 16 (EOT), and at week 22 (4 months post-quit day) and 30 (6 months post-quit day). We used the timeline follow-back (TLFB) procedure at all assessments to assess cigarette consumption at each day following the previous assessment. We have previously used the TLFB to assess cigarette use among high anxiety sensitivity smokers (30) and the assessment has demonstrated good reliability and validity (31). Self-reported abstinence at every assessment was verified by expired carbon monoxide (CO). Abstinence at 16 and 24 weeks following the quit day was additionally verified with saliva cotinine. Self-reported abstinence was overridden by a positive carbon monoxide (>8ppm) or saliva cotinine verification (>10 ng/mL) (32).[1] If neither CO nor cotinine levels were available to verify abstinence at an assessment, abstinence was considered missing data. As in past work (44), we employed PPA and PA as the primary outcomes. PPA was defined as no smoking, not even a puff, in the 7 days prior to any assessment. Failure to maintain PA at any assessment was defined by 7 or more consecutive days of smoking or smoking at least 1 cigarette over the 2 consecutive weeks prior to the assessment. Because some participants quit before the target quit day (week 6), the starting point for measuring abstinence was at baseline.

Anxiety Sensitivity—At prescreen, we used the 16-item Anxiety Sensitivity Index (ASI-16 (2)), which demonstrates good retest reliability ($r = .75$), internal consistency (Cronbach's alpha = .82), and convergent validity with other measures (33). We used this original version of the ASI for prescreen, because at the time this protocol was designed, there were established cut offs for clinical elevations on the ASI-16 (34). At baseline, throughout treatment, and follow-up, we assessed anxiety sensitivity using the newer Anxiety Sensitivity Index-3 (35). This updated version of the ASI, which we report on in this manuscript, has demonstrated improvements over the original version of the ASI, the ASI-16, including better reliability (Cronbach's alpha = .89) and factorial validity with correlations between corresponding subscales ranging from .47 to .99 (35). Furthermore, recent research has supported using a cut-off score of 23 to identify high anxiety sensitivity individuals with the ASI-3 (36).

Anxiety and Depression Symptoms—We administered the Inventory of Depression and Anxiety Symptoms (IDAS (37)) at baseline, throughout treatment and follow-up. The IDAS is a 64-item questionnaire that assesses symptom dimensions of major depression and anxiety disorders. In the current paper, we report on the 10-item Dysphoria subscale of the IDAS, because it has been shown to assess the core emotional and cognitive symptoms of anxiety and depression (37). The IDAS-Dysphoria subscale has demonstrated excellent test-retest reliability (r = .83) and internal consistency (Cronbach's alpha = .90) as well as excellent convergent, discriminant, criterion, and incremental validity (37).

[1]After biochemical verification 13.5% (for ST+EX) and 12.3% (for ST+CTRL) of the reports of weekly abstinence were converted to non-abstinence.

Data Analysis

Data were analyzed using Generalized Linear Mixed Models (GLMM), employing the program HLM 7.01 with a logistic linking function. GLMM includes all subjects, regardless of missing data (hence, it is an intent-to-treat analysis), and does not require imputation of missing data. Other typically used intent-to-treat analyses follow specific rules to impute missing data, rules that are likely to bias the results (some examples of imputation rules that may bias the results are 1) missing data is coded as smoking, or 2) missing data is coded the same as the previous assessment (38)). Thus, GLMM, which computes its results from the obtained data and treats missing data as missing, is the recommended approach for analyzing longitudinal smoking cessation trials (39).

We used a 3-phase piecewise growth curve model to track PPA and PA over the 30-week study (see Figures 2 and 3). The first phase of the growth model consisted of weeks 0–6 (pre-quit treatment phase), the second phase was weeks 7–16 (post-quit/treatment phase), and the third phase was weeks 17–30 (post-treatment phase). Modeling the growth curve starting at week 0 is necessary for intent-to-treat analyses. We modeled change over time as linear within each phase (initial analyses indicated no significant departure from linearity), and modeled a discontinuity in the growth curve between the first and second phase to reflect the expected effects of the scheduled quit day during week 6.

Treatment condition was modeled as a predictor of the slope of change in abstinence (when we refer to abstinence, we refer to both PPA and PA) during each phase of the study, and as a predictor of the discontinuity. Because we hypothesized that the efficacy of exercise would be stronger for persons with high levels of anxiety sensitivity, we included ASI and an ASI × Treatment Condition interaction as moderators of the slopes during each phase of the study and of the discontinuity. Lastly, to explore whether treatment dose predicted abstinence (as was the case in a recent study (40)), and to reduce variance in abstinence related to treatment dose, we also included Session Attendance, Session Attendance × Treatment Condition and Session Attendance × ASI × Treatment Condition as terms in the GLMM models and as moderators of the slopes during each phase of the study.

In order to minimize Type II error, provide a more parsimonious model that fits the data, and more clearly elucidate the overall relations between the predictors and abstinence, we recomputed the models for PPA and PA, respectively, after removing non-significant interaction terms (41,42). Additionally, initial analyses included demographic variables and baseline nicotine dependence as covariates. Because 18 participants had missing data on one or more of these measures, we recomputed the models dropping these covariates to include all randomized participants. Since these models provided identical results, we report results from the analyses with the full sample below. As computed by the program PinT 3.12 (43), this approach had 0.85 power to detect meaningful effects (i.e., medium effect sizes).

RESULTS

Adherence

Participants attended an average of 24 of the 45 total exercise or wellness education sessions over 15 weeks of treatment. There was a significant difference in attendance between the

two conditions ($t(134)=3.04$, $p=.003$), with participants in the ST+EX condition attending an average of 20 (SD=15.73) exercise sessions and participants in ST+CTRL attending an average of 28 (SD=15.21) wellness education sessions. Of participants assigned to the exercise intervention, 94% achieved the prescribed intensity as per protocol (77% to 85% of their maximum heart rate as determined via maximal exercise testing at screening); 6% of the sample did not progress beyond the moderate-intensity range (64%–76%).

Of the 136 participants, 81 participants (60% of the total sample) completed the EOT assessment, 69 participants (51%) completed the 4 months following target quit day assessment, and 66 participants (49%) completed the 6 months following target quit day assessment. There were no significant between-group differences in assessment completion rates at any of these endpoints (see Figure 1). Furthermore, there was no attrition because of exercise-related injuries.

Outcome Analyses

The Efficacy of Exercise—There were no significant 3- or 4-way interactions, so they were dropped and the final model was recalculated, the results for which are listed in Table 2. Consistent with hypothesis, we observed significant ASI × Treatment Condition interactions for the models predicting PPA ($b=-.06$, $SE=.023$, $t(1171)=-2.42$, $p=.016$) and PA ($b=-.06$, $SE=.019$, $t(993)=-2.97$, $p=.003$). To interpret the ASI × Treatment Condition interactions, we recomputed the models for PPA and PA, centering ASI at 23 (i.e., high ASI) and 10.8 (i.e., low ASI and the sample mean), respectively, as recommended by Aiken and West (44). Because the ASI × Treatment Condition interactions were not moderated by Session Attendance, the estimates for PPA and PA were computed at the mean of Session Attendance. Figures 2 and 3 depict the effects of treatment for high and low levels of ASI for PPA and PA, respectively.

As can be seen in Figure 2, among those with high ASI scores, PPA rates were significantly higher for ST+EX than for ST+CTRL at each of the major end points (EOT: M=27.1% vs. 13.0%; 4 months following target quit day: M=21.1% vs. 9.7%; and 6 months following target quit day: M=14.7% vs. 6.4%) ($b=-.91$, $SE=.393$, $t(1171)=-2.33$, $p=.020$), but not among those with low ASI scores (EOT: M=31.6% vs. 26.9%; 4 months following target quit day: M=25.0% vs. 20.9%; and 6 months following target quit day: M=17.7% vs. 14.6%) ($p=.288$).

Similarly, as can be seen in Figure 3, among those with high ASI, estimated PA rates were significantly higher for ST+EX than for ST+CTRL at each of the major end points (EOT: M=25.9% vs. 11.6%; 4 months following target quit day: M=24.8% vs. 11.0%; and 6 months following target quit day: 23.3% vs. 10.2%) ($b=-.98$, $SE=.346$, $t(132)=-2.84$, $p=.005$), but not among those with low ASI scores (EOT: M=33.2% vs. 26.7%; 4 months following target quit day: M=32.5% vs. 26.1%; and 6 months following target quit day: 31.6% vs. 25.4%) ($p=.316$).

To further understand the ASI × Treatment Condition interaction, we examined it from another perspective, by investigating the relation between anxiety sensitivity and abstinence within the different treatment conditions, rather than examining the effect of treatment

condition on abstinence at different levels of anxiety sensitivity. This analysis showed that, in the ST+CTRL condition, participants with higher ASI had lower abstinence rates (b=−.07, SE=.025, t(1171)=2.95, p=.003 for PPA; and b=−.08, SE=.016, t(993)=5.35, p<.001 for PA). These effects replicate earlier findings that smokers with high anxiety sensitivity are less likely to successfully quit smoking than those with low anxiety sensitivity (11–13). On the other hand, in the ST+EX condition ASI scores were not significantly related to abstinence as measured by PPA (b=−.02, SE=.023, t(1171)=−0.76, p=.447), and was only weakly related to prolonged abstinence (b=−.03, SE=.014, t(993)=−1.97, p=.049).

The Relation between Session Attendance and Smoking Cessation—As can bee seen in Table 2, the final models for PPA and PA also revealed significant Session Attendance × ASI interaction terms (b=.18, SE=.061, t(1171)=2.88, p=.004 for PPA and b=.23, SE=.033, t(993)=7.01, p<.001 for PA), suggesting that high attendance, relative to low attendance, was associated with a weaker relation between anxiety sensitivity and both PPA and PA (irrespective of treatment condition). Regarding the other effects of attendance in these final models for PPA and PA, attendance predicted the “discontinuity” in abstinence rates between week 6 and week 7, such that higher attendance was associated with a greater increase in PPA (b=5.67, SE=2.015, t(1171)=2.81, p=.005) and PA (b=4.11, SE=1.417, t(993)=2.90, p=.004) during quit week. Perhaps reflecting a partial regression to the mean, higher attendance was paradoxically related to slower improvement in PPA during the post-quit/treatment phase (b=−.40, SE=.137, t(1171)=−2.93, p=.004). Similarly, for PA, higher attendance was associated with greater decreases in PA during follow-up (b=−.29, SE=.081, t(993)=−3.55, p<.001). However, these relations were not as strong as the association between higher attendance and increases in abstinence during quit week, since higher attendance was still related to higher PPA and PA at both EOT and at 6 months following target quit day (ps<.017). There were no other significant terms in the final models.

Exploratory Analyses—The results from the outcome analyses point to the efficacy of exercise for increasing the odds of quit success among persons with high anxiety sensitivity. The findings further made clear that the intervention exerted its effects during the targeted quit week (see Figures 2a and 3a). In order to gain insight into mechanisms of action of the intervention, we tested two additional models guided by extant research. In the first model, we tested whether individuals presenting with high anxiety sensitivity assigned to the ST+EX condition reported lower anxiety sensitivity during the targeted quit week relative to their counterparts assigned to the ST+CTRL condition. This hypothesis is consistent with our previous work guiding the current study showing that exercise effectively reduces anxiety sensitivity (3, 14–16) and lower anxiety sensitivity is associated with greater odds of quit success (11–13). Accordingly, we modeled the growth curve of ASI scores from week 0 through quit week using multilevel modeling (MLM) with Time (in weeks), Treatment Condition, and Time × Treatment Condition as predictors. Time was centered at quit week so that the main effect of treatment condition tested the differences between treatment conditions during targeted quit week. Since the treatment condition differences in abstinence were found for those with high anxiety sensitivity, we included initial anxiety sensitivity severity as a moderator of the growth curve of ASI scores (by forming interactions between initial AS severity and all of the predictors in the growth curve model for ASI scores). Initial

anxiety sensitivity severity was centered at high anxiety sensitivity (ASI=23) to test whether treatment condition differences at targeted quit week were significant for those with high anxiety sensitivity. Consistent with prediction, results indicated that ASI scores were significantly lower for those in the ST+EX condition (ASI=12.9) than for those in ST +CTRL condition (ASI=19.0; b=6.1, SE=1.748, t(255)=3.51, p=.001) during the targeted quit week. It is important to note that, as expected, these treatment condition differences were moderated by initial anxiety sensitivity severity (b=.34, SE=.122, t(260)=2.99, p=.003), and that they were not significant for those with low initial anxiety sensitivity.

In the second model, we tested whether participants in the ST+EX condition reported lower anxiety and depression symptoms during the targeted quit week relative to those assigned to the ST+CTRL condition. Past work has indicated lower anxiety and depression symptoms during quit week are related to greater odds of quit success, especially among individuals with high anxiety sensitivity (1), and moreover, exercise has shown to be efficacious in reducing anxiety and depression symptoms (16). In order to test this hypothesis, we ran the same model testing treatment differences in ASI scores during the targeted quit week, but with the IDAS-Dysphoria subscale scores as the dependent variable instead. Not surprisingly, initial anxiety sensitivity severity did not moderate treatment condition differences in anxiety and depression symptoms (p=.569), indicating that anxiety and depression symptoms did not vary according to initial anxiety sensitivity severity. Thus, we dropped the non-significant interactions, and reran the model. This final model showed that participants in the ST+EX condition reported significantly lower anxiety and depression symptoms during the targeted quit week (IDAS-Dysphoria subscale =16.3) than participants assigned to the ST+CTRL condition (IDAS-Dysphoria subscale =18.4; b=2.1, SE=.958, t(265)=2.23, p=.027).

DISCUSSION

The current study examined whether a vigorous-intensity exercise regimen could aid smoking cessation among high anxiety sensitivity smokers. Consistent with prediction, estimated PPA and PA rates were significantly higher for ST+EX than for ST+CTRL at each of the major end points among those with high anxiety sensitivity, but not among those with low anxiety sensitivity. These novel data suggest that among sedentary and low active high anxiety sensitivity smokers who receive a standard smoking cessation intervention, exercise increases the odds of quit success compared to a health education control condition.

Providing initial evidence for a specialized smoking cessation intervention, the current study may also shed light on the inconsistent findings regarding the efficacy of exercise for smoking cessation in the literature. A recent review (45) showed that there is considerable variability in terms of the effects of exercise on smoking cessation in previous trials, with many showing no effects, some showing weak effects, and only a few providing evidence of efficacy. The findings of the present study suggest that, as is the case for many interventions, the efficacy of exercise for smoking cessation may not be evident in unselected samples but may only be observable in samples composed of individuals who present with known risk factors for smoking cessation failure which can be effectively targeted by exercise. To this point, it is notable that the exercise intervention significantly attenuated the risk of poor

smoking cessation outcomes conferred by anxiety sensitivity in the current study. Specifically, the relation between anxiety sensitivity and (non-)abstinence was weak in the exercise intervention whereas it was significant and strong in the control intervention.

An important next step in building upon the findings from the present study is to determine the mechanisms underlying the effects of exercise on smoking cessation among those with high anxiety sensitivity. Such work will provide guidance on how to optimize the application of exercise as an intervention for this high-risk group. It is noteworthy that the effects of exercise in the present trial emerged during the targeted quit week, suggesting that its protective effects occur during the initial phases of smoking cessation, which are characterized by greater affective distress especially among those with high anxiety sensitivity (1). Consistent with the theoretical model and empirical findings driving our current investigation, our exploratory analyses suggest that exercise may indeed aid persons with high anxiety sensitivity in their smoking cessation attempt because it reduces affective distress during the targeted quit week and reduces anxiety sensitivity (which amplifies the effects of affective distress on smoking lapse and relapse (1)). In research that builds upon these initial findings, it will be valuable to test the relative importance of these putative change mechanisms (reductions in anxiety and depression symptoms vs. reductions in anxiety sensitivity) while also considering alternative (or perhaps complementary) mechanisms, such as reduced craving and nicotine withdrawal (20,21). Further, examining mediators at different levels of analysis may be important. As one example, given that emerging research implicates improved immune function in the antidepressant effects of exercise (46), it maybe advisable to assess and model immune system functioning in exercise-smoking work.

The analyses also indicated that attendance moderated the association between anxiety sensitivity and abstinence. These findings possibly suggest that anxiety sensitivity confers less risk for negative smoking cessation outcomes as patients show greater adherence to an intervention, although without manipulating adherence it is difficult to rule out possible third-variable explanations. Additionally, there was evidence that higher attendance, in general, was related to positive smoking outcomes for abstinence at all major assessments. Although the efficacy of exercise was evident at all levels of attendance (i.e., there were no treatment condition × attendance interactions), these results may suggest that improving adherence to exercise (and, perhaps, to any intervention) may result in better outcomes. Given these findings, the observed attendance and attrition rates in this trial and other exercise for smoking cessation trials (40), follow-up research manipulating attendance is warranted (47). Such research on enhancing smoking cessation outcomes by increasing attendance may benefit from exploring the efficacy of mobile ’anxiety sensitivity-oriented’ supportive counseling applications, which can isolate the clinical needs of this high-risk subgroup. Additional fruitful efforts in this area may include the development of protocols that are more accessible, acceptable, and thereby, sustainable. Specifically, rather than requiring participants to exercise at fixed times and in a fixed place, as was the case in the present study (i.e., scheduled session on three out of five weekdays at the university), an intervention that offers the participant more flexibility while also providing the needed support for exercise is likely to be associated with greater adherence.

There are a number of interpretive caveats to the present study that warrant further consideration. First, our sample consisted of community-recruited, treatment-seeking sedentary daily cigarette smokers with moderate levels of nicotine dependence. Future studies may benefit by sampling from lighter and heavier smoking populations to ensure the generalizability of the results to the general smoking population. Second, although our sample was generally similar to the ethnic breakdown in the US, smoking is often concentrated among underrepresented and low-income groups (48). Therefore, to rule out a selection bias and increase the generalizability of these findings, it will be important for future studies to recruit a more ethnically/racially diverse sample of smokers and those that specifically fall in low socioeconomic strata. Third, the present data is from a treatment development study, and thus, the sample was only moderate in size and we did not use an alternative anxiety sensitivity- focused treatment in our comparison group (e.g., another psychosocial anxiety sensitivity modification treatment or psychotropic medications). Fourth, we only tested the efficacy of a 15-week supervised vigorous-intensity exercise program, and can therefore, not make any inferences with respect to the possible dose-response relations outside of those focused on attendance. Fifth, we defined PA as no relapse at each of the assessments. Hence, although unlikely, someone who reported relapse at an earlier time point, and therefore did not meet for PA then, could have met for PA at a later time point. Sixth, the follow-up assessment rates were lower than observed in comparable studies, likely because we required assessment to be done in person rather than by phone (i.e., limiting in-person verification to those who report abstinence), which has shown to be associated with greater follow-up assessment rates. Finally, the present investigation utilized established self-report instruments as the principal assessment strategies for anxiety sensitivity. Future work might build upon the present findings and incorporate multi-method approaches to indexing this construct and related variables of interest. Here, it is important that we observed a general decline in ASI scores from prescreen to the baseline assessment. This phenomenon has been frequently observed in other studies (49,50), and it appears that this decline in ASI scores between assessment occasions is specific the first two administrations (i.e., scores remain stable after), suggesting that follow-up studies targeting high anxiety sensitivity samples may administer measures of anxiety sensitivity twice before enrollment (51).

Together, the present findings show promise for vigorous-intensity exercise as an aid to smoking cessation in adults who have high levels of anxiety sensitivity. Furthermore, these findings underscore the importance of considering moderators of the efficacy of exercise on smoking outcomes. These findings encourage the further application of exercise as a targeted intervention for specific liabilities among smokers seeking to quit, and sets the stage for future work to replicate and extend these findings by performing effectiveness research on larger samples.

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Abbreviations

CO	carbon monoxide
EOT	End of treatment
GLMM	Generalized Linear Mixed Models
PPA	point prevalence abstinence
PA	prolonged abstinence

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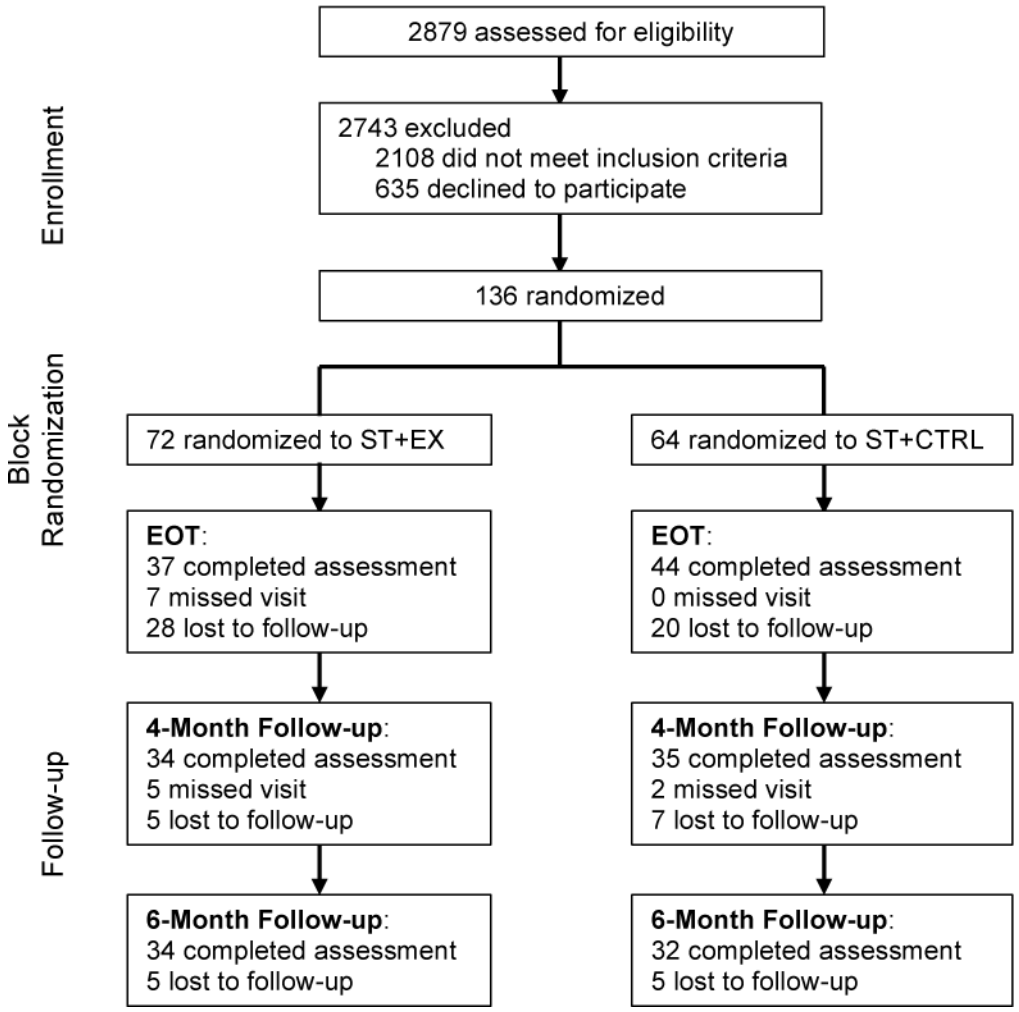

Figure 1.
Consort Flow Diagram

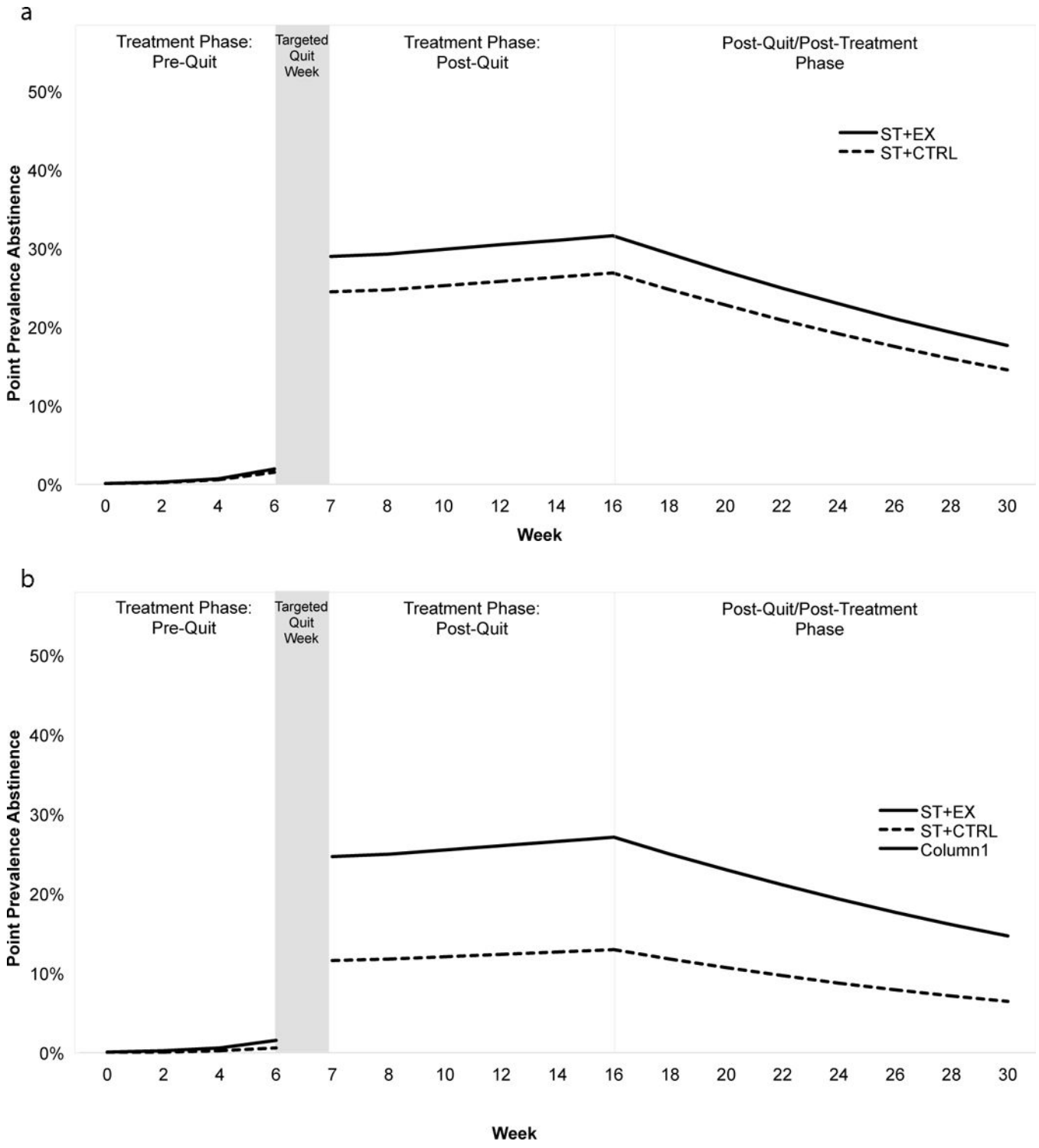

Figure 2.

7-Day Point Prevalence Abstinence Over the Course of Time as a Function of Treatment Condition for Those Anxiety Sensitivity and Low Anxiety Sensitivity.

A. Centered at High ASI. B. Centered at Low ASI

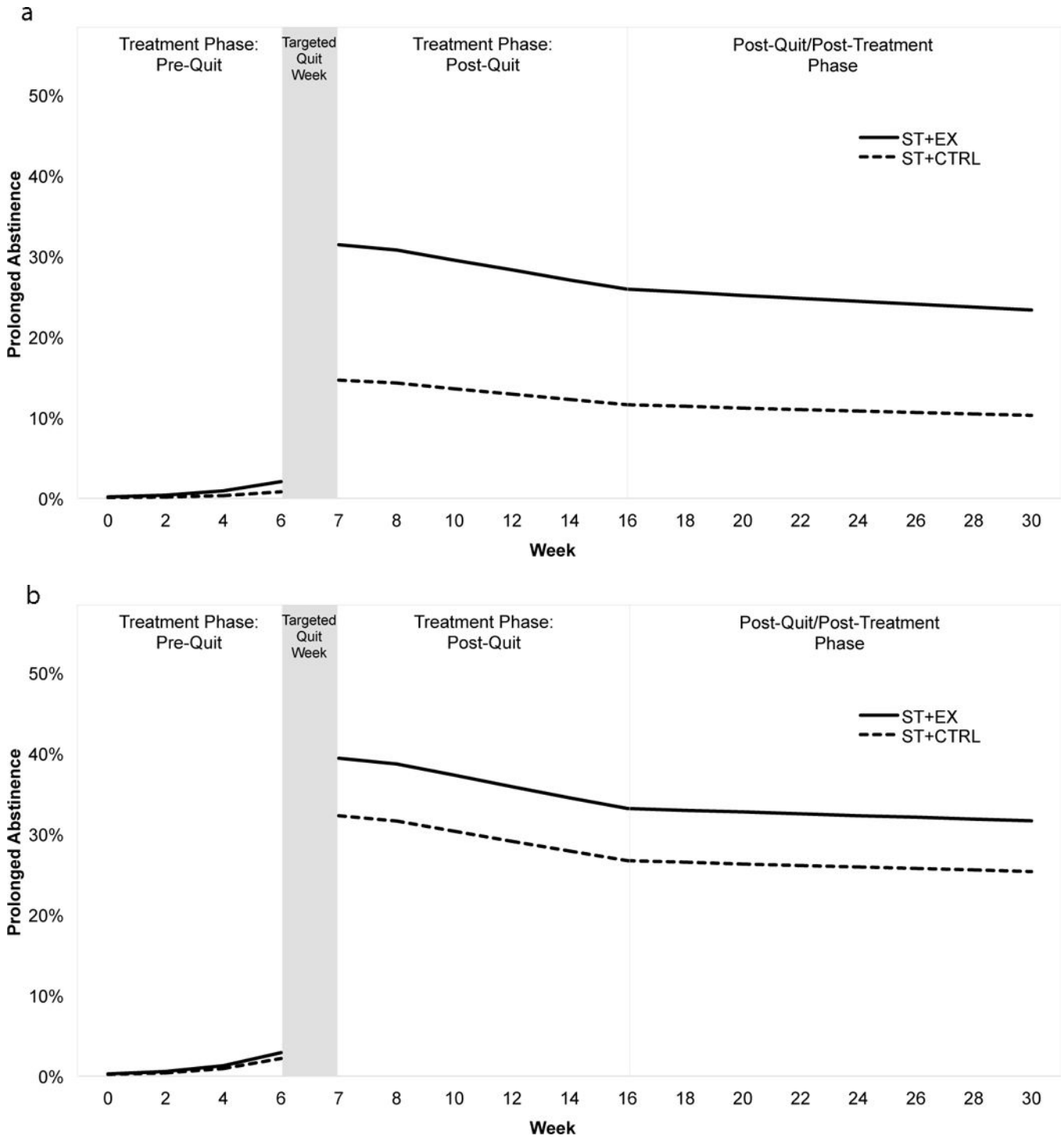

Figure 3.

Prolonged Abstinence Over the Course of Time as a Function of Treatment Condition for Those with High Anxiety Sensitivity and Low Anxiety Sensitivity

A. Centered at High ASI. B. Centered at Low ASI

Table 1

Demographics and Baseline Clinical Characteristics

	ST+EX (*n*=72)			ST+CTRL (*n*=64)			Total Sample (*n*=136)		
	N	***M***	***SD***	***N***	***M***	***SD***	***N***	***M***	***SD***
Age	72	43.12	11.26	64	45.39	11.30	136	44.19	11.29
BMI	69	26.74	4.83	59	26.91	5.17	128	26.82	4.97
Cigarettes per day	70	16.88	7.83	60	16.81	8.53	130	16.85	8.13
CO reading (ppm)	71	15.42	9.02	64	15.70	7.07	135	15.56	8.13
FTND	66	5.29	1.95	59	5.49	1.91	125	5.38	1.93
ASI-3	68	18.04	12.72	62	18.63	10.36	130	18.32	11.62
	N	***%***		***N***	***%***		***N***	***%***	
Gender (female)	36	50.0		35	54.7		71	52.2	
Education (some college)	57	79.2		46	71.9		103	75.7	
Employed full-time	40	55.6		36	56.3		76	55.9	
Married	20	27.8		17	26.6		37	27.2	
Ethnicity (Hispanic or Latino)	5	6.9		6	9.4		11	8.1	
Race									
White	51	70.8		49	76.6		100	73.5	
Black or African American	18	25.0		10	15.6		28	20.6	
Asian	1	1.4		2	3.1		3	2.2	
Other	2	2.8		2	3.1		4	2.9	
Not reported	0	0.0		1	1.6		1	0.7	

Note: p > 0.05 for all between-group comparisons

BMI = Body Mass Index; CO = Carbon monoxide; ppm = parts per million; FTND = Fagerström Test of Nicotine Dependence; ASI-3 = Anxiety Sensitivity Index - 3

Table 2

Results for the Final Model

	PPA				PA			
	b	***SE***	***t***	***p***	***b***	***SE***	***t***	***p***
Intercept	−0.99	0.47	−2.12	0.034	−1.05	0.35	−3.04	0.003
Treatment Condition	−0.91	0.39	−2.33	0.020	−0.98	0.35	−2.84	0.005
ASI	−0.02	0.02	−0.76	0.447	−0.03	0.01	−1.97	0.049
Time Phase 1 (weeks 1–6)	0.50	0.27	1.82	0.069	0.42	0.10	4.12	<0.001
Discontinuity	3.04	0.70	4.36	<0.001	3.07	0.51	−6.00	<0.001
Time Phase 2 (weeks 1–6)	0.01	0.05	0.29	0.773	−0.03	0.03	1.02	0.307
Time Phase 3 (weeks 1–6)	−0.05	0.03	−2.06	0.040	0.00	0.03	−0.18	0.855
Session Attendance	2.92	1.20	2.42	0.016	6.31	0.82	7.74	<0.001
Treatment Condition × ASI	−0.06	0.02	−2.42	0.016	−0.06	0.02	−2.97	0.003
ASI × Session Attendance	0.18	0.06	2.88	0.004	0.23	0.03	7.01	<0.001
Discontinuity × Session Attendance	5.67	2.02	2.81	0.005	4.11	1.42	2.90	0.004
Time Phase 2 × Session Attendance	−0.40	0.14	−2.93	0.004	N/A			
Time Phase 3 × Session Attendance	N/A				−0.29	0.08	−3.55	<0.001

Notes: Treatment Condition was coded ST+EX=0, ST+CTRL=1. ASI was centered at high ASI (ASI=23). Session Attendance was centered at its mean. The Time variables were centered at week 16. Discontinuity was coded such that weeks 1–6 were coded 0, and weeks 7–30 were coded 1.