



Physical effort exertion and pain: Links with trait-based risk for psychopathology

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ARTICLE INFO

Keywords:

Serious mental illness
Schizotypy
Hypomania
Anhedonic depression
Clinical pain
Physical activity

ABSTRACT

People with serious mental illness (SMI) are at an increased risk for physical health complications, such as cardiovascular disease and obesity. Low levels of physical activity is a major contributor to these health complications. One factor associated with limited physical activity in the broader sedentary population is pain. While preliminary findings suggest an association between lack of physical activity and pain in SMI, conclusions are still unclear. Thus, the goal of this correlational study was to examine associations between trait-based risk for psychopathology (hypomanic personality, schizotypy, and anhedonic depression) and the experience of pain following a physical endurance/effort task. Healthy participants (N = 43; 18 females) completed self-report measures of trait-based risk for psychopathology. They also reported on the experience of pain before and after the Time To Exhaustion (TTE) test. Findings revealed that risk for psychosis and anhedonic depression were associated with increases in pain following the TTE test, accounting for other key variables, such as age and self-reported physical exercise. Risk for mania was unrelated to changes in pain. These results suggest that the experience of pain in relation to physical endurance/effort may contribute to diminished physical activity among people at risk for SMI.

1. Introduction

People with serious mental illness (SMI; e.g., bipolar disorder, schizophrenia) are at an increased risk for a variety of physical health complications, including cardiovascular disease and obesity (Correll et al., 2017; Vancampfort et al., 2016a; Gardner-Sood et al., 2015; Vancampfort et al., 2015; Simon et al., 2006). These complications can lead to premature mortality. Those with SMI, on average, have lifespans 10–25 years shorter than the general population (Parks et al., 2006). A number of these physical health concerns can be largely attributed to diminished physical activity (Vancampfort et al., 2017a; Stubbs et al., 2016a; Vancampfort et al., 2016b). Physical activity guidelines from the U.S. Department of Health and Human Services (Physical Activity Guidelines Advisory Committee, 2008) recommend that adults engage in at least 150 minutes of moderate or 75 minutes of vigorous-intensity aerobic activity each week. Physical endurance, or willingness to exert physical effort, can be conceptualized as a necessary but insufficient predictor of general levels of physical activity (Ferreria et al., 2012). Sixty-seven percent of healthy adults meet these guidelines, while only 45% of people with SMI do (Okoro et al., 2014). Thus, increasing physical activity among people with SMI is a critical need (Perez-

Cruzado et al., 2017).

A number of factors play a role in diminished physical activity among people with SMI. A recent meta-analysis examining barriers to physical activity in people with SMI identified low mood, stress, and lack of social support as the most prevalent (Firth et al., 2016). An additional barrier that has received less research attention is the experience of pain. Pain limits physical activity in people with various physical and mental health conditions. In a recent study, adults with obesity—highly prevalent in those with SMI (Vancampfort et al., 2016a,b; Simon et al., 2006)—reported pain as a barrier towards initiating physical activity and as a motive for discontinuing physical activity (McIntosh et al., 2016).

Clinical pain is defined as pain naturally occurring and not elicited experimentally or through a medical procedure (e.g., lumbar puncture; Stubbs et al., 2014). Among people with SMI, rates of clinical pain are high and are associated with reduced quality of life (Almeida et al., 2013). While some studies have shown that prevalence of clinical pain is only slightly higher in schizophrenia than in the general population (Stubbs et al., 2014), other studies suggest it is significantly higher (e.g., upwards of 21% more likely; Birgenheir et al., 2013). Similar findings exist in mood disorders. The world mental health survey asked people

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in 17 different countries to report on chronic pain (i.e., pain persisting for longer than 3 months and categorized as a subdomain of clinical pain). Results indicated that people with major depression were 80% more likely to have chronic pain compared to people without major depression (Gureje et al., 2008). Moreover, a recent large-scale meta-analysis examining pain in people with a bipolar spectrum disorder diagnosis suggested that this group was 2.14 times more likely to have pain (e.g., migraine and chronic pain) compared to healthy controls with no psychiatric diagnosis (Stubbs et al., 2015a). Together, findings indicate clinical pain is a prevalent issue throughout SMI.

Findings concerning clinical pain in SMI are inconsistent with those of experimentally induced pain. A recent meta-analysis suggests that people with schizophrenia show reduced sensitivity (e.g., tolerance, threshold) to experimentally induced pain compared to healthy controls (Stubbs et al., 2015b). While people with major depression typically show similar reduced pain sensitivity (Dickens et al., 2003), these findings depend on pain modality used (Thompson et al., 2016; Bar et al., 2005). Moreover, only a handful of studies have examined sensitivity to experimentally induced pain in bipolar disorder, with no clear consensus emerging (Minichino et al., 2016; Atik et al., 2007; Dworkin et al., 1995). Concerning decreased pain sensitivity observed in schizophrenia, ischemic pain modalities—pain which most closely mimics clinical pain sensations (Melzack and Wall, 2005)—has been shown to cause pain hypersensitivity compared to healthy controls (Girard et al., 2011). This is important to note, as people with major depression also have lower pain threshold and lower pain tolerance compared to healthy controls when stimulated with ischemic pain (Bar et al., 2005). Therefore, the generalizability of experimental pain findings within SMI to clinical pain outcomes is unclear. Thus, due to lack of clarity regarding experimental pain findings in SMI, we believe it is critical to examine how pain may affect physical activity in these populations outside of the context of experimental pain findings.

The few studies that have examined pain in relation to physical activity in SMI show mixed results. One such study examined correlates of meeting physical activity guidelines among people with either a psychotic disorder diagnosis, or people who endorsed at least 1 psychotic symptom based on Composite International Diagnostic Interview (CIDI) criteria (Stubbs et al., 2017a). Results indicated that 11.4% of the variance in low vigorous physical activity was explained by self-reported experience of pain, making it a stronger contributor than decreased social functioning (8.8% variance) and low sleep and energy (7.2% variance). Contrary to that finding, Stubbs et al. (2017b) examined 2407 people with a self-reported lifetime psychosis diagnosis in low-income countries and found that pain was not significantly associated with decreased physical activity. One primary reason for these conflicting findings is that in the Stubbs et al. (2017a) study the authors used the 12-item Short Form Survey (SF-12; Ware et al., 1996) pain item, which measures how much pain interferes with daily activities in the past 30 days. In the other study (Stubbs et al., 2017b), the authors asked participants to report on the presence of bodily aches and pains in the past 30 days. The SF-12 item, while not directly measuring pain, does seem to tap into pain interference regarding physical activity, as it is associated with overall physical health (e.g., Larson, 2002). Relatedly, two recent meta-analyses (Vancampfort et al., 2017b; Stubbs et al., 2016b) showed that pain was a significant predictor of low physical activity in people with depressive symptoms (e.g., low mood, loss of appetite). In Stubbs et al. (2016b), pain and discomfort predicted over 35% of the variance in low physical activity, more than sleep problems (25.2% of variance) and cognition (19.4% of variance). Further, we are aware of only one study examining the relationship between pain and psychopathology risk. Koyanagi et al. (2016) examined pain interference in a group of people with subclinical psychosis and found that they were 78% more likely to report recent (past 30 days) extreme pain compared to those without subclinical psychosis. While it is still unclear how pain affects physical activity, these results suggest that pain may serve as a contributing factor to low physical activity

levels within SMI.

It remains unclear, however, the extent to which pain in relation to physical activity serves as a barrier to engaging in that activity in people with SMI. We are aware of only one study that has specifically examined pain in relation to a physical activity task completed in a laboratory/controlled setting. This study had patients with fibromyalgia, a chronic pain condition, and a healthy comparison group complete a motor task to gauge how physical activity impacted the experience of pain (Dailey et al., 2015). The task included the arrangement of objects in a board, requiring participants to lift these objects overhead. Patients with fibromyalgia reported greater pain after the task compared to healthy controls, suggesting pain in relation to physical activity might serve to lower physical activity performance and engagement in this population. In the current study, we aimed to focus directly on reports of pain in relation to a physical endurance/effort task among people at varying levels of risk for SMI.

One way to gain a better understanding of the potential contribution of pain to diminished physical activity in SMI is to utilize trait-based measures of psychopathology risk. The use of trait-based scales has improved our understanding of psychological factors associated with risk for mood (Kwapil et al., 2000) and psychotic (Kwapil, 1998; Kwapil et al., 2013) disorders. The study of trait-based risk for psychopathology has the potential to inform understanding of the etiology and treatment targets for people with SMI. Importantly, people scoring higher on trait-based risk scales are significantly more likely to develop clinical diagnoses over time than are those who score in the lower range. For example, high levels of schizotypy—a set of traits that involve attenuated psychotic symptoms—have been shown to predict the development of psychotic disorders over a 10-year follow-up (Chapman et al., 1994). Similarly, hypomanic personality traits are predictive of the development of bipolar spectrum disorders (Kwapil et al., 2000). That is, 25% of people scoring 2.5 standard deviations above the mean on indicators of hypomania—including elevated levels of sociability, ambitiousness, positive mood state, increased energy, and perceived uniqueness compared to controls—qualified for a bipolar spectrum disorder diagnosis at a 13-year follow-up, while none of those scoring at the mean or below qualified (Kwapil et al., 2000). Moreover, anhedonia has shown to be a useful indicator in screening and identifying depressive disorders (Bredemeier et al., 2010).

Using trait-based measures of psychopathology risk to study pain in relation to a physical endurance/effort task may also help circumvent potential issues that may arise in clinical samples. For example, those with diagnosed psychotic and mood disorders often take medications that could have significant impact on pain experience (Stubbs et al., 2015b). In addition, obesity and sedentary behavior—highly prevalent in SMI (e.g., Simon et al., 2006)—likely impact pain in relation to physical activity. While examining relationships between constructs of interest and broad phenotypic risk for SMI does not fully capture the characteristic phenomenology of these psychological disorders, it does allow us to examine features that may shed light on potential etiological mechanisms, without many of the confounds that exist in those presenting with diagnosed mental illness (e.g., physical health problems, medication side effects).

To date, the association between pain in relation to physical endurance/effort and risk for psychotic and mood disorders has not been examined. Therefore, the aim of the current study was to investigate the association between trait-based risk for SMI (psychosis and mood disorders) and pain in relation to a physical endurance/effort task. Physical endurance/willingness to exert physical effort can be seen as a necessary but insufficient predictor of general levels of physical activity. In a meta-analysis of eight clinical trials, increasing levels of physical activity had a moderate effect on physical endurance (Ferreria et al., 2012). Thus, given the clear connection between physical activity and endurance, we deemed it appropriate to use the Time to Exhaustion (TTE) test to examine the association between risk for

psychopathology and pain in the context of physical activity. We hypothesized that higher levels of schizotypy, hypomania, and anhedonic depression would be associated with increases in self-reported pain following the TTE test. We predicted that these associations would exist after accounting for the impact of important covariates, including age, sex, average hours of exercise per week, time on the TTE task, and baseline levels of pain.

2. Method

2.1. Participants

Forty-three participants (18 females; Mean age = 24.21 years) responded to online or print flyers distributed in the Boston area or by word of mouth. Potential participants were screened and excluded if they endorsed any of the following: Below the age of 18 or above 65; had ever had a heart attack; ever been diagnosed with angina, asthma, cystic fibrosis, cardiovascular disease, bronchitis, obstructive lung disease, or a neurological or orthopedic condition; ever had a stroke; or if a physician had advised them against mild to moderate exercise. Participants reported on the number of hours per week they typically perform mild to moderate exercise during the phone screen. The Boston University Human Subject Review Board approved this study and all participants provided informed consent.

2.2. Measures

2.2.1. Trait-Based risk for psychopathology

Trait-based risk for psychosis was measured using the Schizotypal Personality Questionnaire-Brief Revised (SPQ-BR; Cohen et al., 2010). Questions cover subclinical presentation of positive (e.g., “I often feel that others have it in for me”), negative (e.g., “I rarely laugh or smile”), and disorganized (e.g., “I sometimes forget what I am trying to say”) symptoms of psychosis. Each item includes a 5-point scale ranging from strongly disagree to strongly agree, with higher responses indicating more severe traits. Level of schizotypy is calculated by summing all responses. Longitudinal analyses using the original SPQ indicate that scores greater than 2.5 standard deviations above the mean on items measuring self-rated ideas of reference and lack of close friends lead to a 15% increased chance of developing a psychotic disorder over an 18-month follow-up (Salokangas et al., 2013). The SPQ-BR has shown strong internal consistency (e.g., $\alpha = 0.91$) and construct validity based on confirmatory factor analysis (Callaway et al., 2014). The SPQ-BR displayed good internal consistency in the current sample ($\alpha = 0.94$).

The Mood and Anxiety Symptoms Questionnaire (MASQ; Clark and Watson, 1991) was used to measure risk for depression. The MASQ is a self-report instrument intended to capture depression and anxiety symptoms on a 5-point scale (1 = not at all; 5 = extremely) during the previous week. Factor analyses of the MASQ suggest a 3-factor structure, including general distress, anxious arousal, and anhedonic depression. The anhedonic depression subscale has shown to be a useful indicator in screening and identifying depressive disorders (Bredemeier et al., 2010), and displays strong reliability (e.g., $\alpha = 0.93$; Watson et al., 1995). As such, we used this subscale as an index of risk for depression. The subscale showed adequate internal consistency in the current sample ($\alpha = 0.83$).

We used the hypomanic personality scale (HPS; Eckblad & Chapman, 1986) as an index of risk for bipolar disorder. In longitudinal studies, people who score 2.5 standard deviations above the mean on the HPS are more likely to develop a bipolar spectrum disorder diagnosis over 13 years than people scoring in the normative range (Kwapil et al., 2000). Items tap into hypomanic personality tendencies (e.g., “I am frequently in such high spirits that I can't concentrate on any one thing for too long”) which are answered as true or false. Scores are calculated by summing true responses. The HPS has displayed good internal consistency ($\alpha = 0.87$) and 15-week test-retest reliability

($r = 0.81$; Eckblad and Chapman, 1986). In the current sample, internal consistency was adequate ($\alpha = 0.85$).

2.2.2. Physical endurance/effort task

Physical endurance/physical effort was measured by the time to exhaustion test (TTE), a commonly used test often used to gauge physical endurance and perception of effort exertion (Salam et al., 2018; McCormick et al., 2015; Marcora et al., 2009; Amann et al., 2008). The baseline portion of the TTE is an incremental ramp test on a stationary bike where participants are first asked to establish peak power output (PPO). In a second phase of the baseline portion, PPO is increased by 25 W each minute until exhaustion (defined as the point at which either the participant voluntarily terminates the test or cadence falls below 60 rpm [RPM] for 5 consecutive seconds). The stationary bike was set in hyperbolic mode, which allowed the power output to be set independently of pedal frequency over a range of 30–120 RPM. The second portion of the TTE test—which is based on their performance from baseline—is used to assess the participant's willingness to expand physical effort and physical endurance, as a function of their baseline level of physical fitness obtained from phase 1. We started phase 2 by calculating 30% of the participant's baseline PPO. Participants were asked to pedal for 3 minutes at this level and to keep their output between 60 and 100 RPM (watts and RPM were displayed on the screen attached to the cycle). For the last portion of the task—once again based on fitness levels obtained from the baseline portion—we calculated 65% of the participant's baseline PPO and had them pedal until voluntary stoppage (or until 20 min had elapsed). They were again asked to keep the RPM between 60 and 100. If RPM fell below 60 for 5 consecutive seconds, we asked them to stop pedaling and the task would be complete.

2.2.3. Pain

Participants were instructed to rate their pain before and after the TTE using a numeric pain rating scale (NPRS). A NPRS—a common tool to measure pain intensity—was used to identify participants' pain ratings stemming from the physical endurance/effort task. The NPRS is a unidimensional measure of pain intensity, which is frequently used in people with chronic pain and healthy individuals in experimentally induced pain studies (see Herr et al., 2004 for an example). Our version of the NPRS used a 0–10 scale, with 0 indicating “No pain” and 10 indicating “Worst pain imaginable.” The NPRS is a reliable tool for measuring pain intensity (e.g., Hawker et al., 2011), with high test-retest reliability based on pre to post medical consultations (Ferraz et al., 1990). To minimize the confounding of reports of pain with fatigue, we instructed participants to report only on painful sensations stemming from the TTE test, such as bodily pain and not sensations such as shortness of breath.

2.3. Statistical analyses

We used SPSS statistics (Version 24.0) to perform all analyses. First, we examined descriptive statistics of all variables. We then ran bivariate correlations among the variables of interest, including risk for psychopathology, TTE test time, and pain reports from the TTE to explore expected relationships between psychopathology risk and pain associated with physical endurance/effort. Following these preliminary analyses, we ran a series of hierarchical regressions to investigate the extent to which trait-based risk for psychosis and mood disorders predicted changes in pain after the TTE task when controlling for covariates of interest. We chose to include demographics and other indices of activity (e.g., average hours of exercise per week) based on theoretical assumptions, regardless of statistical significance. Lastly, we ran a post-hoc dependent samples *t*-test comparing pain change from pre to post TTE to test the extent to which the task manipulated pain in all participants.

Table 1
Descriptive statistics of measures of psychopathology risk, demographics, and activity indices.

	Mean (%)	Standard Deviation	Range
Age	24.21	9.00	18–65
Race			
Non-Hispanic Caucasian	72.1	–	–
Asian-American	20.9	–	–
African-American	2.3	–	–
Multiracial	2.3	–	–
Other not listed	2.3	–	–
Average hours of exercise per week	6.14	4.08	1–18
TTE test time (in seconds)	522.47	356.10	112–1200
SPQ-B	69.26	22.50	34–122
MASQ-Anhedonic depression	53.67	11.64	32–75
HPS	15.95	7.45	0–33
Change in Pain rating	2.30	1.68	0–7

Notes: HPS = Hypomanic Personality Scale; MASQ = Mood and Anxiety Symptom Questionnaire; SPQ-B = Schizotypal Personality Questionnaire- Brief

3. Results

Descriptive statistics for demographics and variables of interest are presented in Table 1.

As shown in Table 2, higher levels of schizotypy were positively associated with increased pain following the TTE test ($r = 0.31$, $p = 0.04$). Anhedonic depression was also positively associated with pain reports following the TTE test ($r = 0.32$, $p = 0.03$). Hypomania was not associated with increased pain after the TTE test ($r = 0.07$, $p = 0.66$). These analyses provided initial support that risk for psychopathology was related to increased pain following a physical endurance/effort task. (Table 3)

We then conducted hierarchical regression analyses separately for each psychopathology risk scale with changes in pain from baseline to post-TTE as the dependent variable. For each model, demographic (sex, age) covariates were entered in block 1, activity indices (average hours of exercise per week, TTE test time) in block 2, baseline pain ratings in block 3, and each relevant psychopathology risk measure in block 4.

In the first model, total schizotypy was a significant predictor of changes in pain ($b = 0.33$, $p < 0.05$; $R^2 = 0.11$). In the second model, anhedonic depression was a significant predictor of changes in pain ($b = 0.31$, $p < 0.05$ $R^2 = 0.10$). In the third model, hypomania was not predictive of changes in pain ($b = 0.01$, $p > 0.05$, $R^2 = 0.01$). In addition, the TTE manipulated pain reports across participants, as post pain rating ($m = 1.14$, $sd = 1.41$) was significantly higher than pre pain rating ($m = 3.40$, $sd = 2.05$; $t(42) = -8.60$, $p < 0.01$). Overall, these findings support our hypotheses that trait-based risk for psychotic and mood disorders are associated with greater pain after a physical endurance/effort task, but did not support our hypothesis that hypomania would also be associated with greater pain.

4. Discussion

The primary goal of the current study was to investigate if risk for SMI was associated with increases in pain in relation to a physical

endurance/effort task. Results suggested that trait-based risk for psychotic and mood disorders was associated with higher pain reports following the TTE test. This association was present after accounting for demographics, average hours of exercise per week, time spent on the TTE test, and baseline pain ratings. These findings are the first to indicate the potential association of pain related to physical endurance/effort with psychopathology risk, thus showing similar patterns observed in SMI concerning the disrupting role pain can have on physical activity.

Findings regarding the association between schizotypy and pain related to the TTE test are consistent with previous reports that suggest that the experience of pain serves as a barrier to engaging in physical activity among people with psychosis (Stubbs et al., 2017a). Our results extend this research to suggest that pain may affect active participation in physical activity in an at-risk population. As such, findings may provide valuable information on how pain experience is involved in the etiology of psychosis. For example, people with schizophrenia show decreased sensitivity to acute pain in certain pain modalities (Stubbs et al., 2015b). Decreased pain sensitivity could lead to a reduction in health-seeking behaviors relating to physical comorbidities—such as decreased hospital visits (Laursen et al., 2009)—as people with psychosis may not experience or recognize painful symptoms that often accompany these physical conditions (Stubbs et al., 2017a). Thus, to better clarify the relationship between physical activity and pain in psychosis, multiple methods are needed to test physical activity level which are not strictly reliant on self-report. Further, examining people with psychosis who display varying levels of clinical pain will provide a more parsimonious picture of the overall relationship between pain and physical activity.

Results also suggested an association between trait-based risk for depression and increased pain following the TTE test. This is in line with previous findings suggesting that pain plays a role in diminished physical activity in people with major depression (Vancampfort et al., 2017b; Stubbs et al., 2016b). As the causal relationship between pain and depression is unclear (i.e., depression and chronic pain are bidirectionally related; see Trivedi, 2004), more longitudinal research is needed. For example, future research should examine the extent to which pain contributes to low physical activity above and beyond depressive symptoms, such as low mood and anhedonia, over time.

Risk for bipolar disorder (i.e., hypomania) was not associated with increased pain following the TTE test. While people with bipolar disorder have reported pain as a barrier to physical activity in previous reports, as well as increased clinical pain prevalence, our lack of a significant finding could be due to our approach to measuring bipolar disorder risk. That is, items on the HPS focus on subclinical tendencies toward mania, as opposed to tendencies toward low mood. It is possible that the association between pain and physical activity in bipolar disorder shown in previous research could be attributed to depressive symptoms. Although it may prove difficult, future research should examine the influence of pain on physical activity in people with bipolar disorder who are experiencing a range of mood symptoms. Doing so may provide a clearer picture regarding the relationships between mania, depression, and pain.

While this study identified important associations between people at risk for SMI and pain from a physical endurance/effort test, several

Table 2
Correlations between trait-based measures, age, change in pain rating, and activity indices.

	Schizotypy (SPQ-B)	Anhedonic depression (MASQ)	Hypomania (HPS)
Age	0.08	0.06	–0.21
Change in pain rating	0.31*	0.32*	0.07
Average hours of exercise per week	0.07	–0.05	0.21
TTE test time	–0.10	–0.05	–0.11

Notes: * $p < 0.05$; HPS = Hypomanic Personality Scale; MASQ = Mood and Anxiety Symptom Questionnaire; SPQ-B = Schizotypal Personality Questionnaire- Brief

Table 3
Trait-based measures as predictors of change in pain rating following the TTE test.

	R^2	B	B (SE)	t	p
Model 1	0.27*				
Age		-0.05	0.03	-1.72	0.09
Sex		-0.63	0.55	-1.15	0.26
Average hours of exercise per week		0.05	0.07	0.78	0.44
TTE test time		0.00	0.00	0.85	0.40
Baseline pain rating		-0.29	0.18	-1.58	0.12
SPQ-B		0.02	0.01	2.26*	0.03
Model 2	0.26*				
Age		-0.05	0.03	-1.64	0.11
Sex		-0.58	0.55	-1.06	0.30
Average hours of exercise per week		0.09	0.69	1.00	0.32
TTE test time		0.00	0.00	0.71	0.48
Baseline pain rating		-0.27	0.18	-1.49	0.15
MASQ-Anhedonic depression		0.05	0.02	2.13*	0.04
Model 3	0.17				
Age		-0.04	0.03	-1.40	0.16
Sex		-0.62	0.58	-1.08	0.29
Average hours of exercise per week		0.06	0.07	0.84	0.41
TTE test time		0.00	0.00	0.61	0.55
Baseline pain rating		-0.37	0.20	-1.80	0.07
HPS		0.03	0.04	0.66	0.51

Notes: * $p < 0.05$; HPS = Hypomanic Personality Scale; MASQ = Mood and Anxiety Symptom Questionnaire; SPQ-B = Schizotypal Personality Questionnaire- Brief

limitations should be noted. The sample consisted of healthy young adults and was relatively small. Nonetheless, despite effect sizes ranging from small to medium in our hierarchical regression analyses ($R^2 = 0.01$ to 0.11), we still had a large enough sample size to detect significant associations between two of our risk measures (SPQ-BR and MASQ) and changes in pain. Relatedly, we did not gather data concerning medication use; however, we did screen for potential painful conditions and assessed pain before the start of the task to gain a baseline measure. Further, one alternative approach to examining associations between psychopathology risk and pain in relation to physical endurance/effort would be to split at-risk measures into low and high scoring groups (e.g., Abplanalp et al., 2017). While this could potentially yield additional insights into what effect pain might have on physical activity among those at highest relative risk for pain, we utilized risk measures in the current study to capture the dimensional nature of psychiatric disorders (e.g., schizophrenia-spectrum disorders). Another limitation centers on our physical task. This task is often used to gauge effort perception during physical endurance and is not typically used to assess pain. While physical endurance/effort can be seen as a necessary but insufficient quality of overall physical activity, future studies may want to use measures designed to specifically gauge physical activity in at-risk populations, such as the International Physical Activity Questionnaire or data collected from accelerometer readings (Vancampfort et al., 2017a).

Moreover, post-hoc analyses showed that pain ratings increased after the TTE task across participants as a whole. While we did not intend for the task to manipulate pain, it is possible that participants conflated other sensations commonly felt during physical endurance/effort with pain, such as fatigue and shortness of breath, even though we instructed them to strictly report on bodily pain sensations. Nonetheless, trait-based risk for psychosis and depression was associated with increases in pain, above and beyond baseline pain ratings. Future studies should incorporate test-retest reliability indices to better gauge the accuracy of pain reports. Finally, schizotypy and anhedonic depression are typically overlapping. Indeed, in our sample they were moderately correlated ($r = 0.66$). While these two constructs likely overlap, particularly in regards to negative affect, previous research has shown them as distinct (e.g., Campellone et al., 2016). Anhedonic depression includes feelings associated with decreased hopefulness and

lack of enjoyment from activities, while schizotypy includes attenuated delusional thinking and social challenges. As such, we believe that our findings suggest pain in relation to physical activity may represent a characteristic that is uniquely associated with risk for both psychosis and low mood problems. For example, physical activity—and more specifically vigorous physical activity—may engender pain analogous to ischemic pain. Findings suggest that people with psychosis and major depression have heightened sensitivity to experimentally induced ischemic pain (Girard et al., 2011; Bar et al., 2005), a modality that is believed to most closely mimic clinical pain (Melzack and Wall, 2005). Pain experienced during a physical effort exertion paradigm such as the TTE test could be broadly classified as ischemic. As such, our findings are consistent with the literature on increased sensitivity to experimentally-induced ischemic pain in psychosis and depression. Nonetheless, as the TTE test was not designed to induce acute pain, future research should examine experimentally induced pain using well-validated paradigms in people at risk for SMI.

Ultimately, these findings speak to the potential importance of pain's interference on physical activity in the SMI population. Interventions that target physical activity in these populations may benefit from incorporating pain control. What is more, targeting pain in at-risk populations may even lower distal risk of mental illness through enhancing engagement in physical activity that may be avoided due to pain. Indeed, interventions which focus on improving physical activity in people with chronic pain often reduce pain intensity while simultaneously increasing physical activity (Geneen et al., 2017). In SMI, however, specialized interventions focusing on pain management and physical activity have yet to be designed and implemented. Moreover, interventions that focus on pain coping, for example, are highly effective in helping combat negative outcomes within chronic pain populations (Riddle et al., 2011). Therefore, interventions focusing on pain coping may be a first step in developing treatments designed to improve physical activity in people with SMI. It is important to note, however, the nuances between experimentally induced pain and clinical pain when designing interventions. Experimentally induced pain outcomes can vastly differ compared to clinical pain, and sensitivity to them may signify distinct underlying processes. Thus, more research is needed to explore the distinct processes that may influence clinical pain presentation in SMI before proper interventions can be created. Furthermore, targeted interventions may need to be developed for different groups, each focusing on how particular symptoms may interact with pain experience. Doing so will most effectively address low levels of physical activity due to pain in SMI populations.

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