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The Effects of Stress on Physical Activity and Exercise

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Abstract

Background—Psychological stress and physical activity (PA) are believed to be reciprocally related; however, most research examining the relationship between these constructs is devoted to the study of exercise and/or PA as an instrument to mitigate distress.

Objective—The aim of this paper was to review the literature investigating the influence of stress on indicators of PA and exercise.

Methods—A systematic search of Web of Science, Pub-Med, and SPORTDiscus was employed to find all relevant studies focusing on human participants. Search terms included “stress”, “exercise”, and “physical activity”. A rating scale (0–9) modified for this study was utilized to assess the quality of all studies with multiple time points.

Results—The literature search found 168 studies that examined the influence of stress on PA. Studies varied widely in their theoretical orientation and included perceived stress, distress, life events, job strain, role strain, and work–family conflict but not lifetime cumulative adversity. To more clearly address the question, prospective studies ($n = 55$) were considered for further review, the majority of which indicated that psychological stress predicts less PA (behavioral inhibition) and/or exercise or more sedentary behavior (76.4 %). Both objective (i.e., life events) and subjective (i.e., distress) measures of stress related to reduced PA. Prospective studies investigating the effects of objective markers of stress nearly all agreed (six of seven studies) that stress has a negative effect on PA. This was true for research examining (a) PA at periods of objectively varying levels of stress (i.e., final examinations vs. a control time point) and (b) chronically stressed populations (e.g., caregivers, parents of children with a cancer diagnosis) that were less likely to be active than controls over time. Studies examining older adults (>50 years), cohorts with both men and women, and larger sample sizes ($n > 100$) were more likely to show an inverse association. 85.7 % of higher-quality prospective research (≥7 on a 9-point scale) showed the same trend. Interestingly, some prospective studies (18.2 %) report evidence that PA was positively impacted by stress (behavioral activation). This should not be surprising as some individuals utilize exercise to cope with stress. Several other factors may moderate stress and PA relationships, such as stages of change for exercise. Habitually active individuals exercise more in the face of stress, and those in beginning stages exercise less. Consequently, stress may have a differential impact on exercise adoption, maintenance, and relapse. Preliminary evidence suggests that combining stress management programming with exercise interventions may allay stress-related reductions in PA, though rigorous testing of these techniques has yet to be produced.

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Conclusions—Overall, the majority of the literature finds that the experience of stress impairs efforts to be physically active. Future work should center on the development of a theory explaining the mechanisms underlying the multifarious influences of stress on PA behaviors.

1 Introduction

1.1 Review of the Problem

The association between physical activity (PA), exercise, and health outcomes is well-established [1, 2]. In the Behavioral Risk Factor Surveillance System (BRFSS) database, the number of unhealthy days reported by 175,850 adults was inversely associated with PA [3]. Those who exercise have a lower incidence of coronary events and cardiovascular disease. There is a strong inverse relation between exercise and obesity and diabetes mellitus [4, 5]. Furthermore, those who exercise have fewer incidences of certain types of cancers [6] and more robust immune responses [7]. Interventions designed to increase PA have resulted in profound reductions in physical ailments [8, 9]. There is a similar picture for exercise and mental health outcomes. Those who exercise suffer from less depression [10], anxiety [11], fatigue [12, 13], and cognitive impairments [14, 15].

Despite the well-known benefits of PA, the practice of this behavior is very low. Approximately 21.9 % of adults in the US participate in light-to-moderate leisure-time PA a minimum of five times per week, and only 11.1 % of adults engage in vigorous leisure-time PA at this same frequency [16]. According to self-report data from the BRFSS, only 48.8 % of US adults meet the minimum level of PA necessary for maintaining good health as determined by the Healthy People 2010 objectives [16].

Recent evidence suggests that one's experience of stress may be an important impediment for achieving healthful levels of PA [17, 18]. Despite the well-known effects of exercise on mental health outcomes, a lesser emphasis has been placed on the reverse relationship [19, 20]. A firmly established reverse link for depression and PA suggests that a similar trend may exist for stress and PA [21, 22]. While related to stress, depression is, nonetheless, a distinctly different construct [23]. At this time, no paper has attempted to synthesize the evidence both for and against the effects of mental stress on exercise behavior. The aim of this review is to fill this gap in the literature and to identify factors that may moderate the relationship, which may help to identify both populations vulnerable to the effects of stress and mechanisms responsible for the relationship.

1.2 Understanding Stress

There is no universal agreement on the definition of stress. McEwen [24] simply states that "Stress is a word used to describe experiences that are challenging emotionally and physiologically." These stressors may be acute (e.g., hassles) or chronic (e.g., bereavement), small in magnitude (e.g., standing in a long line), or traumatic (e.g., violent attack) [25]. Contrary to the view of stress as an impinging stimulus, other definitions provide a glimpse into what systems are challenged and how the human organism reacts. Stress may be defined as a state of threatened homeostasis, which is counteracted by adaptive processes involving affective, physiological, biochemical, and cognitive–behavioral responses in an attempt to regain homeostasis [26, 27]. Stress reactions are always followed by recovery processes, which may be compromised when stressors are severe, prolonged, or unaccustomed [28, 29]. The adaptive capacity to deal with stress is one's fitness, which when exceeded may place the individual at greater risk for disease [30]. This may be manifested in the dysregulation of active processes of adaptation, or allostasis, resulting in cumulative wear and tear of the body, also known as allostatic load [24, 31]. Typically, this has been utilized to explain how chronic stressors relate to physiological maladaptations in middle and later

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life [32]; however, mounting evidence also implicates traumatic childhood experiences, stressors that have a reverberating impact for decades [33, 34]. Therefore, stressful events appear to accumulate from the earliest days of life, and this cumulative adversity may have a profound impact on a wide range of health outcomes [35].

Lazarus and Folkman [36] provide a transactional cognitive component to stress with their concept of appraisal, which indicates that individuals only perceive stress when a challenge or event is both threatening and of such a nature that the individual is unable to cope. In this viewpoint, objective demands and subjective appraisals may differentially impact health behaviors. It is important to note, however, that some stressors may be appraised as positive [24, 37]. Cognitive models of the stress concept have recently been overshadowed by new research on the integrated role of the brain (particularly centers of emotion and memory) as a regulator of stress processes [24].

1.3 Relationship of Stress to Health Outcomes and Behavior

Psychological stress has a deleterious effect on a wide range of physical and mental health outcomes with accumulating evidence that health practices/maladaptive behaviors may mediate these relationships [38]. Stress has been strongly implicated in the pathogenesis of coronary heart disease [39] and the incidence of acute myocardial infarctions [40]. Those under high stress are less likely to survive cardiac events [41]. Alterations in the immune system by stress are well-established [42], and those who report high levels of stress are more likely to become infected [43]. The nervous system is also compromised during times of undue stress [44, 45]. Stress is associated with a host of mental symptoms as well, including cognitive dysfunction, dementia [46], and excessive fatigue [13, 47, 48]. While stress may have a direct effect on health (e.g., dysregulation of hormonal axes), indirect routes toward maladaptation also likely exist [49, 50]. For instance, stress is related to declining physical function over time [51] and obesity [52-54], which contributes to cardiovascular disease. Another likely factor is impaired health/lifestyle practices and maladaptive behaviors, such as decreased exercise and PA and increased sedentarianism [50]. Furthermore, delays in recovery from exercise [29] and dampened muscular and neural adaptations are observed with chronic stress [55, 56]. It is of no wonder that individuals under high stress are much more likely to incur greater healthcare costs [57].

1.4 Understanding Physical Activity (PA)

In contrast to the apparently debilitating effects of unremitting psychological stress, PA appears to have a salubrious effect on many health outcomes. PA is “any bodily movement produced by skeletal muscles that results in energy expenditure [58] above resting (basal) levels [59]. PA broadly encompasses exercise, sports, and physical activities done as part of daily living, occupation, leisure, and active transportation” [60]. Also implicit in this definition is that PA is a physical stressor, though not necessarily an uncomfortable one. Exercise is a behavioral subset of PA and is defined as “Physical activity that is planned, structured, and repetitive and has as a final or intermediate objective the improvement or maintenance of physical fitness” [58]. Dissimilarly, sedentarianism is “activity that involves little or no movement or PA, having an energy expenditure of about 1–1.5 metabolic equivalents (METs). Examples are sitting, watching television, playing video games, and using a computer” [61]. These definitions connote that PA behaviors are specific to a person, situation, and context. Also, they suggest that these concepts are quantified in terms of mode, frequency, duration, and intensity [60].

1.5 Beneficial Effects of PA/Exercise on Psychological Stress

When the PA and stress relationship is explored, it has typically been within the perspective of improving mental health outcomes via exercise [62]. As suggested earlier, those who exercise have lesser rates of depression, negative affectivity, and anxiety [10, 11]. Indeed, PA and exercise have been demonstrated to promote positive changes in one's mental health and ability to cope with stressful encounters [19, 63, 64]. Moreover, exercise interventions appear to improve one's depression status [65, 66].

In terms of psychological stress, similar patterns are observed in cross-sectional, prospective, and experimental studies. Exercise is associated with less subjective stress, a finding that has been observed in numerous populations from athletes to older adults to veterans with post-traumatic stress disorder [67-78]. While it is equivocal whether those who exercise have fewer life events [79-81], there is an association between exercise and fewer daily hassles [82]. It appears that the quantity of calories expended is most important. For instance, Aldana et al. [83] found that individuals who expend more than 3.0 kcal/kg/day in PA during leisure time were 78 and 62 % less likely to have moderate and high perceived stress, respectively. However, the intensity of exercise may play a key role as those who participated in exercise that was of a moderate intensity exhibited approximately half the amount of perceived stress as those who reported no exercise [83]. Intervention and prospective studies demonstrate that exercise and PA programs result in less perceived stress in real-world settings [75, 84–90]. Randomized clinical trials have determined that exercise is an effective method for improving perceived stress, stress symptoms, and quality of life [91-95]. Exercise neutralizes the effects of psychological stressors on cardiac reactivity [96] and dampens stressor-evoked increases in stress hormones [97] and serotonin [98]. For instance, Throne et al. [99] found that a 16-week intervention (exercise four times per week, 40 min) improved stress reactivity in a group of fire fighters. It appears that PA, and not fitness, mollifies the effects of stress [64, 100]; however, there is not universal agreement on this point. Those who are aerobically fit have less cardiac reactivity to stressors [101-103] and also better cardiovascular recovery [104-107]. Apart from these distinctions, a recent review concludes that exercise buffers the effects of stress on physical health [49]. For instance, exercise prevents stress-induced immunosuppression [108]. Considering the seemingly profound effects of exercise on stress, movement has been conceptualized as a method to inoculate individuals against the throes of stressful experience [109]. However, the relationship of PA with stress has not always been consistent. For instance, in two cross-lagged studies, exercise at time 1 did not predict stress at time 2 [20, 110]. Furthermore, several studies have found no relationship between stress and exercise constructs [111, 112] or relationships that were positive instead of negative [113, 114].

1.6 Reciprocal Relationship of Stress and PA

The extant literature largely concludes there are relationships between stress and PA/exercise, and that PA repels the negative effects of psychological stress, but what of the relationships in the opposite direction? In other words, is stress detrimental towards the effort of adopting and maintaining exercise behavior? It has been noted extensively that a dynamic, bi-directional relationship likely exists [19, 21, 24, 38, 49, 50, 83, 115-124], but this direction of influence is often overlooked [53]. Salmon [19] mused that the stress and PA-exercise relationships are open to interpretation, and "people who are less disturbed by stress might simply be more ready to take up exercise training" (p. 46). Zillman and Bryant [117] propose that in response to stress people will engage in unhealthy behaviors, such as poor dietary practices or a lack of exercise, as a means of emotion-focused coping. Indeed, a plethora of research links stress to increased smoking [125-127], use of alcohol [128], and increased substance abuse [27, 129, 130]. While less pernicious, stress is associated with dietary relapse [131-133], binge eating [134], increased caffeine consumption [135] and television viewing [136, 137]. Studies examining composite scores of collective health behaviors, including PA, find that stress is predictive of negative health behaviors [138-143]. In fact, stress accounts for a substantial proportion of variance in collective health behaviors [143]. Considering the multifarious relationships between stress and behavior, it is plausible that stress is related to both PA and exercise as well.

Further evidence of this proposed relationship emanates from studies on depression and negative affect and how these factors predict PA. Negative affectivity, anxiety, anger, and distress inversely predict exercise behavior [21, 144-148]. Negative affect predicts missed practices due to injury and illness, and this may be attenuated with the implementation of a stress inoculation training program [149]. Depression predicted changes in PA in women diagnosed with early-stage breast cancer [150] and was related to less PA in the Alameda County study [151]. Depressed cardiac rehabilitation patients are less likely to adhere to the exercise program; coming to fewer sessions and dropping out at high rates [152]. Concurring with these observations, a recent review of prospective studies found that depression at baseline is inversely related to measures of PA at later periods [22]. Reviews examining factors associated with increased exercise behavior and adherence have found mixed or a lack of evidence of an association between stress and PA, particularly when compared to other factors [153-161]. However, in every review, authors failed to amass the bulk of pertinent literature on the topic. Lutz et al.[20], in an attempt to address the bi-directional relationship of stress and exercise, determined that the relationship was stronger in the direction less often studied, underscoring the notion that stress degrades this healthful behavior. Since this time, however, no review has attempted to synthesize the diverse literature examining the effects of stress on PA. The purpose of this review, therefore, was to fill this gap by systematically identifying, classifying, and appraising the extant literature on this topic across all pertinent disciplines, including sports medicine, health psychology, health promotion and occupational health, among other areas.

2 Methods

2.1 Search for Publications

A search was conducted in Web of Science, SPORTDiscus and PubMed for relevant literature. The search terms utilized were “stress”, “exercise”, and “physical activity”. This yielded a large number of returns. Consequently, the search was narrowed by selecting options in each database. When possible, articles were eliminated for irrelevant fields (e.g., engineering, chemical science, etc), unoriginal data (e.g., review articles, corrections, editorials, magazine articles), non-human subjects, and text not reported in the English language. Starting with Web of Science, titles and abstracts of articles were reviewed by one of the authors (MSK) for relevance with date in descending order. To speed the search, titles containing “stress test”, “oxidative stress”, “stress fracture”, “stress incontinence”, or “urinary stress” were automatically disqualified. Abstracts were also reviewed for relevance and scanned to make sure that PA was the outcome variable of interest and stress variables were the predictors. Case-control studies that investigated PA in stressed populations were retained. After this process was completed for the first database, the inspection of results for SPORTDiscus ensued. Articles were further eliminated if they were duplicated in Web of Science. This resulted in a very small collection of additional articles. With the additional fact that the initial results from PubMed were very large, the search date range was shortened to the years 2000–2012. These returns were searched for relevance as before. Finally, all article reference lists were examined for pertinent reports. The last search for articles via database was in July 2012 (see Fig. 1).

2.2 Study Quality Assessment

Prospective studies (n = 55) were assessed for risk of bias with a quality assessment rating scale modeled after Rhodes and colleagues [162]. As with this former study, this instrument was developed to assess risk of bias as defined by the Cochrane Collaboration [163]. The quality scale comprised nine questions answered with a "yes" or "no" response (e.g., Did the study include a control group comparison? Was an objective measure of physical activity/inactivity used?). Low risk of bias (high quality) was deemed for studies with a score of 7–9, moderate quality and risk of bias for studies with scores between 5 and 6, and high risk of bias (low quality) for studies with a score of 4 or below (see Electronic Supplementary Material, Appendix 1).

3 Results

3.1 The Effects of Psychological Stress on PA/Exercise: State of the Literature

The search yielded a total of 168 papers interested in the impact of stress on PA. Five studies were published in the 1980s, 37 in the 1990s, 86 in the 2000s, and 40 from 2010 to July 2012 (see Fig. 2). The first evidence in the scientific literature of the link between mental stress and PA was reported in the early 1980s [164] (refer to Gardell et al. [165] for an earlier study reported in Swedish). Research at this time addressed the impact of stress on a host of health-promoting and -degrading behaviors, including alcohol use, smoking, dietary practices, and PA [164, 166-168], in particular in relation to their role as risk factors for cardiovascular disease. This early work was epidemiological in nature, typically cross-sectional, employing very large sample sizes [164, 169, 170]. Furthermore, the population of focus frequently was middle-aged adults in occupational settings [169, 170].

Since this time, research designs have varied widely and have extended to include qualitative [171-179], retrospective [77, 180-183], prospective [17, 20, 184-192], and experimental work [193], although most studies are cross-sectional [143, 194-196]. Likewise, studies have narrowed from the examination of stress on the wider scope of health behaviors to a specific focus on the effects of stress on PA and exercise. Furthermore, stress has emerged as a central component of several theoretical models of PA behavior [170, 197-200]. Most studies investigating the relationship between stress and PA have anticipated that stress would debilitate PA behavior. However, some studies have specifically approached the problem from a coping perspective, predicting enhanced PA under stress [168, 188, 201].

The majority of studies identified by the literature review supported the hypothesis that stress has an impact, whether negative or positive, on PA behaviors (n = 134, 79.8 %). However, the literature is not entirely in agreement with regards to the valence of the association. The majority of studies (n = 123, 72.8 %) provide evidence that psychological stress predicts *lesser* PA or exercise. Nevertheless, correlations of stress and exercise in studies supporting the association typically find no relationship greater than –0.28 to –0.42 [89, 143, 202-204]. Conversely, 29 (17.2 %) studies provide evidence of an *increase* in PA with stress. As might be apparent, some papers reported evidence indicating (a) an association in *both* a positive and negative direction; and (b) that some indicators of stress and PA were not associated, but others were in either a positive or inverse direction (see Table 1).

3.2 Supporting Evidence for an Inverse Relationship Between Stress and PA

3.2.1 Cross-Sectional, Retrospective, and Qualitative Studies—Studies conducted over a single time point (cross-sectional, qualitative, and retrospective, n = 114) have established an association between stress and PA. While two-thirds (67.0 %) of cross-sectional studies reported a negative association of stress with exercise, qualitative and retrospective (where respondents self-assess changes in PA) studies unanimously find evidence of an inverse association. These studies were typically of lower quality, with the exception of one study which reported that nearly 30 % of college students who were sufficiently active in high school did not attain this level of PA when transitioning to college [180] (see Electronic Supplementary Material, Appendix 2 for more details).

Stress has been inversely related to exercise and PA behavior most frequently for employee populations (22 studies) [83, 194, 205-224], but also for individuals in community fitness programs [225], those with heart disease [147, 226], pregnant women [174] and those in national probability samples [227, 228]. When examining specific age groups, it is apparent that the results replicate for college-aged and young adults [180, 202, 203, 229-231], middle-aged adults [143, 167, 232, 233], and the elderly [195, 234-237], but no cross-sectional data exist for children and only qualitative data exist for adolescents [171]. The relationship has been found for both genders, although several studies found that men were more vulnerable than women [194, 229, 237, 238], while other studies observed the opposite trend [202, 239, 240]. Stress also was related to lesser PA in several minority populations [177, 195, 198, 219, 241], and ethnicity/race may interact with stress on PA [207, 242]. However, there appears to be no moderating effect of age or education [196]. The associations appear to be true for reports of exercise [243-245], PA measures [202, 203], sedentary behavior/inactivity [170, 195, 197, 209, 230, 246, 247] and days of sports participation [171, 248], but little data exist for energy expenditure [249]. Stress is linked to low levels of PA in chronically stressed populations, such as military spouses [196], cancer survivors and those in treatment [182, 243, 250], low-income and first-time mothers [172, 173, 251], medical school students [229, 252] and caregivers [239, 240, 253-257]. Several case-control studies have demonstrated that stressed populations, such as caregivers and parents of children with cancer, have lower PA and exercise behavior than matched control groups [239, 240, 254, 255, 258].

3.2.2 Prospective Studies—Directionality of the stress and PA association is evidenced by many prospective studies in which a time-lagged effect may be assessed ($n = 55$) (see Table 2). The majority of these studies ($n = 35$; 63.6 %) were rated as high quality, meaning that they were more likely to use validated instruments, control comparisons, appropriate statistical methods, and theoretical frameworks. Some studies, however, were of moderate ($n = 19$) to low ($n = 1$) quality (see Electronic Supplementary Material, Appendix 1). Many studies conducted in naturalistic settings have found evidence that stress is associated with facets of PA at a later time point [17, 20, 79, 181, 210, 245, 259-272]. For instance, in an employee population from a large food processing plant in Texas, USA, Lutz et al. [20] found that perceived stress predicted leisure time PA 2 months later. Furthermore, this association was greater than the cross-lagged relationship of exercise at time 1 on perceived stress at time 2. Likewise, in a random sample of Danish adults, those who were high in stress were 2.63 times more likely to be classified as inactive at baseline and 90 % more likely to become inactive a decade later [270]. Burton et al. [263] found that those low in emotional stress were more likely to initiate brisk PA at least three times a week than those high in stress (35.8 vs. 14.6 %). In this same study, low-stress individuals were also more likely to maintain PA over a 4-year period (69 vs. 36.4 %). On the other hand, a few studies have found no support whatsoever of a relationship [79, 145, 191, 273-277] or evidence for a positive association of stress and PA [17, 188, 259, 261, 262, 264, 267, 269, 278-280] (see below for more details).

Studies employing diary techniques have found that exercise behavior changes in days [269, 281, 282] and weeks when experiencing stressful events [17, 188, 189] and subjective stressful states [265]. Jones et al. [267] found this was true for negative affectivity, but job strain was related to *greater* PA over a 4-week period. Mixed results were also discovered by Lutz et al. [17] who followed a group of 95 young women over a 6-week period. In this study, less-experienced exercisers held steady or declined in self-reported exercise frequency, intensity, and duration during weeks of greater life event stress frequency and impact. Stetson and colleagues [189] utilized the same measure of life events (the Weekly Stress Inventory [283]) and compared periods of low versus high stress among middle-aged women. They found an effect of *stress frequency* but not stress impact on exercise duration (effect size [ES] = 0.14) while *stress impact* influenced the number of planned exercise sessions that were missed (ES = 0.22). In a study with a similar data analytic approach, Steptoe et al. [188] found that exercise frequency and duration of both moderate/vigorous and low-intensity exercise decreased between two low-stress and two high-stress weeks; however, this was not statistically significant (d values = 0.16–0.25). Unfortunately, this study suffered from high attrition, which may have masked any significant results as stressed individuals tend to dropout at higher rates.

Finally, intervention studies targeting stress [284] or exercise/health behaviors [89, 124, 204, 281, 285-287] have found inverse associations between stress and indicators of PA over time. For instance, Urizar et al. [89] found that PA changes over a 10-week period were moderately correlated with maternal stressors over the same period ($r = -0.42$). In a particularly interesting study, Dougall and colleagues [286] were granted permission to access records of students' use of a university fitness center. The frequency of these visits was related inversely to stress levels. Some interventions, however, have found no association [145, 273, 276, 277] or that higher stress relates to greater PA [279]. Improvements in exercise readiness over time are compromised by the experience of stress [124]. Whether stress has a stronger association with adoption or continued participation of an exercise routine/PA programming is undetermined [184, 278, 288]. Indeed, both subjective stress and life events negatively affect adherence to exercise programming [89, 184, 204, 287, 289, 290] and intervention attrition [145], but not all studies agree with this assessment [145, 276]. Post-intervention PA maintenance may be affected to a greater degree by the experience of stress [184, 291]. In an underpowered investigation, Williams and Lord found a trend in this direction, which was not significant [277].

3.2.3 Prospective Evidence of Changes in PA Behaviors During Objective Conditions of Stress—In rare instances, prospective studies have employed designs to compare a period of objective stress (i.e., final examinations) with a less stressful period [185, 187, 191, 192], to compare a stressed and non-stressed population over time [186, 190], or to manipulate a laboratory stressor compared to a control condition [193]. These studies were typically of high quality (rating ≥7), with one exception [185] (see Table 2). Of these seven studies, six discovered a statistically significant effect of stress on exercise and/or PA.

Final examinations are naturalistic stressors which have been studied opportunistically to assess temporal associations of stress and PA behaviors. Examinations are also objectively stressful, typically endure over a longer time frame (as opposed to a discrete conflict) and provide greater ecological validity than laboratory-induced stressors. Oaten and Cheng [192] and Steptoe et al. [187] assessed students during a baseline period near the beginning of a semester and also during final examinations. Control groups were assessed at the end of the semester but not during examinations. Both studies found declines in duration of exercise/PA compared to controls, but Oaten and Cheng [192] also found declines in exercise frequency and the perceived ease of exercise. Final examinations are not uniformly stressful over an entire examination period. In an attempt to capture the most stressful point of this time frame, Sherman et al. [185] measured exercise in a group of 17 students 14 days before their most stressful final examination (as determined by self-rating of anticipated strain). Their exploratory analysis found that exercise decreased on the day of the examination compared with 14 days earlier ($d = 0.62$; $\eta^2 = 0.23$). In a less rigorous design, Griffin et al. [191] found that exercise decreased for those college students experiencing increased demands during examination stress; however, the changes were not significant.

Nevertheless, there was a significant correlation between stress and exercise at baseline. The lack of a significant finding at the second time point may be related to the fact that this study was confounded by a high dropout rate.

Two longitudinal, case-control studies agree that stress has an influence on PA. Smith et al. [186] found that parents of a child who had just received a cancer diagnosis reported lower weekly PA and more television viewing post-diagnosis than parents of a healthy child (approximately a 1,000 kcal difference). The size of the effect post-diagnosis was 1.71 (Cohen's *d*) and 3 months later was 1.13, indicating a large effect. Vitaliano et al. [190], studying caregivers and matched controls both with and without a cancer diagnosis, found that caregivers were higher in stress indicators, as expected, and also lower in reported exercise frequency at two time points. When comparing the caregivers and controls without cancer, the effect sizes (Cohen's *d*) were 0.41 and 0.57.

The study by Roemmich et al. [193] is exceptional in that it identified that a single, acute interpersonal stressor causes reductions in PA. Children participated in two experimental conditions, the order of which was randomized within subjects. The experimental condition was a strong interpersonal stressor, where the child prepared and delivered a videotaped speech on a social topic. The control condition was a passive reading activity. After each condition, children were provided the opportunity to be active on a cycle ergometer or remain sedentary. Results indicated that after the stressor condition, both energy expenditure and total exercise minutes decreased. In fact, PA decreased by 21 % during the stress condition; however, changes in perceived stress were not related to changes in exercise behavior ($r = -0.19$). Furthermore, those children who had high autonomic stress reactivity had even greater reductions in these exercise variables. Altogether, these results indicate that acute and transient life stressors have a negative impact on PA in humans.

3.2.4 Factors that may Influence Prospective Associations Between PA and Stress—The relationship of PA and stress may vary based on several factors. Therefore, results were further broken down by gender, age, sample size, study quality, and whether the study focused specifically on clinical populations or cohorts of employees. Levels of these factors with >80 % of studies finding evidence of an inverse association were deemed as more likely to be negatively affected by stress. Per this cutoff, studies examining older adults (>50 years; 80.0 %), cohorts with men and women and larger sample sizes ($n > 100$; 82.1 %), as well as studies of higher quality (≥7 on a 9-point scale; 85.7 %) were more likely to show an inverse association. Other factors, such as whether a study's subject pool comprised employees or a clinical population, did not clearly differentiate the literature (see Electronic Supplementary Material, Appendix 3).

3.3 Contrary Evidence for an Association Between Stress and PA

Despite this evidence, some studies have found no association whatsoever between stress and PA. In fact, 34 studies in this review found no effect of stress on PA outcomes and several more found marginal or conflicting results [79, 127, 145, 166, 169, 191, 200, 205, 273-277, 292-312]. These studies frequently had less rigorous designs [166], smaller samples sizes [273, 303], and very poor measures of PA/exercise and/or psychological stress [297, 308, 310]. Stress management interventions have failed to demonstrate a concurrent increase in subjective and objective markers of PA [273], and stress did not appear to affect compliance with exercise programming [276]. As mentioned above, eight prospective studies did not find a relationship. For instance, Grace et al. [274], examining a group of pregnant women over three time periods during and after pregnancy, found *no* relationship of role strain or pregnancy (a major life event) with PA.

3.4 Evidence that Stress may Increase PA

Speaking to the point of positive influences of stress, 29 studies found that stress predicts an *increase* in PA behavior [3, 17, 81, 164, 168, 171, 172, 175, 183, 251, 253, 254, 256, 259, 262, 264, 267, 269, 278-280, 313-320], ten of which were prospective (see above). Other studies found trends in this direction [169, 191]. Lutz et al. [17] found that this was only the case for habituated exercisers. Brown et al. [262] found that some life events were associated with increased PA, including distressing harassment, beginning a new close personal relationship, retirement, changing work conditions, major personal achievement, death of a spouse/partner, and income reduction. Seigel et al. [183] reports that in a random sample of young Swedish women, 22.0 % were likely to increase PA, 60.1 % were likely to be unaffected, and only about 16.5 % of respondents were likely to decrease PA with the experience of stress.

3.5 Life Transitions, Major Events, and Trauma

A substantial portion of the literature focused on specific events, life transitions, or distinct experiences of trauma. As noted above [262], some life experiences result in enhancement of PA behavior. Nevertheless, this same study found that exercise declines for women for some types of events, including the birth of one’s first or second baby or grandchild, having a child with a serious illness or disability, beginning work outside the home, major personal illness or injury, major surgery, or moving into an institution [262]. Death of a spouse was deleterious for PA in older women [204]. Transitioning from high school to college or leaving college and entering the workforce full-time is also predictive of a decline in PA [180, 260, 321]. Fan et al. [200] found that being a victim of violence, harassment, or other threats was not related to PA. This is contradicted by evidence that exercise behavior substantially declined for New Yorkers after the trauma of the 9/11 attacks [181]. In contrast, the experience of Hurricane Katrina in the USA has been associated with heightened levels of PA [313].

4 Discussion

4.1 Summary

The majority of the literature finds an inverse association of stress and PA behaviors. The current search uncovered 168 studies reported in the English language exploring these relationships in humans. This demonstrates a high level of interest in the topic for the last two decades, with an apparent acceleration in research production in the area. The literature provided ample support for an association between stress and PA (79.8 %), and of the studies identified, 72.8 % supported the hypotheses that higher stress is associated with lesser exercise and/or PA. Prospective studies with objective markers of stress, one indicator of study quality, nearly unanimously agreed (six of seven studies, 85.7 %) with this conclusion. Studies examining older adults (>50 years), cohorts with men and women, and larger sample sizes ($n > 100$) as well as studies of higher quality (≥7 on a 9-point scale) were more likely to show an inverse association. Other factors, such as whether a study’s subject pool comprised employees or a clinical population, did not clearly differentiate the literature finding inverse relationships between stress and PA and the literature finding a null association. Interestingly, 17.2 % of prospective studies found evidence that stress was predictive of *greater* PA and exercise behavior, and qualitative studies were particularly equivocal in regards to the valence of the association. While these findings cannot be labeled definitively as anomalies, it is clear that stress exerts a generally negative influence on PA.

The review of the literature found many life events and transitions that resulted in changed PA [3, 260, 262]. This specific area of inquiry has garnered substantial interest, with two review articles already published identifying specific life events that relate to perturbations in PA [322, 323]. One recent review determined that five life changes were associated with change in PA: employment status, residence, relationships, family structure, and physical status [322]. Marriage and remarriage are often, but not always, associated with declines in fitness while divorce is associated with gains in fitness, at least in men [266, 324]. Chronic disease diagnosis can be very stressful [325] and a vast literature connects the diagnosis of cancer [182, 243, 264, 315, 326-328] and HIV [329] with changes in PA. However, only a few studies gauge how mental stress associated with these conditions relates to changes in PA [182, 264], and none were able to objectively capture PA before a diagnosis. Another criticism of this approach is that many of the above events may be interpreted as being positive in nature. However, from a classic life stress perspective, any type of event or transition that causes dramatic changes to one's life can result in concomitant changes in behavior and health [330]. Alternatively, being inundated with minor nuisances may also weaken one's attempts for healthy behavior—perhaps to a similar degree as the experience of a small number of major life events [17, 189]. A familiar example includes holiday periods, when many people exercise less and eat more [331]. Given that most humans experience change frequently, clarification is needed to discern the specific conditions under which an event or series of events may perturb PA.

As might be expected, not all studies found an association between stress and PA. However, several studies suggest that the association may be indirect or masked by factors that moderate the relationship, such as exercise stage of change [17, 332, 333]. For instance, Lutz et al. [17] found that that women in the habit of exercising, in other words, at a higher stage of change, exercised more during times of stress. Conversely, infrequent exercisers were less active during periods of strain. This finding was supported by Seigel et al. [183], who found that young women who increased activity with stress were more avid exercisers. One's stage of change for exercise, however, is not itself related to indicators of stress [243, 334]. Budden and Sagarin [210] found no association between exercise and occupational stress, but did find that stress related to perceived behavioral control for exercise, which in turn predicted exercise intention. Intention was predictive of actual exercise behavior. Payne et al. [333] found a similar pattern of results in a group of 286 British employees. Clearly, the influence of stress varies by individual attributes, which in some cases may obscure simple associations between stress and PA.

4.2 Clinical Implications

Stress interferes with the engagement of activity for the majority of people, which has important theoretical, practical, and clinical significance for professionals in the health and exercise fields. This is especially true given that the experience of stress (a) is widely prevalent; (b) has repercussions for a wide range of health issues; and (c) is reported as a growing problem in developed countries around the globe [18]. On the second assertion, it is well-known that a link exists between stress and the development of depression, cardiovascular disease, and many other health endpoints [50]. Convincing evidence is emerging that such links are moderated by PA [49, 53], with some data indicating that the connection is contingent on changes to this behavior [212]. With all of these facts in mind, health policies should include provisions for integrated prevention and treatment of chronic stress and its behavioral and medical sequela. Before this progress can materialize, however, the well-identified associations between stress and health-promoting behavior must be more recognized within the community of PA researchers, practitioners, and other advocates.

At this time, action must be taken to advance PA interventions by interweaving effective stress management techniques. Simply arousing knowledge of stress is not sufficient [335]. First, practitioners should measure objective and subjective measures of stress for each individual. This effort will help to identify those at risk for the effects of stress. Working with an interdisciplinary team, such as psychologists and therapists, will help to promote careful interpretation of these data and will provide the resources to more carefully attune to the client's stressors and associated constrains, barriers, and needs [336]. Furthermore, practitioners should be mindful of stress vulnerability across stages of change and refine prescriptions accordingly to magnify adherence and to prevent relapse and dropout [184, 189]. For people contemplating a new exercise regimen, stress may interfere with attempts to *initiate* PA, and this may translate to an inability to reach healthful levels of exercise [184, 189]. On the other hand, those habituated to exercise exhibit resilience in the face of stress [17, 183]. In addition to exercise habits, it is worthwhile to identify individuals' coping style. Some people use exercise to deal with stress (exercise approach) while others become distracted and succumb to the lure of less healthful behaviors (exercise avoidance). This emphasizes further that prescriptions should be tailored to the individual [60]. Stress differentially impacts various populations and interventions must be modified accordingly [232, 337]. As an example, Urizar et al. [89] suggests that specific coping strategies should be addressed for mothers based on family constraints, including social support, problem solving, reframing cognitions, and strategies to balance motherhood with the need to care for oneself. Relapse prevention counseling is an example of a technique that incorporates stress management [331, 338] and is a recommended intervention for stressed populations [184].

The content of these programs should be comprehensive. Identifying high-risk situations ahead of time is an important strategy [331, 339], and those who can predict stressors are typically better able to diminish losses potentially associated with them [340]. Teaching stressed individuals the importance of exercise as a method to emotionally cope, plus the problem-focused skills to cope with stress aside from exercise, is a dual priority [119, 341]. As exercise is a complex behavior for the newly active, requiring much planning, resources should be put in place to assist the stressed individual with the creation of primary and contingency plans. On this note, interventions that are more flexible and 'user-friendly' are necessary to help clients re-engage with stress-derailed PA regimens [154]. Much has been made of the stress-impulsivity connection and, consequently, a full complement of self-regulation strategies would likely be useful [129, 282, 342]. Simply continuing to exercise on a regular basis is a method to build self-control [88], and it is difficult to obviate well-established and reinforcing habits. Lastly, and perhaps most important, there is evidence that combining an exercise intervention with stress management can result in increased exercise during times of stress or prevent relapse [149, 279, 343]. Such practice has been successfully employed with alcohol and other drug treatments [344, 345]. Mindfulness-based stress reduction (MBSR) is a highly effective technique to promote stress reduction, and enhancing aspects of this program, such as mindful walking, may be an ideal avenue for intervention [346]. In summary, creating interventions to target stress and coping skills may help to facilitate greater PA and, ultimately, improved health outcomes.

4.3 Exercise as a Stressor

From a practical standpoint, exercise and the associated actions required to accomplish it may simply be burdens or minor stressors themselves. For many people, structured exercise is highly inconvenient ("one more thing to do" [189, 347]) during periods of greater strain [348]. As an example, women who work long hours feel unable to exercise due to many demands on their time, interference from family obligations, and other barriers [196]. Similarly, teenagers in the midst of household conflict find it difficult to plan for sports participation [171]. It has been noted that planning for exercise but then missing it due to stress-related circumstances may degrade exercise self-efficacy and add further frustration and dissatisfaction [159]. Langlie [349] found that during times of stress, individuals feel a lack of control and perceive maintaining health behaviors as costly. Consequently, for those who view exercise as a disruption, an inconvenience or another demand on their time, it is not a stretch to predict that exercise will decrease with stress. This may be particularly true when starting a new exercise routine [204, 347]. Indeed, Holmes and Rahe [330] suggest that any perturbation of one's normal daily routine constitutes a stressor. Several studies have considered the potential social stress of PA participation [350-354]. For instance, inactive people are more sensitive to criticism of their bodyweight and fitness, more readily embarrassed, and may derive less affective pleasure and reinforcement from exercise [355], all of which may result in exercise avoidance, particularly when already in a state of mental stress. The perceived threats of comparison and competition, as well as the anticipation of an exhaustive effort may be much less tolerated under these conditions [122, 356]. All of these sources of additional stress should be considered in intervention design. Unfortunately, making one's PA routine more convenient, such as exercising at home, does not necessarily mean that it will result in better adherence to exercise regimens. For instance, King and associates [184, 204] found that life events equally degraded adherence to a home-based or class-based exercise program.

The above discussion should impress upon the clinician and researcher that exercise is itself a mental [85, 356-361] and physical stressor [362-366]. In short, the stress of exercise may in some circumstances interact with psychological stress to dampen PA behavior. Indeed, exercise might by typified as a self-inflicted stressor, often intentionally undertaken with a goal of attaining health and fitness. While such experiences are generally considered adaptive, not all outcomes are positive in nature. From a physical standpoint, for instance, there is always risk of injury [309, 367], which is magnified under conditions of stress [368] and may result in missed exercise participation. Exercise undertaken in unaccustomed volumes can elevate glucocorticoids and stunt physical processes, such as neurogenesis [369]. Ultimately, at very high levels exercise may result in deleterious outcomes, such as unexplained underperformance syndrome. This outcome may be exacerbated by the experience of mental stressors and, likewise, may result in additional sensations of stress [370]. Indeed, increased exercise over a period of days or weeks can contribute to negative shifts in one's mood [371] and increased perceived stress [372]. A recent study found that poor muscular recovery was associated with self reports of chronic stress [29]. As sensations related to muscle damage likely result in impaired PA [373], it is possible that stress may affect exercise behavior by magnifying unpleasant sensations associated with exercise.

4.4 Significance of Literature Finding a Positive Association Between Stress and PA

Findings that stress may elicit increases in PA behavior should not be considered happenstance and may explain studies with null findings [17]. Castro and associates [145] found that women who were anxious at baseline had better adherence to an exercise program over 12 months, and a similar result was found for colorectal cancer patients [264]. Johnson-Kozlow et al. [279] implemented an exercise intervention for a group of students in which stress management was a central feature. It should not be surprising then that with burgeoning stress men *increased* PA in this study. Health behaviors, such as exercise or recreational park use, may actually improve after a major life event, such as the death of a spouse with Alzheimer's, simply because barriers for behavior are removed [374, 375]. Moreover, such observations are consistent with theories that predict changes in behavior in either direction with stress [183, 330, 376, 377]. For instance, resiliency researchers have long stressed that adversity may spur some individuals to higher levels of functioning [376, 377]. Seigel et al. [183] suggests a nomenclature for these disparate responses, referring to increased PA with stress as *behavioral activation* and weakened PA as *behavioral inhibition*, responses that appear to vary by traits of the individual. The rebound hypothesis of stress and PA proposed by Griffin et al. [191] posits that stress can result in a degraded PA response followed within days or weeks by a compensatory uptick in PA. Specifically, these researchers speculate that people may overdo healthy behaviors, such as exercise, to compensate for poor attention to health during the stressful period.

In the face of stress, one may elect to obviate feelings of displeasure by engaging in exercise, a form of emotion-focused coping [62, 168, 378]. Indeed, exercise may result in enhanced feelings of pleasure and is widely accepted as a tool for stress management [118, 201, 379-381]. Stetson et al. [189] found that 69 % of their sample of women exercised to relieve stress. Qualitative research indicates that individuals will use low to moderate intensity exercise (i.e., walking) as a method to regulate emotions [173, 293]. Interestingly, despite the expectation that PA will lessen displeasure, exercise enjoyment appears to be affected during weeks of stress [189]. Nevertheless, people who believe that exercise is a useful method for stress reduction are more likely to engage in a moderate or greater level of exercise [225, 318]. Those who exercise to cope with stress report higher exercise behavior than those who do not cope by exercising [188]. Stress management as a motive for exercise has been found for several populations [178, 382-386]. However, a large sample of highly active fitness enthusiasts reported that stress management ranked far below other sources of motivation, such as exercise enjoyment [387].

These issues decry the general lack of understanding of the relationship between coping with stress and PA. Exercise behavior declines on days when individuals use more emotion-focused coping [201], but in general the use of positive coping behaviors is related to greater PA [250, 300]. The general coping style of the individual may account for these differences, as people with rigid coping styles tend to increase PA behavior with increased stress [280], although this finding is challenged by other data [150]. Moos and Schaefer [388] state that "Among self-efficacious individuals, engaging in PA can be described as a task-oriented way of dealing with stressful events using a behavioral-approach coping style. Alternatively, engaging in PA may be used to *avoid* life stressors among less self-efficacious individuals." This suggests that exercise may serve to both deal with and steer away from stress, and the strategy utilized may vary by one's self-efficacy for exercise. This may be particularly salient for those who are exercise dependent [389, 390] and for those who compensate for stress-induced overeating by exercising [183, 391-393]. These phenomena add an extra layer of complexity to any analysis of stress and exercise and may account for weak relationships observed by many studies.

4.5 Limitations of the Literature: Methodological Considerations

Several limitations in the stress literature have been discerned by this review, particularly as identified by the quality assessment rating (Electronic Supplementary Material, Appendix 1). The most obvious is the limited amount of experimental evidence. The use of control groups should be utilized, as changes in PA are frequently due to other factors, such as a change in seasons [331, 394]. Examination and holiday stressors coincide with more averse weather in many latitudes, which is perhaps the greatest limitation in this area of research. Cross-sectional studies cannot provide indication of the direction of influence. Does stress impact exercise directly, or do inactive individuals self-select more stressful environments [170]? Such a possibility implies that other factors may be responsible for the association. Nevertheless, more than 50 studies in this review utilized a prospective design, which allays some concern.

Apart from issues of design, there are also issues with measurement. First, stress may impact the recall of exercise behavior as opposed to exercise behavior itself, with activity being over- or understated [395]. Objective measures of PA, therefore, are greatly needed, and only a few cross-sectional studies have employed such markers [249, 258]. Furthermore, most subjective measures do not capture the full complexity of the behavior, including occupational and commuting activity [308]. To illustrate this point, Fredman et al. [254] found that caregivers have greater self-reported *total* PA than non-caregivers but lower *leisure time* PA. Moreover, many papers do not inquire about exercise intensity, although it is equivocal as to whether intensity is impacted to the same degree as frequency or duration [17, 229, 241, 251]. It is possible that an individual may shift intensity as the priority for fitness, typically achieved with greater exercise effort, gives way to a greater emphasis on stress management [173]. When athletes are specifically asked what mental factors prevent them from giving 100 % effort in practice, they typically list life events, school demands, and other stressors [396]. Lastly, it is unfortunate that nearly 50 % of prospective studies did not utilize pre-tested PA/exercise measures, with some relying on simple dichotomous measures of exercise behavior [210, 219, 263].

The measurement of stress appears to play an important role in the stress–exercise literature. Measures of stress varied greatly in the studies reviewed, which parallels the multiplicity of stress definitions employed. Studies in this analysis were divided nearly evenly on whether they focused on subjective (i.e., perceived) or objective (e.g., life events, daily hassles) measures of stress, and several studies have also specifically focused on chronically stressed populations [173, 186, 190, 196, 251]. Studies employing measures of life stress sometimes include both positive and negative life events with no differentiation [280], whereas others have focused exclusively on negative experiences [184]. Any challenging experience will tax the human organism at varying degrees, but many studies have favored a summation of life events without considering the weighted impact or magnitude of each individual event [25, 184]. Exercise has been observed to serve as coping during transient stressors [168, 397, 398] and even when experiencing a major life event [175, 184]. Other dimensions of the stress process may also be salient, such as the predictability of the event or an individual’s perceived ability to cope with the stressor [36]. One must also consider the type (e.g., social, financial) and controllability of stress, all of which may influence whether exercise is utilized as a coping device. On days when stress is perceived as controllable, exercise increases [201]. Animal models demonstrate that different types of stressors (i.e., social defeat vs. open field stress) result in either habituation or non-habituation of PA [399]. Indeed, social stress resulted in a significant decline in PA amongst children in the only experimental study to date [193]. Lastly, it is important to note that no research specifically focused on cumulative adversity, a construct associated with many health behaviors [125, 128].

A tertiary area of concerns lies in temporal aspects of stress research. From a measurement perspective, assessments of stress and PA are often mismatched, with one measure inquiring about stress over a given period (e.g., the last month; Perceived Stress Scale [PSS]) and the other inquiring about PA over a different period of time (e.g., the last year, Modifiable Activity Questionnaire [MAQ]) [124, 191, 259, 286, 295]. Prospective studies, while an improvement over cross-sectional ones, do not always gauge stress and PA at each time point [268, 279]. This is important to determine bi-directional associations of stress and PA. Diary studies have provided considerable improvement in this respect, while also being less affected by stress-related memory deficits [17, 189]. Most research has failed to look at relationships in both a concurrent/contemporaneous and time-lagged manner [245]. While it is possible that stress has a weak relationship with PA at any given point of time, a much stronger relationship likely exists between stress and (a) PA at a future time, (b) PA change scores [17, 124, 189], and/or (c) more qualitative measures including exercise adoption, maintenance [184, 199] and intervention adherence. The Physical Activity Maintenance (PAM) model [199] argues that stress most relates to relapse, and a plethora of evidence looking at other health behaviors would support this notion [129]. A cross-lagged analysis would help to determine which direction of influence is stronger between stress and PA, but only one report has undertaken such an analysis [20].

Sample characteristics are germane to the study of stress. It is frequently difficult to recruit truly stressed subjects for research studies, which results in a response or selection bias

[400]. Consequently, a constrained range or low level of stress scores (i.e., not enough variability in stress) may obscure any true effect [191, 275, 303]. Those who drop out of studies tend to have higher stress and anxiety, which could also mask any potential effects [188]. Several studies finding an inverse trend of a stress–PA association have been underpowered [277], while others are overpowered, detecting trivial associations [260, 268, 270, 272, 316]. Studies with large samples of inactive participants (or conversely all active subjects) may not have enough variability in exercise measures to detect an effect [273].

Finally, it should be noted that this review has limitations. Only three databases were searched. Moreover, the search in PubMed was truncated and did not extend before the year 2000. However, these are not likely substantive issues considering (a) the numerous studies discovered; (b) the retrieval of few unique investigations in successive database searches; and (c) the linear distribution of papers across time (Fig. 2). Additionally, this is the first review of its kind; therefore, this analysis adds considerable insight into an area that has produced a large quantity of data. Despite this abundance, the current body of work has not been featured well in reviews summarizing psychosocial influences on PA, necessitating the current report [153-160].

4.6 Future Directions

Possibilities abound for future research in this area. Currently, evidence demonstrating the efficacy of an exercise–stress management intervention is scant. Nevertheless, initial reports are promising [192]. Interventions could be optimized if stress–PA relationships could be titrated. For instance, Oman and King [184] discerned that an increase in major life events, specifically from three to four, did not result in a proportional decline in exercise adherence. This type of research represents an important area of future inquiry and could be coordinated to additionally identify the factors that potentially protect one from, or make one vulnerable to, the effects of stress. Risk factors might include race/ethnicity, family background or individual characteristics, such as lifetime adversity and disadvantaged experiences [34, 35]. These latter two constructs are also indicators of stress, which serve as a reminder that stress instrumentation could be enhanced in future research by incorporating a lifespan perspective. Triangulating self-report measures with participant interviews and corroborating evidence from persons close to study participants would provide a strong advancement to stress measurement [401].

Apart from one experiment [193], there has been a lack of studies manipulating stress to assess the effect of such experiences on PA behaviors. It must be noted, however, that experimental exposure to stress is difficult, if not unethical, to implement. Measuring PA opportunistically during periods of objectively rated low and high stress, such as final examinations or other naturalistic stressors, provides stronger evidence [185, 187, 192]. The model demonstrated by Stults-Kolehmainen and Bartholomew [29], in which populations are screened for both very low and very high levels of chronic perceived stress, is an example of a quasi-experimental design that could be employed. Ecological Momentary Assessment (EMA) is one technique to measure stress and PA in real time, resulting in less vulnerability to stress-related failures in the recall of behavior and emotion [154, 265, 402]. Prospective studies should sample more frequently to minimize the effects of stress on memory and cognition, factors that in themselves may moderate the stress and exercise relationship [403].

These investigations may help to describe shifts in the relationship as individuals progress from sedentary behavior to exercise adoption, maintenance, and periods of relapse. The area of exercise habituation seems very promising [17, 183], as it is likely that novice exercisers are more susceptible to the effects of impulses, lack self-control, and are not resilient to the physical, emotional, and social stressors of exercise itself [351]. Furthermore, as individuals habituate to exercise there are likely concomitant changes in fitness, a potential moderator with minimal emphasis thus far [229]. Other moderators may be genetic (i.e., polymorphisms in genes regulating energy expenditure), physiological (e.g., adrenal sensitivity, muscle activation), health-related (e.g., illness, symptoms), personality-related (e.g., conscientiousness, neuroticism, perfectionism, type B, sensation-seeking [141, 142, 269, 404-407]), social/environmental [232], and related to coping style, though few studies have measured the extent to which individuals use exercise to cope with stress. Researchers may look to the nutrition literature as a similar bifurcation occurs when individuals are exposed to stressors: either more consumption or less or even fasting [168, 408]. This work has revealed mechanisms underlying the stress and caloric intake relationship, such as cortisol reactivity [134, 409-411]. Experimental models in this area are more sophisticated, which points to a need in the current literature reviewed. Hopefully this progress will help to determine the individual factors that may hasten declines in health-promoting behavior when stressed or, in a few cases, spur more activity.

The above discussion underscores the central need for additional models and a theoretical framework that describe the non-linear, bi-directional and dynamic nature of stress and PA relationships [20, 290]. At this time, theoretical models of stress and behavior are largely lacking or are specialized to particular contexts (e.g., worksites, urban life) [170, 200]. Links between stress, coping style, perceptions of energy and fatigue, energy expenditure (including spontaneous PA and non-exercise activity thermogenesis [NEAT]) and metabolism, amongst other factors (e.g., conscientiousness) should be integrated into conceptual models explaining obesity and physical health. Models specifically examining recovery from stressors [29, 170, 282] and sedentary behavior [170, 173, 193, 195, 209] would be useful, as stress is linked to these outcomes. Finally, it should be noted that psychosocial stress and exercise interact during PA itself, a third area of inquiry that will likely inform the complex confounding of these two factors [350, 412, 413].

5 Conclusion

This review is the only manuscript, to the best of our knowledge, that has attempted to synthesize the diverse literature on the association of stress and PA/exercise in the reverse direction of influence. This emerging focus stands in contrast to the vast number of studies that have almost exclusively emphasized the anxiolytic and anti-depressant effects of exercise. The current analysis concludes that stress and PA are associated in a temporal manner. More specifically, the experience of stress influences PA, and the great majority of studies indicate an inverse relationship between these constructs. In other words, stress impedes individuals' efforts to be more physically active, just as it negatively influences other health behaviors, such as smoking, alcohol, and drug use. Interestingly, a smaller number of studies suggest a positive association between stress and PA. While seemingly contradictory, these data are consistent with theories that predict changes in behavior in either direction with stress. The utility of exercise as a coping or stress management technique is notable and may explain this finding. Resiliency research suggests that some individuals thrive under conditions of stress; therefore, future research is needed to understand why some individuals are immune to changes in PA in the face of stress while others become inactive. Few studies employ rigorous experimental designs, which would strengthen this area of inquiry. Nevertheless, available prospective data is of moderate to high quality. Data identifying moderators of the relationship between stress and exercise would help to improve the design of interventions targeted towards at-risk populations, such as older adults. Future empirical research in this area could be guided by a theory of stress and PA, which is lacking at this time.

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Supplementary Material

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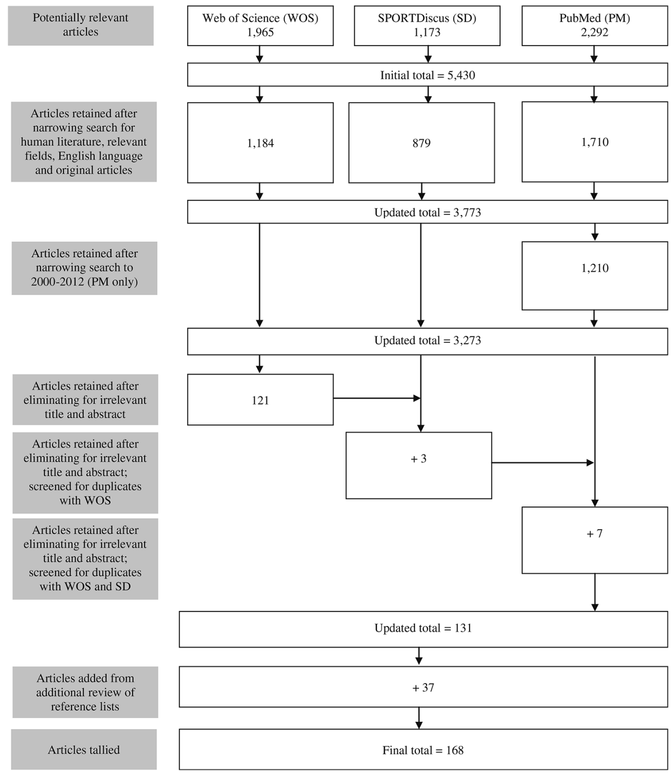

Fig. 1.

Flow chart of literature review for the effects of stress on physical activity

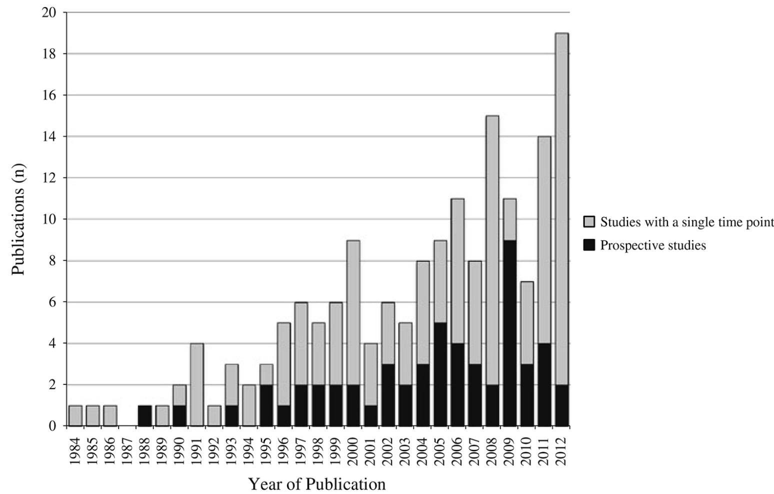

Fig. 2.
Yearly distribution of publications (*n* = 168) examining the association of stress and physical activity/exercise from 1984 to 2012

Table 1

Summary of 168 studies exploring relationships between stress and indices of physical activity and exercise[a]

	n	Inverse association[b]		No association[c]		Positive association[d]	
		n	%	*n*	%	*n*	%
Studies over a single time point							
Qualitative	9	9	100.0	0	0.0	4	44.4
Cross-sectional	100	67	67.0	26	26.0	14	14.0
Retrospective[e]	5	5	100.0	0	0.0	1	20.0
Total	114	81	71.1	26	22.8	19	16.7
Studies with multiple time points							
Prospective—non-objective stress[ef]	48	36	75.0	7	14.6	10	20.8
Prospective—objective stress[f]	7	6	85.7	1	14.3	0	0.0
Total	55	42	76.4	8	14.5	10	18.2
All studies[e]							
Grand total	169	123	72.8	34	20.1	29	17.2

PA physical activity

[a]Some studies provide evidence of multiple associations between stress and indices of PA, resulting in support for more than one direction of the association, which explains why totals may exceed 100.0 %

[b]Studies demonstrating at least one inverse relationship between indicators of stress and PA

[c]Studies demonstrating no relationships whatsoever between indicators of stress and PA

[d]Studies demonstrating at least one positive relationship between indicators of stress and PA

[e]One study was both prospective and retrospective [181], thus inflating study totals

[f]Studies comparing either (a) periods of objective stress (i.e., examinations) to objectively less stressful periods or (b) objectively stressed populations (i.e., caregivers) to objectively less stressed populations (i.e., matched controls) over time

Table 2

Prospective studies of all designs investigating the effects of stress on indices of physical activity

Study	Sample	Participants (*n*)	Theoretical framework or model	Study design	Stress measure(s)	PA measure(s); data transformation	Significant findings, associations, ESs	QR
Allard et al. 2011, [259]	Public sector employees M + W Mean age 45.4 years (SD = 10.2)	3,224	Job strain Job effort–reward imbalance	Prospective 2 years PA measured twice	Copenhagen Psychosocial Q (demand–control; emotional demands; patient care emotional demands) Number of life events in last 6 months, rated by impact	1-item survey (4 responses) Binary respondent classification: inactive at follow-up considered "never spent or stopped spending more than 4 h on low intensity activity or at least 2 h on intense activity per week"	Stress events did not predict change in PA; however, stress events did predict change in BMI Less physical inactivity at follow-up predicted by higher emotional demands (OR = 0.69; 95 % Cl 0.48–0.98) and patient care emotional demands (OR = 0.73; 95 % CI 0.56–0.94) Decision latitude related to higher inactivity at follow-up (OR = 1.95; 95 % CI 1.04–3.66)	6
Bell and Lee 2006, [260]	Random sample of young adults W only Age range 22–27 years	853	Life transitions	Prospective 4 years PA only measured at time 2	Perceived Stress Q for Young Women Transitions Q	Active Australia Survey Summed DUR of walking, moderate and vigorous activities 4-category respondent classification: no, low, moderate, or high PA	Age stopping full-time education was associated with higher stress (partial r^2 = 0.02, $p < 0.001$) and less PA ($p <$ 0.001, $\eta^2 = 0.028$) Age starting full-time work was associated with lower PA (p values <0.001, η^2 = 0.036) Other transitions not related to PA Note: no analysis to predict PA from perceived stress	7
Brown and Siegel, 1988 [79]	Students in private high school, grades 7–11 W only Mean age 13 years, 10 months	364	Major life events	Prospective 8 months Two time points	Life Events Survey	DUR of 14 different activities >1×/week Measured at both time points	Life event stress at BL and not correlated with exercise at time 1 or time 2 (r = −0.03 to −0.04) No other analysis available	6
Brown and Trost, 2003 [261]	Australian population sample W only	7,281	Life transitions Major life events	Prospective 4 years PA measured both times	Events checklist (no validation reported)	BL and follow-up differed BL: FREQ of "vigorous" and "less vigorous"	Life events and transitions strongly associated	7

Study	Sample	Participants (n)	Theoretical framework or model	Study design	Stress measure(s)	PA measure(s); data transformation	Significant findings, associations, ESs	QR
	18–23 years at BL					exercise multiplied by factors of 5 and 3, respectively Binary respondent classification: those above score of 15 considered "active" Follow-up: FREQ and DUR of walking, moderate and vigorous PA multiplied by factors of 3.5, 4 and 7.5, respectively Binary respondent classification: "active" defined as >600 MET min/week	with activity status at follow-up Inactivity predicted by marriage (OR = 1.46, 95 % CI 1.27–1.68), having a first baby (OR = 2.27, 95 % CI 1.90–2.59), having another baby (OR = 2.06, 95 % CI 1.70–2.51), all $p < 0.0001$ Beginning work (OR = 1.15, 95 % CI 1.03–1.20, $p = 0.010$). Becoming a single parent (OR = 1.32, 95 % CI 1.04–1.67, $p = 0.020$) Return to study related to LESS inactivity (OR = 0.77, 95 % CI 0.63–0.94, $p = 0.009$) Changing work related to LESS inactivity (OR = 0.82, 95 % CI 0.74–0.90, $p < 0.0001$)	
Brown et al., 2009 [262]	Australian population sample W only 3 age cohorts: young (18–23 years), middle-aged (45–50 years), and old (70–75 years) at BL	22,595	Life transitions Major life events	Prospective 3 years PA measured both times	Norbeck Life Event Q (modified)	FREQ and DUR of walking, moderate and vigorous PA multiplied by factors of 3.5, 4 and 7.5, respectively 3-category respondent classification: "no PA" (<40 MET min/week), "low" (40–600 MET min/week), and "active" (>600 MET min/ week)	Life events and transitions associated with activity status at follow-up. Associations varied by age-cohort (see paper for details) Transitions associated with decreasing PA (all $p < 0.001$): getting married (OR = 1.27, 95 % CI 1.10–1.46), childbirth (OR = 1.67, 95 % CI 1.43–1.95), illness (OR = 2.23, 95 % CI 1.83–2.71), surgery (OR = 1.55, 95 % CI 1.28–1.88), moving to an institution (OR = 1.97, 95 % CI 1.05–3.67)	7

Study	Sample	Participants (*n*)	Theoretical framework or model	Study design	Stress measure(s)	PA measure(s); data transformation	Significant findings, associations, ESs	QR
							Transitions associated with increasing PA: retirement (OR = 1.52, 95 % CI 1.22–1.88, $p < 0.001$), harassment at work (OR = 1.49, 95 % CI 1.14–1.95, $p < 0.01$) Transitions associated with increasing PA (p values <0.05): beginning a new personal relationship (OR = 1.23, 95 % CI 1.01–1.50), changing work conditions (OR = 1.24, 95 % CI 1.04–1.48), major personal achievement (OR = 1.29, 95 % CI 1.07–1.56), death of a spouse/partner (OR = 1.55, 95 % CI 1.01–2.37), decreased income (OR = 1.20, 95 % CI 1.04–1.38)	
Budden and Sagarin, 2007 [210]	Working adults from diverse occupations M + W Age range 18–74 years	274	Theory of Planned Behavior	Prospective 7 days PA measured only at time 2	Spielberger Job Stress Survey	FREQ and DUR of exercise (2 items) combined into 1 composite score Binary respondent classification: exercise or no exercise	No main effect of occupational stress on PA measures $r = -0.10$ (composite score) to −0.11 (binary score) Occupational stress did inversely relate to PBC to exercise ($r = -0.16$), thus relating to exercise intention and exercise behavior	7
Burton et al., 1999 [263]	Medicare beneficiaries in Maryland, USA M + W >65 years 95.9 % of sample between 65–84 years at BL	2,507	Behavior change model	Prospective 4 years 3 time points Mutiple waves of PA data	GHQ-12 (emotional distress)	1-item survey FREQ of activities such as walking briskly, gardening, or heavy housework Binary respondent classification: those performing “brisk” PA at	There is a relationship of emotional distress measured at the last wave and PA Distress did not predict initiation of PA Moderate distress predicted maintenance of activity status over 4-year lapse of time	6

Study	Sample	Participants (*n*)	Theoretical framework or model	Study design	Stress measure(s)	PA measure(s); data transformation	Significant findings, associations, ESs	QR
						least 3 times a week considered "active"	(OR = 0.43, 95 % CI 0.28–0.67). Severe distress did not predict maintenance, however Low emotional stress, 35.8 % initiate activity, 69 % maintain; medium emotional stress, 18.0 % initiate activity, 40 % maintain; high emotional stress, 14.6 % initiate activity, 36.4 % maintain (Table 3 of study)	
Burton et al., 2010 [273]	Adults enrolled in university worksite 16-week intervention M + W Mean age 36.5 years (SD = 8.6)	16	Resiliency	Prospective Stress/PA intervention (open trial) No control group Measures pre/post	Stress subscale from DASS-21	Modified AIHW Survey Total DUR of PA in previous week Time weighted by intensity factor Pedometer step counts over 7 days	Stress level improved pre-post (*p* = 0.013) Pedometer steps and PA survey data did not improve pre-post	6
Castro et al., 2002 [145]	Sedentary caregivers for relatives with dementia W only Age >50 years Mean age 62.7 years (SD = 9.2)	100	Caregiving stress; stressed population	Prospective 1 year Intervention (RCT)	PSS-14 Screen for Caregiver Burden BDI TMAS	Exercise adherence Program retention Motivational Readiness for PA	BL PSS and Caregiver Burden does not predict PA adherence over 12-month period or months of program contact or total phone or mail contacts BL anxiety and depression does predict PA adherence Those who did not complete the trial had higher BL stress (mean PSS = 22.5, SD = 4.8) and spent more hours at BL in caregiving duties (mean = 100.5, SD = 41.7) than those who did complete the trial	7
Chambers et al., 2009 [264]	Survivors of colorectal cancer M + W	978	Health stress; stressed population	Prospective 3 years post-diagnosis 4 waves of PA data	Constructed Meaning Scale (cancer threat appraisal) Brief Symptom Inventory-18 (anxiety, depression, and somatization)	Modified Active Australia survey items Total DUR of PA in previous week for walking,	Continuous cognitive threat appraisal predicted inactive PA (OR = 0.95, 95 % CI 0.9,1.0) and	7

Study	Sample	Participants (n)	Theoretical framework or model	Study design	Stress measure(s)	PA measure(s); data transformation	Significant findings, associations, ESs	QR
						moderate PA, or vigorous PA. Time-weighted by intensity factor 3-category respondent categorization: inactive (0 min/week), insufficiently active (1–149 min/week), or sufficiently active (>150 min/week)	insufficiently active PA (OR = 0.96, 95 % CI 0.9, 1.0). Overall model (p = 0.031) Previous anxiety predicts increase in low levels of PA (<2 h/week) (OR = 1.11, 95 % CI 1.05–1.19, p = 0.004) No evidence that the distress and PA association changed over time Depression and cognitive threat did not predict increases in PA	
Delahanty et al., 2006 [285]	Individuals in the Diabetes Prevention Program lifestyle intervention M + W	274	None	Prospective Intervention 3 waves of PA data	Perceived Stress Q-30 Beck Depression and Anxiety Inventories	Stages of change for exercise (5 items) Modifiable Activity Q Data analyzed as: continuous PA and dichotomous [coded as meeting guidelines for PA (150 min/week)]	BL perceived stress inversely associated with PA at 3 time points: (BL, r = −0.16, p = 0.01; 1-year PA, r = −0.18, p = 0.003; 2-year PA, r = −0.17, p = 0.007) Similar pattern of results for anxiety and depression Stress did not independently predict PA at any time point when depression, self-efficacy, stage of change, and other factors were modeled Depression predicted PA at BL (p = 0.03) Stress did not alter the gender-PA relationship	7
Dobkin et al., 2005 [291]	Fibromyalgia patients W only Mean age 49.2 years (SD = 8.7)	39	Behavior change theories	Prospective Intervention 3 months follow-up PA measured 3 times	WSI	Average mins of weekly stretching	Stress at BL and during the treatment were the best predictors of poor maintenance of stretching Every 1 SD increase in BL stress related to a −28.29 min change in stretching at 4, 5, and	7

Study	Sample	Participants (*n*)	Theoretical framework or model	Study design	Stress measure(s)	PA measure(s); data transformation	Significant findings, associations, ESs	QR
							6 months ($p < 0.05$) Every 1 SD increase in stress change over 3 months was related to a decline in stretching (−38.58 min) in months 4, 5, and 6 ($p < 0.01$) Stress did not impact weekly changes in any outcome	
Dobkin et al., 2006 [289]	Fibromyalgia patients W only Mean age 49.2 years (SD = 8.7)	39	Behavior change theories	Prospective Intervention 12 weeks PA measured 12 times	WSI	Daily exercise log recording exercise type, FREQ, DUR, and intensity. Energy expenditure calculated	Over 12 weeks, participants with higher BL stress reduced their aerobic exercise participation at faster rates ($p = 0.02$) Every 1 SD increase in stress resulted in a change of −3.19 min of aerobic exercise and −11.33 kcals of energy expenditure With interactions included in the model, stress did not impact initial participation in the aerobic exercise program Those with higher BL stress decreased energy expenditure at a higher rate ($p = 0.02$)	7
Dougall et al., 2011 [286]	First-year students M + W Mean age 20.6 years (SD = 5.34) Age range 17–47 years	149	Life transition	Prospective Intervention (~13 weeks) PA measured weekly	PSS-4	1-item scale modified from Godin Leisure Time Exercise Q (DUR of strenuous activity) Approximate number of times a university fitness center was utilized Stage of change for exercise	Main effect of stress on fitness center use ($\beta = -0.10$, SE = 0.05, $p < 0.05$) but not vigorous exercise or intention to exercise Participants with high stress in the later stages of change had more PA intention than those in earlier stages of change ($p < 0.02$) 3-way interaction for stress, intervention	8

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Study	Sample	Participants (*n*)	Theoretical framework or model	Study design	Stress measure(s)	PA measure(s); data transformation	Significant findings, associations, ESs	QR
							response, and time ($p = 0.05$). At the end of the semester, responders low in stress had higher PA 3-way interaction between stress, time, and stage of change ($p = 0.09$). Those in the later stages of change for exercise and low in stress had higher fitness center use initially	
Dunton et al., 2009 [265]	Healthy, community-dwelling adults who do not regularly exercise M + W Mean age 60.7 years (SD = 8.22) Age range 50–76 years	23	None	Prospective 2 weeks Daily diary study PA assessed at fixed intervals 4×/day	2 items: (1) problematic social interaction; (2) experience of a stressful event NA (average of ratings for: stressed, upset, lonely, annoyed, tense/anxious, sad, discouraged)	Respondents queried about whether they performed 1 of 12 activities (yes/no) and DUR if completed Data transformation: sum of mins for activities over 3.0 METs	Only 10 % of the sample reported a stressful event Stress events did not predict PA ($r = 0.09$) NA (subjective stress) did predict MVPA (HLM COEFF = −0.09, robust SE = 0.02, $p < 0.001$) Within-person variance explained by NA was 0.5 %, and for stress events was 0.8 %	6
Durrani et al., 2012 [124]	Diagnosed with hypertension in e-counseling program Individuals with anxiety or traumatic stress excluded M + W	387	None	Prospective Intervention 4 months PA assessed 2 times	PSS-10 BDI-II	HPLP-II (used to measure readiness for exercise change on a 4-point continuous scale)	BL stress ($r = −0.18$; $p = 0.001$) and depression were inversely associated with BL readiness to change exercise Change in stress and depression over the 4-month intervention inversely correlated with exercise readiness post-intervention ($r = −0.17$; $p = 0.01$)	7
Grace et al., 2006 [274]	Healthcare workers from 3 worksites Pregnant W Mean age 39.5 years (SD = 7.95)	243 (201 non-pregnant)	Role strain	Prospective Case control PA measured at 3 time points	Work-Family Spillover Scale	HPLP-II (8-items for PA)	Levels of PA did not vary across groups and did not change across the pregnancy and postpartum period; however, a trend was	8

Study	Sample	Participants (n)	Theoretical framework or model	Study design	Stress measure(s)	PA measure(s); data transformation	Significant findings, associations, ESs	QR
							observed for decreased inactivity during maternity leave Negative work-to-family spillover and negative family-to-work spillover was not associated with PA at BL ($r = -0.07$ to 0.03, NS) or at the last time point ($r = -0.14$ to 0.22, NS) in either the maternity group or the comparison group When returning to work (final assessment), PA was related to *positive* work-to-family spillover	
Griffin et al., 1993 [191]	College undergraduates M + W Mean age 18.4 years (SD = 1.22)	79	None	Naturalistic Exam stress vs. early semester (7-week period) No control group	PSS-4 items Daily Hassles and Uplifts Positive and Negative Affect Schedule Academic demands (1 item; 1–7 scale)	Wellness Inventory of the Lifestyle Assessment Q Exercise subscale items: efforts to maintain fitness over past 3 days (“I walked or biked whenever possible”; 1–6 response scale)	PSS related to exercise at start of semester ($r = -0.22$, $p < 0.05$), but not at the end of the semester ($r = -0.14$) No association between academic demands, academic stress, hassles, or negative affect with exercise Exercise declined from low stress time of semester to finals; however, this was NS. Early semester: mean = 14.78, SD = 5.19; finals: mean = 14.64, SD = 5.78 Among subjects who experienced an increase in demands from early semester until finals, exercise decreased (but NS) Early semester: mean = 14.98, SD = 5.27; finals: mean = 14.36, SD = 5.57 Among subjects who experienced an increase in	7

Study	Sample	Participants (*n*)	Theoretical framework or model	Study design	Stress measure(s)	PA measure(s); data transformation	Significant findings, associations, ESs	QR
							demands the week before finals (vs. early semester), exercise decreased (but NS). Early semester: mean = 15.15, SD = 5.19; finals: mean = 14.94, SD = 5.37 Exercise increased for those whose academic demands remained the same or declined during finals (NS) When controlling for BL exercise, academic demands at finals and the week before finals did not predict exercise at the second time point	
Groeneveld et al., 2009 [278]	Construction workers at higher risk for CVD M only Mean age 46.1 years (SD = 9.3) Age range 30–65 years	4,017	None	Prospective Intervention	Dichotomous: 12 questions regarding tiredness and stress. Scored as “yes” if 5 of 12 statements were endorsed	Binary respondent classification: participation in the lifestyle program (yes/no); dropout of program (yes/no)	35.7 % of participants were tired/stressed, while only 30.5 % of non-participants were tired/stressed Crude OR = 1.27 (95 % CI 1.08–1.49) Relationship disappeared in multivariate models (age, smoking, type of work, symptoms) Stress had no relationship with dropout from the study (OR = 0.94, 95 % CI 0.56–1.57)	4
Ho et al., 2002 [181]	Residents of NY metro area M + W Mean age 46 years (SD = 11) for M and 47 years (SD = 13) for W	244	Life event	Retrospective and prospective 4-month follow-up	Resident of NY after World Trade Center attack and in World Trade Center during attack Level of distress (1–10): 1 item	1 item 3-category respondent classification: exercise behavior “still abnormal”, “normalized”, or “no initial change”	Residents exercising 33 % less after attacks Those actually at the World Trade Center exercise 1.5 times less (*p* = 0.07) than residents not the World Trade Center 4 months later, residents of NY were exercising 13 % less	6

Study	Sample	Participants (*n*)	Theoretical framework or model	Study design	Stress measure(s)	PA measure(s); data transformation	Significant findings, associations, ESs	QR
Hooper and Veneziano, 1995 [288]	University employees M + W Age not reported	338	None	Prospective Intervention (20 weeks)	1 item from Wellness Q, re.: stress at home (not validated)	Binary respondent classification: exercise program starters vs. non-starters	Stress significantly discriminated starters from non-starters Non-starters: 1.34 (SD = 0.57) on stress at home Starters: 1.22 (SD = 0.44) on stress at home Both groups expressed an ability to cope with the stress	6
Hull et al., 2010 [266]	Young adults M + W Mean age 24.1 years (SD = 1.1)	638	Life transition	Prospective 2 years PA measured 2 times	Cohabitation, marriage, parenthood transitions	Past year leisure time PA Q FREQ and DUR of every type of LTPA activity over last year completed at least 10 times Data expressed as h/week	Marriage does not impact PA in young adults Compared with those who stayed with the same number of children over the 2-year period, having a child (PA change = −3.7, SD = 6.0, $p = 0.01$), having a first child (−3.9, SD = 5.6, $p = 0.02$), and having a subsequent child (−3.5, SD = 6.4, $p = 0.02$) is associated with a reduction in PA	8
Johnson-Kozlow et al., 2004 [279]	College students M + W Mean age 24.4 years (SD = 0.06)	338	Life events	Prospective Intervention 1 year PA measured at 2 time points	Life Experiences Survey	7-day PA recall Data expressed as kcal/kg/week	44 % of sample was inactive at BL No direct relationship, but stress by time interaction was significant ($p = 0.015$) M with higher stress at 1 year had *greater* exercise in the exercise intervention group ($p = 0.008$) In the control condition, M with low stress tended to be more physically active at 1 year No relationship between stress and PA was observed for W	8
Jones et al., 2007 [267]	Public service workers M + W	422	Job strain	Prospective diary study 4 weeks Daily PA	Job Content Q (Framingham version) Positive and Negative	2 items: moderate and vigorous exercise (yes/no	Daily negative affect had an inverse relationship	7

Study	Sample	Participants (*n*)	Theoretical framework or model	Study design	Stress measure(s)	PA measure(s); data transformation	Significant findings, associations, ESs	QR
	Mean age 40 years (W) and 41 years (M) Age range 18–65 years			measure	Affect Schedule Work hours	response) If "yes" response, respondents required to describe the exercise	with exercise for M ($p = 0.001$) but not for W For M, job demand had an effect on daily exercise ($\beta = -0.48$, SE = 0.13, $t = -1.98$, $p = 0.049$). M in low-demand jobs showed greater reductions in PA than M in high-demand jobs There was an interaction with negative affect ($\beta = 0.22$, SE = 0.06, $t = 2.37$, $p = 0.02$). Negative affect also interacted with job control ($\beta = -0.18$, SE = 0.05, $t = -2.51$, $p = 0.01$). When combined with NA, high job control can result in less exercise Long work hours were associated with less exercise for W but not for M	
Jouper and Hassmén, 2009 [287]	Adults in Qigong exercise program M + W Mean age 36.5 years (SD = 17)	87	Tense-energy model	Prospective Non-intervention exercise program	Stress–Energy Scale	Exercise diary (sessions per week) Concentration on Qigong (1–10 scale, 1 item) Exercise intention	Exercise sessions negatively correlated with stress ($r = -0.22$, $p < 0.05$, 1-tailed test), but there was no correlation of stress with exercise intention ($r = 0.07$) or concentration ($r = -0.16$) Stress predicted exercise session ($R^2 = 0.03$)	8
King et al., 1997 [290]	Community-dwelling adults M + W Mean age: M 56.2 years (SD = 4.1); W 57.1 years (SD = 4.3) Age range 50–65 years	269	None	Prospective Intervention RCT Home- vs. group-based exercise	PSS-14 BDI Taylor Manifest Anxiety Scale	Exercise adherence Binary respondent classification: "successful" adhering over 2 years defined as completing >66 % of prescribed workouts	Stress was a strong predictor at year 2 ($p < 0.0001$) Among persons assigned to either home-based program, those initially less stressed (PSS <19) were more likely to be successful	7

Study	Sample	Participants (*n*)	Theoretical framework or model	Study design	Stress measure(s)	PA measure(s); data transformation	Significant findings, associations, ESs	QR
							than those initially more stressed (53.9 vs. 32.4 %, χ^2 [1, *N* = 173] = 7.84, $p < 0.01$) Most successful adherers at year 2 were (a) home-based exercisers, (b) less stressed, (c) more fit, (d) less educated At year 1, the subgroup with the greatest adherence (82.4 %) comprised nonsmokers assigned to home-based exercise and reporting low stress (PSS <19) Energy but not anxiety or depression was a strong predictor of adherence	
LeardMann et al., 2011 [268]	US Military Service personnel M + W 41.5 % born between 1960 and 1969	38,883	None	Prospective 3–5 years PA only measured at time 2	PTSD Checklist-Civilian Version (evaluated twice)	Items from NHIS. FREQ and DUR of strength training, moderate PA and vigorous PA 5-category respondent classification PA only assessed at follow-up	Those with new-onset of PTSD symptoms are less likely to engage in moderate activity at “active” level (OR = 0.71, 95 % CI 0.60–0.84); less likely to engage in vigorous activity at “slightly active” (OR = 0.66, 95 % CI 0.49–0.89), “active” (OR = 0.58, 95 % CI 0.49–0.70), and “very active” (OR = 0.59, 95 % CI 0.46–0.76) levels; more likely to be unable to engage in strength training (OR = 2.06, 95 % CI 1.45–2.93)	6
Lutz et al., 2007 [20]	Blue-collared workers M + W Mean age 43.6 years (SD = 9.8)	203	None	Prospective 2 months PA measured at 2 points	PSS-10	Godin Leisure Time Exercise Q PA recalled over the previous month FREQ of strenuous	In SEM analysis: (a) the stress-to-exercise model provided the best fit and was significantly different than the stability	7

Study	Sample	Participants (*n*)	Theoretical framework or model	Study design	Stress measure(s)	PA measure(s); data transformation	Significant findings, associations, ESs	QR
						exercise used for analyses	model; (b) stress and PA were not concurrently related at time 1 but were concurrently related at time 2; (c) stress at time 1 significantly predicted exercise at time 2 ($r = -0.16$; path COEFF = −0.13), but exercise at time 1 did not predict stress at time 2 ($r = -0.03$; path COEFF = −0.02)	
Lutz et al., 2010 [17]	Undergraduate psychology students W only Mean age 19.3 years (SD = 2.1) Age range 17–33 years	95	None	Prospective 6 weeks PA measured each week	WSI-2 scales used: stress FREQ and stress intensity	Exercise diary recorded daily FREQ, DUR, and perceived intensity of exercise were the outcome variables of interest Stages of change for exercise (each stage modeled as a dichotomous variable)	No main effects of stress events or stress intensity on exercise mins per session When exercise stages were run as dichotomous variables, the maintenance stage was a significant moderator of the stress event and exercise duration relationship ($\beta = 0.52$, SE = 0.11, $t(79) = 4.56$, $p < 0.001$). Similar relationship found for exercise frequency ($\beta = 0.04$, SE = 0.01, $t(79) = 4.12$, $p < 0.001$) and exercise intensity ($\beta = 0.04$, SE = 0.01, $t(75) = 2.69$, $p < 0.001$) When exercise stages were run as dichotomous variables, the maintenance stage was a significant moderator of the stress intensity and exercise duration relationship ($\beta = 0.18$,	6

Study	Sample	Participants (*n*)	Theoretical framework or model	Study design	Stress measure(s)	PA measure(s); data transformation	Significant findings, associations, ESs	QR
							SE = 0.04, $t(79) = 5.00$, $p < 0.001$). Similar relationship found for exercise frequency ($\beta = 0.012$, SE = 0.003, $t(79) = -2.265$, $p < 0.05$) and exercise intensity ($\beta = 0.01$, SE = 0.004, $t(75) = 1.89$, $p < 0.062$)	
Macleod et al., 2001 [414]	Working Scottish adults from 27 worksites M only Mean age at first screening 48 years	5,388 (time 1); 2,595 (time 2)	None	Prospective 5 years PA measured twice	Reeder Stress Inventory (summary score, 1–8)	1-item survey for sedentary behavior (h/week) Binary respondent classification: “sedentary” defined as <3 h/week	At first screening, stress related to more sedentary behavior ($p = 0.005$). 26 % of high-stress group was sedentary vs. 19 % of low-stress group Sum of stress at time 1 and 2 and change in stress from time 1 to 2 not related to sedentary behavior at time 2	5
Miller et al., 2004 [275]	Healthy young adults M + W Mean age 18.3 years (SD = 0.9)	83	None	Prospective 13 days PA measured daily	Salivary cortisol Daily ratings of subjective stress (4×/day)	Paffenberger Activity Scale (1993) Data analyzed as mins of intense PA	Daily (cumulative) stress ratings were not associated with health behaviors, including mins of intense PA ($r = -0.04$)	6
Moen et al., 2011 [284]	Best Buy corporate headquarters employees M &W Average age 32 years	659	Job strain	Prospective Stress intervention (Results Only Work Environment program) vs. control 7 months PA measured twice	Negative work-home spillover Psychological distress	Average FREQ of exercise/week over last 4 weeks	Results Only Work Environment program resulted in no changes in distress vs. control Negative work-home spillover was related to distress ($p < 0.001$) Those in control group decrease more in exercise overtime ($p < 0.05$). Thus, stress management program may help to attenuate decline in PA behavior Effect mediated by reductions in negative work-	8

Study	Sample	Participants (*n*)	Theoretical framework or model	Study design	Stress measure(s)	PA measure(s); data transformation	Significant findings, associations, ESs	QR
							home spillover ($p < 0.05$)	
Oaten and Cheng, 2005 [192]	Introduction to Psychology students M + W Mean age 20 years Age range 18–50 years	57: 30 exam stress; 27 control	Self-regulation model	Naturalistic Exam stress vs. early semester Within-person and control group comparison	GHQ-28 (emotional distress) DASS PSS-10	PA 3-item survey: FREQ and DUR over last week "Ease" of exercise regimen ("How easy was it to fit exercise into your schedule over the last week?") All items on 5-point scale	No difference between groups in exercise behavior at BL Those in exam stress group reported a decline in all exercise FREQ ($df = 1, 26$, $F = 71.39$, $p < 0.001$), DUR ($df = 1, 26$, $F = 35.71$, $p < 0.001$), and reported ease ($df = 1, 26$, $F = 31.24$, $p<0.001$) during exam period. No means reported The control group did not change exercise behaviors pre to post No relationship between change in perceived stress (PSS) or emotional distress (GHQ) and the change in exercise behavior. However, residuals of changes in PSS and GHQ were related to residuals of changes in exercise behavior	8
O'Connor et al., 2009	Government workers M + W Mean age 42.6 years	422	Diathesis-stress perspective	Prospective Diary study 4 weeks	Daily hassles: respondents reported each stressor experienced and rated each on 0–4 scale Only FREQ of hassles	2-item exercise survey Daily exercise participation: binary response	Hassles inversely related to exercise participation over time (COEFF = −0.055, SE = 0.022, $p = 0.013$, 95 % CI 0.907–0.988) Participants with average ($\beta = -0.064$, $t = -2.417$, $p < 0.05$) or high ($\beta = -0.149$, $t = -3.93$, $p < 0.001$) levels of order (a facet of conscientiousness) exercised *more* on days	6

Study	Sample	Participants (*n*)	Theoretical framework or model	Study design	Stress measure(s)	PA measure(s); data transformation	Significant findings, associations, ESs	QR
[269]	Age range 18–65 years				reported	(yes/no)	when they experienced daily hassles	
Oman and King, 2000 [184]	Healthy, sedentary adults M + W Mean age 56.5 years (SD = 4.3) Age range 50–65 years	173	Life events	Prospective RCT intervention 2 years	Social Readjustment Rating Scale	Exercise program adherence: (percentage of prescribed workouts completed) Stage of exercise adoption	Stress not related to adherence in the adoption phase (months 1–6) Life event and exercise adherence were associated during the maintenance phase regardless of exercise intensity or format (home- or class-based) Months 7–12: $F(4, 153) = 3.56$, $p = 0.008$. Months 13–18: $F(4, 140) = 2.52$, $p = 0.044$. Months 19–24: $F(4, 153) = 3.66$, $p = 0.007$	8
Payne et al., 2002 [332]	British employees M + W Age >16 years (32 % between 35 and 44 years)	213	Job strain, Theory of planned behavior	Prospective 1-week lag (PA measured only 1×)	Karasek Job Content Q Data run as continuous and sample divided by median split on job strain	Open-ended question for exercise type and DUR: "What types of exercise did you do today and how long did you devote to each?" Exercise defined as "taking part in purposeful activity which is often structured and pursued for health and fitness benefits" Data run as continuous and dichotomous Psychological predictors of exercise intention also collected (intention, PBC, attitudes, norms, etc.)	No correlation between exercise behavior and work barriers (including work stress; $r = -0.08$), job demands ($r = -0.11$), and job control ($r = 0.08$) Those with increased work demands have greater failure in ability to fulfill their exercise intentions (succeeded, M = 3.63, SD = 0.64; failed, M = 3.95, SD = 0.57; $F(1, 147) = 7.87$, $p < 0.01$, ES = 0.50) Intentions were not associated with job strain Job demands moderated the relationship between self-efficacy and the probability of being an exercise intender who actually exercised	7

Study	Sample	Participants (*n*)	Theoretical framework or model	Study design	Stress measure(s)	PA measure(s); data transformation	Significant findings, associations, ESs	QR
							(OR = 0.93, 95 % CI 0.87–0.99) People in high-strain jobs have less exercise self-efficacy, PBC, and did less exercise at follow-up (however, they did not intend to do any less exercise)	
Payne et al., 2005 [333]	British employees M + W Age range 16–64 years (32 % between 35 and 44 years)	286	Job strain, Theory of planned behavior	Prospective 1-week lag (PA measured only 1×)	Karasek Job Content Q (11 items) Work barriers (hours, stress, travel)	Open-ended question for exercise type and DUR: "What types of exercise did you do today and how long did you devote to each?" Exercise defined as "taking part in purposeful activity which is often structured and pursued for health and fitness benefits" Data calculated as hours (continuous)	No direct effect of job demands ($r = -0.11$) or job control ($r = -0.03$) on exercise behavior Intention, job demands, and job control interacted but only explained 1 % more of the variance in exercise behavior Job demands and control affected exercise indirectly by lowering perceptions of perceived behavior control over exercise Job demands did not moderate the intention/behavior relationship for exercise	7
Payne et al., 2010 [281]	Employees M + W Age >16 years (41 % between 25 and 34 years)	42	Job strain, Theory of planned behavior	Prospective Intervention Diary study Daily for 14 days	Karasek Job Content Q Work-related affect instrument: anxiety and depression	Open-ended question for exercise type and DUR: "What types of exercise did you do today and how long did you devote to each?" Exercise defined as "taking part in purposeful activity which increases the heart rate and produces at least a light sweat and is often structured and pursued for	No main effect of job demands Demands moderated the intention/exercise relationship (COEFF = −0.10, SE = 0.01, $p < 0.01$, OR = 1.04, 95 % CI 1.01–1.06) Anxiety and depression had no main effect on exercise and did not moderate intention-behavior relationships Note: daily planning intervention backfired (people in no intervention group were more	7

Study	Sample	Participants (*n*)	Theoretical framework or model	Study design	Stress measure(s)	PA measure(s); data transformation	Significant findings, associations, ESs	QR
						health and fitness benefits" Data transformed to total hours of exercise/day	likely to exercise)	
Phongsavan et al., 2008 [276]	Patients with anxiety disorders M + W Mean age 39.0 years (SD = 11.9)	73	None	Prospective 8 weeks Exercise and CBT intervention	DASS-21	Modified Active Australia survey items FREQ and DUR of PA in previous week for walking, moderate PA, or vigorous PA 3-category respondent categorization: inactive (0 min/ week), insufficiently active (1–149 min/ week), or sufficiently active (>150 min/ week) Pedometer steps Exercise compliance vs. non-compliance	Relationship between exercise (Active Australia Survey) and stress not analyzed. Stress and pedometer steps association also not reported Those with higher mean scores on stress were more likely to drop out of the PA program, but this was not statistically significant No relationship between stress and PA program compliance	6
Reynolds et al., 1990 [245]	10th graders from California, USA, high schools M + W Age range 14–16 years (median 15 years)	743	None	Prospective 16 months PA measured at BL, 4 and 16 months	Situational Stress Survey (scale included as appendix in article)	FREQ of 19 activities (i.e., ice skating, hiking) rated on 1–7 scale. Each rating associated with a weight to calculate a total PA score. Score represents the total number of times subject engaged in >20 min of nonstop PA (scale included as appendix in article)	At month 4, stress predicts less exercise, in W only, controlling for BMI and BL PA (β = −1.27, F = 6.18, p = 0.01). Stress did not predict PA at month 16 No significant correlations between stress and PA at either follow-up time point At month 4, r = −0.09 At month 16, r = −0.03	6
Rod et al., 2009 [270]	Age-stratified random sample of Danish adults M + W Age range at BL 20–93 years	7,066	Allostasis	Prospective 10 years PA measured at 2 time points	2-item survey: perceived stress intensity and FREQ; combined into single score Stress only assessed at follow-up	Item inquiring about level of LTPA Binary respondent classification: active vs. inactive	Those with medium (OR = 1.19, 95 % CI 1.07–1.32) or high (OR = 2.63; 95 % CI 2.25–3.08) levels of stress were more likely to	5

Study	Sample	Participants (*n*)	Theoretical framework or model	Study design	Stress measure(s)	PA measure(s); data transformation	Significant findings, associations, ESs	QR
							be physically inactive at BL. 12 % of the low-stress group was inactive vs. 26 % of the high-stress group Those stressed were more likely to become physically inactive during follow-up than the low-stress group (OR = 1.90; 95 % CI 1.41–2.55) Those in the high-stress group were not more likely than the low-stress group to become active (OR = 0.78, 95 % CI 0.48–1.14). Authors state “There were no differences in the proportions of inactive persons who became active during follow-up according to stress”	
Rodriguez et al., 2000 [271]	Nulliparous Swedish pregnant W W only Mean age 27 years (SD = 4)	350	Stressed population	Prospective 32 weeks into pregnancy PA measured at 2 time points (weeks 20 and 32)	PSS-11 (Swedish version)	Exercise FREQ (1–5 scale) and DUR over last 4 weeks Exercise type queried Data transformed into single composite score to reflect time in exercise/ week	Exercise decreased from pre-pregnancy to week 20 ($p < 0.001$). There was no change from week 20 to week 32 Stress at week 12 correlated with exercise at week 20 ($r = -0.20$, $p < 0.05$) but not week 32 ($r = -0.07$) Contemporaneous correlation of stress and exercise at week 32 was significant ($r = -0.11$, $p < 0.05$) SEM analysis found significant path from stress at week 12 to exercise at week 20 ($\beta = -0.20$)	7
Roemmich et al., 2003 [193]	Children Boys + girls Boys mean age	25	None	Experimental Laboratory stressor (Trier	Visual analogue scale for perceived stress Cardiovascular stress reactivity (median	Children volitionally cycled at a constant	Significant main effect of stress condition: lesser	8

Study	Sample	Participants (n)	Theoretical framework or model	Study design	Stress measure(s)	PA measure(s); data transformation	Significant findings, associations, ESs	QR
	10.1 years (SD = 1.2) Girls mean age 10.1 years (SD = 1.6) Age range 8–12 years			Social Stress Test) vs. neutral control Crossover design (order randomized on 2 separate days)	split)	moderate intensity over a 30-min post-condition period Data analysis on DUR of cycling; energy expenditure from cycling (kcal)	energy expenditure (df = 1, 23, F = 14.97, $p < 0.001$) and exercise minutes (df = 1, 23, F = 7.61, $p <$ 0.001). No means for main effect reported Subjects reduced their PA by 21 % on the stress condition day Changes in perceived stress were not correlated with changes in exercise behavior ($r = -0.19$, $p > 0.35$) Children with high stress reactivity had a greater decline than children with low reactivity	
Sherman et al., 2009 [185]	Undergraduate students M + W Mean age 20.11 years	54 (only 17 analyzed)	None	Naturalistic Self-rated most stressful final exam vs. period 2 weeks beforehand No control group	Urinary catecholamines (indicator of sympathetic system activation) 2 items: subjective appraisal of exam stress (1–4 scale)	1-item survey: DUR of exercise (min)	Note: analysis of stress and exercise was exploratory 17 participants reported exercising the night before each urine sample was collected There was a decrease in exercise DUR from the pre-test (mean = 61.18, SE = 11.94) to the post-test (mean = 30.88, SE = 7.74), F (1, 16) = 5.67, p = 0.03, $\eta^2 = 0.26$. Cohen's $d = 0.62$ Results suggest that students reduced their exercise during the midterm exam period	6
Smith et al., 2005 [186]	Parents of a child with and without a cancer diagnosis M + W Mean age of stressed	98	Stressed population	Case control Prospective Cancer diagnosis vs. no diagnosis 3 months PA measured	PSS-14 Recent Life Changes Q POMS	Paffenbarger PA Q Data expressed as kcal expended/week Hours of TV viewing/week Hours of sitting/week	Overall, the stressed group reported less PA than the control group F (1, 94 = 43.38, $p < 0.0001$).	9

Study	Sample	Participants (n)	Theoretical framework or model	Study design	Stress measure(s)	PA measure(s); data transformation	Significant findings, associations, ESs	QR
	group 35.5 years (SD = 9.0) Age range 19–58 years			twice (2 weeks after diagnosis and 3 months later)			Parents of cancer patients reported only 400–500 kcal/week of PA vs. 1,400–1,500 kcal/week in parents of healthy children Group × time interaction significant F (1, 94 = 6.04, p < 0.05). Parents of cancer patients increased their PA over time (t (48) = −2.50, p = 0.01), but parents of healthy children did not change ES at time 1 = 1.71; ES at time 2 = 1.13 A group × time interaction was significant for TV viewing F (1, 94 = 5.84, p = 0.01). Parents of children with an illness watched more TV at time 1 but the groups were the same at time 2	
Smith et al., 2008 [272]	Working adults registered in Canadian National Population Health Study M + W Age range 25–60 years	3,411	Job strain Chronic stress exposure	Prospective Stress measured in 1994 PA measured in 1996	Job control subscale of Kasarek Job Content Q Wheaton Stress Q (18-item): personal, environmental, financial stress Composite International Diagnostic Interview (distress; University of Michigan revision) Household income adequacy	Survey of LTPA and sport Energy expenditure from time, DUR, and FREQ in the last 3 months PA expressed as kcal/kg/day	Those in the lowest quartile of job control had the greatest level of psychological distress Low job control measured in 1994 predicted PA in 1996 wave (β = −0.065, t = −3.284, p = 0.001) even when adjusted for many covariates (e.g., BMI, gender, health, back pain, education, etc.) In model comparing all stress exposures, low job control (β = −0.052, t = −2.52, p = 0.012) and high environmental stress (β = −0.07,	6

Study	Sample	Participants (*n*)	Theoretical framework or model	Study design	Stress measure(s)	PA measure(s); data transformation	Significant findings, associations, ESs	QR
							$t = -2.58$, $p = 0.010$) predicted PA Relationships of (a) job control and (b) environmental stress with self-rated health was mediated by PA (p values = 0.026 and 0.024, respectively)	
Sonnentag and Jelden, 2009 [282]	Police officers in Germany M + W (86 % M) Mean age 43.8 years (SD = 7.7)	78	Job stress Self-regulation	Prospective 5 days 2 daily measures (just after work and before bed)	Job stressor measures Situational constraints (i.e., information mishaps, communication tool failures, malfunctioning computers, etc.) Profile of Mood States—fatigue subscale	Daily recording of DUR of “sport activities” (running, cycling, swimming) and sedentary activities (watching TV, reading a newspaper, doing nothing)	Time pressure and role ambiguity did not relate to indices of sport and PA participation Situational constraints inversely related to LTPA (estimate = −0.159, SE = 0.076, $t = -2.106$, $p < 0.05$) Sedentary (low-effort) activities positively related to situational constraints (estimate = 0.253, SE = 0.111, $t = 2.275$, $p < 0.05$) Hours worked inversely related to sedentary (low-effort) activities (estimate = −0.098, SE = 0.039, $t = -2.513$, $p < 0.05$)	7
Steptoe et al., 1996 [187]	College students M + W M mean age 23.0 years (SD = 3.2) W mean age = 21.8 years (SD = 2.7)	180	None	Naturalistic Exam stress vs. early semester Control group comparison	PSS-10 GHQ-28 (emotional distress)	FREQ and DUR of light, moderate, and vigorous PA, including exercise and commuting with a bicycle over last week Light PA not analyzed	Group × time interaction observed ($F = 4.85$, $p < 0.05$) No difference between groups at BL PA DUR decreased between BL and exam time points of semester ($p < 0.05$) FREQ of exercise did not change: BL mean = 2.1 (SD = 2.1), exam mean = 1.92	7

Study	Sample	Participants (*n*)	Theoretical framework or model	Study design	Stress measure(s)	PA measure(s); data transformation	Significant findings, associations, ESs	QR
							(SD = 2.25); NS Note: association not influenced by social support	
Steptoe et al., 1998 [188]	Teachers and nurses M + W Nurses' mean age 39.7 years (SD = 8.7) Teachers' mean age 43.9 years (SD = 11.4)	44	None	Prospective diary study 2 weeks of highest self-rated stress vs. 2 lowest self-rated weeks of stress 8 weeks	PSS-4 Hassles and Uplifts Scale	FREQ, DUR, and type of exercise completed. Exercises classified by intensity (moderate/ vigorous or low-intensity) Assessed weekly Exercise coping (for mood regulation); 1 item taken from Reasons for Exercise Inventory	There were no significant differences in exercise FREQ or DUR with changes in perceived stress, but a trend is seen FREQ of moderate to vigorous intensity exercise decreased during stress (low stress: mean = 2.32, SD = 2.3; high stress: mean = 1.85, SD = 2.7; ES = 0.20). DUR also decreased (low stress: mean = 145.9, SD = 194.1; high stress: mean = 115.8, SD = 2.7; ES = 0.16) FREQ of light exercise decreased during stress (low stress: mean = 2.56, SD = 2.4; high stress: mean = 1.96, SD = 2.8; ES = 0.25). DUR also decreased (low stress: mean = 80.7, SD = 92.5; high stress: mean = 64.6, SD = 55.7; ES =0.17) Those who exercised to regulate mood did report more exercise, however, but this did not change with perceived stress Those who reported using exercise to cope with stress exercised more at moderate to vigorous	6

Study	Sample	Participants (*n*)	Theoretical framework or model	Study design	Stress measure(s)	PA measure(s); data transformation	Significant findings, associations, ESs	QR
							intensity (F (1, 28) = 5.32, $p < 0.01$) and low intensity (F (1, 26) = 4.69, $p < 0.01$) over the entire study period, but this did not vary by stress No analysis of hassles and exercise association reported	
Stetson et al., 1997 [189]	Middle-aged, community-residing, already exercising on their own W only Mean age 34.8 years (SD = 11.1)	82	None	Prospective diary study Self-rated low vs. high stress weeks 8 weeks PA recorded daily	WSI: scores for stress FREQ and stress impact	Exercise History and Health Q (developed by authors, reliability >0.90, except for walking, $r = 0.58$) FREQ and DUR for structured list of 8 activities. Subjects free to add more activities Exercise diary: daily recording of exercise plans (yes/no), actual exercise (yes/no), type, DUR (min), perceived exertion (6–20 scale), and enjoyment (1–5 scale)	69 % of sample reported exercising to cope with stress Stress FREQ associated with exercise DUR Low-stress weeks: mean = 73.56, SD = 38.10; high-stress weeks: mean = 68.06, SD = 31.47 ($p < 0.05$; ES = 0.14) Stress FREQ not associated with exercise FREQ, perceived intensity or number of exercise omissions Stress impact associated with exercise omissions Low-stress weeks: mean = 0.78, SD = 0.72; high-stress weeks: mean = 0.94, SD = 0.97 ($p = 0.07$; ES = 0.22) This indicates that high stress resulted in more cancelled preplanned exercise sessions Stress impact not associated with exercise FREQ, DUR or perceived intensity	7
Twisk et al., 1999 [280]	Dutch adults in the Amsterdam Growth and Health Study	166	Life events	Prospective 2 years PA measured 2×	Everyday Problem Checklist (daily hassles) Life Event List (translated Life Event	Open question, interview-based exercise survey: weekly exercise DUR	Changes in daily hassles positively related to increases in PA (standardized β = 0.27, 95 %	7

Study	Sample	Participants (n)	Theoretical framework or model	Study design	Stress measure(s)	PA measure(s); data transformation	Significant findings, associations, ESs	QR
	cohort M + W 27 years at BL 29 years at follow-up				Survey) Ways of Coping Checklist	and intensity over last 3 months Data expressed as METs/week	CI 0.13–0.43, $p < 0.01$) Association moderated by coping style. Those with a rigid coping style expressed association (standardized $\beta = 0.08$, 95 % CI 0.15–0.49, $p < 0.01$). No association amongst those with a flexible coping style Type A personality interacted with daily hassles and PA. Those categorized as low (standardized $\beta = 0.50$, 95 % CI 0.23–0.77, $p < 0.01$) and high (standardized $\beta = 0.24$, 95 % CI 0.03–0.45, $p < 0.05$) in type A personality had greater PA with more hassles Life events (FREQ and subjective appraisal) did not influence PA	
Urizar et al., 2005 [89]	Sedentary, low income, diverse (74 % Latina) mothers W only Mean age 31.7 years (SD = 8.8)	68	Exercise barriers	Prospective Intervention 10 weeks PA measured 2×	Mother Role Q (maternal stress survey) PSS-14	Stanford 7-Day PA Recall Data expressed as kcal/kg/day Intervention program adherence: number of classes attended also reported	Maternal stress FREQ did not decrease with intervention ($p = 0.06$). Also, impact/intensity of stress and PSS did not change over intervention Increased PA from BL to 10 weeks was associated with decrease in maternal stress ($r = -0.42$, $p < 0.01$), but maternal stress frequency over 10 weeks not related to class attendance ($r = 0.01$, $p = 0.97$) Higher maternal stress frequency at BL related to	8

Study	Sample	Participants (*n*)	Theoretical framework or model	Study design	Stress measure(s)	PA measure(s); data transformation	Significant findings, associations, ESs	QR
							less class attendance (β = −0.18, SE = 0.09, *p* = 0.05) Higher impact/ intensity of maternal stress at BL related to 10-week PA (β = −0.76, SE = 0.30, *p* = 0.01) Perceived stress was not associated with PA or program adherence	
Vitaliano et al., 1998 [190]	4 groups: caregivers of spouses with Alzheimer's vs. matched controls (both conditions split by cancer diagnosis) M + W Mean age 66.1, 54.6, 73, and 63.2 years	165 (80 caregivers)	Stressed population	Case control Prospective 15–18 months PA measured 2×	Hassles and Uplifts Scale Hamilton Depression Scale	Exercise scale inquiring about 10 different activities FREQ/week, DUR Binary respondent classification: dichotomized as active (>90 min of exercise/week) or inactive	Caregivers were more depressed (*p* < 0.001) and reported more hassles (*p* < 0.01) than the control group Caregivers had less PA than controls at both time points (*p* < 0.05) At time 1 among subjects without cancer, caregivers (mean = 1.2; SD = 0.74) had less PA than non-caregivers (mean =1.5; SD = 0.75; ES = 0.41) At time 2 among subjects without cancer, caregivers (mean = 0.9; SD = 0.71) had less PA than non-caregivers (mean = 1.3; SD = 0.74; ES = 0.57)	8
Wilcox and King, 2004 [204]	Randomly selected older adults in a community fitness program M + W Mean age 70.2 years (SD = 4.1)	97	Life events	Prospective Intervention 12 months	Social Readjustment Rating Scale (modified)	Indicators of exercise adherence: (1) home-base exercise participation—daily logs with type, FREQ, DUR of exercise sessions; (2) class-based exercise participation	Number of life events (across all 3 assessments) was negatively associated with home-based exercise participation over the entire 12-month period (total sample, *r* = −0.17, *p* <0.05; for W, *r* = −0.19, *p* = 0.07), but not class-based	8

Study	Sample	Participants (*n*)	Theoretical framework or model	Study design	Stress measure(s)	PA measure(s); data transformation	Significant findings, associations, ESs	QR
						Data calculated as average percentage of completed assigned/ prescribed workouts	participation (total sample, $r = -0.08$; W, $r = -0.20$, $p = 0.06$). Associations between life events and exercise participation were not significant for M Life events during months 1–6 were associated with adherence to exercise during months 7–12 for home-based exercise ($r = -0.21$, $p = 0.02$) but not for class-based exercise ($r = -0.04$). The strongest correlation was between life events at months 1–6 and home-based exercise participation ($r = -0.32$, $p = 0.03$) Subjects who experienced an interpersonal loss had lower class-based participation than those who did not (62.7 vs. 72.3 %; $t(94) = 1.70$, $p < 0.05$, ES = −0.38), but home-based participation rates were unaffected (ES = 0.14). Regression analysis found that interpersonal loss predicted class-based participation ($\beta = 11.69$, SE = 5.83, $p = 0.02$) but not home-based participation Life events, particularly interpersonal loss, appear to have a negative impact on exercise in	

Study	Sample	Participants (*n*)	Theoretical framework or model	Study design	Stress measure(s)	PA measure(s); data transformation	Significant findings, associations, ESs	QR
							W, and this effect appears greater for class-based than for home-based exercise	
Williams and Lord, 1995 [277]	Community-residing older adults W only Mean age 71.6 years (SD = 5.48) Age range 60–85 years	69	None	Prospective Exercise intervention 12 months	DASS	Adherence to 12 months of exercise (assessed at 3 terms, including week 10 and at 12 months) Adherence defined as number of classes attended Binary respondent classification: exercise “continuers” vs. “non continuers”. Those who continued the exercise program after the intervention were classified as “continuers”	Adherence to the intervention was not associated with BL stress (r = 0.04), depression (r = −0.06), or anxiety (r = −0.16) Mood at 10 weeks did correlate with adherence over 12 months (r = 0.39, $p <$ 0.01) Continuing exercise after the intervention (n = 54) was predicted by depression (continuers = 2.1, SD = 3.2; non-continuers = 4.7, SD = 5.4, ES = 0.81) but not stress (continuers = 5.6, SD = 7.1; non-continuers = 8.4, SD = 8.5, ES = 0.39)	6

AIHW Australian Institute of Health and Welfare, *BDI* Beck Depression Inventory, *BMI* body mass index, *CBT* cognitive–behavioral therapy, *CI* confidence interval, *COEFF* coefficient, *CVD* cardiovascular disease, *DASS* Depression Anxiety Stress Scale, *DUR* duration, *ES* effect size, *FREQ* frequency, *GHQ* General Health Questionnaire, *HLM* hierarchical linear modeling, *HPLP* Health Promotion Lifestyle Profile, *LTPA* leisure time physical activity, *M* men, *METs* metabolic equivalents, *MVPA* moderate to vigorous physical activity, *NA* negative affectivity, *NHIS* National Health Interview Survey, *NS* not significant, *NY* New York, *OR* odds ratio, *PA* physical activity, *PBC* perceived behavioral control, *POMS* Profile of Mood States, *PSS* Perceived Stress Scale, *PTSD* post-traumatic stress disorder, *Q* questionnaire, *QR* quality assessment rating (1–9 scale; see text), *RCT* randomized control trial, *SD* standard deviation, *SE* standard error, *SEM* structural equation modeling, *TMAS* taylor manifest anxiety scale, *TV* television, *W* women, *WSI* Weekly Stress Inventory