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The effects of interventions with physical activity components on adolescent mental health: Systematic Review and Meta-Analysis

1. Introduction

Mental health is often defined as a state of well-being which can help an individual cope with their feelings and daily stressors (World Health Organisation, 2018; Mental Health Foundation, 2013). Currently, the prevalence of mental health problems has reached unprecedented levels globally (World Health Organisation, 2018; Rehm & Shield, 2019; Schofield et al. 2019; Vigo et al. 2019). Anxiety, depression, and stress have been identified as common mental health issues impacting individuals worldwide (Rehm & Shield, 2019; Mental Health Foundation, 2016; National Collaborating Centre for Mental Health, 2011). The increasing prevalence of these issues has a significant impact on physical health, social policy, human rights and economics (Schofield et al. 2019; Sickel, Seacat and Nabors, 2019; World Health Organisation, 2019). These issues account for 10-14% of the global burden of disease (Schofield et al. 2019; World Health Organisation 2018) with further evidence indicating that mental health issues account for 183.9 million disability adjusted life years (Schofield et al. 2019; Whiteford et al. 2010).

This burden and increasing prevalence places a major burden on health resources. Mental health costs are surpassing all other health conditions with direct and indirect costs of \$1 billion a year from depression and anxiety (Vigo et al. 2019; Doran & Kinchin, 2019; Evans, 2019; Pincherio, Ivandic and Razzouk, 2017; Trautmann & Wittchen, 2016). Therefore, many governments have identified mental health as a priority area, particularly in young people (Mental Health Foundation, 2018; Silverstone et al. 2016; Keyes, 2013; Burnett-Zeigler et al. 2012). Young people have been categorized as an at-risk group for developing severe mental health disorders with one in five children and young people reporting poor mental health

(World Health Organisation, 2018, Mental Health Foundation, 2016; NAMI, 2015; McGorry et al. 2013). Research suggests that during adolescence around 20 per cent of young people will suffer from anxiety, depression or stress related problems before the age of 18 (World Health Organization, 2018; Werner-Seidler *et al.* 2017). Due to this increasing prevalence of these mental health problems, research has suggested that early intervention during this transitional life phase is imperative to help promote positive mental health, and resilience in these adolescents (He et al. 2018; Weeks et al. 2017; Royal College of Psychiatrists, 2016; Fazel et al. 2014; Burnett-Zeigler et al. 2012; Moses, 2010; Olsson *et al.* 2003). Recent evidence suggests that these interventions could contain an element of physical activity to improve psychological outcomes such as anxiety and depression, in addition to addressing global youth inactivity levels (Jewett et al. 2014; Eime et al. 2013; Vina et al. 2012; Rangul et al. 2012; Ströhle, 2009; Salmon, 2001). In comparison to the unsustainable long-term costs of pharmacological (medication) or psychosocial approaches (psychotherapy or cognitive behaviour therapy, physical activity is considered as more feasible and cost-effective alternative as an intervention component (Gråstén, 2017; Weeks *et al.* 2017; Lam, 2016). This is particularly important as the World Health Organization have highlighted that four in five adolescents aged 11 to 17 years old are not meeting the recommended physical activity guidelines (who.int, 2019).

The relationship between physical activity and mental health, particularly anxiety and depression, has garnered a large amount of attention. Compelling evidence from a systematic review on physical activity as a treatment for severe mental health illness by the European Psychiatric Association (Stubbs et al. 2018) clearly illustrated the importance of physical activity and exercise as an alternative mental health treatment pathway to the traditional pharmacological and psychosocial approaches. The European Psychiatric Association have recommended that physical activity could be used to reduce mental health symptoms while

improving quality of life, physical health and cognition in individuals who face mental health difficulties. Furthermore, three reviews conducted in the adolescent provided reliable evidence that physical activity can have a positive effect on mental health, particularly being used to reduce symptoms of anxiety and depression population, although the authors highlighted that further research is warranted due to the weak research design and small effects of the included reviews (Biddle et al. 2019; Camero et al. 2012; Biddle and Asare, 2011).

Extant research has demonstrated that it may be possible to positively influence mental wellbeing in young people through physical activity, which if sufficient enough can have a positive impact on anxiety, depression and stress disorders. For example, Bonhauser et al. (2005) examined the effects of improving physical fitness on the emotional well-being of 198 adolescents through a school-based intervention. The intervention programme involved three physical activity sessions weekly, each lasting 90 minutes. Over the academic year, the 40-week programme involved different stretching, weight and sports activities for the intervention group, while the control group only received a standard 90-minute exercise class a week. The results of the study showed that anxiety and depression scores decreased, while self-esteem scores increased as a result of the intervention, thus suggesting that physical activity can have an effect on reducing the symptoms of these mental health outcomes. Furthermore, a study by He et al. (2018) reported that adolescents who were more physical active, were significantly less likely to suffer mental health issues.

Traditionally physical activity interventions look at increasing physical activity levels or improving physical fitness rather than a sole focus on mental health outcomes (Dobbins et al. 2012; Bonhauser et al. 2005) or focusing on other health outcomes such as obesity. The examination of mental health outcomes is currently understudied within the adolescent population. However, several intervention studies have examined psychosocial benefits such as academic achievement, cognitive functioning (Archer & Garcia, 2014; Ardoy et al. 2014)

and self-concept (Lubans et al. 2012; Lai et al. 2009). While these studies have highlighted an association between mental health and physical activity, little evidence is known about the causal relationship between physical activity on mental health outcomes in young people. The reason behind this is the complexity of measuring mental health and physical activity in the adolescent population, which may be why the majority of research in this area examines the relationship amongst the adult population (Kuhn et al. 2017; Mental Health Foundation, 2016; Fox, 1999). Promoting physical activity could be an important preventative strategy for mental health outcomes amongst adolescents, but more research is needed to determine this. To address the current evidence gaps, this systematic review will examine the effect of interventions with physical activity components on anxiety, depression and stress outcomes in young people. The objectives of the review were to:

- identify evidence on the effect of physical activity interventions on mental health outcomes; anxiety, stress and depression and
- identify the gaps in research evidence in order to make recommendations for future research.

2. Methods

This systematic review and meta-analysis complies with the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) guidelines (S1 File).

2.1. Eligibility criteria

A study was considered eligible for this review if it met the following inclusion criteria: (a) included participants aged between 10-19 years ; (b) examined interventions with physical activity components and measured anxiety, depression and stress outcomes; (c) included an intervention lasting longer than four weeks that contained physical activity alone, or as part of

a multi-component intervention; and (d) investigated the effects of the intervention on anxiety, depression and stress. For studies to be included in the review they had to be a randomised or cluster randomised controlled trial (RCT).

Excluded studies were those which: (a) included participants from outside the included age bracket; (b) were published in languages other than English; (c) were conference abstracts, study protocols or dissertations; (d) were studies developing interventions without participants; (e) were studies without a relevant control group (i.e. control groups with exercise or physical activity as a component) and (f) were studies that only examined physical health outcomes or physical well-being.

2.2. Search Strategy

Electronic databases were searched in November 2019 with no restriction set on the publication year. Furthermore, the search strategy was limited to articles published in English language only. A systematic search was carried out across nine electronic databases including: *British Education Index*, *Child Development and Adolescent Studies*, *CINAHL*, *Cochrane Central Register of Controlled Trials (CENTRAL)*, *Embase*, *ERIC*, *Medline*, *Psychinfo* and *SportsDiscus*. Search terms included a combination of common variants of young people and mental health outcomes. MEDLINE was used to develop the search strategy, which was then adapted for the other databases as necessary. The specific search terms are detailed in S2 File.

To identify any further published or unpublished government reports and other grey literature, open grey (<http://www.opengrey.eu/>) was complemented with a web search on Google Scholar (<https://scholar.google.co.uk/>), using the phrase ‘physical activity interventions and mental health in young people or adolescents’, with the first 200 citations examined. In addition, manual searches for relevant publications in the following journals were carried out for the last three years (2016-2019); *International Journal of Behavioural Nutrition*

and Physical Activity, Journal of Physical Activity and Health, Journal of Youth and Adolescence, Journal of Adolescent Health, Journal of Child and Adolescent Mental Health, Journal of Psychology of Sport and Exercise, Journal of Sport and Exercise Psychology, Journal of Sport and Health Science, Journal of Medicine and Science in Sport and Exercise and the Journal of Mental Health and Physical Activity. Finally, the reference lists of all included studies were reviewed for relevant citations.

2.3.Data Collection

2.3.1. Study Selection

The initial literature searches were conducted by one reviewer (RN). After duplicates were removed using Covidence (Vertias Health Innovation, 2015) title and abstracts of potentially relevant articles were independently screened by RN and MT. After this initial phase, the relevant full text of the remaining articles were independently screened and evaluated for inclusion by RN and MT according to the inclusion criteria. Any discrepancies were resolved through discussion between the two reviewers to determine the eligibility of the study for the review (RN and MT). Consensus was obtained for all relevant included journal articles.

2.3.2. Data extraction

Two reviewers (RN and MT) independently extracted characteristics, population, intervention, outcomes and analysis from each study. In the case of disagreements, a third reviewer (PB) was consulted. Information from each study was extracted onto Covidence (Vertias Health Innovation, 2015) and then exported to Review Manager 5.3. (RevMan – Cochrane Collaboration, 2014). Information extracted included; type of study, number of participants, outcome measures, details on intervention (setting, duration, frequency, duration,

providers/resources, theoretical framework, content, control), study length, significant findings and risk of bias.

2.3.3. Risk of bias in included studies

Study quality was assessed for risk of bias using the Risk of Bias assessment tool from the Cochrane Handbook for Systematic Reviews of Interventions (Higgins & Green, 2008). Six specific domains were addressed; (a) selection bias (random sequence generation and allocation concealment), (b) performance bias (blinding of participants and personnel), (c) attrition bias (incomplete outcome data) (d) detection bias (blinding of outcome assessment), (e) selective reporting bias (selective outcome reporting) and (f) any other potential sources of bias. Two authors (RN and MT) independently assessed the ‘risk’ of bias within each included study. Each domain was rated as low risk of bias, high risk of bias or unclear risk of bias. Studies were considered high risk of bias when at least one of the criteria were judged as having a high risk of bias in any one of the criteria. Overall risk of bias was assessed as unclear if one or more of the criteria was assessed as unclear, but none were assessed as having a high risk of bias. Studies were considered low risk of bias if all criteria were assessed as low. Any disagreements were discussed until a consensus was reached.

2.3.4. Data Synthesis

Extracted study characteristics, intervention designs, intervention duration, theoretical frameworks and outcome measures were summarised in tabular form and described. Studies were synthesized per outcome measure. Meta-analyses using a Random Effects (RE) model were then conducted using Review Manager 5.4. (Cochrane Collaboration, 2014). Each complex intervention differed in size of intervention type, setting and number of participants and therefore a random-effects meta-analysis was performed for each outcome due to the

differences in variables (Clark & Linzer, 2015; Borenstein et al. 2010; Brockwell & Gordon, 2001; Hedges & Vevea, 1998). A meta-analysis was undertaken if at least two similar comparisons could be performed (Ahn & Kang, 2018; Bown & Sutton, 2010) and suitable data were available.

Continuous outcomes were reported differently across studies. Some studies reported the mean score post-intervention for the outcomes at follow up, whilst others reported mean change from baseline, therefore these studies were split into two separate forest plots. Where possible, the mean difference from baseline to follow up was used in analyses. When the mean difference from baseline was not reported, we extracted the relevant data at the final time point. When studies used different outcome scales to measure an outcome of mental health, the results were calculated by standardised mean differences (SMDs). As per the guidance in the Cochrane Handbook of Systematic Reviews (2019), the final values and change scores were not combined as SMD. Therefore, separate meta-analyses were conducted. Where data were presented separately by gender or multiple intervention groups, we combined these in RevMan. Two studies (Goldfield et al. 2015; Daley et al. 2006) consisted of more than one exercise intervention group and therefore the data from both groups were combined during the analysis process. Funnel plots were used to examine any publication or reporting bias in the included studies (Hoffman, 2015).

Heterogeneity was assessed among the studies by examining forest plots and the I^2 statistic. This allows for a measure of the extent of the variation between the intervention effects among the different included studies (Borenstein et al. 2010; Higgins & Green, 2008). Zero percent indicates no heterogeneity present, while 25 percent, 50 percent and 75 percent indicate low, moderate and high effects sizes of heterogeneity respectively (Werner-Seidler et al. 2017; Higgins et al. 2003). The meta-analyses were conducted to compare the intervention and control groups on the primary outcomes at post-intervention. The variability in participants,

intervention components and outcomes of the included studies presented within this review indicate clinical heterogeneity may exist in the dataset. This can cause significant statistical heterogeneity therefore sub-group analyses were conducted to highlighted relevant clinical information (Gagnier et al. 2012). Subgroup analysis were conducted to examine any significant differences between solely physical activity-based interventions and multi-component interventions included within the review. An overall effect size, the confidence interval and level of heterogeneity are presented in the following sections. Finally, studies that were not included in the meta-analysis were described narratively.

3. Results

3.1. Search results

Following the initial search of databases; 4,518 articles were identified using the search strategy (Fig 1). Articles were uploaded onto Covidence and duplicates were removed, leaving 2,795 articles. Titles and abstracts were screened and a further 2,682 articles removed, leaving 113 articles for full-text review. Studies were excluded during full-text screening for various reasons which are outlined in the characteristics of excluded studies table (S3 file). During this phase one article was merged as the papers were from the same study but included different time-points from baseline to twelve-month follow-up (Melnik et al. 2015; Melnik et al. 2013). Thirteen studies (from fourteen articles) published between 1982-2018, met the eligibility criteria for inclusion in the review.

Please insert Figure 1. here.

3.2.Characteristics of included studies

The studies were carried out in different countries with the majority were conducted in the USA (n=7). One study was conducted in each of the following countries: England, Portugal, China, Korea, Columbia, Germany and Uganda. The included studies (Table 1) were conducted in different settings, ten interventions were based in the school setting, four were based in a hospital or clinical setting and two were set in the community setting. A majority of the studies (n=11) included both adolescent male and female participants (Andias et al. 2018; Frank et al. 2017; Carter et al. 2015; Goldfield et al. 2015; Melnyk et al. 2015; Velasquez et al. 2015; Richards et al, 2014; Khalsa et al. 2012; Melnyk et al. 2009; Daley et al. 2006; Lau et al. 2004) two studies included only female (Jeong et al. 2005) while only one of the studies included only male participants (Hilyer et al. 1982).

The included studies included interventions with a broader population which allows a level of generalisability across the results. Three studies were conducted in adolescents with obesity (Goldfield et al. 2015; Daley et al. 2006; Lau et al. 2004), three were carried out with adolescents from low income or poverty catchment areas (Frank et al. 2017; Velasquez et al. 2015; Richards et al. 2014), two were conducted with adolescents with high depression scores or receiving treatment for depression (Carter et al. 2015; Jeong et al. 2005). One study was conducted in the following adolescent populations, youth offenders (Hilyer et al. 1982); from a Hispanic background (Melnyk et al. 2009), culturally diverse background (Melnyk et al. 2015), rural community (Khalsa et al. 2012) and those adolescents suffering from chronic neck pain (Andias et al. 2018). Data was included for 1,928 participants with ages ranging from 10 to 19 years old.

Please insert Table 1 here.

3.3.Mental Health Outcomes and Assessment

A variety of instruments were employed across the thirteen studies for anxiety, depression and stress outcome measures (S4). The use of difference outcome measures introduces methodological heterogeneity due to differences in study design, risk of bias and assessment measures. Of the included studies, eleven reported a measure of depression (Melnik et al. 2013, Carter et al. 2015; Goldfield et al. 2015; Melnyk et al. 2015; Velasquez et al. 2015; Richards et al, 2014; Khalsa et al. 2012; Melnyk et al. 2009; Daley et al. 2006; Lau et al. 2004; Jeong et al. 2005; Lau et al. 2004; Hilyer et al. 1982), seven reported general anxiety (Carter et al. 2015; Richards et al. 2014; Melnyk et al. 2013; Khalsa et al. 2012; Melnyk et al. 2009; Jeong et al. 2005; Lau et al. 2004) and two reported state and trait anxiety (Andias et al. 2018; Hilyer et al. 1982). Furthermore, two studies examined different domains of stress (Frank et al. 2017; Khalsa et al. 2012), while test anxiety (Khalsa et al. 2012) were only reported in a single study.

3.4.Interventions

Within the included studies, several different types of physical activity were included in the interventions; including yoga (n=3), strength, endurance and resistance type exercises (n=2), aerobic exercises (walking, badminton, climbing, Frisbee, etc.) (n=4), fitness training (e.g. circuits) (n=2), dance movement (n=1) and football (n=1). The interventions included four physical activity and educational sessions, two physical activity and counselling sessions and one study implementing a physical activity and behaviour modification intervention. Six studies offered physical activity only interventions. All 13 studies included interventions that ran for less than one year. Interventions lasted between four weeks and six months. Control groups within each study involved, seven studies with no change to their normal routine and no intervention (Andias et al. 2018; Frank et al. 2017; Velasquez et al. 2015; Richards et al.

2014; Daley et al. 2006; Jeong et al. 2005), two involved treatment as usual control groups (Carter et al. 2015; Hilyer et al. 1982), two included business as usual with dietary advice (Goldfield et al. 2015; Lau et al. 2004) and two involved educational health advice (Melnik et al. 2015; Melnyk et al. 2009). Four of the 13 studies explicitly labelled a theoretical framework in informing the intervention. Two theories were cited; cognitive behaviour theory (n=2), and transtheoretical model (n=2).

3.5.Risk of bias in included studies

The risk of bias across all domains for the studies included in the review is presented in Figs 2 and 3. Frequently, a number of studies were reported as an ‘unclear’ risk of bias across several domains, this judgement was often obtained due to insufficient information. Overall risk of bias was high for eight of the included studies (Andias et al. 2018; Frank et al. 2017; Carter et al. 2015; Richards et al. 2014; Khalsa et al. 2012; Daley et al. 2006; Lau et al. 2004; Hilyer et al. 1982) and an unclear risk of bias was reported overall in three studies (Goldfield et al. 2015; Jeong et al. 2005; Velasquez et al. 2015). Two studies were reported as low risk of bias (Melnik et al. 2015; Melnyk et al. 2009). This level of evidence may suggest that physical activity components within interventions may improve mental health outcomes however no significant effect is evident, therefore these results must be viewed with caution due to the risk of bias across all included studies.

Please insert Figures 2 and 3 here.

Over 50 percent of included studies (n=7) were judged unclear to high risk of bias for incomplete outcome data (attrition bias). A number of these studies failed to highlight their intent-to-treat analysis process which resulted in unclear and high risk in a majority of the

included studies, this introduces possible bias, high methodological heterogeneity and raises uncertainty about the results. Around 70 per cent of the studies were found to be free of selective reporting, however for the other 30 per cent it was impossible to know if all outcomes were all reported due to no published study protocol.

Another notable risk of bias and methodological weakness within the included studies was the lack of blinding (performance and detection bias) with around 40 per cent of studies demonstrating unclear to high risk of bias. Seven studies were judged as high risk while six were judged unclear risk for this domain. Overall the risk of bias from blinding can be reported as high with a number of studies not implementing full blinding procedures or provide insufficient information on blinding within their study or protocol. For example, the mental health outcomes in all studies were assessed through a self-reported questionnaire. There is also a chance that these participants may have been aware of the outcomes being assessed within the study. Evidence suggests that a lack of blinding can affect participant outcomes or introduce bias into the assessment of outcomes (Karanicolas, Farrokhyar & Bhandari, 2010; Higgins & Green, 2008). Furthermore, the unclear risk of bias for blinding could suggest bias is present in the intervention treatment which could impact the reliability of the results (Boutron et al. 2007).

3.6. Effects of interventions

Of the thirteen studies assessed, only eleven provided sufficient information to be included in the meta-analyses (Melnik et al. 2015; Carter et al. 2015; Goldfield et al. 2015; Velasquez et al. 2015; Richards et al. 2014; Khalsa et al. 2012; Melnik et al. 2009; Daley et al. 2006; Jeong et al. 2005; Lau et al. 2004; Hilyer et al. 1982). The additional two studies were included in the qualitative synthesis (Andias et al. 2018, Frank et al. 2017).

3.7.Synthesis of Results from Meta-Analysis

Funnel plots (S5 file) displayed asymmetry suggesting that publication bias may be present in the included studies. This could be due to study effect sizes and level of heterogeneity (Lau et al. 2006; Tang and Liu, 2000). These findings also suggest that there is evidence of publication/reporting bias.

3.7.1. Effect on Anxiety

Seven studies including a total of 1,233 participants examined the impact of physical activity interventions on anxiety, five of these studies examined mean anxiety follow up (Fig 4a) and two examined change in anxiety from baseline (Fig 4b). The effect of physical activity on anxiety at follow was not statistically significant (SMD 0.04; 95% CI -0.20, 0.28; $I^2 = 55\%$) or when measured as change from baseline (SMD -0.33; 95% CI -0.68, 0.03; $I^2 = 0$). A subgroup analysis revealed no statistically significant difference for solely physical activity-based interventions or multi-component interventions.

Please insert Figure 4 here.

3.7.2. Effect on Depression

Twelve studies, including a total of 1,726 participants, examined the effect of a physical activity intervention on depression. Six of these studies examined depression as a mean at follow up (Fig 5a) while five of the included studies examined depression as a change from baseline (Fig 5b). Depression as a mean at intervention follow up was not statistically significant (SMD 0.09; 95% CI -0.20, 0.40; $I^2 = 72\%$). A subgroup analysis comparing physical activity ($p=0.37$) alone against multi-component ($p=0.25$) studies also indicated no significant difference existed for either intervention type. Depression as a change from

baseline was also was also not statistically significant (SMD -0.11; 95% CI -0.29, 0.07; $I^2 = 0\%$). A subgroup analysis revealed no statistically significant difference for solely physical activity-based interventions or multi-component interventions.

Please insert Figure 5 here.

3.8.Synthesis of Findings Not Included in Meta-Analysis

3.8.1. Effect on anxiety

The study by Andias et al. (2018) could not be included within the meta-analysis as it reported the mean difference in state anxiety and trait anxiety and therefore could not be compared to the other study which examined state and trait anxiety through mean at follow up. This study found that anxiety exhibited no significant difference ($p=0.09$) between the control and intervention groups at the end of the 4-week intervention. In addition, there was no significant difference for trait anxiety ($p=0.11$) between the control and intervention groups at the end of the 4-week intervention. Post intervention, the experimental group had lower trait and state anxiety scores than the control group. A study, by Hilyer *et al.* (1982) measured state anxiety and trait anxiety, examining the effects of a physical fitness training and counselling treatment programme for youth offenders. This study examined mean score at follow up and therefore could not be compared to Andias *et al.* (2018) in a meta-analysis. The authors reported a significant difference between the intervention and control groups in trait anxiety ($p<0.001$). State anxiety showed no statistically significant difference between the intervention and control groups ($p=0.06$); however, state anxiety decreased in the intervention group and increased in the control group.

Only one study examined the concept of test anxiety: Khalsa et al. (2012) reported that while there was no statistically significant difference ($p=0.15$) between the Yoga and control groups, the Yoga group exhibited lower test anxiety scores compared to the control group post-intervention.

3.8.2. Effects on stress

Two studies reported on different domains of stress (Frank et al. 2017; Khalsa et al. 2012). Frank et al. (2017) examined seven aspects of stress response; problem solving, emotional regulation, emotional expression, secondary engagement, positive thinking, cognitive restructuring and acceptance. Statistically significant differences were found between the intervention and control groups in emotional regulation ($p=0.05$), positive thinking ($p=0.01$), secondary engagement ($p=0.01$) and cognitive restructuring ($p=0.01$). No significant differences were found in problem solving ($p=0.86$) or emotional expression ($p=0.12$) or acceptance ($p=0.57$). Furthermore, Khalsa et al. (2012) reported that while the intervention group had lower scores on the social stress domain than the control group the difference was not statistically significant ($p=0.15$).

4. Discussion

4.1. Summary of main results

The primary aim of this review was to examine the effects of physical activity interventions on the mental health outcomes of young people. The review identified eleven RCT's and two cluster-RCT's, with more than 1,500 participants, examining the effects of different interventions incorporating elements of physical activity to improve anxiety, depression and stress outcomes in adolescents. The meta-analyses updated the constantly expanding literature on the effects of physical activity intervention on mental health outcome in adolescents. The

results indicated slight improvements in anxiety, depression and stress scores; however, the results were not statistically significant. Previous research also highlights that while there is only a small effect, there is an evident association between physical activity and mental health outcomes (Biddle et al. 2019; Camero et al. 2012; Biddle et al. 2011; Calfas & Taylor, 1994). The findings of the current review are also consistent with the results of the systematic review by Camero et al. (2012) which indicated that there were no statistically significant differences in the determinants of psychological health, i.e. anxiety and depression. However, a longitudinal study by Jewett et al. (2014) examined mental health and involvement in school sport, suggesting that increased involvement in physical activity was a statistically significant predictor of lower stress and depression levels. Similarly, a review by Carter et al. (2016) demonstrated that exercise could have a statistically significant moderate effect on reducing depressive symptoms which was not evidenced in this study. The findings of the review in this study included a broader representation of the adolescent population and demonstrated higher levels of heterogeneity within the findings, which could have influenced the overall results and difference within the inclusion/exclusion criteria compared to the review by Carter et al. (2016).

The results of the meta-analyses of included studies were variable as indicated by the mostly moderate effect of heterogeneity. This might be explained by the difference in intervention duration and post-test data collection time points. The findings also indicated that research amongst the adolescent population often focuses on the physical activity interventions with depression as the outcome with few studies the effects of physical activity interventions on anxiety. The thirteen included studies involved multi-component interventions which utilised physical activity as a main component or solely physical activity interventions. It is difficult to isolate whether it was the physical-activity component of the multi-component

interventions that caused the change because they included other factors/components particularly as there was no difference identified in the sub-group analysis.

Moreover, the adolescent population who are involved in the intervention programmes were often included for reasons other than mental health issues; for example, obesity (Goldfield et al. 2015) or pain management (Andias et al. 2018) which may influence the mental health outcomes examined within this review. There are evident links between the psychological and physiological mechanisms and improvements in mental health and well-being (Warburton et al. 2006; Andersen & Sutherland, 2001). It is evident from the findings of the meta-analyses that the relationship between mental health outcomes and physical activity interventions is still not fully clear. This relationship could also be influenced by other factors such as gender, age, socioeconomic background and intervention setting.

4.2.Summary of Risk of Bias from Included Studies

A majority of the included studies were assessed as unclear or high risk. The lack of published protocols and details within the study hampered the reviewers' ability to assess risks of bias across the domains. Attribution bias was also evident within a number of studies and was particularly problematic in the larger studies and those conducted outside the school setting.

4.3.Limitations

This systematic review and meta analyses has several limitations. Firstly, whilst the search strategy used was comprehensive and included grey literature, it excluded conference proceedings and abstracts. Secondly, the articles included within the study were in English, thereby possibly missing relevant articles in other languages. Given the growing evidence base for mental health and physical activity interventions in countries such as China and Portugal it is important for future researchers to conduct additional searches for non-English publications.

Thirdly, the choice of databases could be a limitation and several studies may have been missed. Furthermore, it is also possible that a level of bias was introduced during the review process despite a protocol being implemented to reduce bias. Potential bias is possible by using a random effects model as this approach does not estimate separate effect (Clark & Linzer, 2015). A fourth limitation is the lack of consistency in how the outcomes were measured across the studies; often the mental health outcomes of stress, anxiety and depression were assessed using different instruments. Finally, several attributes of the included studies may have limited the review result:; (a) the variability of intervention duration, activities and settings; (b) the lack of theoretical underpinnings; and (c) the variety of instruments and data collection time points assessing mental health outcomes.

The strengths of the review include adherence to the review protocol (Gilbody, 2007) and the inclusion of a meta-analysis. Conducting a meta-analysis further increases the strength of the study in regard to interpreting results across studies to examine the intervention effects. The study selection screening process and quality assessment was performed by two researchers, with initial disagreement being resolved by consensus. Furthermore, a solid search strategy was adopted to maximize the likelihood of capturing all relevant studies. Another strength of the review was that all included studies were RCT's and provided details on the randomization procedures employed for sequence generation in each study. Studies included were also found to be free of selective reporting; however, because many of these studies did not have published protocols it is impossible to know for certain if all outcomes were reported on.

5. Conclusions

The present systematic review and meta-analysis has investigated the effects of physical activity interventions on mental health outcomes in adolescents. The ability of physical activity

components within interventions to produce meaningful change in anxiety, depression and stress outcomes in adolescents remains unclear as the results of the meta-analyses showed no overall affect, suggesting that there is no clear benefit of using this component. Additionally, the number of studies contributing sufficient evidence is low which may hamper this evidence. Due to the high and unclear risk of bias in several studies, these results should be interpreted with caution, as it is uncertain whether using physical activity within intervention programmes can interventions improve anxiety, depression and stress outcomes in young people. Further work is required to determine the most suitable approach to creating an intervention with physical activity components to improve mental health outcomes. This should include type of physical activity, intensity of physical activity and multiple outcomes of mental health e.g. anxiety, stress, depression, self-esteem, body image.

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Abbreviations

RE – Random Effects

SD – Standard Deviation

SMD – Standard Mean Difference

Supporting Information

S1 File: PRISMA checklist

S2 File: Search string – MEDLINE

S3 File: Excluded studies

741 **S4 File:** Included studies outcomes and scales

742 **S5 File:** Funnel plots

743

744 **Table Legend**

745 **Table 1:** Characteristics of Included Studies

746

747 **Figure Legend**

748 **Figure 1:** PRISMA flow diagram

749 **Figure 2:** Risk of Bias graph

750 **Figure 3:** Risk of Bias summary

751 **Figure 4a:** Forest plot for anxiety at follow-up

752 **Figure 4b:** Forest plot for change in anxiety from baseline

753 **Figure 5a:** Forest plot for depression at follow-up

754 **Figure 5b:** Forest plot for change in depression from baseline

Table 1. Characteristics of included studies

(Ref, Year) Country	Type of Study	Setting	Population	N	Intervention Duration	Intervention Facilitator	Intervention Type (I: Intervention, C: Control)	Intervention Frequency	Physical activity frequency and intensity	Theoretical Framework
(Andias et al. 2018) Portugal	RCT	School	15-18 years old with chronic idiopathic neck pain	43	4 weeks	Physiotherapists	I: Neuroscience education and exercises C: No intervention and no change to their normal routine.	Once weekly for 45 minutes	15 minutes to 45 minutes	Not stated
(Carter et al. 2015) United States	RCT	Clinical	14-17 years old receiving treatment for depression	79	6 weeks	Certified fitness instructor and project staff	I: Circuit Training C: Treatment as usual (included psychological therapies, medication etc.)	Twice weekly for 1 hour	45 minutes of circuit exercises, 15 minutes of stretching.	Transtheoretical Model
(Daley et al. 2006) England	RCT	School	11-16 years old who have obesity or morbidly obesity	75	8 weeks	One of study authors	I: Exercise therapy and exercise counselling (aerobic exercises – e.g. stepping, dance mat, walking, cycling, rowing) or Exercise Placebo (stretching exercises) C: Usual Care (waitlisted control):	Three times weekly for 1 hour	30 minutes of moderate intensity exercise (40-59% HR)	Transtheoretical Model

(Frank et al. 2017) United States	RCT	School	11-15 years old from a high poverty catchment	159	16 weeks	Yoga instructor	I: Classroom based activities - yoga and a social-emotional wellness promotion programme, called Transformative Life Skills. C: No intervention - continued with business as usual and attended normal school activity.	Three-four times weekly for 30 minutes.	15-20 minutes - low intensity	Not stated
(Goldfield et al. 2015) United States	RCT	Community	14-18 years old with obesity	298	22 weeks	Personal trainers	I: Aerobic Training group - exercise and dietary advice, Resistance Group - weight training and dietary advice. Combined group - aerobic and resistance training and dietary advice. C: No exercise intervention, just dietary advice.	Four times weekly for 45 minutes -90 minutes	45 minutes for both the aerobic and resistance groups – 65-85% HR intensity; 90 minutes for the combined group	Not stated

(Hilyer et al. 1982) United States	RCT	School	15-18 years old youth offenders	43	20 weeks	Fitness instructor/doctoral student	I: Fitness Training and normal rehabilitation C: Treatment as usual – normal rehabilitation	Three alternative days each week for 1 hour and 30 minutes	1 hr and 15 minutes of exercise	Not stated
(Jeong et al. 2005) Korea	RCT	School	15-16 years old with high depression scores but no clinical diagnosis	40	12 weeks	Did not state	I: Dance Movement Therapy C: No treatment - (waitlisted control)	Three times weekly for 45 minutes.	45 minutes	Not stated
(Khalsa et al. 2012) United States	RCT	School	15-19 years old from a rural area	100	11 weeks	Yoga instructor	I: Yoga C: No treatment	Two to Three times a week for 30-40 minutes.	30-40 minutes	Not stated
(Lau et al. 2004) China	RCT	Hospital	10-17 years old with obesity	37	6 weeks	Fitness instructors	I: Resistance Training C: No exercise just nutrition sessions	Three times weekly for 1 hour.	Resistance exercises for 1 hour - 70-85% HR	Not stated
(Melnik et al. 2009) United States	Cluster RCT	School	14-16 years old Hispanic adolescents	17	9 weeks	High school teacher	I: Physical activity (e.g. walking) and a healthy lifestyle programme involving educational information, role playing, nutrition etc. C: Health topics but no physical activity.	Two to three times a week for 50 minutes	20 minutes of physical activity.	Cognitive Behaviour Theory
(Melnik et al. 2013, 2015)	Cluster RCT	School	14-16 years old culturally diverse high	697	15 weeks	High school teacher	I: Physical activity (e.g. walking) and a	Once a week for 50 minutes	20 minutes of physical activity.	Cognitive Behaviour Theory

United States			school adolescents				healthy lifestyle programme involving educational information, role playing, nutrition etc. C: Health topics but no physical activity.			
(Richards et al. 2014) Uganda	RCT	Community	11-14 years old from a low-socioeconomic background	226	11 weeks	Paid staff and trained volunteer football coaches	I: Voluntary competitive sport for development football league and various peace-building activities. C: wait-listed control.	Once a week for 1 hour and 30 minutes	40 minutes	Not stated
(Velasquez et al. 2015) Columbia	RCT	School	10-15 years old from a low-socioeconomic school	114	12 weeks	Yoga instructor	I: After-school Yoga Programme C: No intervention (waitlisted control)	Twice weekly for 2 hours.	2 hours	Not stated