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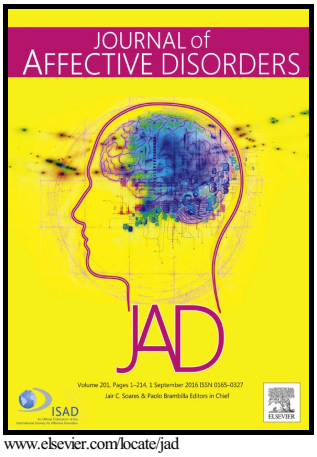

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Journal of Affective Disorders

Physical activity and suicidal ideation: a systematic review and meta-analysis

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Abstract

Background: A potential approach to suicide prevention that has not been closely examined, but which holds promise in terms of widespread dissemination without major side-effects, is physical activity (PA). This systematic review and meta-analysis set out to: (a) explore associations between PA and suicidal ideation (SI) levels, and (b) investigate the effect of PA interventions on SI.

Methods: Major electronic databases were searched from inception up to 05/2017 to identify quantitative studies reporting an association between PA and SI. A quantitative correlates synthesis and random effects meta-analysis were conducted.

Results: Fourteen of 21 studies in adults (67%) (n=130,737), 7/14 (50%) in adolescents (n=539,170) and 2/3 (67%) in older adults (n=50,745) found a significant negative association between PA- and SI-levels. Pooled adjusted meta-analysis of 14 effect sizes over eight studies and 80,856 people found that those who were “active” versus those who were “inactive” were less likely to have SI (OR=0.87, 95%CI=0.76-0.98). Additionally, meeting PA guidelines conferred a significant protective effect against SI (OR=0.91, 95%CI=0.51-0.99, P=0.03; N studies=3, n people=122,395), while not meeting guidelines was associated with increased SI (OR=1.16, 95%CI=1.09-1.24, P<0.001; N=4, n=78,860). Data from the intervention studies (N=3, n=121) was mixed and limited.

Limitations: Our findings are based mainly on cross-sectional studies, while the majority of studies did not include a rigorous physical activity assessment.

Conclusions: The current study suggests that higher PA levels are associated with lower SI. However, the associations observed need to be confirmed in prospective observational studies and controlled trials.

Keywords: suicide; mortality; physical exercise

1. Introduction

Suicide, defined as deaths caused by intentional, self-inflicted poisoning or injury, represents a global public health problem (WHO, 1993). It is the 13th leading cause of years of life lost worldwide (Wang et al., 2013). Globally, there are an estimated 11.4 suicides per 100,000 people, resulting in 804,000 suicide deaths worldwide (Turecki and Brent, 2016). Non-fatal suicidal behaviors occur at significantly higher frequencies than suicides (Turecki and Brent, 2016). International comparisons based on the WHO World Mental Health Survey (2001–2007) data (n=108,705) indicate that the average twelve-month prevalence estimates are 2.0% and 2.1% for suicidal ideation (SI), and 0.3% and 0.4% for suicide attempts in developed and developing countries, respectively (Borges et al., 2010). In developing and developed countries, those who report SI within the previous 12 months have a 15.1% and 20.2% higher 12-month prevalence of suicide, respectively (Borges et al., 2010). Those who attempt suicide have a 12-month suicide risk and repeated suicide attempt risk of about 1.6% and 16.3%, respectively, with a 5-year risk of suicide of 3.9% (Carroll et al., 2014).

As there is a clear relationship between SI and attempted and completed suicide (Turecki and Brent, 2016), identifying risk factors and treatments for people experiencing SI is essential in order to reduce suicide attempts and deaths. In high-income countries, middle-aged and elderly men have the highest risk and highest SI levels, with notably increased levels among those with sleep disturbances, somatic conditions (for example, epilepsy), painful comorbidities, depression, post-traumatic stress disorder and anxiety (Conwell et al., 2011; Krysinska and Lester, 2010; Nevalainen et al., 2016; Stubbs, 2016; Stubbs et al., 2016b). Adolescent suicide rates are increasing, and suicide is the second leading cause of death in those between 15 and 29 years (Turecki and Brent, 2016). The peak incidence of SI occurs during adolescence and young adulthood, with the lifetime prevalence of SI 12 to 33% (Brezo et al., 2007; Nock et al., 2013). Gender is also a clear risk factor with higher rates of SI among women (Nock et al., 2008).

Psychosocial interventions including dialectic and cognitive behavior therapy for those with SI have demonstrated reductions in suicide attempts (Turecki and Brent, 2016). Although these targeted psychotherapeutic interventions are vital and effective in saving the lives of many people each year, they are not widely available. Additionally, evidence for their effectiveness is predominantly derived from those at very high risk for suicide. There is also some evidence that pharmacotherapy and in particular lithium and clozapine are effective in reducing SI among adults (Zalsman et al., 2016).

However, psychotropic medications may have detrimental cardio-metabolic side-effects in adults (Vancampfort et al., 2015b) and adolescents (Galling et al., 2016).

A potential approach to suicide prevention that has not been closely examined, but which holds promise in terms of widespread dissemination without major side-effects, is physical activity. Physical activity can be defined as any activity that involves bodily movement produced by skeletal muscles and that requires energy expenditure (Caspersen et al., 1985). There is robust evidence that physical activity has been shown to reduce several important risk factors for suicide including depressive symptoms (Schuch et al., 2016), anxiety symptoms (Stubbs et al., 2017), symptoms of psychosis (Firth et al., 2015; Rosenbaum et al., 2014), post-traumatic stress symptoms (Rosenbaum et al., 2015), disturbed sleep (Kredlow et al., 2015), alcohol abuse (Hallgren et al., 2017) and chronic somatic conditions (Pedersen and Saltin, 2015). Physical activity can be delivered at low cost and, unlike traditional mental health interventions, it is generally non-stigmatizing. However, to the best of our knowledge no systematic review and meta-analysis has examined the relationship between physical activity and SI, or the effect of physical activity interventions on SI levels. As suicide risks differ across the lifespan and between men and women, this review will assess associations between physical activity and SI in (pre-)adolescents, adults, and older adults and both genders separately.

Given the aforementioned, this systematic review and meta-analysis set out to: (a) explore cross-sectional and prospective associations between physical activity and SI levels, and (b) investigate the effect of physical activity interventions on SI.

2. Material and methods

This systematic review was conducted in accordance with the MOOSE guidelines (Stroup et al., 2000) and in line with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) standard (Moher et al., 2009).

2.1. Search criteria and study selection

Two independent authors (DV, BS) searched PubMed, CINAHL and PsycARTICLES, from database inception to May 16th, 2017 without language restrictions. Key words used were "physical activity" OR "exercise" OR "sports" AND "suicid*" OR "self-harm" OR "self-poisoning" in the title, abstract or index term fields. Manual searches were also conducted using the reference lists from recovered articles. Clinicaltrials.gov, www.crd.york.ac.uk/prospero and www.who.int/trialsearch were searched to identify any unpublished trials. After the removal of duplicates, the reviewers screened titles and abstracts of all potentially eligible articles. Both authors applied the eligibility criteria, and a list of full text articles was developed through consensus. Next, the two reviewers considered the full texts of these articles and the final list of included articles was reached through consensus. A third reviewer (FS) was available for mediation throughout this process.

2.2. Eligibility criteria

We focused on the associations between physical activity and SI (as defined by each study) and on SI and associated mental health outcomes of physical activity interventions in clinical and non-clinical populations. Physical activity was, as described above, defined as any interventions that use bodily movement produced by skeletal muscles and which requires energy expenditure (Caspersen et al., 1985). Included were studies: (a) in pre-adolescents (less than 18 years old), adults (between 18 and 65 years old), and old age people (65 years or older); (b) containing quantitative research including observational studies (cross-sectional and cohort studies) or interventional studies (pre and posttest or randomized controlled interventions) and published in a peer-reviewed journal; (c) reporting any kind of effect size [e.g., odds ratios (OR) correlations, t-tests, and ANOVA]. If both uni-/bivariate and multivariate tests were used for assessing associations, only uni-/bivariate tests were reported for consistency across studies. We excluded studies that focused on: (a) hyperactivity as an eating disorder symptom, and (b) suicide attempts or suicide-related deaths only as these are different

constructs which may need a different and more intensified prevention/treatment approach (Klonsky et al., 2016). We also excluded articles if the physical activity related variable was aerobic fitness, physical activity intention, self-efficacy, or other intermediate (non-behavioral) measures because these variables are less direct indicators of actual physical activity behavior (Caspersen et al., 1985). Case reports, meeting abstracts and expert opinions were excluded.

2.3. Data extraction

One author (DV) extracted data using a predetermined data extraction form, which was subsequently independently validated by two authors (BS and FS). The data extracted included the type of study (cross-sectional, prospective, clinical controlled or randomized controlled trial, one-group pre- and post-test design), the country where the study was performed, age (years), gender (% male) and any specifications of the target population, the SI assessment method, the quality of the physical activity assessment method, physical activity intervention characteristics (frequency, intensity, type and time), the physical activity provider (expert provider or not: experts are defined as physiotherapists, exercise physiologists and physical educators (Stubbs et al., 2016a)), and the primary outcomes of interest including the most adjusted odds ratios (ORs) and 95% confidence intervals (95%CIs) of any associations between physical activity and SI measures. We extracted the ORs and 95%CIs for SI risk when individuals were (not) complying with international physical activity guidelines (i.e., 150min per week of at least moderate or 75min per week of vigorous intensity physical activity) and ORs and 95%CIs for the most active versus most inactive subgroups as defined in the studies. The following categories were used to code the quality of the physical activity measure: (a) self-report with poor, unknown or not reported reliability/validity in the target population, (b) self-report with reported and acceptable reliability/validity, and (c) acceptable objective measurements. Objective measurements included motion sensors such as accelerometers and pedometers, combined heart rate and accelerometer devices. The acceptability of the psychometric properties of measurement tools was assessed according to previous recommendations (DeVon et al., 2007).

2.4. Methodological quality assessment

Two authors completed methodological quality assessment of included cross-sectional and prospective studies using the Newcastle Ottawa Scale (NOS) (Stang, 2010). The NOS is used to assess the methodological quality of non-randomized trials and has acceptable validity and reliability (Stang, 2010). Cross-sectional and prospective studies were given a NOS score. The score ranged from 0 to 9, with a score of 5 or greater being indicative of satisfactory methodological quality. The score is given by considering seven items in three domains: (a) participants selection, (representativeness of the sample, sample size, non-exposed similar in other characteristics, ascertainment of the variable of interest = a subtotal score of 5); (b) comparability, (confounding factors are controlled for = a subtotal score of 1), and (c) outcomes, (adequate assessment of outcome, statistical test and outcomes clearly described= a subtotal score of 3) (Herzog et al., 2013). Due to limited number of intervention studies available and heterogeneity in designs, the methodological quality of the intervention studies was not assessed.

2.5. Coding associations with physical activity in cross-sectional and prospective non-intervention studies and data synthesis

A summary code was presented and calculated following previous recommendations (Sallis et al., 2000; Trost et al., 2002). The summary code is expressed as a percentage. This percentage refers to the number of supporting associations between physical activity and SI. In accordance with previous physical activity correlates studies (Stubbs et al., 2014; Stubbs et al., 2015; Vancampfort et al., 2013; Vancampfort et al.; Vancampfort et al., 2015c; Vancampfort et al., 2014), if only 0-33% of studies supported the association, we considered the association as 'non-existing'. When 34%-59% of identified studies supported an association, then this was referred to as 'unclear'. If 60%-100% of studies supported the association, we considered it as 'existing'. In agreement with previous studies on physical activity correlates (Davy et al., 2012; Vancampfort et al., 2013; Vancampfort et al., 2015a; Vancampfort et al., 2017a; Vancampfort et al., 2016; Vancampfort et al., 2015c; Vancampfort et al., 2014), when correlates were reported in four or more studies the association was considered as 'consistent in the literature'. Different summary codes were presented for (pre-)adolescents (mean age of study participants lower than 18 years), adults (mean age=18<65 years), and older adults (mean age=65 years or above).

2.6. Statistical analyses

First, using Fisher's exact tests, we explored differences in the number of significant correlates between studies: (a) using valid physical activity assessments versus assessments with unknown validity, (b) with a sample size lower than versus equal to or larger than the median sample size, (c) with a number of covariates equal to or larger than versus lower than the median number, and (d) with low versus sufficient methodological quality. Second, due to anticipated heterogeneity, a random effects meta-analysis was employed. Heterogeneity was measured with the I^2 statistic with values above 75 as considered as a high level of heterogeneity (Higgins, 2011). Wherever possible, we pooled data on the most adjusted OR and 95% CI in the analyses, using Comprehensive meta-analysis software (version 3, Biostat, Englewood, USA). Within the meta-analysis, we conducted four main analyses. First, we calculated the pooled adjusted OR and 95% CI of the relationship between meeting recognized physical activity guidelines and the presence of SI. Second, we calculated the OR and 95% CI for SI when individuals did not meet the recommended physical activity guidelines. Third, we calculated the OR and 95%CI for SI among those who were most active versus the least active (as defined by the studies) across all studies. Finally, we calculated the OR and 95%CI and relationship with SI among those who were inactive versus active (as defined by the studies). Finally, publication bias was tested using the Egger's regression method (Egger et al., 1997) and Begg-Mazumdar test (Begg and Mazumdar, 1994), with a p-value <0.05 suggesting the presence of bias. When we encountered publication bias, we conducted a trim and fill-adjusted analysis (Duval and Tweedie, 2000) to remove the most extreme small studies from the positive side of the funnel plot, and recalculated the pooled OR iteratively, until the funnel plot was symmetrical around the (new) OR.

3. Results

3.1. Study selection, characteristics and included participants

The electronic database searches identified 2,233 articles which were considered at the title and abstract level. After excluding irrelevant papers and duplicates, forty-seven full texts were reviewed

and 18 were excluded with reasons (see figure 1 and eTable 1), with 29 unique studies meeting the eligibility criteria. The final sample comprised 720,652 unique persons with a median sample size of 12,081. There were 25 cross-sectional studies (Adams et al., 2007; An et al., 2015; Arat and Wong, 2017; Babiss and Gangwisch, 2009; Brown and Blanton, 2002; Brown et al., 2007; Cho, 2014; Davidson et al., 2013; Dinger and Vesely, 2001; Elliot et al., 2012; Gutierrez et al., 2015; Jeong et al., 2016; Jia et al., 2016; Lee et al., 2013; MacKinnon and Colman, 2016; Min et al., 2017; Ro et al., 2015; Sibold et al., 2015; Song and Lee, 2016; Southerland et al., 2016; Takada et al., 2009; Taliaferro et al., 2009; Tao et al., 2007; Taylor et al., 2017; Unger, 1997), two randomized controlled trials (Abdollahi et al., 2017; Sturm et al., 2012), one study with a single-group, pre-test post-test design (Hoying and Melnyk, 2016), and one longitudinal study (Kang et al., 2014). Eleven studies were conducted in adolescents (Abdel-Baki et al., 2013; Arat and Wong, 2017; Babiss and Gangwisch, 2009; Brown et al., 2007; Hoying and Melnyk, 2016; Jia et al., 2016; Lee et al., 2013; Sibold et al., 2015; Southerland et al., 2016; Tao et al., 2007; Unger, 1997), 15 in adults (Abdollahi et al., 2017; Adams et al., 2007; An et al., 2015; Brown and Blanton, 2002; Davidson et al., 2013; Dinger and Vesely, 2001; Elliot et al., 2012; Gutierrez et al., 2015; MacKinnon and Colman, 2016; Min et al., 2017; Song and Lee, 2016; Sturm et al., 2012; Takada et al., 2009; Taliaferro et al., 2009; Taylor et al., 2017), and three in older adults (Bailey and McLaren, 2005; Kang et al., 2014; Ro et al., 2015).

One study was conducted among employees (Takada et al., 2009), and one with retirees (Bailey and McLaren, 2005), while seven studies focused on the general population (An et al., 2015; Cho, 2014; Kang et al., 2014; MacKinnon and Colman, 2016; Min et al., 2017; Ro et al., 2015; Song and Lee, 2016). Fifteen studies were conducted in school, college or university settings (Adams et al., 2007; Arat and Wong, 2017; Babiss and Gangwisch, 2009; Brown and Blanton, 2002; Brown et al., 2007; Dinger and Vesely, 2001; Elliot et al., 2012; Hoying and Melnyk, 2016; Jia et al., 2016; Lee et al., 2013; Sibold et al., 2015; Southerland et al., 2016; Taliaferro et al., 2009; Tao et al., 2007; Unger, 1997), three in military members or veteran populations (Davidson et al., 2013; Gutierrez et al., 2015; Taylor et al., 2017) including one in veterans with PTSD (Davidson et al., 2013). Two studies were in mental health populations, of which one was performed in people with depression (Abdollahi et al., 2017) and one in people with suicide risk (Sturm et al., 2012). Most studies were conducted in the USA (n=14), followed by South-Korea (n=8). Other countries were China (n=2), Japan (n=1), Australia (n=1), Germany (n=1), Canada (n=1) and Iran (n=1). One international study focused on six

middle-income countries. All cross-sectional and longitudinal studies used a subjective self-report instrument, the vast majority with unknown validity for assessing physical activity levels (23/27), while three used the International Physical Activity Questionnaire (An et al., 2015; Cho, 2014; Gutierrez et al., 2015) and one study used the Yale Physical Activity Survey (Bailey and McLaren, 2005). None of the studies used an objective assessment tool. SI in all but one (Gutierrez et al., 2015) study was assessed with simple yes or no questions. The most commonly used statistical approach to assess correlates was logistic regression analyses (n=21). The mean NOS score for the cross-sectional and prospective studies was 5 (range=3-6). Seventeen of the 26 studies (68%) were of sufficient methodological quality (NOS≥5). An overview of the characteristics of cross-sectional and prospective studies exploring associations between SI and physical activity is presented in Table 1.

Insert Figure 1 about here

Insert Table 1 about here

3.2. Associations between physical activity participation and SI across the lifespan

An overview of the associations between physical activity and SI is presented in Table 2. In 7 of 14 studies (50%) in adolescents, there was a negative association between physical activity and SI levels (i.e. higher physical activity levels were associated with lower SI or vice versa) indicating that it is currently unclear whether a consistent association can be found. In the other 7 studies, physical activity was unrelated to SI levels. Among adults, higher physical activity levels are associated with lower SI levels or vice versa (14/21, 67%). In older adults, higher physical activity levels also appear to be associated with lower SI levels or vice versa (2/3, 67%), but as less than four studies were available, the consistency of the findings is unclear.

Insert Table 2 about here

Due to the limited number of studies with a valid physical activity assessment (n=4), we did not analyze differences in the number of significant correlates in studies with a valid physical activity tool (4/27) versus studies with a physical activity assessment of unknown validity (23/27). The number of significant correlates in studies with a sample size equal to or larger than the median sample size was not different to the number in studies with a sample size lower than the median (P=0.48). Similarly, the number of significant correlates in studies with several covariates was no different to the number observed in studies were maximum one covariate was used (P=1.0). Finally, no differences in the

number of correlates was observed in studies using a physical activity instrument of sufficient quality, compared with studies using a physical activity tool with insufficient methodological quality (P=1.0). .

3.3. *Meta-analysis of the association between physical activity and SI*

3.3.1. Odds of SI among those meeting physical activity guidelines

It was possible to pool adjusted ORs and 95% CI from 9 unique study points (adjusted for a mean of 6 confounders; range=5-7) over three studies and including 122,395 people. Overall, there was evidence that meeting physical activity guidelines conferred a significant protective effect on SI (OR=0.91, 95%CI=0.51-0.99, P=0.03) with low to moderate heterogeneity (I^2= 41%). The Begg-Mazumdar (Kendall's tau b = -0.1, P=0.92) and the Egger test (bias=-0.2; 95%CI = -1.4 to 1.8; P=0.76) indicated no evidence of publication bias.

3.3.2. Odds of SI in people not meeting physical activity guidelines

Across four study points and two unique studies and 78,860 people, adjusted for on average 8 confounders (range=8-9), there was evidence that not meeting physical activity guidelines was associated with increased SI (OR=1.16, 95%CI=1.09-1.24, P<0.001). There was no heterogeneity present (I^2=0%). The Begg-Mazumdar (Kendall's tau b = -0.7, P=0.17) and the Egger test (bias=-0.1; 95%CI = -2.7 to 2.5; P=0.83) indicated no evidence of publication bias.

3.3.3. Odds of SI among those who are active

It was possible to pool 14 effect sizes (mean confounders adjusted for was 5, range=0-10) from eight studies and 80,856 people comparing those who were defined as “active” versus those who were “inactive”. Overall, there was evidence that being active offered a protective effect against SI (OR=0.87, 95%CI=0.76-0.98, P=0.02; I^2=82%; Figure 2). There was considerable heterogeneity (I^2=0.81), but the Begg-Mazumdar (Kendall's tau b = -0.1, P=0.62) and the Egger test (bias=-1.1; 95%CI = -3.6 to 1.4; P=0.37) indicated no evidence of publication bias.

Insert Figure 2 about here

3.3.4. Odds of SI among those who were inactive

Across three studies, there was no evidence that being inactive increased the odds of SI (OR=1.60, 95%CI=0.83-3.11, P=0.16). There was considerable heterogeneity (I^2=0.93), but the Begg-Mazumdar (Kendall's tau b = 0.3, P=0.60) and the Egger test (bias=-3.6; 95%CI = -46.7 to 54.0; P=0.52) indicated no evidence of publication bias.

3.4. *The effect of physical activity interventions on SI and related mental health outcomes*

Characteristics of the three intervention studies are presented in Table 3. In one RCT exercise (35 min walking and flexibility exercises, 3*week, 12 weeks provided by a sports expert) adjunct to cognitive behavioral therapy (CBT), more effectively decreased both depressive symptoms and SI in mild to moderately depressed adults (n=35) versus CBT alone (n=35). In a second pre-posttest study without a control group, 15 weekly sessions of CBT counseling including physical activity, resulted in a non-significant reduction in SI among 6 adolescents. In a third cross-over trial of 9 weeks of mountain hiking (3*week at moderate intensity, 2-3 hours duration) provided by a nurse and physiotherapist, SI reduced significantly in 17 adults deemed at high risk of suicide.

Insert Table 3 about here

4. Discussion

4.1. General findings

To the best of our knowledge, the current review is the first to explore associations between physical activity and SI, and outcomes of physical activity interventions on SI. Our study demonstrated that meeting physical activity guidelines conferred a significant protective effect on SI (OR=0.91, 95%CI=0.51-0.99, P=0.03; N studies=3, n people=122,395), while not meeting guidelines was associated with increased SI-levels (OR=1.16, 95%CI=1.09-1.24, P<0.001; N=4, n=78,860). Moreover, our meta-analysis found that people who were active, were less likely to have SI than those

who were inactive. However, when looking at age-related subgroups, we only found a consistent association between physical activity levels and lower SI in adults. In older adults, a similar association was found, but findings were limited to only three studies, while the relationship between physical activity levels and SI in adolescents is less clear and warrants further investigation. There were however insufficient data to perform meaningful subgroup meta-analyses stratified by age, gender, or having a psychiatric or somatic co-morbidity. Data regarding physical activity interventions were also scarce and mixed, therefore no firm conclusions can be made.

There are plausible explanations for why the relationship between physical activity levels and SI in adolescents is less clear. First, although we did exclude studies on hyperactivity, it cannot be ruled out that hyperactivity, as a manifestation of an underlying eating (anorexia or bulimia nervosa) or attention-deficit/hyperactivity disorder pathology or other mental problem, was a confounding factor. It is known that these disorders are associated with a higher suicide risk in children and adolescents (Mayes et al., 2015). For instance, in our included studies, girls who were frequently physically active at high intensity were at higher risk for thinking about suicide (Lee et al., 2013; Unger, 1997). Second, in the study by Lee et al. (2013), the cross-sectional association between physical activity and SI in adolescents disappeared when controlling for confounding factors such as the presence of depression and a distorted body image. However, physical activity can reduce depression (Radovic et al., 2017) and improve body image (Liu et al., 2015) in adolescents. The study of Babiss and Gangwisch (2009) indeed demonstrates that when sports participation increases, the odds of suffering from depression decreases by 25% and the odds of having SI decreases by 12%. Consistent with the notion that self-esteem and social support act as mediators of these relationships, the inclusion of these variables in multivariate models attenuated the associations for depression (OR=0.83) and SI (OR=0.93). Third, it might be that the type rather than the level of physical activity engaged in is what really matters. For example, in the study by Southerland et al. (2016), the level of physical activity was not related to SI, being engaged in a team activity was. Additionally, the study by Babiss and Gangwisch (2009) demonstrates that interpersonal support from coaches, teammates, parents, and friends may provide those who engage in team activities with a foundation of therapeutic support that reduces the risk of suicide during difficult times. More research is however needed to confirm this hypothesis, also in adults and people at old age.

Although limited, the current evidence from intervention studies shows that physical activity is a promising method for reducing SI. However, it remains unclear which type and dose (i.e. time, frequency, duration) of physical activity is optimal. Moreover, the mechanisms underlying the potential beneficial effects remain to be explored. Physical activity is associated with numerous health benefits, including enhanced emotional and physical health, improved cognitive functioning, improved sleep (Strid et al., 2016), and better quality of life (Rosenbaum et al., 2014). These benefits could mediate a lower risk of suicide among physically active people. For example, deficient serotonergic functioning may play a role in suicide (Arango et al., 2002) and mood improvements associated with physical activity may reflect increased levels of brain serotonin (Melancon et al., 2014). Theoretically, physical activity may be inversely related to SI as a result of neurobiological alterations that occur with physical activity. However, as stated, longitudinal and interventional studies are needed to confirm this hypothesis and explore the directionality of the findings.

Although sedentary behavior was not a focus of this review, it is known that inertia and sedentary behavior are common features of depression (Schuch et al., 2017) which in turn is linked to SI (Hawton et al., 2013). Experimentally induced sedentary behavior has been shown to increase psychological distress (Endrighi et al., 2016), and one prospective cohort study (n=509, 11 year follow-up) (Valtonen et al., 2010), found that a sedentary lifestyle was significantly associated with the emergence of 'hopelessness' in middle aged men. What remains unclear from our review is whether intervention strategies should target sedentary behaviors (i.e. reducing the time spent sitting or breaking up sitting time) or aim to specifically increase planned physical exercise, or both.

Another important observation was that the majority of studies were from the USA and South-Korea. Although South-Korean suicide rates are among the highest in high income countries, over 78% of global suicides occur in low- and middle-income countries (Organization, 2017). These data show that there is a discrepancy between where most of the research is done and where the highest burden is observed and consequently where gains can also be obtained. Interventional studies exploring the efficacy and (cost-) effectiveness of physical activity interventions are needed globally, but particularly in low to middle income countries where treatment rates at individual and community-level are low (Petersen et al., 2016).

4.2. Practical implications

No rigorous age- and gender specific recommendations can be formulated on the currently limited evidence. Nonetheless, our study suggests that complying with international physical activity guidelines may be protective against SI. Therefore, (inter)national suicide prevention strategies should include messages about the importance of complying with international physical activity recommendations. Clinicians should also be mindful of these relationships; routine assessment of physical activity levels is recommended for adults presenting with symptoms of depression, along with risk of self-harm and SI. Inclusion of people with mental health problems and SI in community-based physical activity initiatives might stimulate social interactions and reduce stigma and might be particularly suitable in low to middle income countries (Vancampfort et al., 2017b).

4.3. Limitations

There are several limitations to this review which should be acknowledged. First, the majority of studies did not include a rigorous physical activity assessment. Thus, future studies exploring associations between physical activity and SI should consider including valid physical activity assessment tools. Self-report physical activity questionnaires are known to require motivation to accurately complete details regarding the level (frequency, duration and intensity) and type of physical activity are not always consistently evaluated. Fewer significant associations would be expected in studies that relied on un-validated self-report measures and in self-report versus objective assessments (i.e. accelerometers, pedometers). However, as only a very limited number of studies included a validated instrument, we did not explore differences in findings between un-validated and validated self-report instruments or between self-report and objective tools. Considering the wide diversity in physical activity assessments, our findings do reveal that there is a need for researchers to adopt a clear consensus on which assessment tools should be recommended in suicide prevention research. Second, our findings are based mainly on cross-sectional studies. Cause and effect could not be determined and there is a clear need for more longitudinal and interventional research.

In conclusion, our results demonstrate that participation in physical activity and complying with international physical activity guidelines is associated with lower SI. However, data from prospective studies and randomized controlled trials remain limited.

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Contributors

Dr. Davy Vancampfort- Participated in the conception and design of the study, reviewed studies, extracted data, performed the analysis and wrote the manuscript. Dr. Felipe B. Schuch - Participated in the design of the study, reviewed studies, validated extracted data and wrote the manuscript. Dr. Brendon Stubbs - Participated in the conception and design of the study, reviewed studies, validated extracted data, performed the analysis and wrote the manuscript. All other co-authors - Revised the different versions of article critically for important intellectual content based on their expert background and approved the final manuscript.

Declaration of interest

None.

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Figure 1

Flow diagram for the search results

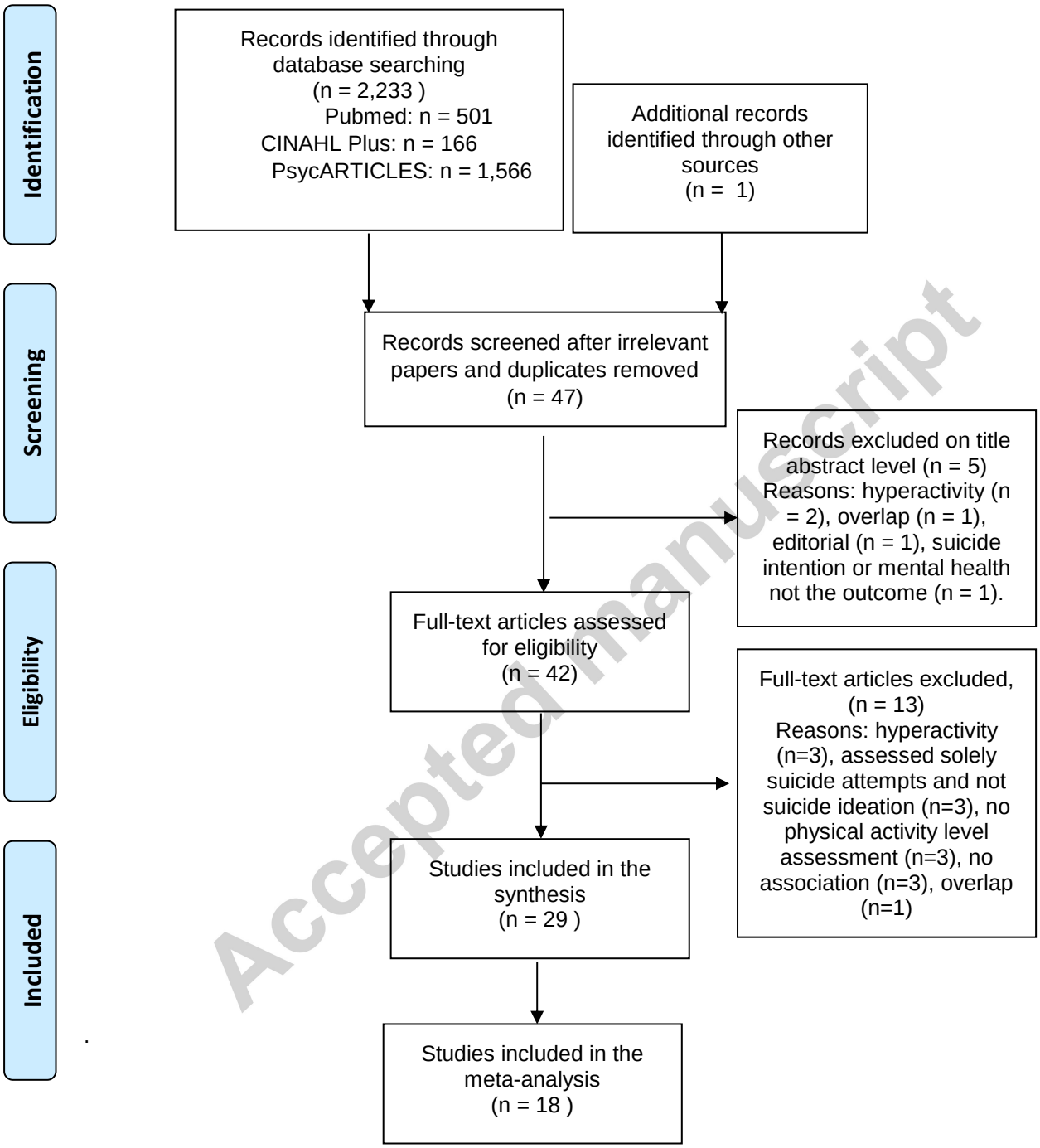

Figure 2

Forest plot of studies comparing suicidal risk (SI) between those who are active versus inactive

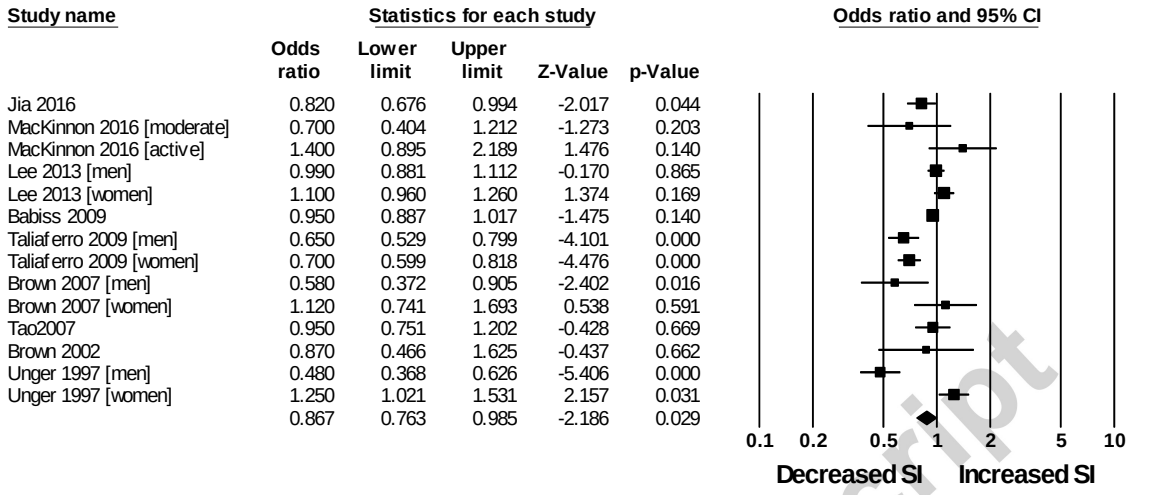

Table 1
Overview of the cross-sectional and prospective studies exploring associations between suicide ideation and physical activity

First author	Design	Country	Participants	Suicide ideation assessment	PA quality	Statistical analysis	Major findings	Covariates	Methodological appraisal
Arat 2017 (Arat and Wong, 2017)	Cross-sectional	6 middle income countries	23,372 adolescents (11-17 years);	Yes or no question	A	Logistic regression analysis	There were differences in countries with only significantly lower SI in China when walking/biking (OR=0.71). In the other 5 countries there were no associations. We coded the study as "unrelated".	6: age, sex, hunger, bullying, parental monitoring, and close friends	6*
Min 2017 (Min et al., 2017)	Cross-sectional	South-Korea	169,029 adults	Item of the CES-D (yes or no)	A	Chi Square tests	9.3% of those complying with PA guidelines had suicide ideation versus 10.9% in those not complying.	0	4
Taylor 2017 (Taylor et al., 2017)	Cross-sectional	USA	736 military members; 75% male	PHQ-9 9th item (yes or no)	A	Logistic regression analysis	Not meeting international PA guidelines predicts SI (Wald $\chi 2$ =8.7, P=0.003, adjusted OR =2.1) and major depressive disorder (Wald $\chi 2$=6.3, p=0.012, adjusted OR =1.8).	0	3
Gutierrez 2016 (Gutierrez et al., 2015)	Cross-sectional	USA	103 veterans; mean age=55 years; 88% male	ASIQ	B	Pearson 's correlations	No significant correlates between PA and SI. The IPAQ total (METS) score correlated negatively with the Beck Depression Index (r=-0.23, P=0.02).	0	4

Jia 2016 (Jia et al., 2016)	Cross-sectional	China	1,378 students (12-18 years); 48% male	Yes or no question	A	Logistic regression analysis	More students who were seldom active had SI than compared with those who were sometimes and always active ($\chi 2=9.0$, p=0.01).	0	4
MacKinnon 2016 (MacKinnon and Colman, 2016)	Cross-sectional	Canada	4,427 TAY (18-24 years; 48% male) and 14,452 adults (25-44years; 48% male)	Yes or no question	A	Logistic regression analysis	Inactive male TAY and female adults had the highest odds of suicidal ideation (OR=2.1 and 1.7, respectively. Conversely, there was no significant effect of inactivity in female TAY (OR =1.1 and 1.0, respectively).	0	6*
Song 2016 (Song and Lee, 2016)	Cross-sectional	South-Korea	35,075 adults with SI; 42% male	Yes or no question	A	Logistic regression analysis	Regular exercise, strength and flexibility training were associated with less SI in men (OR=0.78, 0.78 and 0.82), while in women regular exercise and flexibility training (OR=0.87 for both) but not strength straining (OR=95) associated with less SI.	5: age, marital status, education, occupation and household income.	5*
Southerland 2016 (Southerland et al., 2016)	Cross-sectional	USA	65,182 middle school students	Yes or no question	A	Logistic regression analysis	Those who complied with the PA guidelines had a lower but non-significant risk (OR=0.90) for having SI.	7: race, sex, screen time, substance use, weight status, misperception, and control behaviors	6*

Table 1
Continued

First Author	Design	Country	Participants	Suicide ideation assessment	PA quality	Statistical analysis	Major findings	Covariates	Methodological appraisal
An 2015 (An et al., 2015)	Cross-sectional	South-Korea	4,674 aged 20 years or older; 49% male	Yes or no question	B	Logistic regression analysis	Only in women those not being physical active at all had higher SI levels versus those complying with PA guidelines (OR=1.36, P<0.05); in men the OR of 1.20 was not significant.	9: age, sex, BMI education level, household income, occupation and, smoking status, alcohol intake, number of chronic diseases	6*
Ro 2015 (Ro et al., 2015)	Cross-sectional	South-Korea	49,357 people older than 65; 41% male	Yes or no question	A	Pearson 's correlations	r between PA and SI=-0.102, P<0.01.	0	3
Sibold 2015	Cross-section	USA	13,633 adolesce	Yes or no	A	Logistic regressio	Of students who exercised on 6 to 7	3: sex, age, race	5*

(Sibold et al., 2015)	al		nt students	question		n analysis	days in the past week, 15.9% reported suicidal ideation in the past 12 months, compared to 24.6% who exercised on 0 to 1 day, respectively. Increased exercise frequency was inversely associated with feelings of sadness and suicidal ideation, for both bullied and non-bullied students (p<0.001).		
Cho 2014 (Cho, 2014)	Cross-sectional	South Korea	74,186 adolescents; 51.5% male	Yes or no question	B	Logistic regression analysis	Those who do not meet guidelines for vigorous PA (males; AOR=1.02, females; AOR=1.21), moderate PA (males; AOR=1.10, females; AOR=1.18), and low PA (males; AOR=1.16, females; AOR=1.20) have higher SI.	7: family socio-economic status, grade point, smoking, alcohol consumption, depression, stress, and self-rated health	6*
Kang 2014 (Kang et al., 2014)	Prospective	South Korea	1,204 old age people; mean age=72 years; 58% male	Item of GMS (yes or no)	A	Logistic regression analysis	Those who were inactive had a 3.17 higher risk for SI than those who are physically active.	2: age and sex	6*
Davidson 2013 (Davidson et al., 2013)	Cross-sectional	USA	346 veterans with PTSD; 81% male; mean age=45 years	Yes or no question	A	Chi-square analyses	Presence of exercise in the past month was significantly different between individuals with versus without SI (χ^2= 11.00, p= 0.02).	0	5*

Table 1
Continued

First author	Design	Country	Participants	Suicide ideation assessment	PA quality	Statistical analysis	Major findings	Covariates	Methodological appraisal
Lee 2013 (Lee et al., 2013)	Cross-sectional	South-Korea	74,698 adolescent students	Yes or no question	A	Logistic regression analysis	After controlling for body image, stress, and depression, the significant relationship between physical activity and SI disappeared.	10: grade, type and location of school, economic status, presence of parents, type of residence, grade point, body image,	5*

								stress, and depression	
Elliot 2012 (Elliot et al., 2012)	Cross-sectional	USA	71,860 undergraduate students; 36% male	Yes or no question	A	ANOVA	0 week PA, less SI than 1-2/week, 3-4/week, 5-7/week (P<0.001).	1: gender	4
Babiss 2009 (Babiss and Gangwisch, 2009)	Cross-sectional	USA	14,594 adolescent students; 51% male	Yes or no question	A	Logistic regression analysis	As sports participation increases, the odds of having SI decreases by 12% (OR=0.88).	5: substance abuse, body weight, self-esteem, social support, depression	5*
Takada 2009 (Takada et al., 2009)	Cross-sectional	Japan	4,188 employees; mean age=42 years; 68% male	Yes or no question	A	Logistic regression analysis	No details are provided.	0	4
Taliaferro 2009 (Taliaferro et al., 2009)	Cross-sectional	USA	43,499 college students (18-25years old); 35% male	Yes or no question	A	Logistic regression analysis	Men who performed aerobic activity demonstrated reduced suicide risk: 1-2 times/week (OR=0.74), 3-5 times/week; (OR= 0.64), 6-7 times/week (OR= 0.65). Likewise, for women ORs were 0.82, 0.73 and 0.70.	2: age and race	6*
Adams 2007 (Adams et al., 2007)	Cross-sectional	USA	22,073 female college students (18-25years old)	Yes or no question	A	Logistic regression analysis	Those who were not physically active had greater risk (OR=1.26) for SI compared to those who are more than 3*week physically active.	10: age, grade, relationship status, year in schools, fraternity/ sorority member, race, BMI, hrs/week worked and volunteered, living arrangement.	5*

Table 1
Continued

First author	Design	Country	Participants	Suicide ideation assessment	PA quality	Statistical analysis	Major findings	Covariates	Methodological appraisal
Brown 2007 (Brown et al., 2007)	Cross-sectional	USA	10,530 high school students	Yes or no question	A	Logistic regression analysis	Boys who engaged in frequent, vigorous intensity PA lower risk for having SI (OR=0.52), no associations for girls (OR=1.13).	9: age, race, cigarette smoking, alcohol and drug use, region, unhealthy weight-	5*

								control practices, BMI/weight perception, feeling sad/hopelessness	
Tao 2007 (Tao et al., 2007)	Cross-sectional	China	5,453 students; mean age=15 years; 49% male	Yes or no question	A	Logistic regression analysis	Not low intensity (OR=95) but high intensity physical activity (OR=1.26) is a risk factor for SI.	8: sex, grades, place of birth, paternal and maternal education, size of family, self-esteem, school life satisfaction	6*
Bailey 2005 (Bailey and McLaren, 2005)	Cross-sectional	Australia	194 retired adults	PHQ-9 9th item (yes or no)	B	Correlations	There were no significant correlations between being physically alone (r=-0.12) or with others (r=-0.13) and SI.	0	3
Brown 2002 (Brown and Blanton, 2002)	Cross-sectional	USA	4,728 college students (18-25years old); 38% male	Yes or no question	A	Logistic regression analysis	Inactive men had higher risk, while inactive women a lower. In men lowest risk was for those who were active at light intensity (OR=0.54), while in women the highest risk was for those 6-7/week vigorously physically active (OR=1.99).	6: age, race, BMI/weight perception, smoking status, episodic heavy alcohol use in past 30 days, and number of times lifetime ever drug use.	5*
Dinger 2001 (Dinger and Vesely, 2001)	Cross-sectional	USA	1,074 college students (18-25years old); 45% male	Yes or no question	A	Logistic regression analysis	Low active students have a higher risk for SI (OR=1.19) compared with high active students.	3: sex, age, race	4
Unger 1997 (Unger, 1997)	Cross-sectional	USA	10,506 students (12-18 years); mean age= 16years; 49% male	Yes or no question	A	Logistic regression analysis	Men who exercise had lower risk for thinking about suicide: 1-2/week: OR=0.68; 3-5/week OR=0.63; 6-7/week OR=0.65. Women who exercised had higher risk: 1-2/week: OR=1.25; 3-5/week OR=1.22; 6-7/week OR=1.57.	1: age	5*

Coding of the quality of the physical activity instrument used: A=self-report of poor or unknown reliability/validity, B=self-report with acceptable reliability/validity based on the criteria of De Von et al. (2007), c=objective PA assessment; methodological appraisal=Newcastle Ottawa Scale score which ranges from 0 to 9 with a Newcastle Ottawa Scale score ≥5* indicating sufficient quality; unrelated= the overall conclusion of this study is that there was no significant association between physical activity and suicidal ideation; OR=odds ratio, $\chi 2$=Chi square; PA= physical activity, SI= suicidal ideation, CES-D=Center for Epidemiologic Studies Depression, PHQ-9= Patient Health Questionnaire-9 items, ASIQ= Adult Suicide Ideation Questionnaire,

IPAQ=International Physical Activity Questionnaire, METS= metabolic equivalents, OR=odds ratio, TAY= transition aged youth, GMS= Geriatric Mental State.

Table 2
Summary of the associations between physical activity levels and suicidal ideation

	Significantly related to PA		Unrelated to PA	Summary code	
		Association		Association	% studies reporting associations
(Pre-) adolescents	Sibold 2015 (Sibold et al., 2015); Cho 2014 (boys) (Cho, 2014); Cho 2014 (girls) (Cho, 2014); Jia 2013 (Jia et al., 2016); Babiss 2009 (Babiss and Gangwisch, 2009); Brown 2007 (boys) (Brown et al., 2007); Unger 1997 (boys) (Unger, 1997)	-	Arat 2017 (Arat and Wong, 2017); Southerland 2016 (Southerland et al., 2016); Lee 2013 (boys) (Lee et al., 2013); Lee 2013 (girls) (Lee et al., 2013); Brown 2007 (girls) (Brown et al., 2007); Tao 2007(Tao et al., 2007); Unger 1997 (girls) (Unger, 1997)	?	50% (7/14)

Adults	Min 2017 (Min et al., 2017); Taylor 2017 (Taylor et al., 2017); Mackinnon 2016 (18-24 years; men) (MacKinnon and Colman, 2016); Mackinnon 2016 (25-44 years; women) (MacKinnon and Colman, 2016); Song 2016 (men) (Song and Lee, 2016); Song 2016 (women) (Song and Lee, 2016); An 2015 (women) (An et al., 2015); Davidson 2013 (Davidson et al., 2013); Elliot 2012 (Elliot et al., 2012); Taliaferro 2009 (men) (Taliaferro et al., 2009); Taliaferro 2009 (women) (Taliaferro et al., 2009); Adams 2007 (women) (Adams et al., 2007); Brown 2002 (men) (Brown and Blanton, 2002); Dinger 2001 (Dinger and Vesely, 2001)	-	Gutierrez 2016 (Gutierrez et al., 2015); Mackinnon 2016 (18-24 years; women) (MacKinnon and Colman, 2016); Mackinnon 2016 (25-44 years; men) (MacKinnon and Colman, 2016); Southerland 2016; An 2015 (men) (An et al., 2015); Takada 2009 (men); Takada 2009 (women) (Takada et al., 2009); Brown 2002 (women) (Brown and Blanton, 2002)	--	67% (14/21)
Old age	Ro 2015 (Ro et al., 2015); Kang 2014 (Kang et al., 2014)	-	Bailey 2005 (Bailey and McLaren, 2005)	-	67% (2/3)

PA=physical activity; - =negative correlate or higher physical activity levels (excluding hyperactivity as an eating disorder symptom) associated with lower suicide ideation or vice versa;--= the association is consistently (i.e. reported in at least 4 studies) negative; ?= the association between suicide ideation and physical activity is unknown.

Table 3

Overview of trials exploring the effect of physical activity interventions on suicidal ideation

First author	Country	Design	Participants	Suicide ideation assessment	Intervention characteristics	Major outcomes
Abdollahi 2017 (Abdollahi et al., 2017)	Iran	RCT	35 mildly to moderately depressed adults (mean age=51 years; 60% male) received PA + CBT versus 35 (48 years; 46% male) CBT alone	BSSI	35 min aerobic (walking) + flexibility exercises, 3*week, 12 weeks provided by expert (PhD Sports Science)	BSSI reduced more in the PA+CBT group: from 14.3 to 7.1 versus from 14.8 to 12.7 + Beck depression score reduced more in PA+CBT group:

						from 20.9 to 9.7 versus from 20.5 to 14.5
Hoying 2016 (Hoying and Melnyk, 2016)	USA	One-group pre- and post	31 pre-adolescents (sixth-grade), mean age=11 years; 36% boys	2 items BYI or a score higher than 70 on the BYI	15 weekly sessions CBT counseling including physical activity provided by a nurse	SI in 6 participants reduced non-significantly (ES=0.58, P=0.21).
Sturm 2012 (Sturm et al., 2012)	Germany	Randomized cross-over trial	Group 1: 10 adults; 30% male, mean age=45years Group 2: 10 adults; 30% male, mean age=41years	BSSI	9 weeks mountain hiking 3*week at moderate intensity, 2-3 hours provided by a nurse or physiotherapist versus no-intervention	BSI (n=17) during hiking dropped from 10 to 6 (P<0.001) and in control phase from 10 to 8 (P=0.04) (difference: P=0.25), BDI during hiking dropped from 27 to 14 and in control phase from 19 to 23 (P<0.001)

RCT= randomized controlled trial, PA= physical activity, CBT= cognitive behavioral therapy, BSSI=Beck Scale for Suicidal Ideation, BYI=Beck Youth Inventory, Beck Depression index

Highlights

- Being physically active is associated with lower suicidal ideation.
- Complying with physical activity guidelines may confer a protective effect on suicidal risks.
- There is a high need for well-designed prospective and interventional studies.
- Future research should explore in more detail gender- and age specific recommendations.