Universidad de Huelva

Facultad Educación, Psicologia y Ciencias del Deporte

Physical activity, muscular strength, and depression symptoms among adults: A cross-sectional and prospective population-based study

Memoria para optar al grado de doctor presentada por:

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Adilson Passos da Costa Marques

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Summary

Resumen

La depresión es un trastorno mental que afecta a más de 300 millones de personas en todo el mundo. Las tasas de prevalencia más altas de depresión se observan en el rango de edad de 55 a 74 años, pero la mayor disfunción tiene lugar a partir de los 60 años. El tratamiento más común para la depresión incluye la farmacoterapia y la psicoterapia, que pueden resultar costosas para los sistemas de salud debido a la alta prevalencia del trastorno. Para abordar el problema de salud mental de la depresión que afecta a tantas personas en todo el mundo es importante identificar opciones de tratamiento alternativas y efectivas. La actividad física y el desarrollo de la aptitud física son factores importantes que contribuyen a mejorar la salud, independientemente de la edad. La actividad física regular se asocia con la reducción del riesgo de mortalidad por todas las causas y varias enfermedades crónicas. La actividad física y la aptitud física también están asociadas con la salud mental y la depresión. Existe evidencia que apoya la idea de que la actividad física puede conferir protección contra la depresión. Entre las personas mayores, la actividad física se puede considerar como una alternativa no medicamentosa a los antidepresivos, y parece que hay una subestimación de sus efectos clínicos positivos. Por tanto, esta tesis tuvo como objetivo analizar, de forma transversal y prospectiva, la relación entre la actividad física, la fuerza muscular y los síntomas depresivos, estratificada por características sociodemográficas de adultos y adultos mayores.

Para los estudios se utilizaron datos del Survey of Health, Aging, and Retirement in Europe y del proyecto European Social Survey. Survey of Health, Aging, and Retirement in Europe es una base de datos internacional de información sobre una amplia gama de variables que van desde los comportamientos relacionados con la salud y el ajuste psicológico hasta el nivel socioeconómico y las relaciones sociales y familiares. El European Social Survey es una encuesta internacional que se ha realizado cada dos años en 20 países europeos e Israel. Los

síntomas de depresión se evaluaron utilizando la escala EURO-D de 12 ítems y la Escala de depresión del Centro de Estudios Epidemiológicos (CES-D8). La actividad física fue autoinformada. La fuerza muscular se midió con un dinamómetro. Los participantes informaron sobre su sexo, edad, nivel educativo, estado civil, lugar de residencia, ingresos familiares y enfermedades crónicas. El índice de masa corporal se calculó a partir de la altura y el peso autoinformados (kg/m^2). Se preguntó a los participantes sobre sus hábitos de fumar y de consumo de alcohol.

A partir de los resultados de los estudios, se observó que la práctica de actividad física en el tiempo libre se relacionaba de manera negativa y lineal con los síntomas depresivos, independientemente del sexo o la edad. Los hombres y mujeres que realizaban actividad física moderada o vigorosa una o más veces a la semana tenían menos síntomas de depresión que aquellos que la realizaban menos de una vez por semana. Además, realizar una actividad física moderada y vigorosa disminuyó las probabilidades de sufrir depresión en comparación con realizar una actividad física menos de una vez por la semana. Por otra parte, los hombres y las mujeres con más fuerza de agarre tenían menos probabilidades de tener síntomas de depresión que aquellos con menos fuerza de agarre. La relación negativa entre la fuerza y los síntomas de depresión se observó en hombres y mujeres tanto menores como mayores de 65 años.

Los resultados de este estudio respaldan la evidencia sobre el efecto beneficioso de la actividad física sobre los síntomas de depresión. Aporta a la literatura que esta relación es independiente de las características sociodemográficas. Los beneficios de la actividad física sobre la depresión son transversales y la actividad física se puede recomendar a la mayoría de las personas para la prevención o el tratamiento de la depresión.

Abstract

Depression is a mental disorder that affects more than 300 millions people wordwide. The highest prevalence rates of depression are observed at the age of 55-74 years, but the greater dysfunction occurs over 60 years. The most common treatment for depression includes pharmacotherapy and psychotherapy, which can be expensive for health care systems due to the high prevalence of the disorder. To address the health problem of depression that affects so many people around the world, it is important to identify additional and effective treatment options. Physical activity and physical fitness are important factors that contribute to improving health, regardless of age. Regular physical activity is associated with reducing the risk of all-cause mortality and several chronic medical conditions. Physical activity and physical fitness are also associated with mental health and depression. There is evidence that supports the notion that physical activity can confer protection against depression. Among older people, physical activity can be considered as a non-medication alternative to antidepressants and seems that there is an underestimation of the positive clinical effects. Therefore, this thesis aimed to analyse, cross-sectional, and prospectively, the relationship between physical activity, muscular strength, and depression symptoms, stratified by sociodemographic characteristics of adults and older adults.

For the studies, it was used data from the Survey of Health, Aging, and Retirement in Europe (SHARE) study, and from the European Social Survey project. SHARE is a cross-national panel database of information on a wide range of variables spanning from health behaviour and psychological health to socioeconomic status and social and family networks. The European Social Survey is an academically driven cross-national survey that has been conducted every two years across 20 European countries and Israel. Depression symptoms were assessed using the EURO-D 12-item scale and the Centre for Epidemiological Studies Depression Scale (CES-D8). Physical activity was self-reported. Muscular strength was

measured using a dynamometer. Participants reported their sex, age, educational level, marital status, living place, household income, and chronic diseases. Body mass index was calculated from self-reported height and weight (kg/m2). Participants were asked about their smoking behavior and alcohol consumption.

From the studies' results, it was observed that engaging in leisure-time physical activity was negatively and linearly related to depressive symptoms, independently of sex or age. Men and women engaging in moderate or vigorous physical activity once or more than once a week had fewer depression symptoms than those who engage less than once a week. Furthermore, engaging in moderate and vigorous physical activity decreased the odds of depression compared to engaging in physical activity less than once a week. Men and women with more grip strength were less likely to have depression symptoms than those with less grip strength. The negative relationship between strong grip strength and depression symptoms was observed among men and women under and over 65 years.

These study's results support the documented benefit of physical activity on depression symptoms. It adds to the literature that this relationship is regardless of sociodemographic characteristics. The benefits of physical activity on depression are transversal and physical activity can be recommended for most people for the prevention or treatment of depression.

Introduction

Introduction

Currently, life expectancy has increased, and it is one of humanity's achievements (Prince et al., 2015). Therefore, there is a necessity in improving older people's health to allow a more active contribution to society and to have a good quality of life (Bowling, 2007). Nevertheless, this change in population aging is also linked with the worldwide epidemic of chronic diseases (Prazeres & Santiago, 2015; Puth et al., 2017; Schiotz et al., 2017). Population aging is one of the most important drivers to increase age-dependent disorders, stroke, diabetes, and mental health problems such as depression (Prince et al., 2015).

Depression is a mental disorder related to indicators such as decreased energy, depressed mood, loss of interest, feelings of guilt, poor concentration, sleeping troubles, and disturbed appetite. In the last two decades, depression has been the most prevalent mental disorder among adults (Ferrari et al., 2013; Mathers et al., 2002; WHO, 2017). Depression is associated with heightened comorbidity (Vancampfort et al., 2016), increase health costs (Chisholm et al., 2016), poor adherence to medical treatment (Saz & Dewey, 2001), risk of suicide (Ferrari et al., 2013), and premature mortality (Walker et al., 2015). Depression affects the quality of life, relationships with others, education, and work opportunities (Ferrari et al., 2013). It is a transversal problem, affecting people of different ages, from both sexes, and different educational and socioeconomic backgrounds (Almomani & Bani-Issa, 2017; Lejtzen et al., 2014; WHO, 2017).

It estimated that more than 300 million people suffer from depression symptoms worldwide, having a higher prevalence among women (5.1%) than men (3.6%) (WHO, 2017). The different prevalence between men and women is thought to be linked to biological and psychological differences in susceptibility, and environmental factors (Kuehner, 2017). For instance, during reproductive age, women go through internal endocrine processes associated with the reproductive cycle that can increase the risk of depression (Stickel et al., 2019).

Depression is the non-fatal disease that most contribute to the loss of health, and in 2015 depressive disorders were responsible for the cumulative loss of more than 50 million years of life with the disability (WHO, 2017). From 2005 to 2015, there was an increase of 18.4% in people with depression, essentially due to the increase in life expectancy (Vos et al., 2016). Depression is the third-largest contributor to the global weight of the disease (GBD, 2018). The persistence of depressive symptoms is concerning given the relation with self-harm with loss of functional status in the workforce (GBD, 2018).

The onset of the first episode of depression symptoms occurs from -adolescence to mid-40s. Nearly 40% experience their first episode of depression before the age of 20 years old (Malhi & Mann, 2018). The mean episode of depression duration varies between 13 and 30 weeks with about 70% to 90% of the patients recovering within 1 year (Üstün & Kessler, 2002). However, in the outpatient care setting, 25% get better within 6 months, and it is expected that after 2 years more than 50% of patients still have some depression symptoms (Boschloo et al., 2014; Penninx et al., 2011). The highest prevalence rates of depression are observed at the age of 55-74 years, but the greater dysfunction occurs over 60 years, affecting strongly people's social contributions (Smit et al., 2013). Older people with depressive symptoms have less functionality when compared to those with other chronic diseases (Murray et al., 1996). Untreated depression, in the elderly, is associated with other health consequences, including mortality (Crabb & Hunsley, 2006). Depression in later life increases the perception of poor health, with an excessive recurrence to health care services (Smit et al., 2013). Moreover, depression is frequently concomitant with other age-related disorders, thus, it is often neglected and underdiagnosed in primary health care. Therefore, a minority of people with depression receive adequate treatment (Smit et al., 2013).

The most common treatment for depression includes pharmacotherapy and psychotherapy (Karyotaki et al., 2016; Khan et al., 2012), which, in the long-term, can be

expensive and costly for health care systems due to the prevalence of the disorder (Olfson et al., 2018). To address the health problem of depression that affects so many people around the world, and to effectively allocate health care spending, it is important to identify additional and effective treatment options.

Physical activity and physical fitness (the outcome of physical activity) are important factors that contribute to improving health, regardless of age. The health benefits of physical activity and physical fitness are well established (Hardman & Stensel, 2009; Marques, Peralta, et al., 2018; Marques, Santos, et al., 2018). Regular physical activity is associated with reducing the risk of all-cause mortality and several chronic medical conditions, such as cardiovascular diseases, type 2 diabetes, all-cancer mortality, hypertension (Warburton & Bredin, 2017). Among adults, but mainly among older people, regular physical activity also provides effective functional independence, reduced risk of functional limitations and disability (Paterson & Warburton, 2010), and helps to successful aging and social inclusion (Fougner et al., 2019). Furthermore, physical activity and physical fitness are also associated with mental health and depression (Stubbs et al., 2016). There is evidence that supports the notion that physical activity can confer protection against depression (Schuch et al., 2018). Among older people, physical activity can be considered as a non-medication alternative to antidepressants (Blumenthal et al., 1999), and seems that there is an underestimation of the positive clinical effects (Schuch et al., 2016).

Studies have shown that physical activity provides a protective effect against depression and has a positive effect on depression treatment, in nonclinical and clinical populations (Mammen & Faulkner, 2013; Rebar et al., 2015; Schuch et al., 2018). The protective effects of physical activity on depression are identified regardless of sex and age (Schuch et al., 2018). Besides physical activity and its relationship with depression, in the aging process, there is a decline in physical function and muscular strength in both men and

women (Marques et al., 2014; Milanovic et al., 2013). This decline of physical function and muscular strength is associated with structural and functional changes that contribute to increasing disability, frailty, and falls (Toraman & Yildirim, 2010). Lower muscular strength is also related to mental health issues such as depression symptoms (Fukumori et al., 2015; Lee et al., 2018). The decline in muscular strength might be related to depression symptoms, mainly because it plays an important role in the capacity to perform daily life activities, is associated with the functional performance and the feeling of achievement (Laredo-Aguilera et al., 2018).

Handgrip strength is a maximum hand static force measure commonly used to capture muscular strength and monitoring the health status in the general population and especially in older age (Bae et al., 2019; Leong et al., 2016; Mogi et al., 2018). The handgrip strength is correlated with muscular fitness (Samuel et al., 2012), and it is a powerful predictor of cardiovascular disease (Leong et al., 2015), metabolic syndrome (Lopez-Jaramillo et al., 2014), neurological disorders (Mehta et al., 2002), and future disability (McGrath et al., 2018).

Although some studies have shown that handgrip strength affects depression symptoms (Fukumori et al., 2015; Lee et al., 2018), others have demonstrated that among older people there is not a significant association with depression (Stessman et al., 2017), and that muscular strength did not predict changes in depression (Taekema et al., 2010). Besides that, data from transnational studies assessing the effect of handgrip strength on depression symptoms on older men and women are scarce. The effect of handgrip strength on depression was not observed in transnational population-based samples and the models of analysis in most studies were insufficiently adjusted for potential confounders (e.g. educational level, number of children, number of chronic diseases, body mass index, physical activity) (McGrath et al., 2018).

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Objective of the study and thesis structure

Objective of the study and thesis structure

Considering the problems and concerns presented previously, with this thesis we intend to analyse the relationship between physical activity, muscular strength as a component of physical fitness and depression symptoms. From the main objective of research derive more specific ones, that we intend to analyse through a compilation of several studies. Thus, the final product of this project was 4 studies and 2 systematic reviews. The brief description of each study and the systematic reviews, as well as its purpose, are described below.

Study 1

Age, sex, and other sociodemographic variables such as living place, household members, socioeconomic status, and education level are correlates of both depression (Aluoja et al., 2004; Ferrari et al., 2013; Rancans et al., 2014) and physical activity (Bauman et al., 2012; Marques et al., 2018; Werneck et al., 2019). However, there are few studies evaluating the relationship between depression symptoms and physical activity, stratified by peoples' sociodemographic characteristics. These sociodemographic characteristics might affect the effect of physical activity on depression symptoms. Further evidence on the relationship of depression symptoms and physical activity for distinct sociodemographic characteristics might be of importance for identifying subgroups at risk, designing tailored interventions and public health policies. Given this gap, a study was performed aimed to analyse the relationship between depression symptoms and physical activity, stratified by sociodemographic characteristics of European adults.

Study 2

Lack of physical activity is one of the modifiable risk factors for the onset of depression (Hallgren et al., 2017). Physical activity protects against depression and has a positive effect on depression treatment (Mammen & Faulkner, 2013; Rebar et al., 2015; Schuch et al., 2018). There is evidence that vigorous-intensity physical activity is associated

with a larger decrease in the risk of chronic diseases than moderate-intensity physical activity (Lee et al., 2003). However, older adults are less likely to engage in vigorous-intensity physical activity (Jansen et al., 2015). Thus, it is important to understand the effect of both moderate-intensity physical activity and vigorous-intensity physical activity on depression symptoms. Therefore, a study aimed to analyse the relationship between different levels of physical activity and depressive symptoms, considering important sociodemographic variables (such as gender, age, marital status, educational level, living place, and country), in a representative sample of European older adults, was performed.

Study 3

Depression and physical activity have been the subject of several studies, however, often the sample size is small and restricted to one country or specific area, most studies have a cross-sectional design, which precludes making causal inference. Thus, a study was made aimed to analyse the cross-sectional and prospective relationship between different physical activity intensity levels and depression symptoms in a large sample of European older adults.

Study 4

The outcome of physical activity is physical fitness. Muscular strength is a component of physical fitness. The decline in muscular strength with aging might be related to depression symptoms, since strength plays an important role in the capacity to perform daily life activities, and is associated with functional performance and the feeling of achievement (Laredo-Aguilera et al., 2018). Handgrip strength can be used to assess muscular strength because it can capture muscular capacity. It is also used as a way of monitoring the health status in the general population and particularly in older age (Bae et al., 2019; Leong et al., 2016; Mogi et al., 2018). Although some studies have shown that handgrip strength affects depression symptoms (Fukumori et al., 2015; Lee et al., 2018), others have demonstrated that among older people, there is no significant association with depression (Stessman et al.,

2017). Furthermore, data from transnational studies assessing the effect of handgrip strength on depression symptoms on older people are rare. Therefore, it was performed a study aimed to analyse the relationship between muscular strength and symptoms of depression considering sex and age.

Study 5

Better physical function is significantly associated with less depressive symptoms (Almeida et al., 2017; Kvael et al., 2017). Considering the significant association between muscular strength and the risk of mental illness (Kim, 2019), it can be hypothesised that better muscular strength has a positive effect on reducing or preventing depression. Therefore, a systematic review was conducted, aiming to review the literature regarding the relationship between muscular strength and depression symptoms among adults. Furthermore, a meta-analysis of selected studies was conducted to determine the pooled odds ratio for the relationship between muscular strength and depression symptoms.

Study 6

Physical activity can be performed in several contexts. For adults, walking or cycling while commuting to work seems to be important for enhancing their daily levels of physical activity (Sahlqvist et al., 2012; Yang et al., 2012). As a result, active commuting has been related to health and wellbeing improvement (Berglund et al., 2016; Humphreys et al., 2013). However, there is no clear evidence of the relationship between active travel or active commuting and depression symptoms. Therefore, a systematic review was conducted to analyse the relationship between physical activity in active commuting and depression among adults and older adults.

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General methods

Data source

The present project will use data from the Survey of Health, Aging, and Retirement in Europe (SHARE) study, and from the European Social Survey project.

SHARE is a cross-national panel database of information on a wide range of variables spanning from health behaviour and psychological health to socioeconomic status and social and family networks. The sample in SHARE represents a non-institutionalized population. It included individuals aged 50 and over. The SHARE study is fully described elsewhere (Börsch-Supan et al., 2013; Börsch-Supan & Jürges, 2005). Data were collected through face-to-face interviews done by trained interviewers using a computer-assisted personal interviewing program, and supplemented by a self-completed paper-and-pencil questionnaire (available at http://www.share-project.org/methodological-research.html). Comparable questionnaires were applied in each country. Translation guidelines were applied, and pilots were performed to enhance comparability.

The European Social Survey is an academically driven cross-national survey that has been conducted every two years across 20 European countries and Israel. The survey measures the attitudes, beliefs, and behaviour of European people. The European Social Survey uses a multistage probability cluster sampling designed to provide national representative samples among several European countries. According to national options, participants are sampled through postal code address files, population registers, social security register data, or telephone books. In the sampling procedure statistical precision was kept the same for all countries. In each country, the information was collected using a questionnaire filled-in through an hour-long face-to-face interview that included questions on the use of medicine, immigration, citizenship, socio-demographic and socioeconomic issues, health status, and physical activity. The questionnaire was translated by language experts, into the

language of each of the participating countries. Further details about ESS are available elsewhere (Schnaudt et al., 2014).

Measures

Depression symptoms

From SHARE data, the EURO-D 12-item scale was used to measure depression symptoms. The scale description and validation are described elsewhere (Prince et al., 1999). Score range between zero to 12, with higher scores indicative of higher levels of depression symptoms. A cut-off point of ≥4 points diagnoses a clinically significant depression (Gallagher et al., 2013; Prince et al., 1999). From the ESS, depression symptoms, depression symptoms were assessed using the Centre for Epidemiological Studies Depression Scale (CES-D8). Participants were asked how often they felt depressed, were happy, felt sad, felt lonely, slept restlessly, felt that everything was an effort, enjoyed life, and could not get going. Answers range from none or almost none of the time (1) to all or almost all of the time (4). The two positive items are reverse coded, as a result, a higher score indicates more DS. CES-D8 is a valid and reliable instrument for screening depression among adults (Karim et al., 2015; Missinne et al., 2014).

Physical activity

From SHARE data physical activity was measured as "frequency of moderate physical activity" (e.g., gardening, cleaning the car, going for a walk) and "frequency of vigorous physical activity" (e.g., sports, heavy housework, a job involving physical labour). The response alternatives both for moderate and vigorous activity were: (1) more than once a week, (2) once a week, (3) up to three times a month, and (4) hardly ever or never. The last two response options were grouped into one category called less than once a week. From ESS information on physical activity was assessed with a single item asking, "on how many of the

last 7 days did you walk quickly, do sports, or other physical activity for 30 minutes or longer?". Using the reported information on physical activity a new variable was computed to classified participants into three groups: 1) practice of physical activity ≤1 time/week; 2) practice of physical activity 2-4 times/week; and 3) practice of physical activity ≥5 times/week. Although physical activity was assessed with a single item, there is evidence in previous studies where physical activity is not the primary focus and more detailed measures are not feasible, that a single question is an acceptable alternative (Wanner et al., 2014).

Muscular strength

Muscular strength was measured twice on each hand using a dynamometer (Smedley, S Dynamometer, TTM, Tokyo, 100 kg). Participants were standing or sitting, with the elbow at a 90° angle, the wrist in neutral position, keeping the upper arm tight against the trunk, and the inner lever of the dynamometer adjusted to the hand. Participants squeezed the dynamometer with their hands as hard as possible and sustain it for 5 seconds. Prior to the assessment, participants had the opportunity to train. Values were recorded twice for each hand alternating between left and right hand. Valid measurements were values of two measurements in one hand that differed by less than 20 kg. Grip strength measurements with values 0 kg or ≥100 kg were excluded as well as if grip strength was only measured once in one hand.

Covariables

Participants reported their sex, age, educational level, marital status, living place, household income, and chronic diseases. Both SHARE and European Social Survey databases provide two variables of education attainment: a recoded variable that focuses on achieved levels of education (primary, lower secondary, upper secondary, post-secondary, and tertiary education), according to the International Standard Classification of Education (UNESCO, 2012), and years of full-time education. Respondents were asked to describe whether they live

with or without a husband/wife/partner, and the corresponding legal situation. Marital status was classified into the following: married (including in a registered partnership) or not married (including widowed, divorced, separated, or never married). To determine the living place, participants were asked to report whether they lived in a big city, suburbs or outskirts of a big city, town or small city, country village, or home in the countryside. Those who indicated that they lived in a big city, or suburbs, or outskirts of a big city were grouped into a new category named urban areas; those who responded that they lived in a country village or home in the countryside were grouped into rural areas. Household income was determined based on decile. Using this data, 1st to 3rd decil, 4th to 7th decil, and 8th to 10th were grouped to create three groups: low, middle, and high, respectively. The presence or absence of chronic disease was reported by the participants themselves, based on information provided to them by a doctor. The following diseases were considered: heart attack or other heart problems, hypertension, high blood cholesterol, diabetes, chronic lung disease, cancer, stomach or duodenal ulcer, Parkinson's disease, hip fracture/femoral fracture, and Alzheimer's disease/dementia. To produce a single score, the number of chronic diseases was summed as performed previously (Marques et al., 2017). Body mass index was calculated from self-reported height and weight (kg/m2). Body mass index categories were calculated according to the World Health Organization guidelines (WHO, 2000): normal weight (18.5-24.9 kg/m2), overweight (25-29.9 kg/m2), and obese (≥30 kg/m2). Participants were asked about their smoking behavior and alcohol consumption in the last 3-months. Responses were from "not at all" to "daily or almost every day".

Ethics

The SHARE protocol was approved by the Ethics Committee of the University of Mannheim and by the Ethics Council of the Max-Planck-Society for the Advancement of

Science, verifying the procedures to guarantee confidentiality and data privacy. The Ethics Committee of the University of Mannheim, and the Ethics Council of the Max-Planck-Society for the Advancement of Science approved the SHARE protocol, verifying the procedures to ensure confidentiality and data privacy (http://www.share-project.org/organisation/dates-facts.html). Data were collected in each country by trained researchers, following the SHARE protocol. The survey is fully described elsewhere (Börsch-Supan et al., 2013; Börsch-Supan & Jürges, 2005).

The ESS study protocol subscribed the Declaration on Professional Ethics of the International Statistical Institute, and the ESS was approved by the ESS ERIC Research Ethics Committee. The legal bases used in ESS are in accordance with the General Data Protection Regulation and national laws of each country involved in the study.

Data analysis

In the 4 fisrt studies, descriptive statistics were calculated for all variables (means, standard deviation, and percentages) for the entire sample and stratified by sex. The comparison between men and women according to participants' characteristics was be tested by the Chi-Square test and Independent sample t-test. When observed an interaction effect between sex and other independent variables, the subsequent analysis was be perform stratified by sex. In cases when the interaction effect was not observed, the analysis, in some cases, was performed for the entire sample but adjusted for sex. In the original studies, all data analysis was performed using IBM SPSS Statistics version 25 (SPSS Inc., an IBM Company, Chicago, Illinois, U.S.A.). For all tests, the statistical significance will be set at $p<0.05$.

Study 1

The relationship between depressive symptoms and physical activity, stratified by socioeconomic variables, was examined by linear regression models, using method Enter. Analyses for multicollinearity were tested with the variance inflation factor and tolerance. It was not observed multicollinearity problems among variables. A single model was performed for each socioeconomic variable, for depressive symptoms and physical activity.

Study 2

ANOVA was performed, to analyse the relationships between moderate-intensity physical activity, vigorous-intensity physical activity and depression symptoms. General linear models were used to calculate the parameters estimates for the depression symptoms score according to different levels of physical activity intensity. Logistic regressions were conducted to analyze the relationship between moderate-intensity physical activity, vigorous-intensity physical activity, and depression. Analyses were stratified by gender because an interaction effect was observed between gender and physical activity on depression symptoms.

Study 3

The cross-sectional and prospective association between moderate and vigorous physical activity with the score of depression was analysed by ANCOVA. Women are more prone to have depression symptoms than men (Llorente et al., 2018), therefore, analysis were stratified by sex. Binary logistic regressions were conducted to assess the association between physical activity trajectory over the years and depression symptoms. An interaction effect was observed between age (50-64 years, 65-80 years, and ≥80 years) and PA, on depression symptoms.

Study 4

The association between grip strength and depression was assessed by multivariable binary logistic regressions. The interaction effect between sex and grip strength, and between

age (50-64 years vs. ≥65 years) and grip strength, on depression symptoms was tested by ANOVA. Interaction effects were significant, thus, analyses were stratified by sex, age, and sex, and age at the same time. Several models were performed.

Study 5

Data from all studies were pooled using Review Manager 5.3. From the 16 observational studies, data from 9 was used for meta-analysis (Ashdown-Franks et al., 2019; Brooks et al., 2018; Fukumori et al., 2015; Han et al., 2019; Lee, 2018; Lee et al., 2018; McDowell et al., 2018; Smith et al., 2019; Soriano-Maldonado et al., 2016). Homogeneity of the odds ratio of the studies included in the meta-analysis was assessed using I2 statistics. Values of ≥50% were considered substantial heterogeneity (Higgins et al., 2003). As there was significant heterogeneity, a random-effects model was used to calculate the pooled odds ratio. Sensitivity analyses were carried out by successively omitting one study at each turn.

Study 6

The details for each study, including design, participant characteristics and sample size, measures, main results, and study quality were presented consistently using a table.

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Studies

Study 1. Leisure-time physical activity is negatively associated with depression symptoms independently of the socioeconomic status

Abstract

Objective: There are few studies evaluating the relationship between depression symptoms (DS) and physical activity (PA) considering peoples' sociodemographic characteristics. This study aimed to analyse the relationship between DS and PA, stratified by sociodemographic characteristics of European adults. Methods: Participants were 29285 adults (13943 men, 47.6%; 15342 women, 52.4%), aged 50.9±17.4 from the European Social Survey round 7. DS was assessed with the Centre for Epidemiological Studies Depression Scale (CES-D8). Leisure-time PA (LTPA) was self-reported. The analysed sociodemographic characteristics were sex, age, living place, household members, marital status, income, and educational level. The relationship between DS and PA, stratified by sociodemographic variables, was examined by linear regression models. Results: Engaging in LTPA was negatively and linearly related to DS, independently of being men or women, being younger, middle or older adult, living in an urban or rural area, having children or not, being single or married, being wealthy or poor, employment status, and to having a lower or a higher education level. Age was the variable with both the least and the greatest effect of LTPA on DS. The least effect of LTPA on DS was observed in younger adults (β=-0.08, 95% CI: -0.11, -0.05) and the greatest effect in retired people (β=-0.33, 95% CI: -0.36, -0.29). Conclusion: Independently of sociodemographic characteristics, LTPA is associated with DS and can benefit everyone. Public health policies for promoting mental health should include PA promotion as an important strategy for the prevention or treatment of DS.

Keywords: sport; exercise; adults; mental health; sociodemographic; European Social Survey

Introduction

Depression is a mental disorder related to indicators such as decreased energy, depressed mood, loss of interest, feelings of guilt, poor concentration, sleeping troubles, and disturbed appetite. In the last two decades, depression has been the most prevalent mental disorder among adults (Stubbs et al., 2016; WHO, 2017). Depression is associated with heightened comorbidity (Vancampfort et al., 2016), increase health costs (Chisholm et al., 2016), poor adherence to medical treatment (Saz & Dewey, 2001), risk of suicide, and premature mortality (Walker et al., 2015).

Depression affects the quality of life, relationships with others, education and work opportunities (WHO, 2017). It is a transversal problem, affecting people of different ages, from both sexes, and from different educational and socioeconomic backgrounds (WHO, 2017). Studies have shown that total physical activity (PA), but mainly leisure-time PA (LTPA) provides a protective effect against depression and has a positive effect on depression treatment, in nonclinical and clinical populations (Rebar et al., 2015; Schuch et al., 2018). The protective effects of PA on depression are identified regardless of sex and age (Schuch et al., 2018).

Sociodemographic factors, such as age, sex, living place, household members, socioeconomic status, employment status, and education level are correlates of both depression (Rancans et al., 2014) and PA (Marques, Santos, Martins, et al., 2018; Werneck et al., 2019). Younger adults, women, people living in urban areas, low educated, with low income, and unemployed are more prone to have depression symptoms (DS) (Llorente et al., 2018; Rancans et al., 2014). As these factors are determinant of both depression and PA, they might influence the effect of PA on DS. However, there are few studies evaluating the relationship between DS and LTPA, stratified by peoples' sociodemographic factors. Further evidence on the relationship of DS and LTPA for distinct sociodemographic characteristics

might be of importance for identifying subgroups at risk, designing tailored interventions and public health policies. Given this gap, this study aimed to analyse the relationship between DS and LTPA, stratified by sociodemographic characteristics of European adults.

Methods

Participants and procedures

Participants were from the European Social Survey round 7. The European Social Survey is a cross-national survey conducted since 2000, every two years, across Europe and Israel. The survey measures behaviour, beliefs, and attitudes of European people over 15 years, using national representative samples among countries. In each country, participants were sampled by postal code address files, population registers, social security register data, or telephone books. In every country, information was collected through an hour-long face-to-face interview, including questions on the use of medicine, immigration, citizenship, socio-demographic and socioeconomic issues, health perception, and LTPA. The questionnaire was translated, by language experts, into the language of each of the participating countries. Further details about the survey are available elsewhere (Schnaudt et al., 2014). The study protocol subscribed the Declaration on Professional Ethics of the International Statistical Institute (http://www.europeansocialsurvey.org/about/ethics.html).

The European Social Survey round 7, comprised 40185 participants from 21 countries (Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Hungary, Ireland, Israel, Lithuania, Netherlands, Norway, Poland, Portugal, Slovenia, Spain, Sweden, Switzerland, United Kingdom). Only adults and European people were selected for the present study. Thus, participants younger than 18 years of age (n=2778) and Israeli people were excluded (n=2562). Those who did not report PA and DS and sociodemographic factors

were also excluded (n=5560). The final sample comprised 29285 individuals (13943 men, 15342 women), with a mean age 50.9±17.4 (50.6±17.3 for men, 51.1±17.54 for women).

The study protocol subscribes to the Declaration on Professional Ethics of the International Statistical Institute.

Measures

Depression symptoms

DS was assessed using the Centre for Epidemiological Studies Depression Scale (CES-D8). Participants were asked how often they felt depressed, were happy, felt sad, felt lonely, slept restlessly, felt that everything was an effort, enjoyed life, and could not get going. Answers range from none or almost none of the time (1) to all or almost all of the time (4). The two positive items are reverse coded, as a result, a higher score indicates more DS. The CED-D8 score ranged from eight to 32. The answers options were recoded from zero to three. To identify clinically significant symptoms, a score of nine was used as cut-off, as recommended (Briggs et al., 2018). CES-D8 is a valid and reliable instrument for screening depression among adults (Karim et al., 2015).

Leisure-time physical activity

The frequency of LTPA was assessed using a one-single question "On how many of the last 7 days did you walk quickly, do sports or other physical activity for 30 minutes or longer?" Although it was assessed by a single question, there is evidence that it is an acceptable way to assess PA in epidemiologic studies (Wanner et al., 2014).

Sociodemographic factors

Participants reported their sex, age, living place, household members, marital status income, employment status, and educational level. Marital status was recoded into living with a partner or living without a partner. Socioeconomic status was calculated based on deciles' household income. Three groups were created, and participants were clustered as followed:

1st to 3rd deciles (low socioeconomic status), 4th to 7th deciles (middle socioeconomic status) and 8th to 10th deciles (high socioeconomic status). Participants reported if they lived in a large city, in the suburbs or surroundings of a large city, in a village or a small town, in a village or a country house. Those who answered that lived in a large city, in the suburbs or surroundings of a large city were grouped into urban area; and those who reported living in a village or country house were grouped into rural area, as in a previous study (Marques et al., 2019).

Potential confounders

Multimorbidity, sedentary time and body mass index (BMI) are determinants of physical activity (Birk et al., 2019; Marques, Santos, Peralta, et al., 2018). Therefore, analysis was controlled for these potential confounders. Chronic diseases (heart or circulation problems, high blood pressure, breathing problems, allergies, diabetes, and cancer) were assessed by asking participants to indicate whether they currently have, or had been diagnosed any chronic diseases (yes/no) in the last 12 months. Multimorbidity was defined as the co-occurrence of two or more of these conditions. Participants were asked to report how much time, in total, they spend watching television on an average day. Responses were from no time to more than 3 hours, using intervals of 30 minutes. BMI was calculated from self-reported height and weight (kg/m2).

Data analysis

Descriptive statistics were calculated for all variables (means and percentages) with a 95% confidence interval (CI). The relationship between DS and LTPA, stratified by socioeconomic variables, was examined by linear regression models, using method Enter. Analyses for multicollinearity were tested with the variance inflation factor (VIF) and tolerance. It was not observed multicollinearity problems among variables. A single model was performed for each socioeconomic variable, for DS and LTPA. First, a crude model was

performed and then the analysis included a fully adjusted model for the other socioeconomic factors and potential confounders (multimorbidity, television watching time, and BMI. Analyses were conducted using population size weights to correct the population sample sizes from different countries. Analyses were performed by SPSS 25.

Results

Participants' characteristics and the relationship between DS and LTPA, stratified by sociodemographic variables, are presented in table 1. Men presented lower DS than women (14.68%, 95% CI: 13.11, 16.24 vs. 23.40%, 95% CI: 21.96, 24.83) and engaged more often in PA (3.25, 95% CI: 3.20, 3.29 vs. 2.99, 95% CI: 2.95, 3.04). As age increased, the prevalence of DS also increased from 15.65% (95% CI: 13.66, 17.64) at the age of 18-39 years to 22.03% (95% CI: 20.25, 23.81) at ≥60 years. In contrast, frequency of LTPA decreased from 3.20 (95% CI: 3.14, 3.25) times/week to 3.05 (95% CI: 2.99, 3.10) times/week. For socioeconomic status, the same pattern was observed. Increased socioeconomic status corresponded to a lower level of depression, but in reverse, the frequency of LTPA increased. On the other hand, having children was related with lower DS (17.55%, 95% CI: 15.81, 19.30 vs. 20.14%, 95% CI: 18.81, 21.47) and with lower frequency of LTPA (2.97, 95% CI: 2.92, 3.03 vs. 3.20, 95% CI: 3.16, 3.24 times/week) when compare to those with who did not have children. The same was observed for marital status. Married people had lower prevalence of DS (27.90%, 95% CI: 26.28, 29.53 vs. 13.89%, 95% CI: 12.51, 15.27) than single people; and have slightly lower frequency of LTPA (3.15, 95% CI: 3.11, 3.18 vs. 3.07, 95% CI: 3.02, 3.12 times/week). Those who were or disabled and unemployed presented a higher prevalence of DS than employed people and students. Finally, the educational level did not seem to be related to the DS, but those from higher educational level engaged slightly less frequently in LTPA than those with low and middle educational level.

Table 1. Participants' characteristics (n=29350), and relationship between CES-D8, physical activity and sociodemographic characteristics.

		Clinical depression symptoms[1]	Physical activity ≥30 min/day
	% (95% CI)	%	M (95% CI
Sex			
Men	48.49 (47.65, 49.34)	14.68 (13.11, 16.24)	3.25 (3.20, 3.29)
Women	51.51 (50.69, 52.33)	23.40 (21.96, 24.83)	2.99 (2.95, 3.04)
Age groups			
18-39 years	29.62 (28.63, 30.61)	15.65 (13.66, 17.64)	3.20 (3.14, 3.25)
40-59 years	36.32 (35.38, 37.26)	19.36 (17.60, 21.11)	3.12 (3.07, 3.17)
≥60 years	34.06 (33.10, 35.01)	22.03 (20.25, 23.81)	3.05 (2.99, 3.10)
Living place			
Urban	65.75 (65.06, 66.43)	19.98 (18.68, 21.28)	3.14 (3.11, 3.18)
Rural	34.25 (33.30, 35.21)	17.60 (15.77, 19.42)	3.07 (3.01, 3.12)
Children			
No	62.54 (61.81, 63.26)	20.14 (18.81, 21.47)	3.20 (3.16, 3.24)
Yes	37.46 (36.53, 38.40)	17.55 (15.81, 19.30)	2.97 (2.92, 3.03)
Marital status			
Single	37.67 (36.74, 38.60)	27.90 (26.28, 29.53)	3.15 (3.11, 3.18)
Married	62.33 (61.61, 63.05)	13.89 (12.51, 15.27)	3.07 (3.02, 3.12)
SES			
Low	31.28 (30.31, 32.26)	31.04 (29.29, 32.79)	2.93 (2.87, 2.99)
Middle	41.01 (40.11, 41.91)	16.64 (14.96, 18.32)	3.17 (3.12, 3.22)
High	27.71 (26.71, 28.71)	9.49 (7.36, 11.62)	3.25 (3.19, 3.30)
Employment status			
Employed	52.87 (52.06, 53.68)	13.97 (12.46, 15.47)	3.20 (3.15, 3.24)
Student	4.20 (3.05, 5.35)	14.76 (9.46, 20.07)	3.40 (3.27, 3.53)
Retired	27.09 (26.09, 28.10)	22.85 (20.86, 24.84)	3.03 (2.96, 3.09)
Unemployed	5.89 (4.75, 7.03)	27.99 (23.87, 32.10)	3.13 (3.00, 3.26)
Sick or disabled	2.67 (1.50, 3.83)	61.16 (56.67, 65.66)	2.12 (1.93, 2.32)
Housework	7.28 (6.15, 8.41)	23.24 (19.42, 27.06)	3.08 (2.96, 3.20)
Education			
Low	21.48 (20.44, 22.53)	19.25 (16.97, 21.54)	3.12 (3.05, 3.19)
Middle	56.90 (56.13, 57.68)	18.90 (17.50, 20.31)	3.15 (3.11, 3.19)
High	21.61 (20.57, 22.65)	19.78 (17.51, 22.05)	3.03 (2.96, 3.09)

Abbreviation: CES-D8, Center for Epidemiological Scale – Depression; CI, confidence interval; SES, socioeconomic status

[1] To identify clinically significant symptoms, a score of nine was used as cut-off.

Table 2 presents the relationship between DS symptoms and LTPA, stratified by each sociodemographic characteristic. The frequency of LTPA was negatively and linearly related to DS, independently of being men or women, being younger, middle or older adult, living in an urban or rural area, having or not having children, being single or married, being wealthy or poor, employment status, and having a lower or a higher education level. Age was the variable with the least and the greatest effect of LTPA on the DS. The least effect of

frequency of LTPA on DS was observed in younger adults (β=0.08, 95% CI: -0.11, -0.05), and the greatest effect in older (β=0.40, 95% CI: -0.43, -0.37) and retired people (β=0.43, 95% CI: -0.46, -0.39). However, in both cases, the effect was negative and significant.

Table 2. Relationship between depression symptoms and physical activity stratified by each sociodemographic variable.

	β (95% CI)
Sex	
Men	-0.19 (-0.21, -0.16)
Women	-0.27 (-0.30, -0.25)
Age groups	
18-39 years	-0.08 (-0.11, -0.05)
40-59 years	-0.17 (-0.20, -0.14)
≥60 years	-0.40 (-0.43, -0.37)
Living place	
Urban	-0.24 (-0.26, -0.22)
Rural	-0.24 (-0.27, -0.21)
Children	
No	-0.28 (-0.30, -0.25)
Yes	-0.18 (-0.21, -0.15)
Marital status	
Single	-0.31 (-0.35, -0.28)
Married	-0.19 (-0.21, -0.17)
SES	
Low	-0.31 (-0.35, -0.28)
Middle	-0.22 (-0.24, -0.19)
High	-0.12 (-0.16, -0.10)
Employment status	
Employed	-0.11 (-0.13, -0.09)
Student	-0.07 (-0.16, -0.01)
Retired	-0.43 (-0.46, -0.39)
Unemployed	-0.15 (-0.24, -0.06)
Sick or disabled	-0.32 (-0.45, -0.18)
Housework	-0.18 (-0.25, -0.12)
Education	
Low	-0.23 (-0.26, -0.19)
Middle	-0.24 (-0.27, -0.22)
High	-0.24 (-0.28, -0.20)

Abbreviation: CI, confidence interval; SES, socioeconomic status

When the models were again performed for each sociodemographic characteristic, but mutually adjusted for all other variables, the linear and negative relationship between DS and LTPA remained significant for all sociodemographic characteristics (figure 1). Younger age continued to be the variable showing the least effect of LTPA on DS (younger adults: β=-

0.08, 95% CI: -0.11, -0.06). On the other hand, older age (β=-0.31, 95% CI: -0.34, -0.28) and being retired (β=-0.33, 95% CI: -0.36, -0.29) showed the greatest effect of LTPA on DS. The effect of LTPA on DS ranged from β=-0.11 (95% CI: -0.14, -0.08) for those with high socioeconomic status, to β=-0.28 (95% CI: -0.41, -0.15) among those who were sick or disabled.

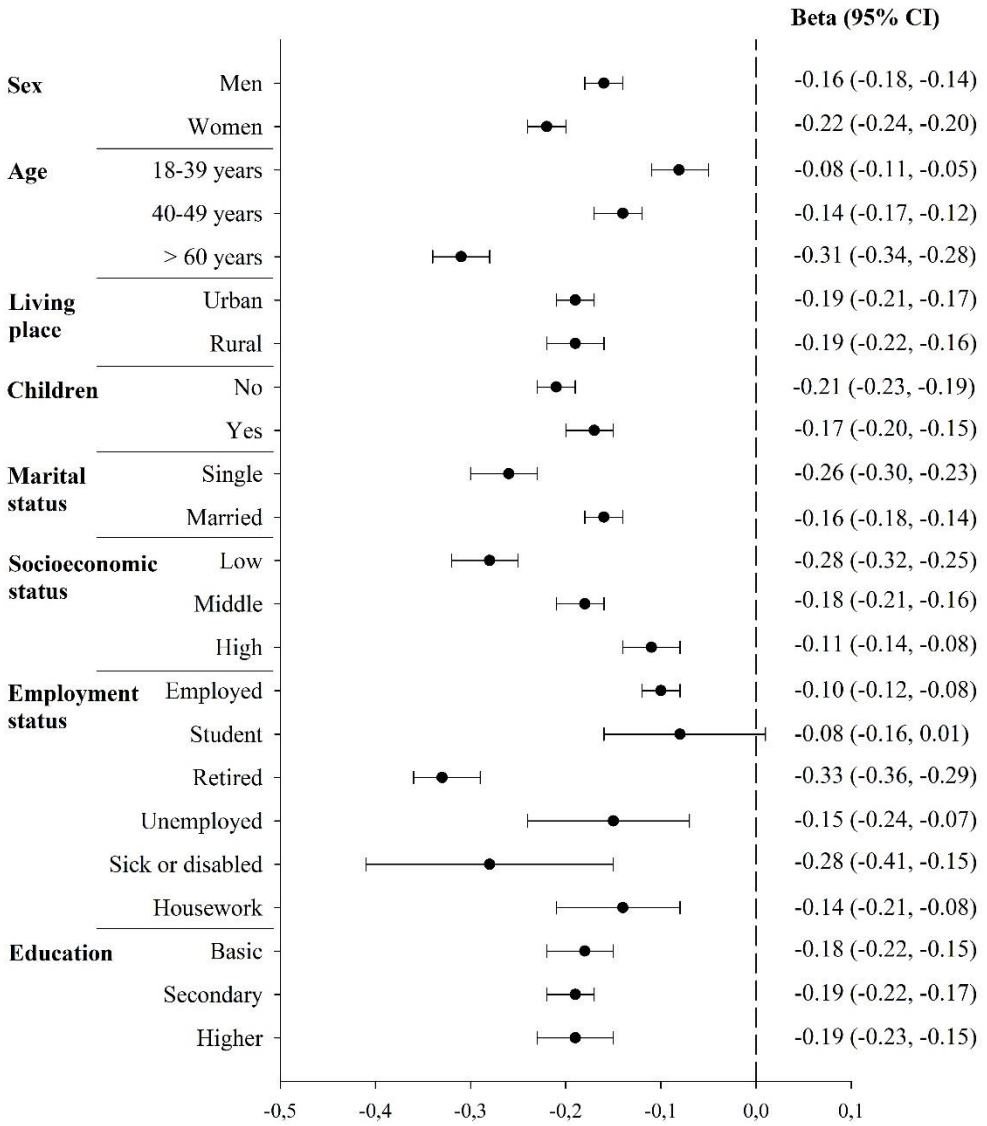

Figure 1. Relationship between depression symptoms and physical activity stratified by each sociodemographic variable and mutually adjusted for all other variables.

Discussion

Results from the present study showed that people who reported engaging more often in LTPA had fewer DS, regardless of their sociodemographic characteristics. It seems that the benefits of LTPA on depression are transversal and that LTPA can be recommended for most people for the prevention or treatment of depression. This is particularly important, because depression is a worldwide serious problem (Stubbs et al., 2016; WHO, 2017) associated with heightened comorbidity (Vancampfort et al., 2016), premature mortality (Walker et al., 2015), and increased health costs (Chisholm et al., 2016). Nonetheless, a variance in the protective effect of LTPA on DS was observed accordingly to sociodemographic characteristics. In this study, those who presented a higher prevalence of DS seem to benefit the most from LTPA protection. For instance, women, people older than 60 years, single, less wealthy, and retired people benefit more from LTPA than men, younger people, married, wealthy, and employed.

Women, older people, and those from lower socioeconomic status reported less LTPA than men, younger people, and those from higher socioeconomic status. Taking into account that they do not benefit from PA for being less active, it may explain the differences observed between sexes and among age groups on the prevalence of DS, which is in accordance with previous studies (Llorente et al., 2018; Rancans et al., 2014). Besides that, LTPA intensity tends to decrease with age, in both men and women; therefore, an age-related intensity decrease occurs. When compared with older people who maintained or increased LTPA intensity, this activity decrease is associated with an increased risk of DS (Lampinen et al., 2000). Thus, for those who are less active, providing more opportunities for PA can be an effective strategy to prevent DS (Werneck et al., 2018). This might explain the stronger effect of LTPA on DS in women and in older people when compared to men and younger people. Regarding the socioeconomic status, although its relationship with depression is complex, it is

significantly associated with DS, indicating that low socioeconomic status increases the risk of persistence of depression (Llorente et al., 2018). As for sex and age, the strong effect of LTPA on DS among people with lower socioeconomic status can be explained by their less likelihood of being active. It suggests that engaging in more LTPA increases its protective effects on DS.

Differences in DS between single and married people were observed previously (Bulloch et al., 2009; St John & Montgomery, 2009), and for that reason, it is recommended to stratify analyses of depression on marital status (St John & Montgomery, 2009). In this study, single people presented a higher prevalence of DS than married people did, however the protective effect of LTPA frequency on DS was also stronger on singles. Besides the biological benefits of LTPA, it also improves psychosocial wellbeing (Marques et al., 2016), helps social interaction, creates a social identity and prevents loneliness (Schrempft et al., 2019). For that reason, promoting PA among single people can be considered an effective approach to prevent depression.

Employment seems to have a protective effect on DS, mainly because of the economic and social benefits of paid work (Theorell et al., 2015; Yoo et al., 2016). However, the relationship between employment and depression may be different among countries, since social and economic recognition determine work conditions (Fernandez-Nino et al., 2018). Changes in employment status, as well as being sick or being retired with no pension is associated with having depression (Fernandez-Nino et al., 2018). The effect of LTPA on DS is independent of the employment status and seems particularly important among retired people. In fact, retired people could benefit more from LTPA because it is also associated with age. For them, LTPA could be a factor that improves and increases social interaction preventing loneliness (Schrempft et al., 2019).

The relationship between DS and PA has been reported in several cross-sectional and prospective studies (Rebar et al., 2015; Schuch et al., 2018). Taking into account that pharmacological treatment for depression is very expensive (Zaprutko et al., 2019), LTPA might be important to reduce the economic impact of depression treatment. Furthermore, because the benefits of LTPA in depression are independent of sociodemographic status, PA can be recommended for the prevention and treatment of depression; in particular women, people older than 50 years, single, less wealthy, and retired that were identified as more vulnerable.

The benefits of PA for depression seem consistent, and there are some mechanisms of action that could explain it. The relationship between PA and depression may be explained by biological mechanisms, such as the increase of neurogenesis, inflammatory and oxidant markers reduction (Schuch et al., 2016), and the activation of the endocannabinoid system (Brellenthin et al., 2017). Individuals with depression are known to have decreased hippocampal volume and levels of markers of neurogenesis, and increased levels of inflammatory and oxidant markers (Lindqvist et al., 2017), which can be regulated through PA (Lavebratt et al., 2017). Psychological factors can also explain the effect of PA on depression (Schuch et al., 2018). PA improves wellbeing (Marques et al., 2016), self-esteem, self-efficacy and body attractiveness (Opdenacker et al., 2009). These psychological constructs are negatively associated with depression (Hilbert et al., 2019). Furthermore, PA leads to improvements in fitness levels, which are related to both subjective and objective improvements in the health status (Marques et al., 2016). Improving fitness levels is important because there is evidence that depression severity is inversely related to cardiorespiratory fitness (Papasavvas et al., 2016). In fact, it is likely that a bundle of biological and psychosocial factors explains the effect of PA on depression, instead of a single mechanism (Schuch et al., 2018).

The present study discloses important new findings regarding the association between DS and LTPA. One of the main straights of this study is the use of a large representative sample from several European countries and numerous socio-demographic characteristics, assessed in the European Social Survey. Considering the large sample and the heterogeneity of the participants, the generality of these results is also a strength of the study. Despite its strengths, some limitations must be acknowledged. The main limitation regards the LTPA measure. LTPA was self-reported, which is more likely to be biased than when using an objective measurement (Grimm et al., 2012). Due to some factors, such as social desirability, there may be an overestimation when respondents are questioned about their LTPA frequency (Adams et al., 2005). Furthermore, for this study sample, the validity and reliability of the question to assess the frequency of LTPA was not tested. Nonetheless, self-reported LTPA is a reliable method for epidemiologic studies (Craig et al., 2003) and is still the mainstay of surveillance studies (Pedisic & Bauman, 2015). Also, the lack of information on LTPA, such as duration and more detail about frequency, is a limitation. Lastly, the cross-sectional design of the study precludes making causal inference.

Conclusions

Depression is a serious health problem affecting millions of people worldwide, from all strata of society, and thus a major public health concern. This study demonstrated that, independently of sociodemographic characteristics, LTPA is associated with depression and can benefit everyone, but in particular more vulnerable groups such as women, older, single, less wealthy, sick or disabled, and retired people. Public health policies for promoting mental health should include LTPA promotion as an instrument for the prevention or treatment of depression. Governments and authorities should view these findings as serious and as an achievable opportunity. Furthermore, LTPA presents both physical and psychological benefits

and can be considered as an overall health-promoting strategy, facing multiple problems at a time.

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Study 2. Different levels of physical activity and depression symptoms among older adults from 18 countries: A population-based study from the Survey of Health, Ageing and Retirement in Europe (SHARE)

Abstract

Objective: Analyse the relationship between different levels of physical activity (PA) and depression symptoms in a representative sample of European older adults. Methods: Data on PA, depression symptoms and sociodemographic variables from 64688 (28015 men) older adults participating in SHARE wave 6 was collected through a face-to-face interview. The EURO-D 12-item scale was administered for depression symptoms. Participants reported the frequency they engaged in moderate-intensity PA (MPA) and vigorous-intensity PA (VPA). Results: Men and women engaging in MPA and VPA once or more than once a week had fewer depression symptoms than those who engage less than once a week. MPA and VPA once or more than once a week were inversely associated with the depression symptoms score. Furthermore, engaging in MPA and VPA decreased the odds of depression (cut-off point of ≥4 depression symptoms) compared to engaging in PA less than once a week. Conclusions: Policies for promoting mental health should include PA for the prevention or treatment of depression symptoms. PA presents physical and psychological benefits and can be used as an overall health-promoting strategy, facing numerous problems at a time.

Keywords: quantitative study; aging; exercise

Introduction

Depression is a leading cause of disease burden worldwide in terms of years lost to disability and prevalence (GBD, 2018; WHO, 2018), affecting quality of life, relationship with others, education and work opportunities (Ferrari et al., 2013; WHO, 2017). It is also associated with physical comorbidity, such as diabetes, arthritis, asthma, chronic lung disease, angina and stroke (Lotfaliany et al., 2018), and other major groups of mental disorders (Plana-Ripoll et al., 2019), health costs (Chisholm et al., 2016), poor adherence to medical treatment (Saz & Dewey, 2001), risk of suicide (Ferrari et al., 2013), and premature mortality (Walker et al., 2015). Although depression is a global health problem, there is gender heterogeneity. Women have almost twice the odds of being diagnosed with major depression than men (Salk et al., 2017).

Low physical activity (PA) is one of the modifiable risk factors for the onset of depression (Hallgren et al., 2017). PA is associated with lower risk of depression and suggested to be a an n evidence-based treatment for depression (Mammen & Faulkner, 2013; Rebar et al., 2015; Schuch et al., 2018; Schuch, Vancampfort, Richards, et al., 2016). Among older people, exercise was found to have a similar effect to antidepressants in the treatment of depression (Blumenthal et al., 1999), and seems that there is an underestimation of the positive clinical effects (Schuch, Vancampfort, Rosenbaum, et al., 2016). The underlying mechanisms that may explain the benefits of PA for depression are suggested to be twofold: biological and psychosocial. Proposed biological mechanisms include the neuroplasticity, anti-inflammatory and antioxidant benefits of regular PA. Several reviews have associated depression to the inflammatory profile (Kohler et al., 2017; Valkanova et al., 2013), and regular PA is known to reduce a number of inflammatory markers (Fedewa et al., 2017; Fedewa et al., 2018). Similarly, oxidative stress may contribute towards the pathophysiology of depression, and PA could can have a counterbalancing role (Kandola et al., 2019). Also,

literature has shown that people with depression have lower levels of peripheral brain derived neurotrophic factor (BDNF) (Molendijk et al., 2014), which may contribute to the pathophysiology of depression. Regular PA increases concentration of several neurotrophic factors, including BDNF, thus possibly having a protective effect on depression (Coelho et al., 2013; Huang et al., 2014). As for psychosocial mechanisms, PA is associated to improved self-esteem and self-efficacy and more social support, that represent protective factors for depression symptoms (Kandola et al., 2019).

However, the effect of PA on depression for both genders is not consensual. Even though most studies have found PA to be associated to depression in men and women (Mammen & Faulkner, 2013; Rebar et al., 2015; Schuch et al., 2018), some studies have reported gender differences. In a systematic review of prospective studies Mammen and Faulkner (2013) identified four studies reporting a significant effect of PA in reducing the risk of depression only for women. The authors suggested that this might be because women benefit more from the social aspects of PA than men, resulting in a greater effect on depression. On the opposite, some studies have reported this association to be significant only for men, proposing that women's PA may be more related to household chores than to leisure-time and thus not benefiting as much as men's PA (de Oliveira et al., 2018; Werneck et al., 2018).

When examining the associations between PA and depression few studies make direct comparisons between different PA intensities. A recent randomized controlled trial has found that, among adults, vigorous PA (VPA) was more effective in lowering depression severity than moderate PA (MPA) and that light intensity PA was the only one that remained associated with lower depression severity at 12-month follow-up (Helgadottir et al., 2017). However, older adults are less likely to engage in VPA (Jansen et al., 2015) and it is still unclear if VPA brings greater benefit than MPA among older adults. These two factors

combined yield for a better understanding of the associations of both MPA and VPA on depression symptoms. Considering this, the main research question this study sought to answer was whether greater intensity and frequency of PA had a stronger association with depressive symptoms among older adults. Therefore, this study aimed to analyse the relationship between different levels of PA and depression symptoms, considering important sociodemographic variables, in a representative sample of European older adults.

Methods

Participants and procedures

Data from the population based Survey of Health, Aging, and Retirement in Europe (SHARE) wave 6 was used for the analysis in this manuscript. The SHARE is a biennial cross-national survey on ageing. It collects information on individuals aged 50 and over in several European countries and Israel since 2000 and has previously been described (Börsch-Supan et al., 2013). The total sample of SHARE wave 6 was 68231 participants. For this analysis, those participants who reported on PA participation and depression symptoms were included. The final sample comprised 64688 participants (28015 men, 36673 women), from the 18 following countries: Austria, Belgium, Croatia, Czech Republic, Denmark, Estonia, France, Germany, Greece, Israel, Italy, Luxembourg, Poland, Portugal, Slovenia, Spain, Sweden, and Switzerland.

Data were collected through face-to-face interviews at the participant's house location and had a duration of approximately 90 minutes. A translation of the questionnaires for each country was carried out and pilots were performed to enhance comparability. The SHARE protocol was approved by the Ethics Committee of the University of Mannheim and by the Ethics Council of the Max-Planck-Society for the Advancement of Science, verifying the procedures to guarantee confidentiality and data privacy.

Measures

Physical activity

Participants reported the number of days they engage in MPA (e.g. brisk walking, gardening or household activities); as well as in VPA (e.g. hiking, sports, carrying heavy loads). Response options were more than once a week, once a week, up to 3 times a month, and hardly ever or never. The last two response options were grouped into "less than once a week", as performed previously (Marques, Peralta, Martins, de Matos, et al., 2017).

Depression symptoms

The EURO-D 12-item scale was administered as a screening measure for depression symptoms. The scale description and its validating process are described in detail elsewhere (Prince et al., 1999). It has been demonstrated that an optimal cut-off point of ≥4 depression symptoms diagnoses a clinically significant case of depression (Gallagher et al., 2013; Prince et al., 1999).

Sociodemographic variables

Age, education level, marital status, and living place were self-reported. Education was categorized according to the International Standard Classification of Education Degrees (UNESCO, 2006), and grouped in three levels: low educational level (up to lower secondary education, ISCED code 0 to code 2), medium educational level (secondary education, ISCED codes 3 and 4), and high educational level (higher education, ISCED codes 5 and 6). Marital status was dichotomized into married (including in a registered partnership) or not married (including never married, separated, divorced or widowed). Living place was categorized in a big city, a suburb or the outskirts of a big city, a large town, a small town, or a rural area.

Based on a list of 14 diseases, participants were asked to report the presence or absence of diseases that were diagnosed by a doctor. Participants could also add other diseases diagnosed by a doctor unnamed in the list (Börsch-Supan et al., 2013). To produce a

single score, the number of chronic diseases was summed as performed previously (Marques, Peralta, Martins, Matos, et al., 2017). Body mass index (BMI) was calculated from self-reported height and weight (kg/m2). BMI categories were calculated in accordance with World Health Organization guidelines (WHO, 2000): normal weight (18.5-24.9 kg/m2), overweight (25-29.9 kg/m2), and obese (≥30 kg/m2). The limitation to perform the daily life activities was assessed by Global Activity Limitation Indicator (GALI) (Berger et al., 2015). Participants were asked about their smoking behavior and alcohol consumption in the last 3-months. Responses were from "not at all" to "daily or almost every day".

Statistical analysis

Descriptive statistics were calculated for all variables (means, standard deviation, and percentages). ANOVA was performed, to analyse the relationships between MPA, VPA and depression symptoms. General linear models were used to calculate the parameters estimates for the depression symptoms score according to different levels of PA intensity. Logistic regressions were conducted to analyze the relationship between MPA, VPA and depression (cut-off point of ≤4 depression symptoms). First, an unadjusted model was performed. After that, analyses were adjusted for age, marital status, educational level, living place, country, number of non-communicable diseases, body mass index, limitations to perform daily activities, smoking habits, and alcohol consumption. Analyses were stratified by gender because an interaction effect was observed between gender and PA on depression symptoms. Data analysis was performed using SPSS 25. Statistical significance was set at $p<0.05$.

Results

Participants' characteristics are presented in table 1.

Table 1. Participants' characteristics – Survey of Health, Aging, and Retirement in Europe (SHARE).

	% or Mean (95% CI)		
	Total sample (n=64688)	Men (n=28015)	Women (n=36673)
Age	67.3 (67.2, 67.4)	67.8 (67.7, 67.9)	67.0 (66.9, 67.1)
Age group			
50-64 years	41.7 (41.3, 42.1)	40.1 (39.5, 40.7)	43.0 (42.5, 43.5)
≥65 years	58.3 (57.9, 58.7)	59.9 (59.3, 60.5)	57.0 (56.5, 57.5)
Education			
Low	40.0 (39.6, 40.4)	36.5 (35.9, 37.1)	42.6 (42.1, 43.1)
Middle	37.5 (37.1, 37.9)	38.7 (38.2, 39.3)	36.6 (36.1, 37.1)
High	22.5 (22.2, 22.8)	24.7 (24.2, 25.3)	20.8 (20.4, 21.2)
Marital status			
Not married	31.5 (30.7, 32.2)	22.8 (21.8, 23.8)	38.5 (37.4, 39.5)
Married	68.5 (67.8, 69.3)	77.2 (76.2, 78.2)	61.5 (60.5, 62.6)
Living place			
Big city	17.0 (16.7, 17.4)	16.0 (15.5, 16.5)	17.7 (17.2, 18.1)
Suburbs of a big city	10.3 (10.0, 10,6)	10.9 (10.5, 11.4)	9.9 (9.6, 10.3)
Large town	15.0 (14.6, 15.3)	14.5 (14.0, 15.1)	15.2 (14.8, 15.7)
Small town	25.4 (25.0, 25.8)	25.6 (25.0, 26.3)	25.2 (24.7, 25.7)
Rural area	32.3 (31.9, 32.8)	32.9 (31.2, 33.6)	32.0 (31.4, 32.5)
EURO depression scale (score)	2.5 (2.4, 2.5)	2.0 (2.0, 2.0)	2.8 (2.8, 2.8)
EURO depression scale (score)			
No	72.6 (72.3, 73.0)	80.5 (80.0, 80.9)	66.6 (66.2, 67.1)
Yes	27.4 (27.0, 27,7)	19.5 (19.1, 20.0)	33.4 (32.9, 33.8)
Moderate PA			
Less than once a week	17.4 (17.1, 17.6)	16.0 (15.6, 16.4)	18.4 (18.0, 18.8)
Once a week	13.6 (13.3, 13.8)	13.7 (13.3, 14.1)	13.5 (13.1, 13.8)
More than once a week	69.1 (68.7, 69.4)	70.3 (69.8, 70.8)	68.1 (67.7, 68.6)
Vigorous PA			
Less than once a week	52.1 (51.7, 52.5)	48.2 (47.6, 48.8)	55.2 (54.6, 55.7)
Once a week	14.3 (14.0, 14.6)	14.2 (13.8, 14.6)	14.2 (13.9, 14.6)
More than once a week	33.6 (33.2, 33.9)	37.7 (37.1, 38.2)	30.4 (29.9, 30.9)

Table 2 depicts the parameters estimates for depression symptoms score according to different levels of PA intensity. In the unadjusted model, for men and women, the engagement in MPA or VPA once or more than once a week was negatively correlated with the depression symptoms score. When the model was adjusted, MPA once a week (men: β=-0.55, 95% CI: -0.88, -0.22; women: β=-0.33, 95% CI: -0.63, -0.03) and more than once a week (men: β=-0.96, 95% CI: -1.22, -0.69; women: β=-0.40, 95% CI: -0.62, -0.18) were negatively associated with the depression symptoms score. Similarly, VPA once a week (men: β=-0.70, 95% CI: -1.11, -0.28; women: β=-0.37, 95% CI: -0.71, -0.22) and more than once a

week (men: β=-0.99, 95% CI: -1.31, -0.66; women: β=-0.49, 95% CI: -0.76, -0.22) were also negatively associated with the depression symptoms score.

Table 2. Parameters estimates of depression score according to physical activity intensity levels and frequency – Survey of Health, Aging, and Retirement in Europe (SHARE).

	Parameters estimates for the depression score	
	Model 1	Model 2
Men	β (95% CI)	β (95% CI)
MPA		
Less than once a week	1.00 (ref.)	1.00 (ref.)
Once a week	-1.02 (-1.10, -0.93)***	-0.55 (-0.88, -0.22)**
More than once a week	-1.37 (-1.43, -1.31)***	-0.96 (-1.22, -0.69)***
VPA		
Less than once a week	1.0 (ref.)	1.00 (ref.)
Once a week	-0.79 (-0.86, -0.72)***	-0.70 (-1.11, -0.28)**
More than once a week	-0.84 (-0.89, -0.79)***	-0.99 (-1.31, -0.66)***
Women		
MPA		
Less than once a week	1.00 (ref.)	1.00 (ref.)
Once a week	-1.11 (-1.20, -1.03)***	-0.33 (-0.63, -0.03)*
More than once a week	-1.58 (-1.64, -1.52)*	-0.40 (-0.62, -0.18)***
VPA		
Less than once a week	1.00 (ref.)	1.00 (ref.)
Once a week	-0.79 (-0.86, -0.72)***	-0.37 (-0.71, -0.22)*
More than once a week	-0.91 (-0.96, -0.85)***	-0.49 (-0.76, -0.22)***

Abbreviation: CI, confidence interval; MPA, moderate physical activity; VPA, vigorous physical activity
Model 1: Unadjusted analyses. Model 2: Analyses were adjusted for age, marital status, educational level, living place, country numbers of non-communicable diseases, body mass index, limitation to perform activities, smoking habits and alcohol consumption.
* $p<0.05$, ** $p<0.01$, * $p<0.001$.

Table 3 presents the results of the relationship between depression (using the cut-off point of ≥4 depression symptoms) and PA. In the adjusted model, MPA once a week for men (OR=0.67, 95% CI: 0.46, 0.97) or more than once a week for men and women (men: OR=0.42, 95% CI: 0.31, 0.57; women: OR=0.59, 95% CI: 0.43, 0.79) decreased the odds of depression (cut-off point of ≥4 depression symptoms) compared to those who engage in MPA less than once a week. Men who engage in VPA once a week (OR=0.67, 95% CI: 0.46, 0.97) and men and women who engage in VPA more than once a week (men: OR=0.58, 95% CI:

0.45, 0.76; women: OR=0.72, 95% CI: 0.56, 0.93) also had lower likelihood of having depression (cut-off point of ≥4 depression symptoms) when compared to those who rarely engage in VPA.

Table 3. Relationship between depression (cut-off point of ≥4 depression symptoms) and physical activity at different levels of intensity and frequency – Survey of Health, Aging, and Retirement in Europe (SHARE).

	Depression (≥4 depression symptoms)	
	Model 1	Model 2
Men	OR (95% CI)	OR (95% CI)
MPA		
Less than once a week	1.00 (ref.)	1.00 (ref.)
Once a week	0.45 (0.36, 0.58)***	0.67 (0.46, 0.97)*
More than once a week	0.32 (0.27, 0.38)***	0.42 (0.31, 0.57)***
VPA		
Less than once a week	1.00 (ref.)	1.0 (ref.)
Once a week	0.46 (0.36, 0.58)***	0.67 (0.46, 0.97)*
More than once a week	0.39 (0.33, 0.46)***	0.58 (0.45, 0.76)***
Women		
MPA		
Less than once a week	1.00 (ref.)	1.0 (ref.)
Once a week	0.54 (0.45, 0.65)***	0.76 (0.52 10.12)
More than once a week	0.39 (0.34, 0.44)***	0.59 (0.43, 0.79)***
VPA		
Less than once a week	1.00 (ref.)	1.0 (ref.)
Once a week	0.67 (0.57, 0.79)***	0.88 (0.64, 10.20)
More than once a week	0.53 (0.47, 0.61)***	0.72 (0.56, 0.93)*

Abbreviation: OR, odds ration; CI, confidence interval; MPA, moderate physical activity; VPA, vigorous physical activity
Model 1: Unadjusted analyses. Model 2: Analyses were adjusted for age, marital status, educational level, living place, country, numbers of non-communicable diseases, body mass index, limitation to perform activities, smoking habits and alcohol consumption.
* $p<0.05$, ** $p<0.01$, *** $p<0.001$.

Discussion

This study sought to investigate the associations of different PA levels with depression symptoms, using a large sample of older adults from 18 countries. It was found that for men and women engaging in MPA and VPA once a week or more was associated with lower depression symptoms. Furthermore, MPA and VPA once a week or more decreased the odds

of depression (cut-off point of ≥4 depression symptoms) compared to those who engage in PA less than once a week.

The association between PA and depression symptoms is well documented (De Mello et al., 2013; Rebar et al., 2015; Schuch et al., 2018). The results of the present study support those of previous study results (Mammen & Faulkner, 2013; Rebar et al., 2015; Schuch et al., 2018). However, this study results add that engaging in PA at least once a week was associated with lower depression symptoms score in men and women, and odds of depression (cut-off point of ≥4 depression symptoms) in men, irrespectively of intensity. Also, MPA was found to be associated with depression symptoms. This means that low amounts of PA, in this case MPA once a weak, is associated to reduced depression symptoms in older people, mainly in men, further supporting current literature (Werneck et al., 2018). These results are particularly important for older people because they have more difficulties to achieve the recommended levels of PA. In addition, due to age related changes in multiple body systems, they also do not engage in PA with higher intensity levels, such as VPA (Jansen et al., 2015). It means that even older people who engage in MPA may benefit from PA practice.

Several mechanisms may explain the association between MPA, VPA and depression. Both depression and PA are associated with inflammatory markers and oxidative stress. On the one hand, the inflammatory profile and oxidative stress may contribute towards the pathophysiology of depression (Kandola et al., 2019; Kohler et al., 2017; Valkanova et al., 2013). On the other hand, regular PA presents anti-inflammatory and antioxidant benefits (Fedewa et al., 2017; Fedewa et al., 2018; Kandola et al., 2019). These associations may partly explain why PA is associated with lower risk of depression and less depression symptoms. Furthermore, PA has psychosocial benefits, including improving self-esteem, self-efficacy and social support, which may also represent protective factors for depression

symptoms (Kandola et al., 2019). This is of importance, especially among older adults, as lower levels of social interaction and self-esteem are more common in older ages.

The role of gender in the relationship between PA and depression is not fully clear. Although previous studies found contradicting results according to gender (Mikkelsen et al., 2010; Werneck et al., 2018), other found evidence of no gender differences (Mammen & Faulkner, 2013; Rebar et al., 2015; Schuch et al., 2018). In this study, it was observed that MPA and VPA were associated with depression symptoms in both men and women, strengthening the idea that PA associations with depression maybe regardless of gender in older people. Notwithstanding, some gender differences were found. Among men, engaging in MPA and VPA once a week was associated with lower odds of depression (cut-off point of ≥4 depression symptoms). Whereas for women, only those who reported practicing MPA and VPA more than once a week seemed to benefit from it to the extent of reducing the odds of depression (cut-off point of ≥4 depression symptoms), suggesting that older women may need to more regularly engage in PA than men, in order to benefit in the same way. Taking into account that women are more prone to have depression than men (Ferrari et al., 2013; Salk et al., 2017), practicing PA, may be a relevant strategy to reduce depression symptoms specially among women.

In order to understand the relationship between PA and depression, it is important to consider the characteristics of PA, such as frequency and intensity (Helgadottir et al., 2017). Nonetheless, most studies simply account for PA intensity or PA frequency. Rarely, studies considered at the same time PA intensity and frequency (Schuch et al., 2018). Recognising this gap, the present study provides PA frequency and intensity differentiation. One of the main strengths of this study was the use of a representative sample from several countries. The large and representative sample, as well as the heterogeneity of the participants, allows these results to be generalised. Despite the strengths, some limitations have to be recognised.

The main limitation is the cross-sectional design, which precludes making causal inferences. Furthermore, PA was self-reported, which is subject to bias (Grimm et al., 2012). Nonetheless, self-reported PA is a reliable method for epidemiologic studies (Craig et al., 2003) and it is still the mainstay of surveillance studies (Pedisic & Bauman, 2015). Also, the lack of information on PA, such as duration and more detail about frequency, is a limitation. Lastly, depression was not clinically diagnosed. The EURO-D 12-item scale is a screening tool for depression symptoms. Notwithstanding, a cut-off point of ≥4 depression symptoms has been demonstrated to diagnose clinically significant cases of depression (Gallagher et al., 2013; Prince et al., 1999).

Conclusion

Regardless of gender, MPA and VPA were associated with lower depression symptoms and lower odds of depression (cut-off point of ≥4 depression symptoms). Policies for promoting mental health should include PA, as even a low amount (MPA once a weak) was associated with depression. Additionally, PA presents physical and psychological benefits and can be used as an overall health-promoting strategy, facing numerous problems at a time.

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Study 3. Cross-sectional and prospective relationship between physical activity and depression symptoms

Abstract

This study aimed to analyse the cross-sectional and prospective relationship between moderate and vigorous physical activity (PA) and depression symptoms. This study analysed 32392 European late middle-aged to older adults, from 14 European countries across a four-year follow-up. Data was collected in the fourth (in 2011) and sixth (in 2015) wave, from the Survey of Health, Ageing and Retirement in Europe (SHARE). For the present analysis, participants were considered who responded to the EURO-D 12-item scale of depression symptoms and reported the intensity and frequency of PA. ANCOVAs were conducted to assess the cross-sectional and prospective associations. For both men and women, engaging in moderate or vigorous PA in 2011 was associated with a lower score of depression in 2011 and 2015. From the prospective analysis, moderate and vigorous PA in 2011 was inversely associated with the score of depression. This association remains significant in the fully adjusted for self-rated health, sociodemographic characteristics, and the presence of chronic diseases. Moderate and vigorous PA at least once a week is negatively related to the score of depression, both in men and women. PA is negatively associated with depression symptoms, and from prospective analysis PA predicts lower depression scores four years later.

Keywords: sport; exercise; older people; mental health; SHARE

Introduction

The prevalence of depression has been rising globally with an estimate that more than 300 million people suffer from this condition (WHO, 2017). Additionally, it is estimated that about one-third of depressive cases evolve into moderate-to-severe symptomatic depressions (Ferrari et al., 2013). Depression, following heart disease, is projected to be the second-largest contributor to the global burden of disease by 2020 (Chapman & Perry, 2008), and it is already considered as the greatest non-fatal disease contributory to the loss of health (WHO, 2017).

The prevalence of depression is the highest among the 55-74 years old age group (WHO, 2017). Comparing with other chronic diseases, it appears that older people suffering from depression are less functional (Murray & Lopez, 1996). However, as other age-related diseases might have concomitant symptoms, depression appears to be often neglected and even underdiagnosed in primary health care (Smit et al., 2013). In late middle aged to older people, serious health consequences are associated with untreated or poorly treated depressions, including increased mortality (Crabb & Hunsley, 2006).

The development of depression seems to increase with low levels of physical activity (PA) (Mammen & Faulkner, 2013). Strong evidence exists regarding the positive effects of PA for both the prevention and treatment of depression, being even considered an alternative to antidepressant medication (Blumenthal et al., 1999). Depression and PA have been the subject of several studies, however, often the sample size is small and restricted to one country or specific area, and most studies do not control for moderate and vigorous PA intensity levels, respectively. Thus, the present study aims to analyse the cross-sectional and prospective relationship between different PA intensity levels and depression symptoms in a large sample of European late middle aged to older adults.

Methods

This study analysed data from the Survey of Health, Ageing and Retirement in Europe (SHARE) from wave 4 (performed in 2011) and wave 6 (performed in 2015). SHARE is a multidisciplinary and cross-national survey resulting from the need to study and provide answers regarding the growing and upcoming challenges of population ageing. SHARE's data collection has been conducted biannually, since 2000. Including about 140.000 individuals aged 50 or older, from European countries and Israel, SHARE is a multicultural database of health microdata, socio-economic status, social and family networks. In the present study, including waves 4 and 6, participants were from the 14 following countries: Austria, Germany, Sweden, Spain, Italy, France, Denmark, Switzerland, Belgium, Czech Republic, Poland, Portugal, Slovenia, and Estonia (Calvo-Perxas et al., 2016). The total sample consisted of 34772 men and women that participated in both wave 4 and wave 6. For the present study, the final sample comprised 32392 participants (13511 men, 18881 women) that responded to the 12-item depression scale and reported on PA.

All interviews were conducted by trained interviewers at the participant's house location and had a duration of approximately 90 minutes. SHARE's questions encompass a large spectrum of subjects, such as health, and social variables. For the research community, SHARE's data is available free of charge (www.share-project.org) (Calvo-Perxas et al., 2016). Participants were informed about the objectives of the study and informed written consent was obtained. The study was in accordance with the ethical standards in sport and exercise science research (Harriss & Atkinson, 2011). All methods were performed in accordance with the relevant guidelines and regulations; and participation was anonymous and there were no incentives for participation. The SHARE's protocol was approved by the Ethics Committee of the University of Mannheim and by the Ethics Council of the Max-Planck-Society for the Advancement of Science.

Measurements

Covariates

Individual's characteristics were measured at the baseline and include age, sex, marital status, education level, living place, country, self-rated health and the number of chronic diseases. Age was recoded into 50-64 years, 65-79 years, and ≥80 years. According to the International Standard Classification of Education-97 (ISCED- 97) codes, education was collected and categorized in three groups: (i) low education level, including participants with no education or ISCED-97 codes 1 and 2; (ii) middle educational level, which included participants with ISCED-97 codes 3 and 4; (iii) high education level, which included participants with ISCED-97 codes 5 and 6. Marital status was coded into married, including a registered partnership or living together; and not married, including single, separated, divorced or widowed. To determine the participants' living place, they were asked to report on whether they lived in a big city, a suburb or the outskirts of a big city, a large town, a small town, or in rural area or village. Self-related health was accessed through a single-item question about their general health perception, using a 5-point scale response (excellent, very good, good, fair and poor). This scale was inverted for data analysis; therefore, higher values represent better health perception.

Number of chronic diseases

To determine the number of chronic medical diseases participants were asked to report the presence or absence of diseases that were previously diagnosed by a doctor, based on a list with 14 listed diseases (heartattack, hypertension, cholesterol, stroke, diabetes, lung disease, asthma, arthritis, osteoporosis, cancer, ulcer, Parkinson disease, cataracts, hip femoral fracture). Participants could also add other medical conditions, diagnosed by a doctor, unnamed in the list (Gallagher et al., 2013). In order to produce a single score, the number of

chronic diseases was summed as performed previously (Lindwall et al., 2011; Marques et al., 2017).

Physical activity

With the purpose to measure intensity and frequency of PA, participants were asked to report on how many days per week they practiced moderate PA such as, brisk walking, gardening or household activities; as well as the frequency of vigorous PA, including activities like hiking, sports, carrying heavy loads. To measure its frequency, for both moderate and vigorous activities, the responses were categorized into: (1) more than once a week, (2) once a week, (3) up to three times a month, and (4) hardly ever or never. The responses up to three times a month and hardly ever or never were grouped into a category named "less than once a week" as performed previously (Lindwall et al., 2011; Marques et al., 2017).

Depression

The EURO-D 12-item scale was developed and validated to assess and compare cross-nationally symptoms of depression in Europe (Prince et al., 1999). This scale asks about the presence or absence of depression symptoms in 12 domains s that are: depressed mood, pessimism, suicidality, guilt, sleep, interest, irritability, appetite, fatigue, concentration, enjoyment, and tearfulness. Each depression's domain is scored one if present and zero if absent. The sum of all domains results in the total score between 0 and 12. In each of the EURODEP study sites the score's validation was carried out and an optimal cut-off point of 4 or more points to diagnose a clinically significant depression was demonstrated (Gallagher et al., 2013; Prince et al., 1999).

Data analysis

Descriptive statistics were calculated (means, standard deviation, and percentages) for the entire sample, and were stratified by sex. ANOVA tests were performed, to analyse the

bivariate cross-sectional and prospective relationships between, moderate and vigorous PA and the score of depression symptoms, in 2011 and 2015. Using ANCOVA, the cross-sectional and prospective association between moderate and vigorous PA, with the score of depression was analysed. For the cross-sectional analysis, different models were performed. Model 1 is the unadjusted analysis between the PA and the depression score. Model 2 was adjusted for age, marital status, educational level, living place, country, and self-rated health. Model 3 was further adjusted for the number of chronic diseases. A fourth model was created for prospective analysis. Model 4 was further adjusted from Model 3's variables, depression score at baseline. Women are more prone to have depression symptoms than men (Llorente et al., 2018), therefore, analysis were stratified by sex. Binary logistic regressions were conducted to assess the association between PA trajectory over the years and depression symptoms. An interaction effect was observed between age (50-64 years, 65-80 years, and ≥80 years) and PA, on depression symptoms. Thus, analyses were stratified by sex, age-groups. Data analysis was performed using SPSS 25. Statistical significance was set at two-sided $p<0.05$.

Results

Table 1 shows the sociodemographic characteristics of the participants. The depression score was significantly higher in women than in men, both in 2011 ($p<0.001$) and in 2015 ($p <0.011$). Moreover, significantly more women than men (33.8% vs. 18.4% in 2011; 34% vs. 19.6% in 2015) presented depressive symptoms (≥4 EURO depression score). Regarding the practice of PA, men engaged significantly more often in moderate PA ($p <0.001$) and vigorous PA ($p <0.001$) per week than women.

Table 1. Participants' characteristics (n=32392).

	2011 (% or M±SD)			2015 (% or M±SD)		
	Men	Women	*p*	Men	Women	*p*
Age	65.4±9.0	65.0±9.7	<0.001	69.4±9.3	68.9±10.0	<0.001
Age group			<0.001			<0.001
50-64 years	49.5	51.6		33.3	36.2	
65-79 years	43.0	39.9		51.3	47.9	
≥80 years	7.6	8.5		15.4	15.9	
Education			<0.001			<0.001
Low	36.3	42.3		36.3	42.3	
Middle	40.4	38.2		40.4	38.1	
High	23.3	19.5		23.4	19.5	
Marital status			<0.001			<0.001
Not married	22.9	39.1		42.4	67.8	
Married	77.1	60.9		57.6	32.2	
Living place			<0.001			<0.001
Big city	13.1	15.2		13.5	15.2	
Suburbs of a big city	10.1	9.5		11.4	9.8	
Large town	14.8	16.7		13.7	15.1	
Small town	24.4	24.4		25.1	25.0	
Rural area	37.6	34.2		36.3	35.0	
EURO depression scale (score)	1.9±1.9	2.9±2.3	<0.001	2.0±2.0	2.9±2.3	<0.001
Depressive symptoms (score ≥4)	18.4	33.8	<0.001	19.6	34.0	<0.001
Self-rated health	2.9±1.1	2.8±1.1	<0.001	2.8±1.0	2.7±1.0	<0.001
Number of chronic diseases	1.6±1.4	1.7±1.5	<0.001	1.7±1.5	2.0±1.7	<0.001
Moderate PA			<0.001			<0.001
Less than once a week	14.1	17.1		16.1	18.7	
Once a week	13.6	14.2		11.9	12.6	
More than once a week	72.3	68.7		72.0	68.7	
Vigorous PA			<0.001			<0.001
Less than once a week	45.1	55.6		49.8	58.0	
Once a week	14.4	14.4		13.5	13.1	
More than once a week	40.5	30.0		36.7	28.9	

Abbreviation: M, media; SD, standard deviation; PA, physical activity.
[a] Tested by Chi Square.
[b] Tested by t test.

Table 2 presents the cross-sectional parameters estimates of depression score according to PA intensity and frequency. For both genders, moderate and vigorous PA were negatively associated with the depression score.In the fully adjusted model (analyses adjusted for age, marital status, educational level, living place, country, self-rated health, and the number of chronic diseases), for men, practicing moderate PA once a week (β=-0.37, 95% CI: -0.50, -0.24, p<0.001) and more than once a week (β=-0.56, 95% CI: -0.66, -0.46, p<0.001) was negatively associated with the score of depression. For vigorous PA, similar results were observed (once a week: β=-0.29, 95% CI: -0.40, -0.17, p<0.001; more than once a week: β=-

0.32, 95% CI: -0.41, -0.24, p<0.001), PA was negatively associated with depression score. Regarding women, practicing moderate PA once a week (β=-0.37, 95% CI: -0.50, -0.25, p<0.001) and more than once a week (β=-0.56, 95% CI: -0.65, -0.47, p<0.001) was also negatively associated with a lower score of depression. Similarly, this results were also observed for practicing vigorous PA (once a week: β=-0.35, 95% CI: -0.46, -0.24, p<0.001; more than once a week: β=-0.17, 95% CI: -0.25, -0.08, p<0.001).

Table 2. Cross-sectional parameters estimate of depression score according to physical activity intensity levels and frequency.

	Parameters estimates of predicting the score of depression in 2011		
	Model 1	Model 2	Model 3
Men	β (95% CI)	β (95% CI)	β (95% CI)
MPA in 2011			
Less than once a week	ref.	ref.	ref.
Once a week	-0.97 (-1.06, -0.87)*	-0.37 (-0.51, -0.24)*	-0.37 (-0.50, -0.24)*
More than once a week	-1.31 (-1.38, -1.24)*	-0.56 (-0.66, -0.46)*	-0.56 (-0.66, -0.46)*
VPA in 2011			
Less than once a week	ref.	ref.	ref.
Once a week	-0.75 (-0.83, -0.67)*	-0.31 (-0.43, -0.20)*	-0.29 (-0.40, -0.17)*
More than once a week	-0.87 (-0.92, -0.81)*	-0.36 (-0.45, -0.28)*	-0.32 (-0.41, -0.24)*
Women			
MPA in 2011			
Less than once a week	ref.	ref.	ref.
Once a week	-1.04 (-1.13, -0.95)*	-0.41 (-0.53, -0.28)*	-0.37 (-0.50, -0.25)*
More than once a week	-1.41 (-1.47, -1.34)*	-0.58 (-0.67, -0.49)*	-0.56 (-0.65, -0.47)*
VPA in 2011			
Less than once a week	ref.	ref.	ref.
Once a week	-0.89 (-0.97, -0.82)*	-0.42 (-0.53, -0.31)*	-0.35 (-0.46, -0.24)*
More than once a week	-0.88 (-0.93, -0.81)*	-0.21 (-0.29, -0.12)*	-0.17 (-0.25, -0.08)*

Abbreviation: MPA, moderate physical activity; VPA, vigorous physical activity; CI, confidence interval
Model 1: Unadjusted analyses.
Model 2: Analyses were adjusted for age, marital status, educational level, living place, country and self-rated health.
Model 3: Analyses were adjusted for age, marital status, educational level, living place, country, self-rated health, and the number of chronic diseases.
* $p<0.001$.

Table 3 shows the prospective analysis of parameters estimates predicting the score of depression. Moderate and vigorous PA practice, once or more than once a week were negatively associated with the depression score four years later. Even when the model was fully adjusted (model 3), this relationship remained significant. Regarding men, engaging in

moderate PA (more than once a week: β=-0.26, 95% CI: -0.40, -0.12, p<0.01) and vigorous PA showed a significant reduction of depression score (more than once a week: β=-0.13, 95% CI: -0.24, -0.03, p<0.05). Among women, moderate PA (once a week: β=-0.26, 95% CI: -0.42, -0.10, p<0.01; more than once a week: β=-0.52, 95% CI: -0.64, -0.40, p<0.01) and vigorous PA (more than once a week: β=-0.20, 95% CI: -0.31, -0.10, p<0.001) significantly reduced the depression score. In general, prospective analysis showed that PA predicts lower depression scores four years later.

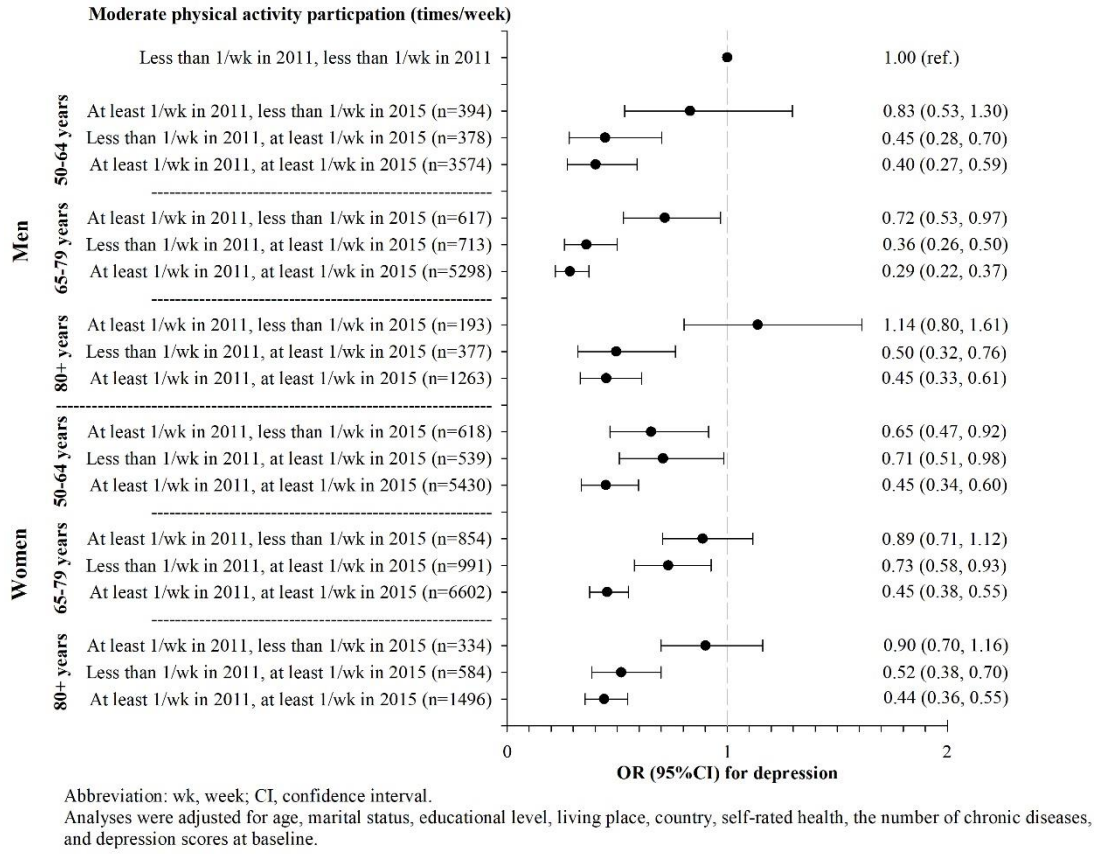
Table 3. Prospective parameters estimate of Depression Score to physical activity intensity levels and frequency.

	Parameters estimates of predicting the score of depression in 2015		
Men	Model 1 β (95% CI)	Model 2 β (95% CI)	Model 3 β (95% CI)
MPA in 2011			
Less than once a week	ref.	ref.	ref.
Once a week	-0.64 (-0.77, -0.51)***	-0.25 (-0.44, -0.06)**	-0.12 (-0.30, 0.06)
More than once a week	-0.83 (-0.93, -0.74)***	-0.43 (-0.57, -0.28)***	-0.26 (-0.40, -0.12)**
VPA in 2011			
Less than once a week	ref.	ref.	ref.
Once a week	-0.55 (-0.65, -0.45)***	-0.15 (-0.30, 0.01)	-0.07 (-0.22, 0.07)
More than once a week	-0.63 (-0.70, -0.56)***	-0.21 (-0.32, -0.09)***	-0.13 (-0.24, -0.03)*
Women			
MPA in 2011			
Less than once a week	ref.	ref.	ref.
Once a week	-0.82 (-0.93, -0.70)***	-0.35 (-0.52, -0.18)***	-0.26 (-0.42, -0.10)**
More than once a week	-1.23 (-1.32, -1.15)***	-0.70 (-0.83, -0.57)***	-0.52 (-0.64, -0.40)**
VPA in 2011			
Less than once a week	ref.	ref.	ref.
Once a week	-0.66 (-0.76, -0.57)***	-0.26 (-0.40, -0.12)***	-0.13 (-0.26, -0.01)
More than once a week	-0.79 (-0.86, -0.71)***	-0.31 (-0.42, -0.20)***	-0.20 (-0.31, -0.10)***

Abbreviation: MPA, moderate physical activity; VPA, vigorous physical activity; CI, confidence interval
Model 1: Unadjusted analyses.
Model 2: Analyses were adjusted for age, marital status, educational level, living place, country, self-rated health, and the number of chronic diseases.
Model 3: Analyses were adjusted for age, marital status, educational level, living place, country, self-rated health, the number of chronic diseases in 2011, and depression scores at baseline.
* p <0.05**, p<0.01, **p<0.001

Figures 1 and 2 present the results of the logistic regression analyses of the relationship between PA trajectory from 2011 to 2015 and depression symptoms (depression score ≥4). For moderate PA, in all age groups for both men and women, being active in the

present decreases significantly the odds of having depressive symptoms, even if they hadn't practiced PA less than once a week, compared to those consistently less active (engage in PA less than once a week). Except for women aged 50-64 years, those who practiced PA at least once a week but stopped practicing do not differ significantly from those who were consistently less active. Very similar results were observed for vigorous PA in all age groups for men and women. Those who engage in vigorous PA at least once a week consistently or only in the present had less likelihood of having depressive symptoms when compared to those consistently less active.



Abbreviation: wk, week; CI, confidence interval.
Analyses were adjusted for age, marital status, educational level, living place, country, self-rated health, the number of chronic diseases, and depression scores at baseline.

Figure 1. Relationship between moderate physical activity and depression symptoms.

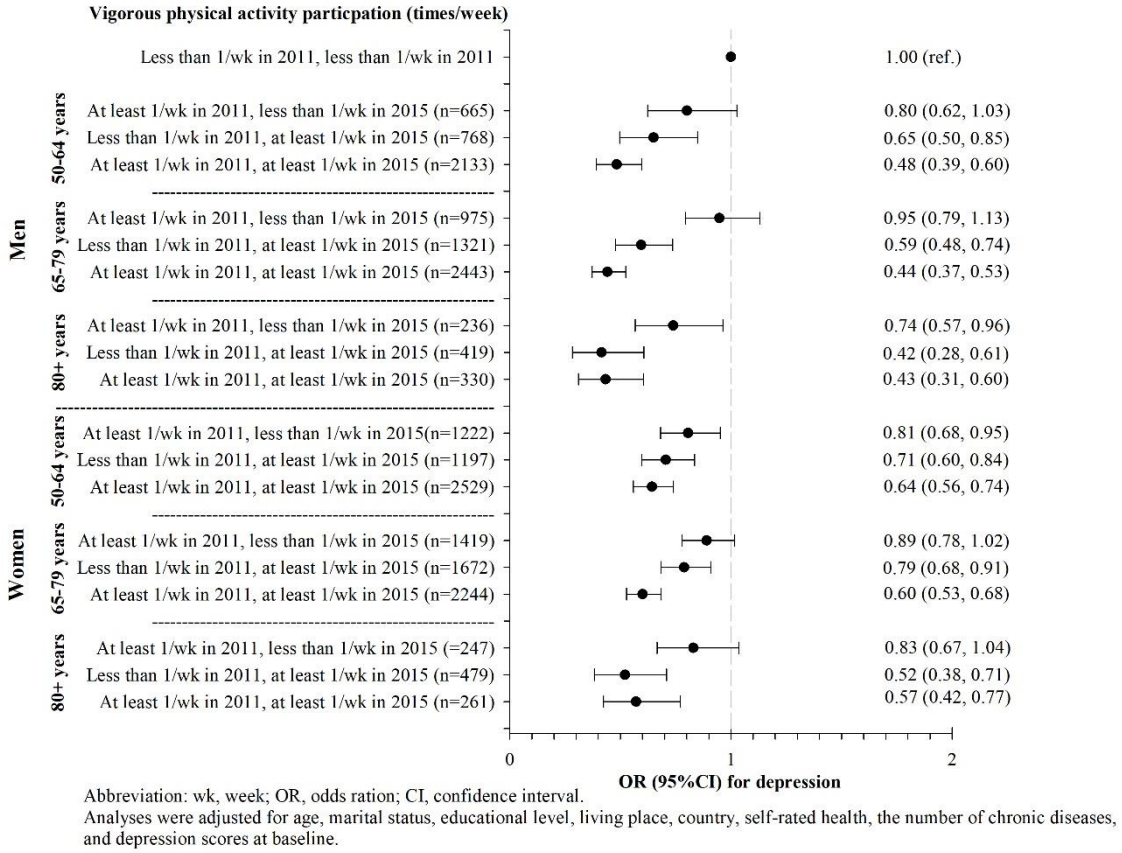


Figure 2. Relationship between vigorous physical activity and depression symptoms.

Discussion

The cross-sectional and prospective relationship between PA and the depression score were analysed through 4 years (2011-2015) in a large sample of European late middle-aged to older adults from 14 countries. The main result of this study emphasizes that those who practice PA less than once a week are more prone to have higher scores of depression, than those who engage in PA at least once a week. This result was found for both sexes in the cross-sectional and prospective analysis. Moreover, engage in moderate or vigorous PA at least once a week consistently or only in the present is related to lower odds of having depressive symptoms when compared to those consistently less active.

Emphasizing the importance of regular PA practice, these study results corroborate the current literature associating PA with lower depression scores or depression symptomatology

(Rebar et al., 2015; Schuch et al., 2016). The positive effects of PA in depression symptomology are well documented (De Mello et al., 2013; Rebar et al., 2015; Schuch et al., 2018), it is even considered by some authors as comparable to antidepressant treatments (Dinas et al., 2011). A review of four meta-analyses reached the conclusion that PA effects seem to be similar to those of medication and psychotherapy for mild-to-moderate depression (Knapen et al., 2015). This review, also noted that PA seems to be a valuable complement to standard clinical approaches for severe depression (Knapen et al., 2015). Furthermore, in late-life treatment-resistant depressions, it was found that combining PA with antidepressant medication seems to have a promising beneficial effect (Mura & Carta, 2013). Nonetheless, more detailed clinical approaches are necessary for optimal PA and medication prescription to strongly support its clinical administration (Strohle, 2009).

In order to better understand the relationship between PA and depression, it is important to consider the characteristics of PA, such as frequency and intensity (Helgadottir et al., 2017). However, most studies only account for the amount of PA, and intensity and frequency is rarely considered at the same time (Schuch et al., 2018). Acknowledging this gap, the present study provides PA frequency and intensity differentiation. Regarding intensity, it was found that moderate PA had a stronger inverse association with the depression score, than vigorous PA, in both cross-sectional and prospective analysis. This may be related to the proportion of older adults practicing these intensities of PA. Older adults are not expected to have the capacity to practice high amounts of vigorous PA, thus moderate PA is a more achievable way to practice PA and collect its benefits. Regarding frequency, practicing PA more than once a week had a stronger inverse association with the depression score, than practicing once a week, in both cross-sectional and prospective analysis. However, it is important to point out that, engage in PA once a week was still inversely associated with the depression score, supporting the idea that even little PA is beneficial. Furthermore,

practicing PA at least once a week consistently over the years or only in the present is associated with a reduced risk of depressive symptoms when compared to those who practice less than once a week over the years.

Previous studies have found contradicting results considering sexes. For example, Mikkelsen et al. (2010) reported that whereas women seem to be significantly at higher risk of depression when practicing low levels of PA, men did not. Contrary, other studies disclosed that men that did not achieve the recommended levels of PA had a higher likelihood of depression, but for women these results were less clear (Werneck et al., 2018). In this study, both men and women presented inverse associations between PA and the depression score, however, it is interesting to notice that the association was of a higher magnitude among women, especially in the prospective analysis. Notwithstanding, these study results demonstrate that PA is beneficial and has a similar impact on depression score reduction for both men and women.

Some limitations must be acknowledged. PA was self-reported, which is more likely to be biased than using an objective measurement (Grimm et al., 2012). Moreover, PA data indicate intensity and frequency, however, there is no information about the duration. This would be of importance to understand the effect PA duration in each session on depressive symptoms. Due to some factors, such as social desirability, there may be an intensity and frequency overestimation when respondents are questioned about their PA levels (Adams et al., 2005). Furthermore, the self-report PA does not allow a clear distinction to be made between moderate PA and vigorous PA, because moderate PA and vigorous PA are mixed or not-separated. Additionally, the depression score measurement, although being a properly validated methodology (Prince et al., 1999), might be susceptible to bias. For instance, mood fluctuations might influence participants' responses. Another limitation is the lack of information regarding light intensity PA. There is some research considering that depression

may limit late middle-aged to older adults to be more physically active, and thus, light PA plays an important role, presenting a beneficial association with depression (Loprinzi, 2013a).

Despite these limitations, the study presents some strengths. One of the major strengths is the use of a large sample of late middle-aged to older adults from several European countries, which helps to mitigate the limitations of the indirect measurement of PA and depression. Furthermore, using a large European sample of late middle-aged to older adults is considered relevant to provide strong evidence to policymakers, in order to strengthen the need for reflection upon the possible positive impact on society (Allmark, 2004). Lastly, the use of a cross-sectional and prospective design is recommended as it allows to better determine the prevalence and to identify the causal associations between the studied variables (Loprinzi, 2013b; Mann, 2003).

Considering the results of this study and its limitations, for future research, it would be interesting to further explore the role of PA intensity and frequency on the association with depression in late middle-aged to older adults. It would be also interesting to test our findings with less bias and more objective measurements of PA and depression, using accelerometers and medical diagnosed depression. Future studies with large sample sizes should seek to extend the follow-up period with regular inter-assessment intervals to have a better understanding of time effects on the associating between PA and depression.

Conclusion

PA is inversely associated with depression, both cross-sectional and prospectively. From prospective analysis, it is clear that PA predict depression scores four years later. PA seems to provide positive effects on both prevention and treatment of depression. It is important to notice that it is enough to practice moderate PA to have a depression score reduction and that these results are significant for both men and women.

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Study 4. Grip strength and depression symptoms among middle-age and older adults

Abstract

Objective: To analyse the relationship between grip strength and symptoms of depression considering sex and age in adults from 18 countries. Methods: Cross-sectional data on adults aged ≥50 years from the Survey of Health, Aging, and Retirement in Europe wave 6 (collected in 2015) were analysed. Grip strength was measured hand using a handgrip dynamometer. The EURO-D 12-item scale was used to measure depression symptoms. Multivariable logistic regression analysis was conducted. Data analyses were conducted between November 5, 2019, and February 7, 2020. Results: Men and women who were in the 2nd, 3rd and 4th quartile of grip strength were less likely to have depression symptoms than those in the 1st quartile of grip strength. Having more grip strength decreased the odds of depression symptoms by 30% (OR: 0.70; 95% CI: 0.65, 0.77) and 47% (OR: 0.53; 95% CI: 0.49, 0.57) for adults aged 50-64 years and ≥65 years, respectively, when compared to those with the lowest grip strength. The negative relationship between strong grip strength and depression symptoms were observed among men and women under and over 65 years. Conclusion: There was an association between grip strength and depression symptoms. For clinical practice and geriatric health professionals, assessing adults' grip strength can be used as a signal to screen physical and mental health.

Keywords: handgrip; physical function; European adults; mental health

Introduction

Throughout the aging process, there is a decline in physical functioning and muscular strength in both men and women (Marques et al., 2014; Milanovic et al., 2013). This decline is associated with structural changes, such as lower muscle mass, and functional changes, such as reduced strength, balance, coordination and flexibility, that contribute to increasing disability, frailty, and falls (Toraman & Yildirim, 2010). Lower muscular strength is also related to mental health issues such as depression symptoms (Fukumori et al., 2015; Lee et al., 2018). The decline in muscular strength might be related to depression symptoms, since strength plays an important role in the capacity to perform daily life activities, and is associated with functional performance and the feeling of achievement (Laredo-Aguilera et al., 2018).

Grip strength is a maximum hand static force measure commonly used to capture muscular strength. It is also used as a way of monitoring the health status in the general population and especially in older age (Bae et al., 2019; Leong et al., 2016; Mogi et al., 2018). Grip strength is correlated with muscular fitness (Samuel et al., 2012), and it is a powerful predictor of cardiovascular disease (Leong et al., 2015), metabolic syndrome (Lopez-Jaramillo et al., 2014), neurological disorders (Mehta et al., 2002), and future disability (McGrath et al., 2018).

Although some studies have shown that grip strength has an effect on depression symptoms (Fukumori et al., 2015; Lee et al., 2018), and is inversely associated with incident depression, especially in women (McDowell et al., 2018); others have demonstrated that among older people, there is no significant association with depression (Stessman et al., 2017), and that muscular strength did not predict changes in depression (Taekema et al., 2010). Additionally, data from transnational studies assessing the effect of grip strength on depression symptoms on older men and women are scarce. A recent study among older adults

from in low and middle-income countries observed that grip strength was associated with higher odds for depression (Ashdown-Franks et al., 2019).

The effect of grip strength on depression has not been consistently observed in transnational population-based samples, and the models of analysis in most studies have been insufficiently adjusted for potential confounders (e.g., educational level, number of children, number of chronic diseases, body mass index, physical activity) (McGrath et al., 2018). The declining age process should take sex and age group into account. There is evidence that women are more prone to have depression symptoms than men, and older people (Llorente et al., 2018). Therefore, this study aimed to analyse the relationship between grip strength and symptoms of depression considering sex and age among adults from 18 countries.

Methods

Participants and procedures

Data from the Survey of Health, Aging, and Retirement in Europe (SHARE) wave 6 (collected in 2015) were analysed. SHARE is a cross-national survey conducted biannually in several European countries and Israel since 2000. It is a multidisciplinary survey that provides answers regarding the growth and future challenges of population aging. More information about SHARE can be found somewhere else (Börsch-Supan et al., 2013). The sample of SHARE wave 6 included 68,231 participants. For the present study, the population included those who reported depression symptoms, whose grip strength was evaluated, and reported information that allowed for their characterization (sex, age, education level, number of children, number of chronic diseases, weight, height, and level of physical activity). The final sample consisted of 60,380 participants (26,765 men and 33,615 women), age range from 50 to 103 years (67.42±9.70), from 18 countries (Austria, Belgium, Croatia, Czech Republic,

Denmark, Estonia, France, Germany, Greece, Israel, Italy, Luxembourg, Poland, Portugal, Slovenia, Spain, Sweden, and Switzerland).

Data were collected through face-to-face interviews at the participant's home and lasted for approximately 90 minutes. Questionnaires were translated according to the country; pilots were performed to enhance comparability. The SHARE protocol was approved by the Ethics Committee of the University of Mannheim and by the Ethics Council of the Max-Planck-Society for the Advancement of Science, verifying the procedures to guarantee confidentiality and data privacy.

Measures

Sociodemographic variables

Participants reported their sex, age, education level, number of children, and country of residence. Age was recoded into 50-64 years and ≥65 years. According to the International Standard Classification of Education-97 (ISCED-97) codes, education level was grouped as low education level (no education or ISCED-97 codes 1 and 2), middle educational level (ISCED-97 codes 3 and 4), and high education level (ISCED-97 codes 5 and 6).

Number of chronic diseases

Based on a list of 14 listed diseases, participants were asked to report the presence or absence of diseases that were previously diagnosed by a doctor. Participants could also add other medical conditions, diagnosed by a doctor, unnamed in the list (Gallagher et al., 2013). In order to produce a single score, the number of chronic diseases was summed as performed previously (Marques et al., 2017).

Body mass index

Body mass index was calculated from self-reported height and weight and calculated according to kilograms over meters squared.

Physical activity

Participants reported on how many days per week they practiced moderate physical activity (e.g., brisk walking, gardening, or partaking in household activities), as well as the frequency of vigorous physical activity (e.g., hiking or participating in sports). For both moderate and vigorous activities, the responses included “more than once a week”, “once a week”, “up to three times a month”, and “hardly ever or never”. The last two possible responses were grouped into “less than once a week”.

Alcohol consumption

Participants were asked how often they drank six or more alcoholic drinks in the previous three months. Alcohol consumption was dichotomized into “yes” for those who reported drinking six or more alcoholic drinks monthly, and “no” for those who reported drinking less than six drinks per month.

Depression symptoms

The EURO-D 12-item scale was used to measure depression symptoms. The scale description and validation are described elsewhere (Prince et al., 1999). Scores range between 0-12, with higher scores indicative of higher levels of depression symptoms. A cut-off point of ≥4 points diagnoses clinically significant depression (Gallagher et al., 2013; Prince et al., 1999).

Grip strength

Grip strength was measured twice on each hand using a handgrip dynamometer (Smedley, S Dynamometer, TTM, Tokyo, 100 kg). Participants could sit or stand, with his or her elbow at a 90° angle, the wrist in neutral position, while keeping the upper arm tight against the trunk and the inner lever of the dynamometer adjusted to the hand. Participants squeezed the dynamometer with their hand as hard as possible for a period of 5 seconds. Prior to the assessment, participants had the opportunity to practice. Values were recorded twice for each hand, alternating between left and right hands. Valid measurements were values of two

measurements in one hand that differed by less than 20 kg. Grip strength measurements with values of 0 kg or ≥100 kg were excluded; measurements with only grip strength recorded in one hand were also excluded.

Data analysis

Data analyses for this study were conducted between November 5, 2019, and February 7, 2020. Descriptive statistics for all variables were calculated (percentage or mean and 95% confidence interval [CI]). Multivariable binary logistic regressions were conducted to assess the association between grip strength and depression. The interaction effect between sex and grip strength, and between age (50-64 years vs. ≥65 years) and grip strength, on depression symptoms was tested by ANOVA. Interaction effects were significant, thus, analyses were stratified by sex, age, and sex and age at the same time. Several models were performed. The first model was crude. The second model was adjusted for age, educational level, number of children, and country. The final model was adjusted for model two and further for the number of chronic diseases, body mass index, moderate and vigorous physical activity, and alcohol consumption. Data analysis was performed using SPSS 25. Statistical significance was set at $p<0.05$.

Results

The participants' characteristics are presented in table 1. The mean EURO-D depression score was 1.93 (95% CI: 1.91, 1.96) for men and 2.74 (95% CI: 2.72, 2.77) for women and 18.81% (95%CI: 17.73, 19.89) of men and 32.34 (95%CI: 31.46, 33.22) of women presented depression. The average grip strength was 42.22 kg (95%CI: 42.10, 42.35) for men and 26.06 kg (95%CI: 25.98, 26.13) for women.

Table 1. Participants' characteristics (n=60,380).

	Sex		Age-group		Grip strength			
	Men	Women	50-64 years	≥65 years	1st quartile	2nd quartile	3rd quartile	4th quartile
Education								
Low	36.10 (35.14, 37.07)	42.00 (41.18, 42.82)	29.88 (28.85, 30.91)	46.10 (45.32, 46.87)	51.50 (50.45, 52.55)	40.50 (39.21, 41.78)	34.41 (33.11, 35.72)	28.86 (27.46, 30.26)
Middle	38.87 (37.93, 39.82)	36.94 (36.08, 37.79)	42.58 (41.65, 43.51)	33.86 (33.00, 34.72)	30.97 (29.71, 32.22)	36.72 (35.39, 38.05)	40.72 (39.48, 41.96)	44.06 (42.81, 45.30)
High	25.02 (23.98, 26.07)	21.06 (20.11, 22.02)	26.24 (25.19, 27.29)	20.04 (19.10, 20.99)	17.53 (16.16, 18.90)	22.79 (21.32, 24.25)	24.87 (23.48, 26.27)	27.08 (25.67, 28.50)
Number of children	2.12 (2.10, 2.13)	2.12 (2.11, 2.13)	2.05 (20.3, 2.07)	2.17 (2.15, 2.18)	2.09 (20.7, 2.11)	2.10 (2.08, 2.12)	2.12 (2.10, 2.14)	2.17 (2.15, 2.19)
Number of chronic diseases	1.65 (1.63, 1.67)	1.82 (1.80, 1.84)	1.29 (1.28, 1.31)	2.08 (2.06, 2.10)	2.16 (2.14, 2.19)	1.74 (1.72, 1.77)	1.58 (1.56, 1.60)	1.42 (1.39, 1.44)
Body mass index	27.05 (26.99, 27.11)	26.10 (26.03, 26.17)	26.66 (26.59, 26,73)	26.42 (26.36, 26.48)	25.86 (25.76, 25.96)	26.33 (26.24, 26.43)	26.73 (26.65, 26.82)	27.29 (27.20, 27.38)
Moderate physical activity								
Less than once a week	15.02 (13.91, 16.12)	16.89 (15.92, 17.87)	11.66 (10.51, 12.81)	19.29 (18.35, 20.23)	27.09 (25.81, 28.37)	14.77 (13.24, 16.30)	11.58 (10.08, 13.08)	8.67 (7.09, 10.24)
Once a week	13.66 (12.55, 14.77)	13.55 (12.55, 14.54)	13.70 (12.56, 14.84)	13.52 (12.55, 14.50)	14.88 (13.50, 16.26)	14.20 (12.67, 15.73)	13.11 (11.62, 14.60)	11.96 (10.41, 13.51)
More than once a week	71.32 (70.68, 71.96)	69.56 (68.97, 70.15)	74.64 (74.02, 75.26)	67.19 (66.58, 67.79)	58.03 (57.06, 59.00)	71.03 (70.14, 71.92)	75.31 (74.52, 76.11)	79.38 (78.63, 80.13)
Vigorous physical activity								
Less than once a week	47.33 (46.46, 48.20)	54.39 (53.67, 55.11)	40.49 (39.55, 41.44)	59.15 (58.48, 59.82)	65.63 (64.76, 66.51)	51.93 (50.79, 53.08)	45.86 (44.68, 47.04)	38.79 (37.50, 40.09)
Once a week	14.39 (13.29, 15.50)	14.66 (13.67, 15.65)	15.97 (14.84, 17.09)	13.50 (12.52, 14.48)	11.66 (10.25, 13.06)	14.98 (13.45, 16.50)	15.88 (14.41, 17.34)	16.21 (14.70, 17.72)
More than once a week	38.28 (37.34, 39.22)	30.95 (30.06, 31.84)	43.54 (42.62, 44.46)	27.35 (26.45, 28.24)	22.71 (21.39, 24.02)	33.09 (31.74, 34.44)	38.26 (37.01, 39.52)	44.99 (43.77, 46.22)
Alcohol (drink ≥6 drinks)								
Yes	18.14 (17.06, 19.23)	6.57 (5.54, 7.61)	14.32 (13.18, 15.45)	9.76 (8.76, 10.75)	8.68 (7.25, 10.11)	11.54 (9.99, 13.10)	12.90 (11.41, 14.39)	14.21 (12.68, 15.74)
No	81.89 (81.38, 82.40)	93.43 (93.15, 93.70)	85.68 (85.22, 86.15	90.24 (89.92, 90.57)	91.32 (90.88, 91.76)	88.46 (87.90, 89.02)	87.10 (86.53, 87.68)	85.79 (85.17, 86.41)
EURO-D scale (score)	1.93 (1.91, 1.96)	2.74 (2.72, 2.77)	2.25 (2.22, 2.27)	2.48 (2.46, 2.51)	3.01 (2.97, 3.05)	2.34 (2.30, 2.37)	2.13 (2.10, 2.16)	1.93 (1.90, 1.97)
Depression								
Yes	81.19 (80.67, 81.71)	67.66 (67.06, 68.27)	75.70 (75.09, 76.30)	72.16 (71.61, 72.72)	62.95 (62.04, 63.86)	74.53 (73.69, 75.36)	78.02 (77.27, 78.77)	81.22 (80.51, 81.94)
No	18.81 (17.73, 19.89)	32.34 (31.46, 33.22)	24.30 (23.23, 25.37)	27.84 (26.95, 28.73)	37.05 (35.87, 38.24)	25.47 (24.04, 26.90)	21.98 (20.57, 23.39)	18.78 (17.29, 20.27)
Grip strength (kg)	42.22 (42.10, 42.35)	26.06 (25.98, 26.13)	36 (36.58, 36.87)	30.66 (30.54, 30.77)	23.52 (23.40, 23.64)	31.57 (31.43, 31.70)	36.39 (36.24, 36.54)	43.34 (43.15, 43.52)

Abbreviation: M, mean; CI, confidence interval.

Table 2 shows the association between quartile of relative grip strength and risk of depression by sex. The results of the crude models, for men and women, showed that grip strength was inversely associated with depression. When the models were adjusted for age, educational level, number of children, and country, and further for the number of chronic diseases, body mass index, moderate and vigorous physical activity, and alcohol, the associations remained unchanged. Men and women who were in the 2nd, 3rd and 4th quartiles of grip strength were less likely to have depression than those who were in the 1st quartile of grip strength. Among men, those who had the highest quartile of grip strength had 43% lower odds of having depression than those with the lowest quartile of grip strength (odds ratio [OR]: 0.57; 95% CI: 0.52, 0.63) after controlling for all variables in the model. Among women in the highest quartile of grip strength there was a 41% likelihood of having depression when compared to women with the lowest quartile of grip strength (OR: 0.59; 95% CI: 0.55, 0.64).

Table 2. Association between quartile of relative grip strength and risk of depression by sex.

Men	Model 1 OR (95% CI)	Model 2 OR (95% CI)	Model 3 OR (95% CI)
Grip strength quartiles			
1st quartile	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)
2nd quartile	0.55 (0.51, 0.60) *	0.55 (0.51, 0.60) *	0.69 (0.63, 0.76) *
3rd quartile	0.48 (0.44, 0.52) *	0.48 (0.44, 0.52) *	0.65 (0.60, 0.71) *
4th quartile	0.38 (0.34, 0.41) *	0.38 (0.34, 0.41) *	0.57 (0.52, 0.63) *
Women	**Model 1 OR (95% CI)**	**Model 2 OR (95% CI)**	**Model 3 OR (95% CI)**
Grip strength quartiles			
1st quartile	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)
2nd quartile	0.61 (0.57, 0.65) *	0.61 (0.58, 0.65) *	0.76 (0.71, 0.81) *
3rd quartile	0.49 (0.46, 0.52) *	0.49 (0.46, 0.52) *	0.66 (0.62, 0.71) *
4th quartile	0.40 (0.37, 0.43) *	0.40 (0.37, 0.43) *	0.59 (0.55, 0.64) *

Abbreviation: OR, odds ratio; CI, confidence interval.
Model 1: Unadjusted analyses. Model 2: Analyses were adjusted for age, educational level, number of children, and country. Model 3: Analyses were adjusted for model and number of chronic diseases, body mass index, moderate and vigorous physical activity, and alcohol consumption.
*p<0.001.

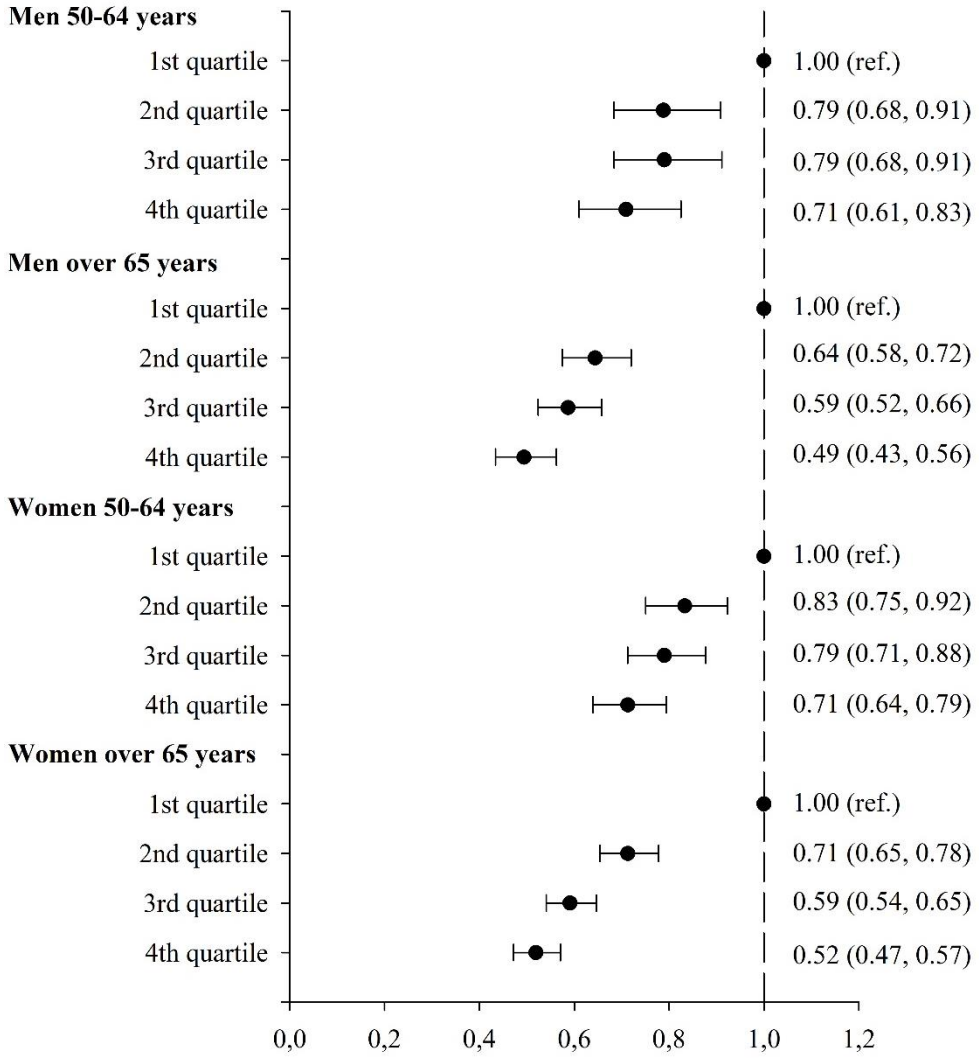
Table 3 shows the association between quartile of relative grip strength and risk of depression by age group. Regardless of age group, in all models (crude, adjusted, and fully adjusted), individuals who were in the 2nd, 3rd, and 4th quartile of grip strength were less likely to have depression than those who were in the 1st quartile. Being in the highest quartile for grip strength decreased the odds of depression by 30% (OR: 0.70; 95% CI: 0.65, 0.77) and 47% (OR: 0.53; 95% CI: 0.49, 0.57) for older people aged 50-64 years and ≥65 years, respectively, when compared to those with the lowest grip strength.

Table 3. Association between quartile of relative grip strength and risk of depression by age group.

50-64 years	Model 1 OR (95% CI)	Model 2 OR (95% CI)	Model 3 OR (95% CI)
Grip strength quartiles			
1st quartile	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)
2nd quartile	0.66 (0.61, 0.72) *	0.67 (0.61, 0.72) *	0.80 (0.74, 0.87) *
3rd quartile	0.60 (0.56, 0.65) *	0.60 (0.55, 0.65) *	0.78 (0.72, 0.85) *
4th quartile	0.52 (0.48, 0.56) *	0.51 (0.47, 0.55) *	0.70 (0.65, 0.77) *
≥65 years	Model 1 OR (95% CI)	Model 2 OR (95% CI)	Model 3 OR (95% CI)
Grip strength quartiles			
1st quartile	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)
2nd quartile	0.54 (0.50, 0.57) *	0.54 (0.50, 0.57) *	0.69 (0.65, 0.74) *
3rd quartile	0.41 (0.38, 0.44) *	0.41 (0.39, 0.44) *	0.60 (0.56, 0.64) *
4th quartile	0.32 (0.30, 0.35) *	0.33 (0.30, 0.35) *	0.53 (0.49, 0.57) *

Abbreviation: OR, odds ratio; CI, confidence interval.
Model 1: Unadjusted analyses. Model 2: Analyses were adjusted for sex, educational level, number of children, and country. Model 3: Analyses were adjusted for model and number of chronic diseases, moderate and vigorous physical activity, alcohol, and body mass index.
* $p<0.001$.

Figure 1 presents the results of the association between quartile of relative grip strength and risk of depression stratified by sex and age. The significant and negative relationship between strong grip and depression were observed among men and women under and over 65 years.



Abbreviation: OR, odds ratio; CI, confidence interval.
Analyses were adjusted for education level, number of children, country, number of chronic diseases, body mass index, moderate and vigorous physical activity, alcohol drink.

Figure 1. Association between quartile of relative grip strength and risk of depression for sex and age group, using logistic regression.

Figure 2 shows the piecewise relationship between grip strength and the probability of depression modelled with a spline stratified by sex and age. Different splines were observed according to sex and age group. Increment in grip strength among older men and women presents a more accentuated slope than their middle-aged peers, especially in the first 40 kg.

Increments in grip strength among women appear to account for a greater decrease in the probability of depression than for men.

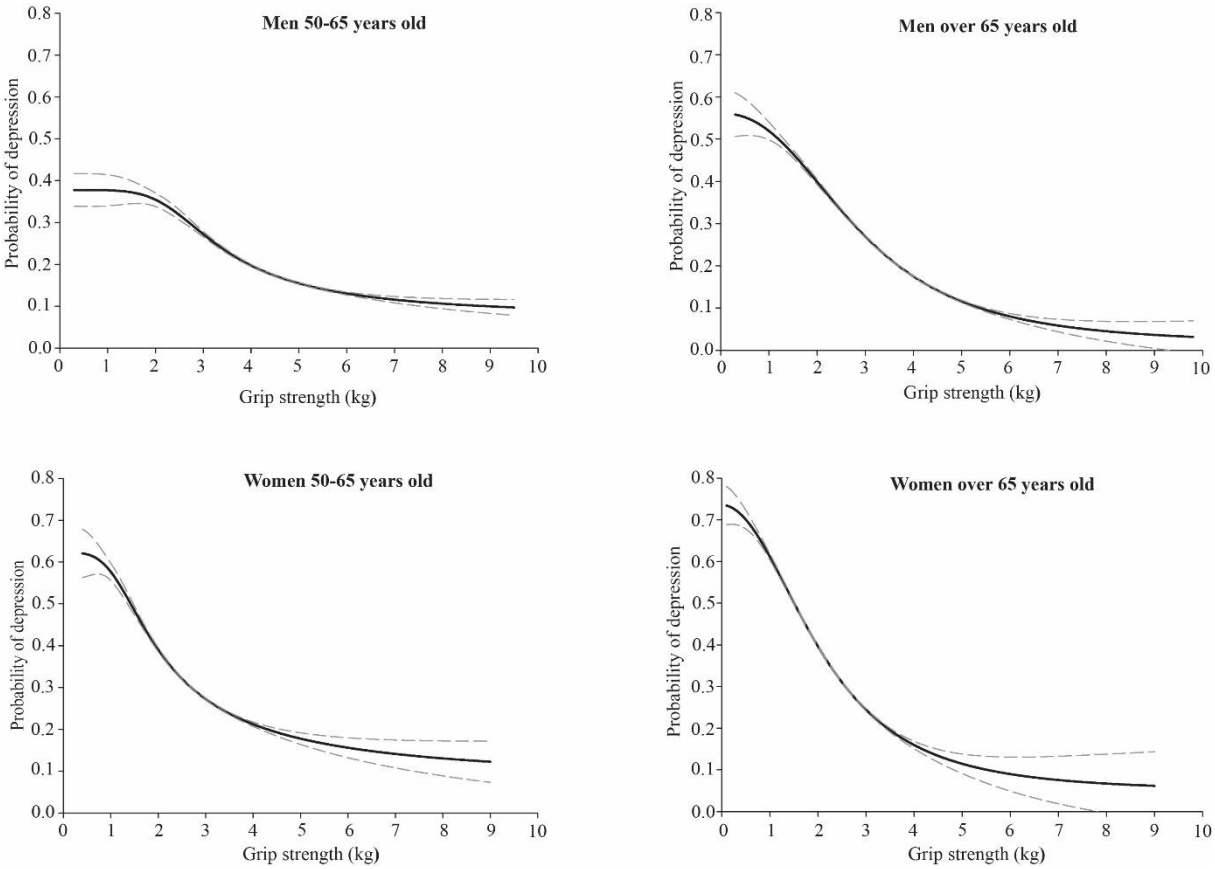


Figure 2. Spline curves for the relationship between grupstrength and the probability of depression by sex and age.

Discussion

In this transnational population-based study, the relationship between grip strength and symptoms of depression, considering sex and age, in adults and older adults, was analysed. We found that higher grip strength is significantly associated with having lower odds of depression. In particular, among men and women, those with higher grip strength were less likely to have depression symptoms than those with the lowest grip strength.

Although women and older adults are more prone to have depression symptoms than men (Salk et al., 2017), grip strength, an important indicator of musculoskeletal function, seemed to have the same effect on depression regardless of sex or age. In this study, people with higher grip strength had significantly fewer depression symptoms relative to those with less grip strength. Depressive symptoms remained associated with reduced grip strength in adjusted models independent of sex and age. This is consistent with previous studies from other countries. In Japan and Korea, lower grip strength was associated with depressive symptoms in both cross-sectional and longitudinal analysis, regardless of sex, suggesting that muscular strength may prevent depression (Fukumori et al., 2015; Lee et al., 2018). In studies carried out in Brazil and the United States, decreasing muscular strength was also significantly associated with depression (Brooks et al., 2018; Lino et al., 2016). These results reinforce the importance of promoting muscular strength among older people. Physical activity recommendations suggest that older people should engage in muscle-strengthening activities that involve major muscle groups two or more days a week (WHO, 2010). This is particularly important for adults aged 60 and older, since every year there is a decline in muscle strength (between 1.5% to 3.5%) and power (Kim & Choi, 2013). Furthermore, a recent meta-analysis, including 33 randomized clinical trials involving 1877 participants, observed that resistance training, regardless of the participant health status, training volume, or significant improvements in strength, significantly reduced depressive symptoms among adults (Gordon et al., 2018). A physical activity routine that includes both aerobic and muscle-strengthening activities is likely to be optimal for the prevention of depression (Bennie et al., 2020), thus public health policy and mental health professionals should include resistance training as a preventive measure and treatment strategy to depression.

Depression is a frequent and serious psychopathology diagnostic. Sub-types of depression may affect muscular strength differently. However, highlighting the possible

relationships between muscular strength and depression, which have generally been considered separate phenomena, is an innovative step in improving the knowledge of this possible association. Although the relationship between muscular strength and depression is not fully understood, several psychological and physiological mechanisms may explain the relationship. Reduced muscular strength is associated with poor physical functioning that jeopardizes the performance of daily life tasks, which in turn can affect feelings of achievement (Laredo-Aguilera et al., 2018). Older adults with higher muscular strength have greater mobility and, consequently, less disability. Thus, they can engage in social activities and receive social support, leading to lower risk of depression (Grav et al., 2012). As for potential physiological mechanisms, in response to the muscle contraction, muscles release cytokines and myokines into the circulation. It is believed that myokines might protect against the risk of depression (Kohler et al., 2017). Moreover, frailty (Soysal et al., 2017) and sarcopenia (Kim & Choi, 2013) are associated with inflammatory profile, which may possibly increase risk for depression (Steptoe et al., 2012; Steptoe et al., 2009). Furthermore, grip strength is suggested to be an indicator of cognitive impairment in people with major depression (Firth et al., 2018), and is associated with greater left and right hippocampal volume and reduced white matter hyperintensitie (Firth et al., 2020). A meta-analysis concluded that reduced hippocampal grey matter volume reductions was evident in major depressive disorder patients, compared to healthy individuals (Schmaal et al., 2016), while white matter hyperintensities are considered an important marker of ageing related cognition decline (Firth et al., 2020).

Several limitations of this study warrant mention. First, because of its cross-sectional design, it is not possible to verify the causal relationship between grip strength and depression symptoms. Thus, a potential reverse relationship cannot be excluded. Additionally, grip strength is also a common marker of overall physical health which is increasingly recognized

to be related to mental health conditions. Second, there was no information about each participant's family history of depression that may affect depressive symptoms, nor information on the type of depression and its overall burden on the participant's daily life and quality of life perception. Third, there was no information about hand size, which could affect grip strength. Furthermore, the existence of cultural variation on the use of grip strength in daily social routines was not considered. Despite these limitations, our study had some strengths. The use of a large representative sample from several countries with many socio-demographic characteristics was a major strength of the present study. In addition, considering the large sample and the heterogeneity of the participants, we believe that our findings may be generalizable.

Conclusion

The results of this study found an association between grip strength and depression symptoms. Higher grip strength decreased the risk of depressive symptoms among men and women from different age groups. These results suggest that there was an interrelationship between physical and psychological factors among older adults. Thus, to promote mental health, it is also important to promote physical health, enhancing older adults' muscular strength. For clinical practice and geriatric health professionals, assessing older adults' grip strength can be used to screen for physical and mental health.

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Study 5. The effect of muscular strength on depression symptoms in adults: a systematic review and meta-analysis

Abstract

The aim was to systematically review the relationship between muscular strength (MS) and depression symptoms (DS) among adults and conduct a meta-analysis to determine the pooled odds ratio (OR) for the relationship between MS and DS. Strategies employed in this systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines. Studies published up to December 2019 were systematically identified by searching in PubMed, Scopus, and Web of Science electronic databases. Inclusion criteria were: 1) cross-sectional, longitudinal and intervention studies; 2) outcomes included depression or DS; 3) participants were adults and older adults; 4) articles published in English, French, Portuguese, or Spanish. A total of 21 studies were included in the review, totalling 87508 adults aged ≥18 years, from 26 countries. Systematic review findings suggest that MS has a positive effect on reducing DS. Meta-analysis findings indicate that MS is inversely and significantly related to DS (OR = 0.76, 95% CI: 0.67, 0.85). Interventions aiming to improve MS have the potential to promote mental health and prevent depression. Thus, public health professionals could use MS assessment and improvement as a strategy to promote mental health and prevent depression.

Keywords: anxiety; mental health; handgrip; fitness

Introduction

Depression is a mental health disorder affecting more than 300 million adults around the world (WHO, 2017). It is the largest contributor to worldwide disability, and leads to almost one million suicide deaths annually (WHO, 2017). The most common treatment for depression includes pharmacotherapy and psychotherapy (Karyotaki et al., 2016; Khan et al., 2012), which, in the long-term, can be expensive and costly for health care systems due to the prevalence of the disorder (Olfson et al., 2018). In order to address the health problem of depression that affects so many people around the world and to effectively allocate health care spending, it is important to identify additional and effective treatment options.

Regular physical activity increases physical fitness, which is related to a decreased risk of all-cause mortality in healthy people (Garber et al., 2011). Physical fitness is a multi-component construct, including cardiorespiratory fitness, muscular fitness, flexibility, balance, and speed. There is longitudinal evidence that cardiorespiratory fitness, a component of physical fitness, is related to depression, preventing it or having a treatment effect (Lindegard et al., 2019; Papasavvas et al., 2016). Muscular strength is a component of muscular fitness that defines how much strength an individual can voluntarily produce by contracting muscles, and has been associated with a lower risk of mortality in the adult population (Garcia-Hermoso et al., 2018). Two types of contractions exist: isometric when the length of the muscle remains the same; and isotonic, when the length of the muscle changes, which can be eccentric or concentric. The most common tests to assess muscular strength are the handgrip strength and the isometric knee extension, which are related to overall strength (Bohannon, 2015; Yeung et al., 2018). Both cardiorespiratory fitness and muscular strength are in part genetically determined and part a result of physical activity and exercise participation. Thus, it is plausible that greater muscular strength also has a positive effect on depression. However, the effect of muscular strength on mental health and depression

symptoms is still not clear. Some studies have shown that decreased muscular strength is related to depression (Fukumori et al., 2015), while other studies did not find a significant association (Gopinath et al., 2017; Stessman et al., 2017).

Muscular strength is positively related to physical function (Veronese et al., 2017). This is particularly important because a better physical function is significantly associated with less depressive symptoms (Almeida et al., 2017; Kvael et al., 2017). Also, muscular strength is associated with physical activity and exercise habits (USDHHS, 2018), which are known to be negatively associated with depression symptoms (Marques et al., 2020; Marques et al., 2019). In this line, the possible effects of muscular strength on depression may be mediated by physical activity, which can partly explain this association. Taking into account the significant association between physical activity and the risk of mental illness, it can be hypothesised that better muscular strength may also have a positive effect on reducing or preventing depression. Therefore, a systematic review was conducted, aiming to review the literature regarding the relationship between muscular strength and depression symptoms among adults. Furthermore, a meta-analysis of selected studies was conducted to determine the pooled odds ratio for the relationship between muscular strength and depression symptoms.

Methods

Strategies employed in this systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines (Moher et al., 2009).

Data sources and searches

Studies published up to the 31st of December 2019 were systematically identified by searching in PubMed, Scopus, and Web of Science electronic databases. The search was performed using the following combination of terms: handgrip OR hand-grip OR “hand

strength" OR "grip strength" OR "muscular strength" OR "muscular fitness" OR "muscular train*" AND depression OR depressive OR "mental health" OR anxiety OR "psychological functioning". Retrieved titles and abstracts were assessed for eligibility for inclusion by two authors. Duplicate entries were removed. Relevant articles were retrieved for a full read. The same two authors reviewed the text of potential studies, and decisions to include or exclude studies in the review were made by consensus.

Study selection

Articles published up to December 2019 were eligible for inclusion. Specific criteria were: 1) design criterion: cross-sectional, longitudinal and interventional studies; 2) outcome measure criterion: studies were included if the outcomes included depression; 3) participants: adults and older adults; 4) language criterion: articles published in English, French, Portuguese, or Spanish; 5) exclusion criterion: articles were excluded if they did not meet inclusion criteria or did not include findings related to the inclusion criteria. Published conference proceedings, conference abstracts, and theses or studies including animals were also excluded. Finally, studies focusing on general mental health, anxiety, and mood were excluded because they preclude concluding the isolated effect of muscular strength on depression.

Data extraction and quality assessment

The following information was extracted from each study: author's name and year of publication, study design, country, sample characteristics (number of participants, sex, age), the instrument for assessing depression symptoms, the instrument for assessing muscular strength, main results, and study quality. For intervention studies, the following were extracted: duration of intervention, description of the program, intensity, duration, and frequency. For longitudinal studies, the time of follow-up was also extracted. The methodological quality of the studies was assessed using the Quality Assessment Tool for

Quantitative Studies. It is a 19-item checklist, assessing methodological domains: selection bias, study design, confounders, blinding, data collection methods, withdrawals and dropouts, intervention integrity, and analyses. A global rating is determined based on the scores of each component. Two researchers rated the studies in each domain, as well as the overall quality of each study. Discrepancies were resolved by consensus.

Data synthesis and analysis

This review analysed the relationship between muscular strength and depression. The details for each study are presented consistently. Data from all studies were pooled using Review Manager 5.3. For the five clinical trial studies, the instruments used to assess muscular strength or the depression symptoms were different among studies. From the 16 observational studies, data from 9 was used for meta-analysis (Ashdown-Franks et al., 2019; Brooks et al., 2018; Fukumori et al., 2015; Han et al., 2019; Lee, 2018; Lee et al., 2018; McDowell et al., 2018; Smith et al., 2019; Soriano-Maldonado et al., 2016). The seven studies not included were eliminated based on the heterogeneity of the association measure between muscular strength and depression symptoms. Two reported the comparison between the effect of high vs. low muscular strength on depression (Laredo-Aguilera et al., 2019; Park et al., 2019); two reported the muscular strength difference between depressed vs. not depressed cases, and the other three reported results stratified by weight status or quartiles of muscular strength (Wu et al., 2017). Homogeneity of the odds ratio of the studies included in the meta-analysis was assessed using I2 statistics. Values of ≥50% were considered substantial heterogeneity (Higgins et al., 2003). As there was significant heterogeneity, a random-effects model was used to calculate the pooled odds ratio. Sensitivity analyses were carried out by successively omitting one study at each turn. A Forest plot was performed to showcase each included study log-odds, odds ratio (95% confidence interval [CI]), standard error and weight as lines, and the pooled odds ratio from all studies as a diamond.

Results

Literature search

The primary search in the databases yielded 782 citations. After excluding the duplicates (n=359), the title and abstract of 423 articles were screened. Of these, 378 citations were discarded after reviewing the title and the abstract because it was clear that they did not contain an assessment of muscular strength and depression symptoms. After having and reading the full text of the remaining 45 citations, 24 were discarded either because they did not have depression symptoms as the outcome variable (n=15), were not focused on muscular strength (n=4), were not empirical studies (n=3), or were written in a language other than English, French, Portuguese, or Spanish (n=2). The flow diagram is presented in Figure 1.

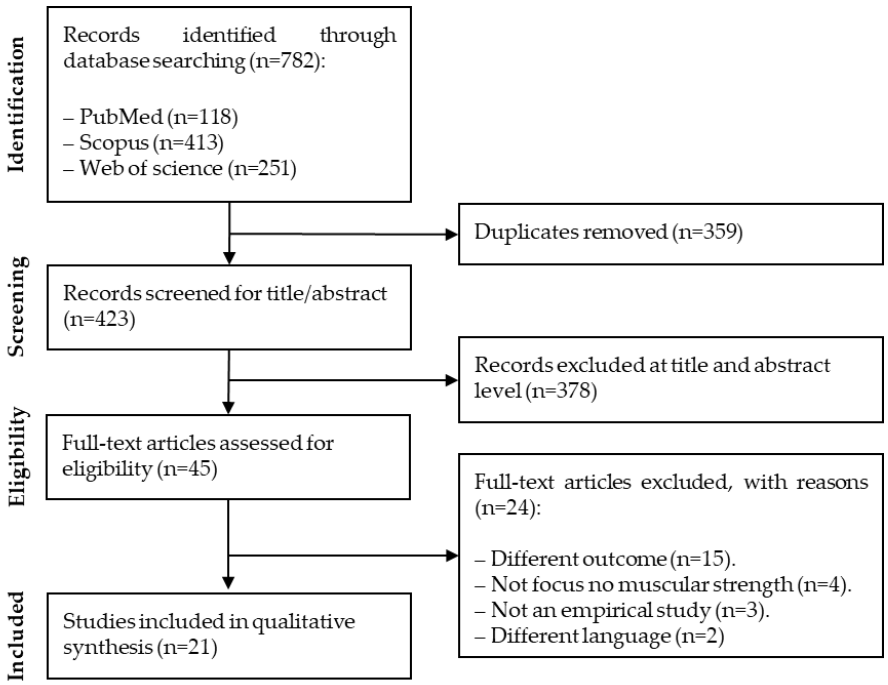

Figure 1. Flow diagram of study selection.

Study characteristics

Table 1 presents the studies' characteristics. A total of 21 studies were included in the review, totalling 87508 adults aged ≥18 years, from 26 countries. Most studies were cross-sectional (n=12), five were clinical trials, and four were prospective studies. Five studies were performed in South Korea, two in Brazil, two in Spain, two in the United States, and the others were performed in Australia, Belgium, China, Denmark, Finland, Ireland, Japan, Turkey, and United Kingdom. One study was performed in six countries (China, Ghana, India, Mexico, Russia, South Africa). Geriatric Depression Scale, Patient Health Questionnaire, and the Beck Depression Inventory were the most used scales to assess depression symptoms (each scale in 4 studies). The other scales used were the Center for Epidemiologic Studies Depression Scale, EuroQol Five-Dimension Questionnaire, Hamilton Depression Rating Scale Hopkins' Symptom Checklist, Mental Health Inventory, and Psychosis Evaluation Tool for Common use by Caregivers. Seven studies were considered to be of weak methodological quality, seven of moderate quality, and the other seven of strong quality.

Principal findings

The description of the studies reporting the relationship between muscular strength and depression symptoms is presented in table 1. Results from two clinical trials (Kim et al., 2019; Krogh et al., 2009) and one observational study (Gopinath et al., 2017) were inconsistent. A relationship between muscular strength and depressive symptoms was not observed. However, in one study, the neurotransmitter factors, such as serotonin, dopamine, epinephrine, and norepinephrine significantly decreased in the strength exercise group but not for the control group (Kim et al., 2019). From the other clinical trial studies, muscular strength decreased depression symptomatology (Aidar et al., 2014; Moraes et al., 2019; Sener et al., 2016). Results demonstrated significant differences in all indicators of depression after completing 12 weeks of training (Aidar et al., 2014), that low muscle strength increased

depression symptomatology in patients with fibromyalgia (Sener et al., 2016), and that strength training intervention significantly decreased depressive symptoms (Moraes et al., 2019). The other observational studies showed that independent of sex, age, and country, depression symptoms were significantly associated with reduced handgrip strength (Ashdown-Franks et al., 2019; Brooks et al., 2018; Fukumori et al., 2015; Laredo-Aguilera et al., 2019; Lee, 2018; Park et al., 2019; Smith et al., 2019; Smith et al., 2018; Soriano-Maldonado et al., 2016; Suija et al., 2013; Vancampfort et al., 2013). Furthermore, adults in the lower tertile or quartile for muscle strength had a significantly higher risk for depressive symptoms compared with those in the third tertile or fourth quartile (Han et al., 2019; Lee et al., 2018; McDowell et al., 2018; Wu et al., 2017).

Table 1. Studies' characteristics.

Author, year	Study design	Country and sample's characteristics	Depression measure	Muscular strength measure	Main results	Study quality
Krogh et al., 2009	Clinical trial	Denmark n=165, 122 women, age range=18 to 55, mean age 38.9±9.46; strength training (n=55); aerobic training (n=55); relaxation training (n=55).	Hamilton Depression Rating Scale (HAM-D17)	Knee extension; Chest press; Leg press	(Ø) – At 4 months, the mean change in HAM-D17 score was –1.3 (–3.7 to 1.2; p = 0.3) for the strength group versus the relaxation group. At 12 months, the mean differences in HAM-D17 score were –0.2 (–2.7 to 2.3) for the strength group versus the relaxation group. Findings do not support a biologically mediated effect of strength exercise on symptom severity in depressed patients.	Strong
Suija et al., 2013	Prospective	Finland n=5497, 51% women, age=31 (all participants were born in 1966).	Hopkins' Symptom Checklist (HSCL-25)	Trunk extension test; Hand dynamometer	(+) Depressive symptoms were most common among males and females in the lowest quintile group of trunk extension test and among males in the lowest quintile group of handgrip strength compared to the middle quintile group.	Strong
Vancampfort et al., 2013	Cross-sectional	Belgium n=120; schizophrenia: n=80, mean age 36.8±10.0; control: n=40, mean age 37.1±10.3.	Psychosis Evaluation Tool for Common use by Caregivers (PECC)	Standing broad jump; Sit-ups; Handgrip strength	(+) Standing broad jump (-0.35, p<0.01), handgrip strength (-0.28, p<0.01) and sit-ups (-0.33, p<0.01) were inversely associated to depressive symptoms. Low physical fitness was associated with depressive symptoms.	Moderate
Aidar et al., 2014	Clinical trial	Brazil Control group: n=24, 6 men, mean age=51.7±0.8 Experimental group: n=13, 9 men, mean age=52.5±7.7.	Beck Depression Inventory (BDI)	Squat; Bench press; Horizontal leg press; Military press; Abdominal crunch; Front lat pull-downs; Lunges	(+) There were significant differences in all indicators of depression between the experimental group and control group after completing 12 weeks of training. A negative correlation between the strength gains as determined with the 1RM test and the levels of depression was found.	Weak
Fukumori, 2015	Prospective	Japan n=4314, 58.5% women, age range 40 to 79, mean age 66.3±9.0.	Mental Health Inventory (MHI-5)	Digital dynamometer (Takei Scientific Instruments Co., Ltd)	(+) Men and women with lower handgrip strength had higher odds of having depressive symptoms at baseline. Lower handgrip strength was associated with the longitudinal development of depressive symptoms after 1 year (OR=1.13, 95%CI=1.01, 1.27).	Strong

Sener et al., 2016	Clinical trial	Turkey n=79; experimental group: n=39 women with fibromyalgia; mean age 42±10.3 years; control group: n=40 women; mean age 38.3±8.4 years.	Beck Depression Inventory (BDI)	Digital Grip Dynamometer (T.K.K.5401)	(+) In the fibromyalgia group, right and left handgrip strength were moderately negative correlated with depression scores (r=0.263 p=0.025; r=0.233 p=0.048). Low muscle strength increased depression and anxiety symptomatology in patients with fibromyalgia.	Moderate
Soriano-Maldonado et al., 2016	Cross-sectional	Spain n=444 were included in the analysis; mean age 52.0±8.0 years.	Beck Depression Inventory II (BDI II)	Digital Grip Dynamometer (T.K.K. 5101)	(+) The odds of severe symptoms of depression was 4.8% (95% CI: 8.2% to 1.2%; P=0.010) lower for each additional kilogram in the handgrip test in women with fibromyalgia.	Weak
Gopinath et al., 2017	Cross-sectional	Australia n=947 men and women; aged ≥65 years.	Center for Epidemiologic Studies Depression Scale (CES-D-10)	Jamar hand dynamometer (Sammons Preston Inc.)	(Ø) Handgrip strength was not associated with depressive symptoms and quality of life.	Weak
Wu et al., 2017	Cross-sectional	China n=1046, 486 men, 560 women, aged ≥60.	Geriatric Depression Scale (GDS)	Dynamometer (EH101; CAMRY, Guangdong)	(+) Men and women in the lower quartile for muscle strength had a significantly higher risk for depressive symptoms compared with those in the fourth quartile. Muscle strength are inversely associated with depressive symptoms in elderly Chinese.	Weak
Brooks et al., 2018	Cross-sectional	USA n=3421 community-dwelling, non-institutionalized adults; 1660 men, 1761 women; aged ≥60 years, mean age was 69.9±6.9 years.	Patient Health Questionnaire (PHQ-9)	Dynamometer	(+) Depression was significantly associated with reduced handgrip strength in older adults.	Weak
Lee, 2018	Cross-sectional	South Korea n=4810, 2167 men, 2643 women; mean age 50.9±16.7 years.	Depressive mood was assessed using one question: 'During the past year, did you ever feel so sad or hopeless for 2 weeks or more in a row that you stopped performing usual activities?	Digital Grip Dynamometer (T.K.K.5401)	(+) Handgrip strength was negatively associated with depressive mood (OR=0.82, 95% CI: 0.69-0.99) and suicidal ideation (OR=0.73, 95% CI: 0.54-0.99). In sex-specific relationship, handgrip strength was negatively associated with depressive mood and suicidal ideation in women (OR=0.71, 95% CI: 0.55-0.93) but not in men.	Moderate
Lee et al., 2018	Cross-sectional	South Korea	Patient Health Questionnaire (PHQ-9)	Digital Grip Dynamometer (T.K.K.5401)	(+) Handgrip strength was inversely associated with the PHQ-9 score. The odds	Moderate

		n=4298, 1860 men, 2438 women; age range (19–80 years); subjects were divided into three groups (young adult (19-39 years), middle aged (40–59 years), and elderly (60–80 years).			ratios of depression symptoms were statistically significant for participants in the first and second quartile of handgrip strength compared to those with the highest quartile. There was about a 50% mediation effect of EQ5D in the relationship between handgrip strength and depression.	
McDowell et al., 2018	Prospective	Ireland n=4505, 2544 men, 1961 women; aged ≥50 years.	EuroQol Five-Dimension Questionnaire (EQ5D)	Baseline hydraulic dynamometer	(+) In the total sample, the middle and high strength tertiles were significantly associated with 31.5% (p=0.04) and 34.1% (p=0.02) reduced odds of developing depression, respectively. The interaction between sex and strength was not statistically significant.	Strong
Smith et al., 2018	Cross-sectional	USA n=2812, 1380 men, 1432 women, mean age 68.9±0.3 and 69.5±0.3	Center for Epidemiological Studies Depression Scale (CES-D)	Takei Digital Grip Strength Dynamometer	(+) Women with moderate to major depressive symptoms had 1.60 kg (95% CI: 0.91 to 2.30) lower handgrip strength compared to women with minimal or no depressive symptoms. No association was observed in men. Obese men (-3.72 kg, 95% CI:-7.00, -0.43) and women (-1.83 kg, 95% CI:-2.87, -0.78) with moderate to severe depressive symptoms had lower handgrip strength.	Moderate
Ashdown-Franks et al., 2019	Cross-sectional	China, Ghana, India Mexico, Russia, South Africa n=34129, China 13175, Ghana 4305, India 6560, Mexico 2313, Russia 3938, South Africa 3838; mean age 62.4±16 years	Patient Health Questionnaire (PHQ-9)	Smedley Handgrip Dynamometer	(+) Individuals with weak handgrip strength had a higher prevalence of depression than those without (8.8% vs. 3.8%; p<0.001). In all countries, weak handgrip strength was associated with a 1.45 (95% CI:1.12-1.88) times higher odds for depression, although some between-country differences were noted (particularly in Ghana). Age and sex-stratified analysis showed similar results.	Strong
Han et al., 2019	Cross-sectional	South Korea n=3169, 1451 men, 1718 women; aged 59-69 years, mean age 55±6.25 years.	Patient Health Questionnaire (PHQ-9)	Digital Grip Dynamometer (T.K.K.5401)	(+) Older adults in the lowest tertile of handgrip strength measures were more likely to have experienced depressive symptoms compared to those in the highest tertile.	Moderate

Kim et al., 2019	Clinical trial	South Korea n=21 women, aged 67-81 years, mean age 76.40±3.27 years; control group (n=10; mean age 76.40±3.27 years) and intervention group (n=11, mean age 76.10±3.85 years).	Korean version of the Short form of the Geriatric Depression Scale (SGDS-K)	The exercise program was 3 times/week for 24 weeks. Part I from 1-4 weeks, Part II from 5-8 weeks, Part III from 9-15 weeks, and advanced long-term training from sixteen to 24 weeks. The exercise program consists of warm-up (for 10 min), main exercise (for 30–60 min) and warm-down (for 10 min).	(Ø) In neurotransmitter factor, serotonin, dopamine, epinephrine, and norepinephrine significantly decreased in the strength exercise group but not for the control group. There were no significant differences for both the strength exercise group and control group.	Weak
Laredo-Aguilera et al., 2019	Cross-sectional	Spain n=38 active women, aged >65 years, mean age 72.29±5.21 years.	Spanish version of the Short form of the Geriatric Depression Scale (SGDS-S)	Digital Grip Dynamometer (T.K.K. 5101)	(+) The group with a higher handgrip strength result had a better total score for depression. Significant and negative correlations were found between handgrip strength and depression.	Weak
Moraes et al., 2019	Clinical trial	Brazil n=27 older adults with major depressive disorder; aerobic training (n=9, 1 man and 8 women, aged 60-78; 70.88±5.94 years), strength training (n=9, 8 men, 1 woman, aged 60-81; 72.89±7.06 years), control group (n=7, 2 men and 5 women, aged 61-77; 69.28±5.5.28years).	Hamilton Depression Rating Scale (HAM-D), and Beck Depression Inventory (BDI)	The 1-repetition maximum test was applied. The scale of perception of effort from 6 to 20 was used to quantify the subject's effort during activity.	(+) The aerobic training and strength training intervention groups showed significant reductions in depressive symptoms from pre to post intervention when compared to the control group.	Moderate
Park et al., 2019	Prospective	South Korea n=13901, 5996 men, 7905 women; aged > 60 year, mean age 69.54±7.06 years.	Korean version of the Short form of the Geriatric Depression Scale (SGDS-K)	Handgrip Dynamometer (TANITA No. 6103, Tokyo)	(+) Individuals with depression only and individuals with low handgrip strength plus depression had significantly higher risks of all-cause mortality. Men and women with higher handgrip strength had significantly lower depression scores.	Strong
Smith et al., 2019	Cross-sectional	United Kingdom n=3741 community-dwelling, 1257 men, 2484 women; aged 54-89 years, mean age 68.4 years.	Center for Epidemiologic Studies Depression scale (CES-D8)	Hand-held dynamometer	(+) Grip strength was negatively associated with depressive symptoms, when analysis was adjusted for sex and age. When fully adjusted the association remained significant but was weaker.	Strong

Meta-analysis

Figure 2 shows the forest plot of the odds ratio and 95% CI of each study and the odds ratio of the random-effects model. A moderate heterogeneity among studies was detected (I2 =55%; $\chi 2$=17.96, df=8; p=0.02). Based on 9 observational studies (Ashdown-Franks et al., 2019; Brooks et al., 2018; Fukumori et al., 2015; Han et al., 2019; Lee, 2018; Lee et al., 2018; McDowell et al., 2018; Smith et al., 2019; Soriano-Maldonado et al., 2016), including 62831 cases, the presence of depression symptoms was negatively associated with muscular strength. The pooled odds ratio from the random-effects model was 0.85 (95% CI: 0.80, 0.89).

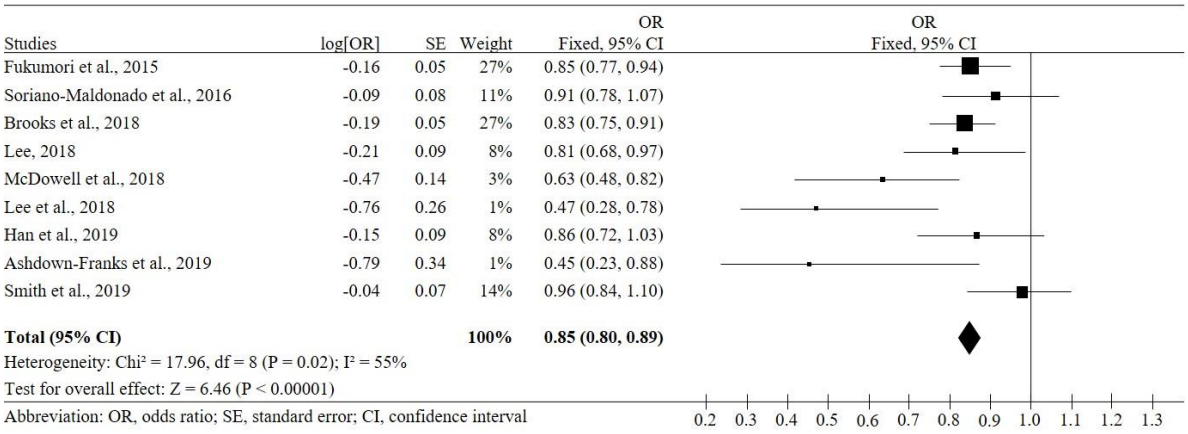

Figure 2. Pooled-odds of the association between muscular strength and depression symptoms.

Discussion

This study sought to review the relationship between muscular strength and depressive symptoms in adults and older adults. Findings suggest that increased muscular fitness may have a beneficial effect on depression symptoms. Furthermore, meta-analysis findings indicate that muscular fitness is inversely and significantly related to depression symptoms among adults and older adults. This is of importance because depression is the greatest non-communicable disease contributing to the loss of health (WHO, 2017) and it is associated

with comorbidity (Vancampfort et al., 2016), higher risk of suicide (Ferrari et al., 2013), and premature mortality (Walker et al., 2015).

Muscular strength is recognized as an important health indicator, mainly because it is associated with a lower risk of mortality in the adult and older adults population, regardless of age (Garcia-Hermoso et al., 2018). Also, it is independently associated with cardiometabolic risk and metabolic syndrome in adults and older adults (Fraser et al., 2016; Silventoinen et al., 2009). Especially among older adults, muscular fitness is associated with sarcopenia (Manini & Clark, 2012), functional limitations and disabilities (McGrath et al., 2018). Thus, it is considered a useful marker of frailty in the older adult population (Takahashi et al., 2017). In this systematic review and meta-analysis, muscular fitness was also found to be inversely associated with depressive symptoms. Several mechanisms may explain the observed inverse association between muscular strength and depression symptoms. One possible mechanism is the relationship between muscular strength and sarcopenia (Manini & Clark, 2012), functional limitations and disabilities (McGrath et al., 2018). The relation between muscular strength and these health outcomes may transfer to depression by increased disability, as people with lower muscular strength are less independent and have more difficulties performing activities of daily living (Liu et al., 2014), which is linked to depression symptoms (Haynie et al., 2001; Vest et al., 2011). Moreover, muscular strength is also associated with frailty and health-related quality of life (Musalek & Kirchengast, 2017). Another possible explanation is the release of cytokines and myokines into the circulatory systems in response to muscle contraction. It is suggested that myokines might protect against the risk of depression (Kohler et al., 2017). Furthermore, older adults' inflammatory profile is associated with frailty and sarcopenia, which can increase the risk of depression (Kim & Choi, 2013; Soysal et al., 2017; Steptoe et al., 2012).

When examining the association between muscular strength and depression, one must consider the potential mediating role of physical activity. Physical activity, most notably muscle-strengthening activities, is known to be the most important modifiable factor related to muscular strength, therefore, higher muscular strength levels are likely to be related to greater physical activity levels (USDHHS, 2018). Furthermore, muscular strength and physical activity share most of the mechanisms through which they may affect depression symptoms. Notwithstanding, physical fitness mirrors both participation in physical activity and the state of physiological systems, being suggested that because of that the relationship between physical fitness and health outcomes may be stronger than the relationship between physical activity and those same health outcomes (Kaminsky et al., 2013). Also, changes in fitness due to participation in physical activity are not immediate and may take weeks to be measurable. Some of the studies included in this review controlled the analysis for physical activity participation and still concluded that muscular strength was associated with depression, independently of physical activity (Ashdown-Franks et al., 2019; Han et al., 2019; Lee, 2018; Lee et al., 2018; Smith et al., 2019). The mediating role of physical activity in the relationship between muscular strength and depression symptoms has not been explored yet, and thus future research should investigate how much of this relationship is mediated by physical activity.

Depression has one of the greatest disease burdens in several countries worldwide (Ferrari et al., 2013). It is usually treated using pharmacotherapy and psychotherapy (Karyotaki et al., 2016; Khan et al., 2012), but both treatment options are expensive and increase the health costs for health care systems (Olfson et al., 2018). To address this public health problem and possibly reduce the present and future burden of the disease different strategies are needed. The association between muscular strength and depression symptoms observed in this review indicates that promoting muscular fitness through physical activity

and exercise might be used as a potential strategy to fight depression. Furthermore, a recent systematic review and meta-analysis revealed that resistance training had a moderately positive effect on disability and function in older adults with or at risk for disability (Olsen et al., 2019). This is important because disability and function are related to depression. Also, measures of muscular strength, such as the handgrip, could be used as one of several indicators of depression, or for the development of depression symptoms, and its assessment could be promoted in the primary health care systems, as it is already suggested to be for mortality (Garcia-Hermoso et al., 2018). Early detection and prevention of depression symptoms, and mental health promotion in the health care systems, may lead to healthier populations and reduced health care costs. Moreover, improving muscular fitness would not only promote mental health but also promote cardiometabolic health and quality of life (Fraser et al., 2016; Musalek & Kirchengast, 2017; Olsen et al., 2019).

To our knowledge, this is the first systematic review to investigate associations, between muscular fitness and depression symptoms in adults and older adults, using a meta-analysis to determine the pooled odds ratio for the relationship between muscular strength and depression symptoms. Nevertheless, these systematic reviews and meta-analysis findings should be taken in light of some limitations that must be acknowledged. Most studies used the handgrip strength as a measure of muscular strength, while other studies used different measures. This leads to heterogeneity in the muscular strength outcome. Even though the studies were assessed according to their methodological quality, they were not weighted or ranked according to it for the systematic review. Thus, findings from studies with weaker quality and smaller sample sizes were given no less importance than findings from studies with strong research designs and larger sample sizes. Also, most included studies were cross-sectional and therefore associations temporal direction cannot be certainly assessed. Search terms were selected to identify articles that associate muscular strength and depression.

Nonetheless, some articles were eventually left out because, in the title or abstract, they did not have a term that could be associated with muscular strength or depression.

Conclusion

Muscular strength is inversely and significantly related to depression symptoms among adults and older adults. This may be partially explained by physical activity, but also by the associations between muscular fitness and functional limitations and disabilities, as well as frailty and health-related quality of life, which in turn are related to depression symptoms. Interventions aiming to improve muscular fitness have the potential to promote mental health and prevent depression. Thus, public health professionals could use muscular strength assessment and improvement as a strategy to promote mental health and prevent depression. These findings are of the utmost importance for public policies where the strength of the connection between physical and mental factors, in the promotion of mental health and wellbeing, is not always duly considered.

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Study 6. Active commuting and depression symptoms in adults: a systematic review

Abstract

Physical activity (PA) is suggested to have a protective effect against depression. One way of engaging in PA is through active commuting. This review summarises the literature regarding the relationship between active commuting and depression among adults and older adults. A systematic review of studies published up to December 2019, performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis guidelines, was conducted using three databases (PubMed, Scopus, and Web of Science). A total of seven articles were identified as relevant. The results from these studies were inconsistent. Only two presented a significant relationship between active commuting and depression symptoms. In those two studies, switching to more active modes of travel and walking long distances were negatively related to the likelihood of developing new depressive symptoms. In the other five studies, no significant association between active travel or active commuting and depression was found. The relationship between active commuting and depression symptoms in adults is not clear. More studies on this topic are necessary in order to understand if active commuting can be used as a public health strategy to tackle mental health issues such as depression.

Keywords: active travel; walking; cycling; mental health

Introduction

Depression is a mental health problem that affects more than 300 million adults worldwide (WHO, 2017). The prevalence of depression has been rising globally, and it was projected to be the second-largest cause for the burden of disease by 2020 (Chapman & Perry, 2008). Depression is already the greatest non-communicable disease contributing to the loss of health (WHO, 2017), due to its association with comorbidities (Vancampfort et al., 2016), risk of suicide (Ferrari et al., 2013), and premature mortality (Walker et al., 2015). Most cases of depression are treated using pharmacotherapy and psychotherapy (Karyotaki et al., 2016; Khan et al., 2012). However, both types of therapies are expensive and increase health costs for health care systems (Olfson et al., 2018).

Physical activity (PA) is suggested to have a protective effect against depression and a positive effect on the treatment of depression in non-clinical and clinical populations, regardless of sex and age (Rebar et al., 2015; Schuch et al., 2018). As non-pharmacology therapy, PA does not show drug side effects such as weight gain, insomnia, dry mouth, or withdrawal symptoms (Tasci et al., 2019). On the contrary, besides the positive benefits on depression, it is also associated with positive public health gains such as physical performance and cardiovascular improvements (Tasci et al., 2019).

PA can be performed in several contexts, including sports activities, occupational context, leisure-time activities, domestic activities, and in active commuting. For some adults, walking or cycling while commuting to work or to other places seems to be important for enhancing their daily levels of PA (Sahlqvist et al., 2012; Yang et al., 2012), because is likely to be sustained when incorporated into people's daily routine (Hillsdon & Thorogood, 1996). As a result, active commuting has been related to health and wellbeing improvement (Berglund et al., 2016; Humphreys et al., 2013) and associated with fewer transport-related carbon emissions (Chapman et al., 2018). Thus, it can be expected that commuting actively

might also be related to depression symptoms. However, so far, there is no clear evidence of the relationship between active travel or active commuting and depression symptoms. Therefore, the purpose of this study was to review the literature regarding the relationship between PA in active commuting and depression among adults and older adults.

Methods

This systematic review was performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines (Moher et al., 2009).

Inclusion Criteria

Articles that presented a relationship between active travel and active commuting and depression symptoms published in peer-reviewed journals up to December 2019 were eligible for inclusion. Eligibility criteria included the following: (1) cross-sectional, prospective, and cohort studies (study design criterion); (2) outcomes included depression or depressive symptoms (outcome measure criterion); (3) active travel or active commuting (relationship criterion); (4) adults and older adults (participants criterion); (5) articles published in English, Portuguese, or Spanish (language criterion); and (6) articles that did not meet the inclusion criteria or did not include findings related to the inclusion criteria were excluded (exclusion criteria).

Search Strategy

Studies published up to December 2019 were identified by searching in electronic databases. The search was undertaken in the PubMed, Scopus, and Web of Science databases. Articles that assessed the relationship between active travel or active commuting and depression were included in this review. The search was performed using the following combination of terms: travel* OR transport* OR commute* OR cycle OR cycling OR bicycle* OR bike* OR walk* OR/AND depress* OR mental health OR psychological health

OR anxiety OR psychological function*. Search terms were defined previously and used in each database to identify articles for review. Two reviewers (A.M. and M.P.) independently screened titles and abstracts to identify studies that met the inclusion criteria. Duplicate articles were removed. Relevant articles were retrieved for a full read. Two authors (A.M. and M.P.) reviewed the full text of potential studies, and decisions to include or exclude studies in the review were made by consensus. Disagreements were solved by consensus and, when necessary, a third reviewer served as a judge (D.H.-N. or D.F.).

Data Extraction and Harmonisation

Based on PRISMA (Moher et al., 2009), a data extraction form was developed. The following information was extracted from each article: authors' name and year of publication; study design; country; sample characteristics (number of participants, sex, and age); the instrument for assessing depression symptoms; the instrument for assessing active travel or active commuting; main results; and study quality. The extraction was performed by one author (A.M.), and coding was verified by two authors (M.P. and D.H.-N.).

Study Quality and Risk of Bias

Study methodological quality was assessed using a checklist criteria from the Quality Assessment Tool for Quantitative Studies (National Collaborating Centre for Methods and Tools, 2008). The checklist comprises 19 items, assessing eight methodological domains: selection bias, study design, confounders, blinding, data collection methods, withdrawals and dropouts, intervention integrity, and analyses. Each section is classified as strong, moderate, and with weak methodological quality. Then, a global rating is determined based on the scores of each component. Two researchers rated the articles (M.P. and D.F.) in each domain and the studies' overall quality. Discrepancies were resolved by consensus.

Synthesis of Results

This review analysed the relationship between active travel or active commuting and depression. The details for each study, including design, participant characteristics and sample size, measures, main results, and study quality, are presented in a consistent manner.

Results

Search Results

Figure 1 presents the flow citation through the systematic review process. The systematic search yielded 3938 publications. After excluding the duplicates (n = 2246), the title and abstract of 1692 articles were screened. After eliminating 1606 articles at the title and abstract level, 86 articles remained and were subsequently read. From the 86 articles, 35 were eliminated for having a different outcome, 40 were eliminated because they were not focused on active travel or active commuting, three were eliminated for not being empirical studies, and one was deleted because it was written in Mandarin. Thus, seven articles were identified as relevant.

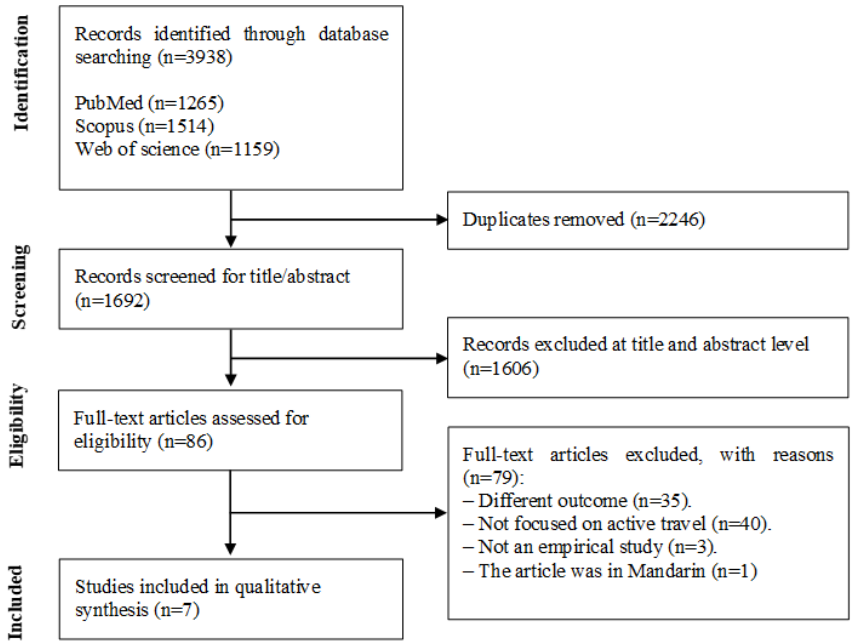

Figure 1. Flow diagram of study selection.

Study Characteristics

Table 1 presents the studies' characteristics. From the seven articles, five had prospective designs and two had cross-sectional designs. In total, all studies combined included 47,300 adults aged over 18 years. Geographically, two were performed in the United States; two in Japan; one in Canada; one in the United Kingdom; and one in several Latin American countries (Argentina, Bolivia, Brazil, Colombia, Ecuador, México, Panamá, Peru, Uruguay, and Venezuela). The Center for Epidemiologic Studies Depression Scale (CES-D) was the most used scale to assess depression symptoms (in five articles). In most articles, the walking distance was self-reported and included leisure time and active commuting. The seven studies were considered of moderate quality.

The older study included in the systematic review was published in 2010, and it examined the effect of walking on incident depressive symptoms in Japanese-American older men with and without chronic disease (Smith et al., 2010). The authors used a cohort of men from Hawaii born between 1900 and 1919. Several rounds of examinations were performed; the seventh (which was used in the study) was in 1999–2000. The CES-D 11 scale was used to screen for depressive symptoms, and walking activity was self-reported. It was found that older men, without chronic diseases, in the intermediate (odds ratio (OR) = 0.52, 95% confidence interval (CI): 0.32–0.83) and highest (OR = 0.61, 95% CI: 0.39–0.97) walking groups had significantly lower odds of developing eight-year incident depressive symptoms.

Posteriorly, using a one-year follow-up longitudinal survey, Kai et al. (2011) examined the prospective association of walking to work with depressive symptoms among 634 Japanese workers. Depression symptoms were screened by the CES-D scale, and walking activity was self-reported. The authors reported that baseline mean walking to work time was 29.2 ± 18.0 minutes per day. Walking to work tertiles were calculated; mean values of the low, medium, and high walking to work time tertiles were 13.8 ± 7.0, 29.6 ± 1.9, and 49.7 ±

16.1, respectively. No significant association was found between the depressive symptoms and tertiles of walking to work duration.

In an effort to determine whether walking or depressive symptoms were the stronger predictor of each other, Julien et al. (2013) examined the longitudinal associations between walking and depressive symptoms in a population-based sample of 498 Canadian urban-dwelling older adults. Four repeated measures over a five-year period were performed. The geriatric depression scale was used to assess depressive symptoms, and walking was self-reported. Although depressive symptoms predicted walking frequency, walking frequency did not predict depressive symptoms at subsequent time points.

Later, a cross-sectional study based on the National Survey of American Life investigated the odds of having depressive symptoms accordingly to walking frequency in 2978 African-American adults (Torres et al., 2015). Walking was measured by self-reported frequency, and depressive symptoms were measured with modified versions of the CES-D scale. In this study, women who reported walking often presented lower odds for depressive symptoms than women who reported never walking (OR = 0.56, 95% CI: 0.38–0.82); however, no significant results were found for men.

In the same year, Kuwahara et al. (2015) published a cohort study of 29,082 Japanese workers, examining the prospective associations of physical activity during commuting with the risk of depressive symptoms. During a mean follow-up of 4.7 years, 6177 adults developed depressive symptoms. Physical activity and depressive symptoms (similar to the CES-D scale) were assessed by a self-reported questionnaire. The hazard ratio (HR) for individuals who stand or walk during work was 0.86 (95% CI: 0.81–0.92) compared with sedentary workers. However, walking to and from work was not found to be associated with the risk of depressive symptoms.

More recently, Knott et al. (2018) examined whether changes in commute mode were associated with differences in the severity of depressive symptoms in 5474 working adults from the United Kingdom in a population-base prospective cohort study (mean follow-up, 4.65 years). Mode, frequency, and distance of commuting to work were self-reported. The severity of depressive symptoms was assessed using the two-item Patient Health Questionnaire. Baseline asymptomatic adults who altered from inactive to active commuting to work reported less severe symptoms at follow-up than those who remained inactive ($\beta = -0.10$, 95% CI: −0.20–0.00). However, among baseline symptomatic adults, longer trips for work were associated with worse symptoms at follow-up ($\beta = 0.64$, 95% CI: 0.13–1.16).

The most recent study examined the cross-sectional associations between commute patterns and mental health in 5438 adults using survey data from 11 Latin American cities (Wang et al., 2019). Commuting was self-reported, and depression was measured using the CES-D scale. No association was found between non-motorised modes of travel and depression.

Table 1. Characteristics of the studies.

Author, Year	Study Design	Sample and Country	Depression Measure	Active Commuting Measure	Observations	Main Results	Quality
Smith et al., 2010	Prospective cohort.	n = 3196 Japanese-American men who were involved in the Honolulu Heart Program aged 71–93 years; mean age 77 years. United States.	Center for Epidemiologic Studies Depression Scale (CES-D 11)	Participants reported how many city blocks they walked each day. Blocks were converted into miles using 12 blocks per mile as a conversion factor. This assessment was developed from the Harvard Alumni Survey.	Walking distance included leisure-time and active commuting.	Those who walked more had significantly lower rates of prevalent depressive symptoms in cross-sectional analyses. Elderly men, without chronic diseases, who walked longer distances per day were less likely to develop new depressive symptoms over eight years of follow-up.	Moderate
Kai et al., 2011	Prospective (1-year follow-up).	n = 634: 536 men, 98 women aged 20–60 years; 36.7 ± 9.2 years. Japan.	Center for Epidemiologic Studies Depression Scale (CES-D)	The duration of leisure-time physical activity and commuting by walking were measured using a self-report questionnaire.	Walking distance included leisure-time physical activity and commuting to work.	The adjusted odds ratio (OR) of depressive symptoms in the highest tertile of leisure-time physical activity was 50% lower (OR = 0.50, 95% CI: 0.26–0.97) than those in the lowest tertile. In contrast, no significant association was found between the risk of depressive symptoms and duration of commuting by walking.	Moderate
Julien et al., 2013	Prospective (5-years follow-up). VoisiNuAge Study.	n = 498: 236 men, 262 women aged 68–84 years (74.86 ± 4.18 men and 74.90 ± 3.97 women). Canada.	Geriatric Depression Scale (GDS)	Physical Activity Scale for the Elderly (PASE).	Walking distance included leisure-time and active commuting.	Depressive symptoms predicted walking frequency (higher depressive symptoms were related to fewer walking days), but walking frequency did not predict depressive symptoms at subsequent time points.	Moderate
Torres at el., 2015	Cross-sectional. National Survey of American Life (NSAL).	n = 2978: 1903 men, 1075 women aged ≥18 years. United states.	Center for Epidemiologic Studies Depression Scale (CES-D)	Walking was measured with responses to one question from the Americans' Changing Lives questionnaire.	Walking distance included leisure-time and active commuting.	Women who reported often walking had lower odds for depressive symptoms than women who reported never walking (OR = 0.56, 95% CI: 0.38–0.82). Walking frequency was not related to depressive symptoms in men.	Moderate

Kuwahara et al., 2015	Prospective (5-year follow-up). Japan Epidemiology Collaboration on Occupational Health (J-ECOH) Study.	n = 29,082 workers: 24,676 men, 4406 women aged 20–64 years; mean age 42.7 years. Japan.	Epidemiologic Studies Depression Scale (CES-D), Self-Rating Depression Scale (SDS)	Participants were asked whether they regularly engaged in any physical activity during leisure. Duration of walking to and from work was self-reported and categorised as <20minutes, 20-40 minutes, and ≥ 40 minutes.	It assessed leisure-time physical activity, physical activity at work, and active commuting.	Leisure exercise showed a U-shaped association with the risk of depressive symptoms. Walking to and from work was not associated with depressive symptoms.	Moderate
Knott et al., 2018	Population-based prospective cohort. UK Biobank.	n = 5474, aged 37–73 years. United Kingdom.	Patient Health Questionnaire (PHQ-2)	Participants reported the frequency of trips from home to work (trips/week); the distance travelled (miles); and the mode of transport used (”car or motor vehicle” (hereafter ”car” for simplicity), ”public transport”, and ”walk” and/or ”cycle”).	Paper was focused on modes of travel to work.	Participants who were asymptomatic at baseline and switched to more active modes of commuting tended to report a lower severity of symptoms at follow-up than those who continued to travel inactively (β = −0.10, 95% CI: −0.20–0.00). Among commuters who were symptomatic at baseline, longer journeys were associated with worse symptoms at follow-up (β = 0.64, 95% CI: 0.13–1.16). Shifting from exclusive car use towards more active commuting may help prevent and attenuate depressive symptoms in working adults.	Moderate
Wang et al., 2019	Cross-sectional. La Encuesta CAF 2016.	n = 5438. Argentina, Bolivia, Brazil, Colombia, Ecuador, México, Panamá, Peru, Uruguay, and Venezuela.	Center for Epidemiologic Studies Depression Scale (CES-D)	Participants reported commuting time during a “normal day”, uncongested commuting time, and travel mode commonly used for the commute.	Different modes of travel were assessed.	Every 10 more minutes of commuting time is associated with a 0.5% (p = 0.011) higher probability of screening positively for depression. There were not found any significant associations between non-motorised modes of travel and depression.	Moderate

Discussion

This review summarises studies, published up to December 2019, which met the defined criteria. Seven studies were systematically reviewed to address the relationship between active commuting and depression symptoms. In general, although some studies demonstrate that active commuting might be negatively related to depression symptoms, the evidence suggests that the active commuting and depression relationship is unclear.

From the seven studies screened, only two presented a significant relationship between active commuting and depression symptoms. In those two studies (Knott et al., 2018; Smith et al., 2010), switching to more active modes of travel and walking long distances were negatively related to the likelihood of developing new depressive symptoms. When examining the effect of walking on incident depressive symptoms in older men, Smith et al. (Smith et al., 2010) observed that those who walked more had lower rates of prevalent depressive symptoms and that those with chronic diseases who walked longer distances per day were less likely to develop eight-year incident depressive symptoms. Furthermore, the authors suggested that there seems to be a threshold effect in the protective effect of walking on the development of incident depressive symptoms, as few differences were found between the intermediate and high walking groups. This finding is of importance, especially for older adults who have more difficulties in engaging in high volumes of physical activity. More recently, using data from the UK Biobank, a study investigated whether changes in commute mode were associated with differences in the severity of depressive symptoms (Knott et al., 2018). It was found that adults who altered from inactive to active commuting to work reported less severe symptoms at follow-up than those who remained inactive. This suggests that commuting behaviours change matters, and thus, active commuting may be used as an intervention strategy to prevent the development of depressive symptoms. Previous investigations in physical activity have shown that, for health purposes, present behaviours

may be more important than past behaviours (Marques et al., 2017). Active travel offers a suitable way of integrating PA into daily life, and those who use active modes of commuting have higher levels of PA (Sahlqvist et al., 2012; Yang et al., 2012). As a result, people who often use more active ways to travel might have better health status (Berglund et al., 2016; Chapman et al., 2018; Humphreys et al., 2013). Hypothetically, it means that active commuting can also have a protective effect on depression symptomology or reduce depression symptoms (Rebar et al., 2015; Schuch et al., 2018). However, different types of PA have different effects on mental health status.

Among adults, there is evidence that leisure-time PA is more related to mental health problems, and specifically to depression, than other forms of PA (Joshi et al., 2016; Lampinen et al., 2000; Siefken et al., 2019). In five out of seven articles, a significant relationship between active commuting and depression symptoms was not found (Julien et al., 2013; Kai et al., 2011; Kuwahara et al., 2015; Torres et al., 2015; Wang et al., 2019). Cross-sectional evidence from two studies showed that the association between active commuting and depression is not consistent. In one study, performed among Latin American adults, it was found that non-motorised modes of travel were not associated with depression (Wang et al., 2019). On the other hand, a study among African-American adults reported that, while women who reported walking often presented a lower probability for depressive symptoms than women who reported never walking, the same pattern was not observed in men (Torres et al., 2015). In order to prevent an increase in depressive symptoms, physical activity may need to improve fitness (Dishman et al., 2012). However, walking in many cases is probably not performed at a high enough intensity to improve fitness. This difference between sexes may be due to a large percentage of African-American women being obese and, thus, having lower exercise capacity (Torres et al., 2015). This can lead to walking being a more intense physical activity among African-American women compared to African-American men. The

other three studies had a longitudinal design and, in general, concluded that walking was not associated with depressive symptoms at follow-up (Julien et al., 2013; Kai et al., 2011; Kuwahara et al., 2015). In a one-year follow-up longitudinal survey performed among Japanese workers, it was found that depressive symptoms were not associated with tertiles of walking to work durations (Kai et al., 2011). Similarly, in a cohort study with a mean follow-up of 4.7 years also among Japanese workers, walking to and from work was not related to the risk of depressive symptoms (Kuwahara et al., 2015). Lastly, a study among Canadian older adults verified that, while depressive symptoms predicted walking frequency at subsequent time points, walking frequency did not predict depressive symptoms (Julien et al., 2013). The lack of a significant relationship between active commuting and depression symptoms in these articles are in agreement with previous studies among men and women, which showed that walking distance was not related to depression symptoms (Kull et al., 2012; McKercher et al., 2009; Mytton et al., 2016). For those who use an active mode of transportation, transit connectivity matters more for mental health than active travel (Mytton et al., 2016; Wang et al., 2019). Furthermore, there is a difference between walking and cycling as a mode of active transportation. Most studies focus on walking as a way of active transportation. Those who usually walk as an active mode of transportation undertake at a lower intensity than cycling (Costa et al., 2015; Mytton et al., 2016). This is of particular importance, because PA intensity is a determinant of health. Thus, perhaps in some studies, the level of PA intensity while walking was too low to cause effects on mental health and depression symptoms.

Inconsistent findings identified in this systematic review can be a reflection of the different methodologies used and the different geographical areas and social contexts examined. Measures of active commuting widely varied from study to study, although all were self-reported. Some studies focused on volume (Kai et al., 2011; Kuwahara et al., 2015;

Smith et al., 2010), others on frequency (Julien et al., 2013; Torres et al., 2015); one study focused only on the mode of commuting (Wang et al., 2019) and another one examined the transition from non-active commuting to active commuting (Knott et al., 2018). The type of active commuting also differed among studies. Most investigated only walking (Julien et al., 2013; Kai et al., 2011; Kuwahara et al., 2015; Smith et al., 2010; Torres et al., 2015), while two studies investigated active commuting without specifying the type (Knott et al., 2018; Wang et al., 2019). Additionally, the context of the commuting was different among studies. Three studies referred to commuting to and from work (Kai et al., 2011; Knott et al., 2018; Kuwahara et al., 2015). The others did not specify the context of commuting. Due to this, comparability among studies is very limited. Regarding physical activity and active commuting volume and frequency are important information. Results may differ based on these variables. Although some studies examined volume or frequency, they used different time frames. Studies rarely consider both volume and frequency together. Another important aspect for comparability of the results is the type of active commuting, mainly because different types of commuting (e.g., walking versus cycling) have different intensities and volumes associated to them. Future studies should include frequency and volume and be as specific as possible when analysing active commuting. Preferably, similar methods should be used among studies to improve comparability. In addition to the studies being undertaken in different geographic areas and using different ways to measure active transport, it is important to mention that different scales were used to assess symptoms of depression. The use of different scales between the articles may also have contributed to the inconsistency of the results that were observed.

The social and built environment is an important factor to be considered in mental health. The neighbourhood socioeconomic level and built-environment characteristics are associated with a higher probability of screening positively for depression (Sampson et al.,

2019). Walking or cycling in some built-environments can contribute to the development of depression symptoms (Sampson et al., 2019; Wang et al., 2019). Furthermore, for some people, active transportation is the only mode of transportation, because they do not have a car or access to mass transit options. In these cases, an active mode of transportation is not an option, it is a mandatory condition. As a result, transport exclusion is associated with social exclusion, which might increment potential mental health problems such as depression (Lucas, 2012).

These study review findings should be considered in light of some limitations. Firstly, in all screened articles, the information on commuting and depression was self-reported, which may be subject to bias. Moreover, self-reported PA may have led to overestimates of total PA. Secondly, several articles do not make a clear distinction between active transport as a form of displacement and active transport as a form of leisure (e.g. walking for leisure). This lack of distinction precludes a more rigorous analysis of the relationship between active transport and depression symptoms. Thirdly, some studies were focused on specific populations, such as Japanese-American older men in Hawaii, African-American adults, or workers. This may compromise the generalisability of the results to the general population. Finally, two studies were cross-sectional, which makes it impossible to infer causality. Finally, search terms were selected to identify articles that associate active transportation and depression symptoms. Nevertheless, several articles were subsequently excluded, because neither the title nor abstract contained terms that could be associated with active travel or active commuting.

Conclusions

This systematic review shows that the relationship between active commuting and depression symptoms in adults and older adults is inconsistent. Overall, out of seven studies,

only two found beneficial effects of active commuting on depression symptoms. Active commuting improves daily PA levels, which is known to be related to depression symptoms. Thus, hypothetically, active commuting could be related to depression. However, five studies did not find a significant relationship between active commuting and depression symptoms. More studies on this topic are necessary in order to understand if active commuting can be used as a public health strategy to tackle mental health problems such as depression. Future studies should include frequency and volume and be as specific as possible when analysing active commuting. Preferably, similar methods should be used among studies to improve comparability. Furthermore, future studies should be more specific regarding the context of commuting.

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General conclusion

General conclusion

This thesis aimed to analyse the relationship between physical activity, muscular strength, as a component of physical fitness, and depression symptoms among European adults from several countries. Furthermore, considering that active commuting is a simple way for enhancing daily levels of physical activity, it was also reviewed the literature regarding the relationship between physical activity in active commuting and depression among adults and older adults. This is particularly important because depression is a problem that affects men and women of different ages, from different socioeconomic backgrounds (Almomani & Bani-Issa, 2017; WHO, 2017); it worsens the quality of life, relationships with others, education, and work opportunities (Ferrari et al., 2013; WHO, 2017). Moreover, the most common treatment for depression includes pharmacotherapy and psychotherapy (Karyotaki et al., 2016; Khan et al., 2012), which are expensive and costly for health care systems (Olfson et al., 2018). Therefore, identifying forms of prevention or treatment of depression without associated costs, such as physical activity or improving physical fitness, is an important contribution to public health and for the sustainability of health systems.

From the present study, it was concluded that:

1. The benefits of leisure-time physical activity on depression are transversal and leisure-time physical activity can be recommended for most people for the prevention or treatment of depression. This is particularly important, because depression is a worldwide problem (Stubbs et al., 2016; WHO, 2017) associated with heightened comorbidity (Vancampfort et al., 2016), premature mortality (Walker et al., 2015), and increased health costs (Chisholm et al., 2016). Women, older people, and those from lower socioeconomic status reported less leisure-time physical activity than men, younger people, and those from higher socioeconomic status. Taking into account that they do not benefit from physical

activity for being less active, it may explain the differences observed between sexes and among age groups on the prevalence of depression symptoms.

2. Men and women engaging in moderate and vigorous physical activity intensity once a week or more were associated with lower depression symptoms. Furthermore, moderate and vigorous physical activity intensity once a week or more decreased the odds of depression symptoms compared to those who engage in physical activity less than once a week. It means that even low amounts of physical activity, in this case, moderate physical activity intensity once a weak, is associated with reduced depression symptoms in older people, mainly in men. This is an important finding because older people face difficulties to achieve the recommended levels of physical activity. Besides, due to age-related changes in body systems, they also do not engage in physical activity with higher intensity levels (Jansen et al., 2015). It means that even the elderly who engage in moderate physical activity intensity may benefit from physical activity practice.

3. Grip strength is associated with lower odds of depression. Among men and women with higher grip strength are less likely to have depression symptoms than those with the lowest grip strength. These results reinforce the importance of promoting muscular strength among older people. Physical activity recommendations suggest that older people should engage in muscle-strengthening activities that involve major muscle groups ≥2 days a week (WHO, 2010). This is important for adults aged 60 and older because every year there is a decline in muscle strength and power (Kim & Choi, 2013).

4. Although the benefits of physical activity in depression have been demonstrated, the effect of physical activity in commuting on depression is not clear.

These study's results support the well-documented benefit relationship between physical activity and depression symptoms (De Mello et al., 2013; Rebar et al., 2015; Schuch et al., 2018). It adds to the literature that this relationship is regardless of their

sociodemographic characteristics. It seems that the benefits of physical activity on depression are transversal and that physical activity can be recommended for most people for the prevention or treatment of depression. Physical activity is associated with depression and can benefit everyone but in particular more vulnerable groups such as women, older, single, less wealthy, sick or disabled, and retired people. Furthermore, engaging in physical activity at least once a week was associated with lower depression symptoms and odds of depression irrespectively of physical activity intensity.

Active commuting may be used as a strategy to prevent the development of depressive symptoms. Active travel offers a suitable way of integrating physical activity into daily life, and those who use active modes of commuting have higher levels of physical activity (Sahlqvist et al., 2012; Yang et al., 2012). Therefore, people who often use active ways to travel might have better health status (Berglund et al., 2016; Chapman et al., 2018; Humphreys et al., 2013). However, the systematic review it was observed that the relationship between active commuting and depression relationship is still unclear.

The observed relationships between muscular strength and depression is an innovative step in improving the knowledge of this possible association. Although the relationship between muscular strength and depression is not yet fully understood, muscular strength is inversely related to depression symptoms among adults and older adults. This may be partially explained by physical activity, but also by the associations between muscular fitness and functional limitations, disabilities, frailty, and health-related quality of life, which in turn are related to depression symptoms. Interventions to improve muscular fitness has the potential to promote mental health and prevent depression. In consequence, public health professionals could use muscular strength assessment and improvement as a strategy to promote mental health and prevent depression. These findings are of the greatest importance for public policies where the strength of the connection between physical and mental factors,

in the promotion of mental health and wellbeing, is not always duly considered. Thus, a physical activity routine that includes both aerobic and muscle-strengthening activities is likely to be optimal for the prevention of depression (Bennie et al., 2020).

Strengths and limitations

From these studies, some strengths and limitations should be acknowledged and kept in mind. The European Social Survey and the Survey of Health, Aging, and Retirement in Europe databases that comprise a large and representative sample size from several European countries, as well as several socio-demographic characteristics of the study sample. Another strength, considering the sample size and the heterogeneity of the participants, is the generality of these results. Due to the large sample, there was an adequate statistical power. A prospective analysis in study 3 allows for the examination of the cause and effect relationship between physical activity and depressive symptoms.

For the original studies, the main limitation is was the lack of information on physical activity, such as type, duration, and frequency, which limits a precise calculation of physical activity volume. Physical activity was self-reported which is susceptible to bias. Due to some factors, such as social desirability, there may be an overestimation of physical activity frequency (Adams et al., 2005). Furthermore, for this study sample, the validity and reliability of the questions to assess the frequency of physical activity were not tested. Nonetheless, self-reported physical activity is a reliable method for epidemiologic studies (Craig et al., 2003) and is still the backbone of surveillance studies (Pedisic & Bauman, 2015). Grip strength is a common marker of overall physical health which is recognized to be related to mental health conditions. However, there was no information about hand size, which could affect grip strength. Furthermore, the existence of cultural variation on the use of grip strength in daily social routines was not considered.

There was no information about each participant's family history of depression that may affect depressive symptoms, nor information on the type of depression and its overall burden on the participant's daily life and quality of life perception. Depression was not clinically diagnosed. The EURO-D 12-item scale is a screening tool for depression symptoms. Notwithstanding, a cut-off point of ≥4 depression symptoms has been demonstrated to diagnose clinically significant cases of depression (Gallagher et al., 2013; Prince et al., 1999). Additionally, the depression score measurement, although being a properly validated methodology (Prince et al., 1999), might be susceptible to bias. For instance, mood fluctuations might influence participants' responses.

In the systematic review that analysed the effect of muscular strength on depression symptoms in adults, most studies used the handgrip strength as a measure of muscular strength, while other studies used different measures. This leads to heterogeneity in the muscular strength outcome. Even though the studies were assessed according to their methodological quality, they were not weighted or ranked according to it for the systematic review. Thus, findings from studies with weaker quality and smaller sample sizes were given no less importance than findings from studies with strong research designs and larger sample sizes. Also, most studies were cross-sectional and for that reason, it is not possible to verify causality. Search terms were selected to identify articles that associate muscular strength and depression. Even so, some articles were left out because they did not have a term that could be associated with muscular strength or depression.

For the systematic reviews of active commuting, several articles do not make a clear distinction between active transport as a form of displacement and active transport as a form of leisure. This lack of distinction precludes a more rigorous analysis of the relationship between active transport and depression symptoms. Some studies were focused on specific

populations or workers, which may compromise the generalisability of the results to the general population.

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Conclusiones generales

Conclusiones generales

Esta tesis tuvo como objetivo analizar la relación entre la actividad física, la fuerza muscular, como componente de la aptitud física, y los síntomas depresivos entre adultos de varios países europeos. Además, considerando que el desplazamiento activo es una forma sencilla de mejorar los niveles diarios de actividad física, también se revisó la literatura sobre la relación entre la actividad física en el desplazamiento activo y la depresión en adultos y adultos mayores. Esto es particularmente importante porque la depresión es un problema que afecta a hombres y mujeres de diferentes edades, y de diferentes niveles socioeconómicos (Almomani & Bani-Issa, 2017; WHO, 2017); empeorando la calidad de vida, las relaciones con los demás, la educación y las oportunidades laborales (Ferrari et al., 2013; WHO, 2017). Además, el tratamiento más común para la depresión incluye la farmacoterapia y la psicoterapia (Karyotaki et al., 2016; Khan et al., 2012), que son costosas para las personas y costosas para los sistemas de salud (Olfson et al., 2018). Por tanto, identificar formas de prevención o de tratamiento de la depresión sin costes asociados, como la actividad física o la mejora de la forma física, es una contribución importante a la salud pública y a la sostenibilidad de los sistemas sanitarios.

Del presente estudio se concluyó que:

1. Los beneficios de la actividad física en el tiempo libre sobre la depresión son transversales y puede recomendarse para la mayoría de las personas con vistas a la prevención o el tratamiento de la depresión. Esto es particularmente importante porque la depresión es un problema mundial (Stubbs et al., 2016; WHO, 2017) asociado con una mayor comorbilidad (Vancampfort et al., 2016), mortalidad prematura (Walker et al., 2015) y un aumento de los costes en salud (Chisholm et al., 2016). Las mujeres, las personas mayores y las personas de nivel socioeconómico más bajo mostraron menos actividad física en el tiempo libre que los hombres, las personas más jóvenes y las personas de nivel socioeconómico más alto.

Teniendo en cuenta que no se benefician de la actividad física por ser menos activos, esto puede explicar las diferencias observadas entre géneros y entre grupos de edad sobre la prevalencia de los síntomas depresivos.

2. Los hombres y mujeres que realizan una actividad física intensa y moderada una vez a la semana o más tuvieron menos síntomas de depresión. Además, realizar actividad física moderada y vigorosa una vez a la semana o más disminuyó la probabilidad de sufrir síntomas de depresión en comparación con aquellos personas que realizaban actividad física menos de una vez por la semana. Esto indica que incluso una cantidad baja de actividad física, en este caso, una intensidad de actividad física moderada de una vez a la semana, se asocia con una reducción de los síntomas de depresión en las personas mayores, principalmente en los hombres. Este es un hallazgo importante porque las personas mayores se enfrentan con mayores dificultades para alcanzar los niveles recomendados de actividad física. Además, debido a los cambios en los sistemas corporales relacionados con la edad, tampoco realizan actividad física con niveles de intensidad más altos (Jansen et al., 2015). Así, incluso las personas mayores que realizan una actividad física de intensidad moderada pueden beneficiarse de la práctica de actividad física.

3. La fuerza de agarre se asocia con menores probabilidades de depresión. Los hombres y las mujeres con mayor fuerza de agarre presentan menos síntomas de depresión en comparación con aquellos y aquellas con menor fuerza de agarre. Estos resultados refuerzan la importancia de promover la fuerza muscular entre las personas mayores. Las recomendaciones de actividad física sugieren que las personas mayores deben participar en actividades de fortalecimiento muscular que involucren a los principales grupos musculares 2 días o más a la semana (WHO, 2010). Esto es importante para los adultos de 60 años o más porque cada año hay una disminución en la fuerza y en la potencia muscular (Kim y Choi, 2013).

4. Aunque se han demostrado los beneficios de la actividad física en la depresión, no está tan claro el efecto de la actividad física en los desplazamientos sobre la depresión.

Los resultados de este estudio respaldan la relación de beneficios bien documentada entre la actividad física y los síntomas de depresión (De Mello et al., 2013; Rebar et al., 2015; Schuch et al., 2018). Agrega a la literatura que esta relación es independiente de sus características sociodemográficas. Parece que los beneficios de la actividad física sobre la depresión son transversales y que la actividad física se puede recomendar a la mayoría de las personas para la prevención o el tratamiento de la depresión. La actividad física está asociada con la depresión y puede beneficiar a todos, pero en particular a los grupos más vulnerables, como las mujeres, las personas mayores, las solteras, las de menor estatus socioeconómico, las enfermas o discapacitadas y las personas jubiladas. Además, realizar actividad física al menos una vez a la semana se asoció con menores síntomas de depresión y menores probabilidades de depresión, independientemente de la intensidad de la actividad física.

Los desplazamientos activos se pueden utilizar como estrategia para prevenir el desarrollo de síntomas depresivos. El transporte activo ofrece una alternativa adecuada para integrar la actividad física en la vida diaria, y aquellas personas que utilizan modos activos de desplazamiento presentan asimismo niveles más altos de actividad física (Sahlqvist et al., 2012; Yang et al., 2012). Por lo tanto, las personas que a menudo usan formas activas de desplazarse pueden tener un mejor estado de salud (Berglund et al., 2016; Chapman et al., 2018; Humphreys et al., 2013). Sin embargo, en la revisión sistemática se observó que la relación entre el desplazamiento activo y la depresión aún no está clara.

Las relaciones observadas entre la fuerza muscular y la depresión suponen un paso innovador para mejorar el conocimiento de esta posible asociación. Aunque la relación entre la fuerza muscular y la depresión aún no se comprende por completo, la fuerza muscular está inversamente relacionada con los síntomas de depresión entre los adultos y los adultos

mayores. Esto puede explicarse en parte por la actividad física, pero también por las asociaciones entre aptitud muscular y limitaciones funcionales, discapacidades, fragilidad y calidad de vida relacionada con la salud, que a su vez se encuentran relacionadas con los síntomas de depresión. Las intervenciones para mejorar la aptitud muscular tienen el potencial de promover la salud mental y prevenir la depresión. En consecuencia, los profesionales de la salud pública podrían utilizar la evaluación y mejora de la fuerza muscular como una estrategia para promover la salud mental y prevenir la depresión. Estos hallazgos son importantes para las políticas públicas donde no siempre se considera debidamente la relación entre la fuerza y los factores físicos y mentales en la promoción de la salud y el bienestar mental. Por lo tanto, es probable que una rutina de actividad física que incluya actividades aeróbicas y de fortalecimiento muscular resulte beneficiosa para la prevención de la depresión (Bennie et al., 2020).

Puntos fuertes y limitaciones

A partir de estos estudios, se deben reconocer y tener en cuenta algunos aspectos fuertes y también algunas limitaciones. Las bases de datos de European Social Survey y de Survey of Health, Aging, and Retirement presentan un tamaño de muestra grande y representativo de varios países europeos, así como varias características sociodemográficas de la muestra del estudio. Otra fortaleza, considerando el tamaño de la muestra y la heterogeneidad de los participantes, es la posibilidad de generalizar estos resultados. Debido a la gran muestra, se tuvo una potencia estadística adecuada. Un análisis prospectivo en el estudio 3 permitió examinar la relación de antecedente y consecuente entre la actividad física y los síntomas depresivos.

Para los artículos originales presentados, la principal limitación puede ser la falta de información sobre la actividad física, como tipo, duración y frecuencia, lo que limita un cálculo preciso del volumen de actividad física. La actividad física fue autoinformada, lo que

es susceptible de sesgo. Debido a algunos factores, como la deseabilidad social, puede haber una sobreestimación de la frecuencia de la actividad física (Adams et al., 2005). Además, para esta muestra de estudio, no se evaluó la validez y fiabilidad de las preguntas para evaluar la frecuencia de actividad física. No obstante, la actividad física autoinformada es un método que ha mostrado ser fiable en estudios epidemiológicos (Craig et al., 2003) y sigue siendo la columna vertebral de los estudios de vigilancia epidemiológica (Pedisic y Bauman, 2015). La fuerza es un marcador común de la salud física general que se reconoce que está relacionada con las condiciones de salud mental. Sin embargo, no hubo información sobre el tamaño de la mano, lo que podría afectar a la fuerza de agarre. Además, no se consideró la existencia de variación cultural en el uso de la fuerza de agarre en las rutinas sociales diarias.

Por otra parte, tampoco se pudo analizar información sobre los antecedentes familiares de depresión de cada participante, ni información sobre el tipo de depresión y su carga general sobre la vida diaria y la percepción de la calidad de vida del participante. Además, la depresión no se diagnosticó clínicamente. La escala EURO-D de 12 ítems es una herramienta de detección de síntomas de depresión. No obstante, hay evidencia en relación a un punto de corte de ≥ 4 síntomas de depresión para diagnosticar casos de depresión clínicamente significativos (Gallagher et al., 2013; Prince et al., 1999). Además, la medición de la puntuación de depresión, aunque es una metodología debidamente validada (Prince et al., 1999), podría ser susceptible de sesgo. Por ejemplo, las fluctuaciones del estado de ánimo pueden influir en las respuestas de los participantes.

En la revisión sistemática que analizó el efecto de la fuerza muscular sobre los síntomas de depresión en adultos, la mayoría de los estudios usaron la fuerza de agarre como una medida de la fuerza muscular, mientras que otros estudios usaron diferentes medidas. Esto conduce a la heterogeneidad en el resultado de la fuerza muscular. Si bien los estudios fueron evaluados según su calidad metodológica, no fueron ponderados ni clasificados de

acuerdo con ella para la revisión sistemática. Por lo tanto, los hallazgos de estudios con una calidad más débil y tamaños de muestra más pequeños no recibieron menos importancia que los hallazgos de estudios con diseños de investigación sólidos y tamaños de muestra más grandes. Además, la mayoría de los estudios fueron transversales y por esa razón no es posible verificar la causalidad ni relaciones de carácter prospectivo. Además, se seleccionaron términos de búsqueda para identificar artículos que asociaban fuerza muscular y depresión. Aun así, algunos artículos se dejaron fuera porque no tenían un término que pudiera asociarse con fuerza muscular o depresión.

Para la revisión sistemática de los desplazamientos activos, varios artículos no establecieron una distinción clara entre el transporte activo como forma de desplazamiento y el transporte activo como forma de ocio. Esta falta de distinción impide un análisis más riguroso de la relación entre transporte activo y síntomas de depresión. Algunos estudios se centraron en poblaciones o trabajadores específicos, lo que puede comprometer la generalizabilidad de los resultados a la población general.

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Appendixes

Appendix 1. Publication from the doctoral thesis

Marques, A., Peralta, M., Gouveia, R., Martins. J., Sarmento, H., & Gomez-Baya, D. (2019). Leisure-time physical activity is negatively associated with depression symptoms independently of the socioeconomic status. *European Journal of Sport Science*. DOI: 10.1080/17461391.2019.1701716.

Marques, A., Matos, M. G., Bordado, J., Gouveia, E., Peralta, M., & Gomez-Baya, D. (2020). Different levels of physical activity and depression symptoms among older adults from 18 countries: A population-based study from the Survey of Health, Ageing and Retirement in Europe (SHARE). *European Journal of Sport Science*. DOI: 10.1080/17461391.2020.1795273

Marques, A., Bordado, J., Peralta, M., Gouveia, E.R., Tesler, R., Demetriou, Y., & Gomez Baya, D. (2020). Cross-sectional and prospective relationship between physical activity and depression symptoms. *Scientific Reports, 10,* 16114. DOI: 10.1038/s41598-020-72987-4

Marques, A., Gaspar de Matos, M., Henriques-Neto, D., Peralta, M., Gouveia, E. G., Tesler, R., Martins, J., & Gomez Baya, D. (2020). Grip strength and depression symptoms among middle-age and older adults. Mayo Clinic Proceedings, 95(10), 2134-2143. DOI: 10.1016/j.mayocp.2020.02.035

Marques, A., Gomez-Baya, D., Peralta, M., Frasquilho, D., Santos, T., Martins, J., Ferrari, G., & Matos, M. G. (2020). The effect of muscular strength on depression symptoms in adults: A systematic review and meta-analysis. *International Journal of Environmental Research and Public Health, 17,* 5674. DOI: 10.3390/ijerph17165674

Marques, A., Gomez-Baya, D., Peralta, M., Frasquilho, D., Santos, T., Martins, J., Ferrari, G., & Matos, M. G. (2020). The effect of muscular strength on depression symptoms in adults: A systematic review and meta-analysis. *International Journal of Environmental Research and Public Health, 17,* 5674. DOI: 10.3390/ijerph17165674

Appendix 2. Journal impact factor report of the published articles

Article 1

Marques, A., Peralta, M., Gouveia, R., Martins. J., Sarmento, H., & Gomez-Baya, D. (2019). Leisure-time physical activity is negatively associated with depression symptoms independently of the socioeconomic status. *European Journal of Sport Science*. DOI: 10.1080/17461391.2019.1701716.

1. Clarivate Analytics (Web of Science)
1.1. Impact factor: 2.42
1.2. Category: Sport Sciences

2. SCImago
2.1. SCImago Journal Rank (SJR): 1.13
2.2. H index: 47

Article 2

Marques, A., Matos, M. G., Bordado, J., Gouveia, E., Peralta, M., & Gomez-Baya, D. (2020). Different levels of physical activity and depression symptoms among older adults from 18 countries: A population-based study from the Survey of Health, Ageing and Retirement in Europe (SHARE). *European Journal of Sport Science*. DOI: 10.1080/17461391.2020.1795273

1. Clarivate Analytics (Web of Science)
1.1. Impact factor: 2.42
1.2. Category: Sport Sciences

2. SCImago
2.1. SCImago Journal Rank (SJR): 1.13
2.2. H index: 47

Article 3

Marques, A., Bordado, J., Peralta, M., Gouveia, E.R., Tesler, R., Demetriou, Y., & Gomez Baya, D. (2020). Cross-sectional and prospective relationship between physical activity and depression symptoms. *Scientific Reports, 10,* 16114. DOI: 10.1038/s41598-020-72987-4

1. Clarivate Analytics (Web of Science)
1.1. Impact factor: 4.12
1.2. Category: Multidisciplinary Sciences

2. SCImago
2.1. SCImago Journal Rank (SJR): 1.414
2.2. H index: 179

Article 4

Marques, A., Gaspar de Matos, M., Henriques-Neto, D., Peralta, M., Gouveia, E. G., Tesler, R., Martins, J., & Gomez Baya, D. (2020). Grip strength and depression symptoms among middle-age and older adults. *Mayo Clinic Proceedings, 95*(10), 2134-2143. DOI: 10.1016/j.mayocp.2020.02.035

1. Clarivate Analytics (Web of Science)
1.1. Impact factor: 7.09
1.2. Category: Medicine, General & Internal

2. SCImago
2.1. SCImago Journal Rank (SJR): 2.18
2.2. H index: 171

Article 5

Marques, A., Gomez-Baya, D., Peralta, M., Frasquilho, D., Santos, T., Martins, J., Ferrari, G., & Matos, M. G. (2020). The effect of muscular strength on depression symptoms in adults: A systematic review and meta-analysis. *International Journal of Environmental Research and Public Health, 17*, 5674. DOI: 10.3390/ijerph17165674

1. Clarivate Analytics (Web of Science)
1.1. Impact factor: 2.47
1.2. Category: Public, Environmental & Occupational Health

2. SCImago
2.1. SCImago Journal Rank (SJR): 0.739
2.2. H index: 92

Article 6

Marques, A., Gomez-Baya, D., Peralta, M., Frasquilho, D., Santos, T., Martins, J., Ferrari, G., & Matos, M. G. (2020). The effect of muscular strength on depression symptoms in adults: A systematic review and meta-analysis. *International Journal of Environmental Research and Public Health, 17*, 5674. DOI: 10.3390/ijerph17165674

1. Clarivate Analytics (Web of Science)
1.1. Impact factor: 2.47
1.2. Category: Public, Environmental & Occupational Health

2. SCImago
2.1. SCImago Journal Rank (SJR): 0.739
2.2. H index: 92

Appendix 3. Copy of the published articles

Los artículos publicados, que forman parte del apartado "Appendix 3", han sido retirados de la tesis debido a restricciones relativas a derechos de autor. En sustitución de los artículos ofrecemos la siguiente información: referencia bibliográfica, enlace a la revista y resumen.

- Marques, A., Peralta, M., Gouveia, R., Martins. J., Sarmento, H., & Gomez-Baya, D. (2019). Leisure-time physical activity is negatively associated with depression symptoms independently of the socioeconomic status. European Journal of Sport Science. DOI: 10.1080/17461391.2019.1701716.

Enlace al texto completo del artículo:https://doi.org/10.1080/17461391.2019.1701716

RESUMEN:

Objective: There are few studies evaluating the relationship between depression symptoms (DS) and physical activity (PA) considering peoples' sociodemographic characteristics. This study aimed to analyse the relationship between DS and PA, stratified by sociodemographic characteristics of European adults.

Methods: Participants were 29,285 adults (13,943 men, 47.6%; 15,342 women, 52.4%), aged 50.9 ± 17.4 (50.6 ± 17.3 men, 51.1 ± 17.5 women) from the European Social Survey round 7. DS was assessed with the Centre for Epidemiological Studies Depression Scale (CES-D8). Leisure-time PA (LTPA) was self-reported. The analysed sociodemographic characteristics were sex, age, living place, household members, marital status, income, and educational level. The relationship between DS and PA, stratified by sociodemographic variables, was examined by linear regression models.

Results: Engaging in LTPA was negatively and linearly related to DS, independently of being men or women, being younger, middle or older adult, living in an urban or rural area, having children or not, being single or married, being wealthy or poor, employment status, and to having a lower or a higher education level. Age was the variable with both the least and the greatest effect of LTPA on DS. The least effect of LTPA on DS was observed in younger adults (β = −0.08, 95% CI: −0.11, −0.05) and the greatest effect in retired people (β = −0.33, 95% CI: −0.36, −0.29).

Conclusion: Independently of sociodemographic characteristics, LTPA is associated with DS and can benefit everyone. Public health policies for promoting mental health should include PA promotion as an important strategy for the prevention or treatment of DS.

- Marques, A., Matos, M. G., Bordado, J., Gouveia, E., Peralta, M., & Gomez-Baya, D. (2020). Different levels of physical activity and depression symptoms among older adults from 18 countries: A population-based study from the Survey of Health, Ageing and Retirement in Europe (SHARE). European Journal of Sport Science. DOI: 10.1080/17461391.2020.1795273

Enlace al texto completo del artículo: https://doi.org/10.1080/17461391.2020.1795273

RESUMEN:
Objective: Analyse the relationship between different levels of physical activity (PA) and depression symptoms in a representative sample of European older adults. **Methods:** Data on PA, depression symptoms and sociodemographic variables from 64688 (28015 men) older adults participating in SHARE wave 6 was collected through a face-to-face interview. The EURO-D 12-item scale was administered for depression symptoms. Participants reported the frequency they engaged in moderate-intensity PA (MPA) and vigorous-intensity PA (VPA). **Results**: Men and women engaging in MPA and VPA once or more than once a week had less depression symptoms than those who engage less than once a week. MPA and VPA once or more than once a week were inversely associated with the depression symptoms score. Furthermore, engaging in MPA and VPA decreased the odds of depression (cut-off point of ≥4 depression symptoms) compared to engaging in PA less than once a week. **Conclusions**: Policies for promoting mental health should include PA for the prevention or treatment of depression symptoms. PA presents physical and psychological benefits and can be used as an overall health-promoting strategy, facing numerous problems at a time.

- Marques, A., Gaspar de Matos, M., Henriques-Neto, D., Peralta, M., Gouveia, E. G., Tesler, R., Martins, J., & Gomez Baya, D. (2020). Grip strength and depression symptoms among middle-age and older adults. Mayo Clinic Proceedings, 95(10), 2134-2143. DOI: 10.1016/j.mayocp.2020.02.035

Enlace al texto completo del artículo: https://doi.org/10.1016/j.mayocp.2020.02.035

RESUMEN:

Objective

To analyze the relationship between grip strength and symptoms of depression, considering sex and age, in adults from 18 countries.

Methods

Cross-sectional data for adults 50 years and older from the Survey of Health, Aging, and Retirement in Europe wave 6 (collected in 2015) were analyzed. Grip strength was measured twice on each hand using a handgrip dynamometer. The EURO-D 12-item

scale was used to measure depression symptoms. Multivariable logistic regression analysis was conducted. Data analyses were conducted between November 5, 2019, and February 7, 2020.

Results

Men and women who were in quartiles 2, 3, and 4 of grip strength were less likely to have depression symptoms than those in the first quartile of grip strength. Having more grip strength decreased the odds of depression symptoms by 30% (odds ratio 0.70; 95% CI, 0.65 to 0.77) and 47% (odds ratio, 0.53; 95% CI, 0.49 to 0.57) for adults aged 50 to 64 years and 65 years and older, respectively, when compared with those with the lowest grip strength. The negative relationship between strong grip strength and depression symptoms was observed among men and women younger and older than 65 years.

Conclusion

There was an association between grip strength and depression symptoms. For clinical practice and geriatric health professionals, assessing adults' grip strength can be used as a signal to screen for physical and mental health.

Appendix 3. Copy of the published articles

Article 1

Marques, A., Peralta, M., Gouveia, R., Martins. J., Sarmento, H., & Gomez-Baya, D. (2019). Leisure-time physical activity is negatively associated with depression symptoms independently of the socioeconomic status. *European Journal of Sport Science*. DOI: 10.1080/17461391.2019.1701716.

Article 2

Marques, A., Matos, M. G., Bordado, J., Gouveia, E., Peralta, M., & Gomez-Baya, D. (2020). Different levels of physical activity and depression symptoms among older adults from 18 countries: A population-based study from the Survey of Health, Ageing and Retirement in Europe (SHARE). ***European Journal of Sport Science*****. DOI: 10.1080/17461391.2020.1795273**

Article 3

Marques, A., Bordado, J., Peralta, M., Gouveia, E.R., Tesler, R., Demetriou, Y., & Gomez Baya, D. (2020). Cross-sectional and prospective relationship between physical activity and depression symptoms. *Scientific Reports, 10,* 16114. DOI: 10.1038/s41598-020-72987-4

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Cross-sectional and prospective relationship between physical activity and depression symptoms

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This study aimed to analyse the cross-sectional and prospective relationship between moderate and vigorous physical activity (PA) and depression symptoms. This study analysed 32,392 European late middle-aged to older adults, from 14 European countries across a 4-year follow-up. Data was collected in the fourth (in 2011) and sixth (in 2015) wave, from the Survey of Health, Ageing and Retirement in Europe (SHARE). For the present analysis, participants were considered who responded to the EURO-D 12-item scale of depression symptoms and reported the intensity and frequency of PA. ANCOVAs were conducted to assess the cross-sectional and prospective associations. For both men and women, engaging in moderate or vigorous PA in 2011 was associated with a lower score of depression in 2011 and 2015. From the prospective analysis, moderate and vigorous PA in 2011 was inversely associated with the score of depression. This association remains significant in the fully adjusted for self-rated health, sociodemographic characteristics, and the presence of chronic diseases. Moderate and vigorous PA at least once a week is negatively related to the score of depression, both in men and women. PA is negatively associated with depression symptoms, and from prospective analysis PA predicts lower depression scores 4 years later.

The prevalence of depression has been rising globally with an estimate that more than 300 million people suffer from this condition[1]. Additionally, it is estimated that about one-third of depressive cases evolve into moderate-to-severe symptomatic depressions[2]. Depression, following heart disease, is projected to be the second-largest contributor to the global burden of disease by 2020[3], and it is already considered as the greatest non-fatal disease contributory to the loss of health[1].

The prevalence of depression is the highest among the 55–74 years old age group[1]. Comparing with other chronic diseases, it appears that older people suffering from depression are less functional[4]. However, as other age-related diseases might have concomitant symptoms, depression appears to be often neglected and even underdiagnosed in primary health care[5]. In late middle aged to older people, serious health consequences are associated with untreated or poorly treated depressions, including increased mortality[6].

The development of depression seems to increase with low levels of physical activity (PA)[7]. Strong evidence exists regarding the positive effects of PA for both the prevention and treatment of depression, being even considered an alternative to antidepressant medication[8]. Depression and PA have been the subject of several studies, however, often the sample size is small and restricted to one country or specific area, and most studies do not control for moderate and vigorous PA intensity levels, respectively. Thus, the present study aims to analyse the cross-sectional and prospective relationship between different PA intensity levels and depression symptoms in a large sample of European late middle aged to older adults.

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Methods

This study analysed data from the Survey of Health, Ageing and Retirement in Europe (SHARE) from wave 4 (performed in 2011) and wave 6 (performed in 2015). SHARE is a multidisciplinary and cross-national survey resulting from the need to study and provide answers regarding the growing and upcoming challenges of population ageing. SHARE's data collection has been conducted biannually, since 2000. Including about 140,000 individuals aged 50 or older, from European countries and Israel, SHARE is a multicultural database of health microdata, socio-economic status, social and family networks. In the present study, including waves 4 and 6, participants were from the 14 following countries: Austria, Germany, Sweden, Spain, Italy, France, Denmark, Switzerland, Belgium, Czech Republic, Poland, Portugal, Slovenia, and Estonia[9]. The total sample consisted of 34,772 men and women that participated in both wave 4 and wave 6. For the present study, the final sample comprised 32,392 participants (13,511 men, 18,881 women) that responded to the 12-item depression scale and reported on PA.

All interviews were conducted by trained interviewers at the participant's house location and had a duration of approximately 90 min. SHARE's questions encompass a large spectrum of subjects, such as health, and social variables. For the research community, SHARE's data is available free of charge (www.share-project.org)[9]. Participants were informed about the objectives of the study and informed written consent was obtained. The study was in accordance with the ethical standards in sport and exercise science research[10]. All methods were performed in accordance with the relevant guidelines and regulations; and participation was anonymous and there were no incentives for participation. The SHARE's protocol was approved by the Ethics Committee of the University of Mannheim and by the Ethics Council of the Max-Planck-Society for the Advancement of Science.

Measurements. *Covariates.* Individual's characteristics were measured at the baseline and include age, sex, marital status, education level, living place, country, self-rated health and the number of chronic diseases. Age was recoded into 50–64 years, 65–79 years, and ≥ 80 years. According to the International Standard Classification of Education-97 (ISCED- 97) codes, education was collected and categorized in three groups: (1) low education level, including participants with no education or ISCED-97 codes 1 and 2; (2) middle educational level, which included participants with ISCED-97 codes 3 and 4; (3) high education level, which included participants with ISCED-97 codes 5 and 6. Marital status was coded into married, including a registered partnership or living together; and not married, including single, separated, divorced or widowed. To determine the participants' living place, they were asked to report on whether they lived in a big city, a suburb or the outskirts of a big city, a large town, a small town, or in rural area or village. Self-related health was accessed through a single-item question about their general health perception, using a 5-point scale response (excellent, very good, good, fair and poor). This scale was inverted for data analysis; therefore, higher values represent better health perception.

Number of chronic diseases. To determine the number of chronic medical diseases participants were asked to report the presence or absence of diseases that were previously diagnosed by a doctor, based on a list with 14 listed diseases (heartattack, hypertension, cholesterol, stroke, diabetes, lung disease, asthma, arthritis, osteoporosis, cancer, ulcer, Parkinson disease, cataracts, hip femoral fracture). Participants could also add other medical conditions, diagnosed by a doctor, unnamed in the list[11]. In order to produce a single score, the number of chronic diseases was summed as performed previously[12,13].

Physical activity. With the purpose to measure intensity and frequency of PA, participants were asked to report on how many days per week they practiced moderate PA such as, brisk walking, gardening or household activities; as well as the frequency of vigorous PA, including activities like hiking, sports, carrying heavy loads. To measure its frequency, for both moderate and vigorous activities, the responses were categorized into: (1) more than once a week, (2) once a week, (3) up to three times a month, and (4) hardly ever or never. The responses up to three times a month and hardly ever or never were grouped into a category named "less than once a week" as performed previously[12,13].

Depression. The EURO-D 12-item scale was developed and validated to assess and compare cross-nationally symptoms of depression in Europe[14]. This scale asks about the presence or absence of depression symptoms in 12 domains s that are: depressed mood, pessimism, suicidality, guilt, sleep, interest, irritability, appetite, fatigue, concentration, enjoyment, and tearfulness. Each depression's domain is scored one if present and zero if absent. The sum of all domains results in the total score between 0 and 12. In each of the EURODEP study sites the score's validation was carried out and an optimal cut-off point of 4 or more points to diagnose a clinically significant depression was demonstrated[11,14].

Data analysis. Descriptive statistics were calculated (means, standard deviation, and percentages) for the entire sample, and were stratified by sex. ANOVA tests were performed, to analyse the bivariate cross-sectional and prospective relationships between, moderate and vigorous PA and the score of depression symptoms, in 2011 and 2015. Using ANCOVA, the cross-sectional and prospective association between moderate and vigorous PA, with the score of depression was analysed. For the cross-sectional analysis, different models were performed. Model 1 is the unadjusted analysis between the PA and the depression score. Model 2 was adjusted for age, marital status, educational level, living place, country, and self-rated health. Model 3 was further adjusted for the number of chronic diseases. A fourth model was created for prospective analysis. Model 4 was further adjusted from Model 3's variables, depression score at baseline. Women are more prone to have depression symptoms than men[15], therefore, analysis were stratified by sex. Binary logistic regressions were conducted to

	2011 (% or M ± SD)			2015 (% or M ± SD)		
	Men	Women	*p*	Men	Women	*p*
Age	65.4 ± 9.0	65.0 ± 9.7	< 0.001	69.4 ± 9.3	68.9 ± 10.0	< 0.001
Age group			< 0.001			< 0.001
50–64 years	49.5	51.6		33.3	36.2	
65–79 years	43.0	39.9		51.3	47.9	
≥ 80 years	7.6	8.5		15.4	15.9	
Education			< 0.001			< 0.001
Low	36.3	42.3		36.3	42.3	
Middle	40.4	38.2		40.4	38.1	
High	23.3	19.5		23.4	19.5	
Marital status			< 0.001			< 0.001
Not married	22.9	39.1		42.4	67.8	
Married	77.1	60.9		57.6	32.2	
Living place			< 0.001			< 0.001
Big city	13.1	15.2		13.5	15.2	
Suburbs of a big city	10.1	9.5		11.4	9.8	
Large town	14.8	16.7		13.7	15.1	
Small town	24.4	24.4		25.1	25.0	
Rural area	37.6	34.2		36.3	35.0	
EURO depression scale (score)	1.9 ± 1.9	2.9 ± 2.3	< 0.001	2.0 ± 2.0	2.9 ± 2.3	< 0.001
Depressive symptoms (score ≥ 4)	18.4	33.8	< 0.001	19.6	34.0	< 0.001
Self-rated health	2.9 ± 1.1	2.8 ± 1.1	< 0.001	2.8 ± 1.0	2.7 ± 1.0	< 0.001
Number of chronic diseases	1.6 ± 1.4	1.7 ± 1.5	< 0.001	1.7 ± 1.5	2.0 ± 1.7	< 0.001
Moderate PALess than once a week	14.1	17.1	< 0.001	16.1	18.7	
Once a week	13.6	14.2		11.9	12.6	< 0.001
More than once a week	72.3	68.7		72.0	68.7	
Vigorous PA			< 0.001			
Less than once a week	45.1	55.6		49.8	58.0	< 0.001
Once a week	14.4	14.4		13.5	13.1	
More than once a week	40.5	30.0		36.7	28.9	

Table 1. Participants' characteristics (n = 32,392). *M* media, *SD* standard deviation, *PA* physical activity. [a]Tested by Chi Square. [b]Tested by t test.

assess the association between PA trajectory over the years and depression symptoms. An interaction effect was observed between age (50–64 years, 65–80 years, and ≥ 80 years) and PA, on depression symptoms. Thus, analyses were stratified by sex, age-groups. Data analysis was performed using SPSS 25. Statistical significance was set at two-sided $p < 0.05$.

Results

Table 1 shows the sociodemographic characteristics of the participants. The depression score was significantly higher in women than in men, both in 2011 ($p < 0.001$) and in 2015 ($p < 0.011$). Moreover, significantly more women than men (33.8% vs. 18.4% in 2011; 34% vs. 19.6% in 2015) presented depressive symptoms (≥ 4 EURO depression score). Regarding the practice of PA, men engaged significantly more often in moderate PA ($p < 0.001$) and vigorous PA ($p < 0.001$) per week than women.

Table 2 presents the cross-sectional parameters estimates of depression score according to PA intensity and frequency. For both genders, moderate and vigorous PA were negatively associated with the depression score. In the fully adjusted model (analyses adjusted for age, marital status, educational level, living place, country, self-rated health, and the number of chronic diseases), for men, practicing moderate PA once a week (β = − 0.37, 95% CI − 0.50, − 0.24, p < 0.001) and more than once a week (β = − 0.56, 95% CI − 0.66, − 0.46, p < 0.001) was negatively associated with the score of depression. For vigorous PA, similar results were observed (once a week: β = − 0.29, 95% CI − 0.40, − 0.17, p < 0.001; more than once a week: β = − 0.32, 95% CI − 0.41, − 0.24, p < 0.001), PA was negatively associated with depression score. Regarding women, practicing moderate PA once a week (β = − 0.37, 95% CI − 0.50, − 0.25, p < 0.001) and more than once a week (β = − 0.56, 95% CI − 0.65, − 0.47, p < 0.001) was also negatively associated with a lower score of depression. Similarly, this results were also observed for practicing vigorous PA (once a week: β = − 0.35, 95% CI − 0.46, − 0.24, p < 0.001; more than once a week: β = − 0.17, 95% CI − 0.25, − 0.08, p < 0.001).

Table 3 shows the prospective analysis of parameters estimates predicting the score of depression. Moderate and vigorous PA practice, once or more than once a week were negatively associated with the depression score 4 years later. Even when the model was fully adjusted (model 3), this relationship remained significant. Regarding

	Parameters estimates of predicting the score of depression in 2011		
	Model 1 β (95% CI)	Model 2 β (95% CI)	Model 3 β (95% CI)
Men			
MPA in 2011			
Less than once a week	ref	ref	Ref
Once a week	− 0.97 (− 1.06, − 0.87)*	− 0.37 (− 0.51, − 0.24)*	− 0.37 (− 0.50, − 0.24)*
More than once a week	− 1.31 (− 1.38, − 1.24)*	− 0.56 (− 0.66, − 0.46)*	− 0.56 (− 0.66, − 0.46)*
VPA in 2011			
Less than once a week	ref	ref	Ref
Once a week	− 0.75 (− 0.83, − 0.67)*	− 0.31 (− 0.43, − 0.20)*	− 0.29 (− 0.40, − 0.17)*
More than once a week	− 0.87 (− 0.92, − 0.81)*	− 0.36 (− 0.45, − 0.28)*	− 0.32 (− 0.41, − 0.24)*
Women			
MPA in 2011			
Less than once a week	ref	ref	Ref
Once a week	− 1.04 (− 1.13, − 0.95)*	− 0.41 (− 0.53, − 0.28)*	− 0.37 (− 0.50, − 0.25)*
More than once a week	− 1.41 (− 1.47, − 1.34)*	− 0.58 (− 0.67, − 0.49)*	− 0.56 (− 0.65, − 0.47)*
VPA in 2011			
Less than once a week	ref	ref	Ref
Once a week	− 0.89 (− 0.97, − 0.82)*	− 0.42 (− 0.53, − 0.31)*	− 0.35 (− 0.46, − 0.24)*
More than once a week	− 0.88 (− 0.93, − 0.81)*	− 0.21 (− 0.29, − 0.12)*	− 0.17 (− 0.25, − 0.08)*

Table 2. Cross-sectional parameters estimate of depression score according to physical activity intensity levels and frequency. Model 1: Unadjusted analyses. Model 2: Analyses were adjusted for age, marital status, educational level, living place, country and self-rated health. Model 3: Analyses were adjusted for age, marital status, educational level, living place, country, self-rated health, and the number of chronic diseases. *MPA* moderate physical activity, *VPA* vigorous physical activity, *CI* confidence interval. *$p < 0.001$.

	Parameters estimates of predicting the score of depression in 2015		
	Model 1 β (95% CI)	Model 2 β (95% CI)	Model 3 β (95% CI)
Men			
MPA in 2011			
Less than once a week	Ref	Ref	Ref
Once a week	− 0.64 (− 0.77, − 0.51)***	− 0.25 (− 0.44, − 0.06)**	− 0.12 (− 0.30, 0.06)
More than once a week	− 0.83 (− 0.93, − 0.74)***	− 0.43 (− 0.57, − 0.28)***	− 0.26 (− 0.40, − 0.12)**
VPA in 2011			
Less than once a week	Ref	Ref	Ref
Once a week	− 0.55 (− 0.65, − 0.45)***	− 0.15 (− 0.30, 0.01)	− 0.07 (− 0.22, 0.07)
More than once a week	− 0.63 (− 0.70, − 0.56)***	− 0.21 (− 0.32, − 0.09)***	− 0.13 (− 0.24, − 0.03)*
Women			
MPA in 2011			
Less than once a week	Ref	Ref	Ref
Once a week	− 0.82 (− 0.93, − 0.70)***	− 0.35 (− 0.52, − 0.18)***	− 0.26 (− 0.42, − 0.10)**
More than once a week	− 1.23 (− 1.32, − 1.15)***	− 0.70 (− 0.83, − 0.57)***	− 0.52 (− 0.64, − 0.40)**
VPA in 2011			
Less than once a week	Ref	Ref	Ref
Once a week	− 0.66 (− 0.76, − 0.57)***	− 0.26 (− 0.40, − 0.12)***	− 0.13 (− 0.26, − 0.01)
More than once a week	− 0.79 (− 0.86, − 0.71)***	− 0.31 (− 0.42, − 0.20)***	− 0.20 (− 0.31, − 0.10)***

Table 3. Prospective parameters estimate of Depression Score to physical activity intensity levels and frequency. Model 1: Unadjusted analyses. Model 2: Analyses were adjusted for age, marital status, educational level, living place, country, self-rated health, and the number of chronic diseases. Model 3: Analyses were adjusted for age, marital status, educational level, living place, country, self-rated health, the number of chronic diseases in 2011, and depression scores at baseline. *MPA* moderate physical activity, *VPA* vigorous physical activity, *CI* confidence interval. *$p < 0.05$**, $p < 0.01$, **$p < 0.001$.

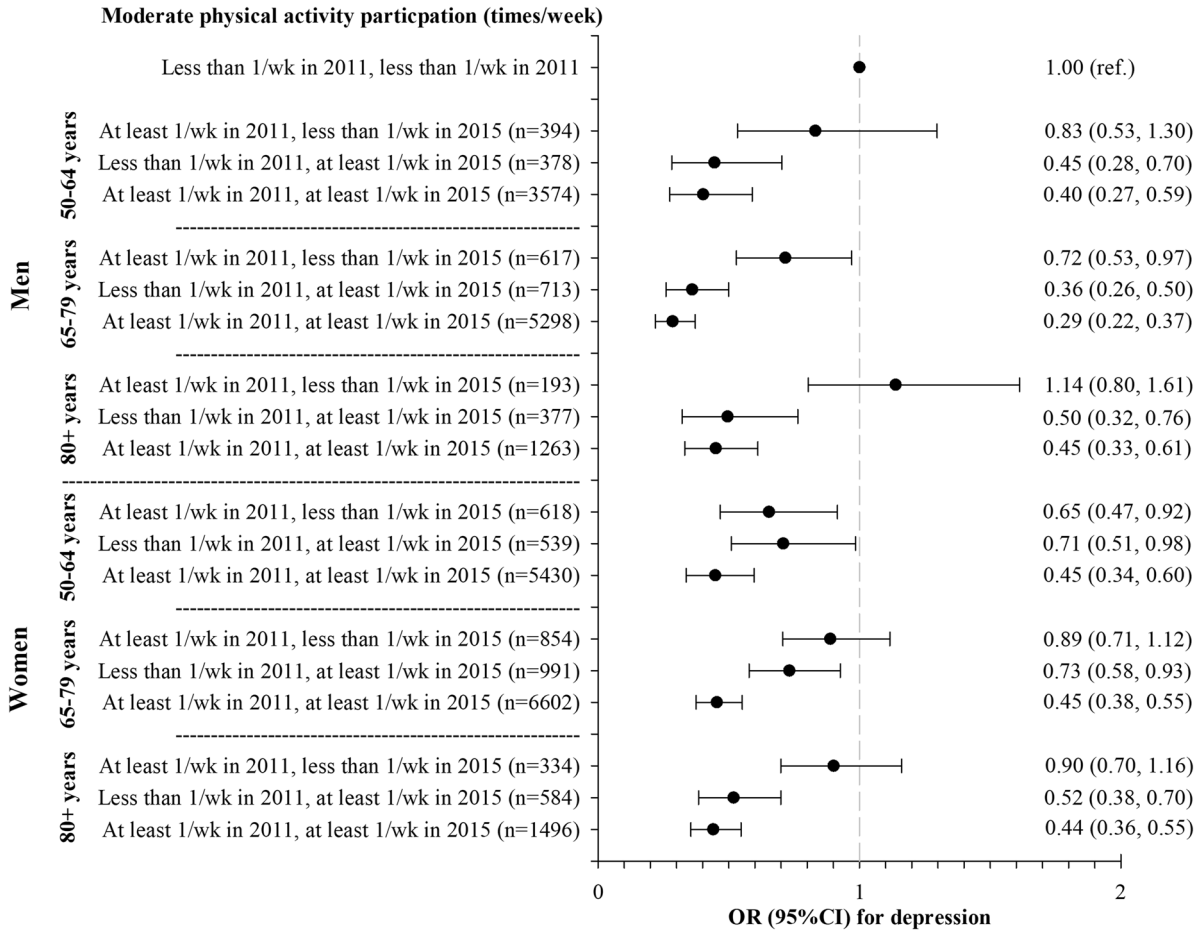

Figure 1. Relationship between moderate physical activity trajectory from 2011 to 2015 and depression symptoms (depression score ≥4). Analyses were adjusted for age, marital status, educational level, living place, country, self-rated health, the number of chronic diseases, and depression scores at baseline. *wk* week, *OR* odds ratio, *CI* confidence interval.

men, engaging in moderate PA (more than once a week: β = − 0.26, 95% CI − 0.40, − 0.12, $p < 0.01$) and vigorous PA showed a significant reduction of depression score (more than once a week: β = − 0.13, 95% CI − 0.24, − 0.03, $p < 0.05$). Among women, moderate PA (once a week: β = − 0.26, 95% CI − 0.42, − 0.10, $p < 0.01$; more than once a week: β = − 0.52, 95% CI − 0.64, − 0.40, $p < 0.01$) and vigorous PA (more than once a week: β = − 0.20, 95% CI − 0.31, − 0.10, $p < 0.001$) significantly reduced the depression score. In general, prospective analysis showed that PA predicts lower depression scores 4 years later.

Figures 1 and 2 present the results of the logistic regression analyses of the relationship between PA trajectory from 2011 to 2015 and depression symptoms (depression score ≥ 4). For moderate PA, in all age groups for both men and women, being active in the present decreases significantly the odds of having depressive symptoms, even if they hadn't practiced PA less than once a week, compared to those consistently less active (engage in PA less than once a week). Except for women aged 50–64 years, those who practiced PA at least once a week but stopped practicing do not differ significantly from those who were consistently less active. Very similar results were observed for vigorous PA in all age groups for men and women. Those who engage in vigorous PA at least once a week consistently or only in the present had less likelihood of having depressive symptoms when compared to those consistently less active.

Discussion

The cross-sectional and prospective relationship between PA and the depression score were analysed through a 4-year period (2011–2015) in a large sample of European late middle aged to older adults from 14 countries. The main result of this study emphasizes that those who practice PA less than once a week are more prone to have higher scores of depression, than those who engage in PA at least once a week. This result was found for both sexes in the cross-sectional and prospective analysis. Moreover, engage in moderate or vigorous PA at least once a week consistently or only in the present is related to lower odds of having depressive symptoms when compared to those consistently less active.

Emphasizing the importance of regular PA practice, these study results corroborate the current literature associating PA with lower depression scores or depression symptomatology[16,17]. The positive effects of PA in

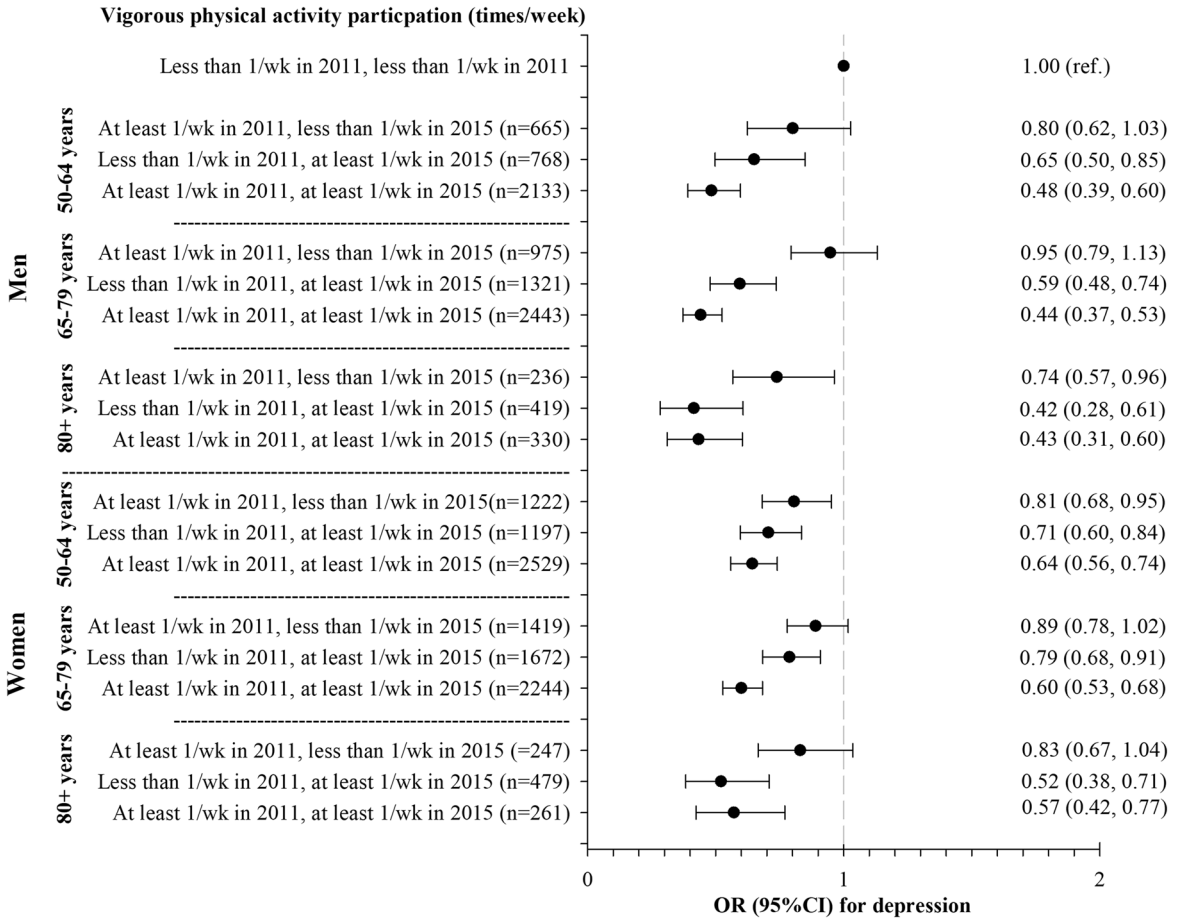

Figure 2. Relationship between vigorous physical activity trajectory from 2011 to 2015 and depression symptoms (depression score ≥4). Analyses were adjusted for age, marital status, educational level, living place, country, self-rated health, the number of chronic diseases, and depression scores at baseline. *wk* week, *OR* odds ratio, *CI* confidence interval.

depression symptomology are well documented[16,18,19], it is even considered by some authors as comparable to antidepressant treatments[20]. A review of four meta-analyses reached the conclusion that PA effects seem to be similar to those of medication and psychotherapy for mild-to-moderate depression[21]. This review, also noted that PA seems to be a valuable complement to standard clinical approaches for severe depression[21]. Furthermore, in late life treatment-resistant depressions it was found that combining PA with antidepressant medication seems to have a promising beneficial effect[22]. Nonetheless, more detailed clinical approaches are necessary for optimal PA and medication prescription to strongly support its clinical administration[23].

In order to better understand the relationship between PA and depression, it is important to consider the characteristics of PA, such as frequency and intensity[24]. However, most studies only account for the amount of PA and intensity and frequency is rarely considered at the same time[19]. Acknowledging this gap, the present study provides PA frequency and intensity differentiation. Regarding intensity, it was found that moderate PA had a stronger inverse association with the depression score, than vigorous PA, in both cross-sectional and prospective analysis. This may be related to the proportion of older adults practicing these intensities of PA. Older adults are not expected to have the capacity to practice high amounts of vigorous PA, thus moderate PA is a more achievable way to practice PA and collect its benefits. Regarding frequency, practicing PA more than once a week had a stronger inverse association with the depression score, than practicing once a week, in both cross-sectional and prospective analysis. However, it is important to point out that, engage in PA once a week was still inversely associated with the depression score, supporting the idea that even little PA is beneficial. Furthermore, practicing PA at least once a week consistently over the years or only in the present is associated with a reduced risk of depressive symptoms when compared to those who practice less than once a week over the years.

Previous studies have found contradicting results considering sexes. For example, Mikkelsen, et al.[25] reported that whereas women seem to be significantly at higher risk of depression when practicing low levels of PA, men did not. Contrary, other studies disclosed that men that did not achieve the recommended levels of PA had a higher likelihood of depression, but for women these results were less clear[26]. In this study, both men and women presented inverse associations between PA and the depression score, however, it is interesting to notice that the association was of a higher magnitude among women, especially in the prospective analysis. Notwithstanding, these study results demonstrate that PA is beneficial and has a similar impact on depression score reduction for both men and women.

Some limitations must be acknowledged. PA was self-reported, which is more likely to be biased than using an objective measurement[27]. Moreover, PA data indicate intensity and frequency, however, there is no information about the duration. This would be of importance to understand the effect PA duration in each session on depressive symptoms. Due to some factors, such as social desirability, there may be an intensity and frequency overestimation when respondents are questioned about their PA levels[28]. Furthermore, the self-report PA does not allow a clear distinction to be made between moderate PA and vigorous PA, because moderate PA and vigorous PA are mixed or not-separated. Additionally, the depression score measurement, although being a properly validated methodology[14], might be susceptible to bias. For instance, mood fluctuations might influence participants' responses. Another limitation is the lack of information regarding light intensity PA. There is some research considering that depression may limit late middle aged to older adults to be more physically active, and thus, light PA plays an important role, presenting a beneficial association with depression[29].

Despite these limitations, the study presents some strengths. One of the major strengths is the use of a large sample of late middle aged to older adults from several European countries, which helps to mitigate the limitations of the indirect measurement of PA and depression. Furthermore, using a large European sample of late middle aged to older adults is considered relevant to provide strong evidence to policymakers, in order to strengthen the need for reflection upon the possible positive impact on society[30]. Lastly, the use of a cross-sectional and prospective design is recommended as it allows to better determine prevalence and to identify the causal associations between the studied variables[31,32].

Considering the results of this study and its limitations, for future research, it would be interesting to further explore the role of PA intensity and frequency on the association with depression in late middle aged to older adults. It would be also interesting to test our findings with less bias and more objective measurements of PA and depression, using accelerometers and medical diagnosed depression. Future studies with large sample sizes should seek to extend the follow-up period with regular inter-assessment intervals to have a better understanding of time effects on the associating between PA and depression (Supplemenrat information S1).

Conclusion

PA is inversely associated with depression, both cross-sectional and prospectively. From prospective analysis, it is clear that PA predict depression scores 4 years later. PA seems to provide positive effects on both prevention and treatment of depression. It is important to notice that it is enough to practice moderate PA to have a depression score reduction and that these results are significant for both men and women.

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Author contributions

A.M. participated in the design of the study, data analysis, and interpretation of the results; J.B. contributed to the interpretation of the results; M.P. contributed to data analysis and interpretation of results; R.T. and E.G. contributed to the interpretation of the results and data analysis; Y.D. contributed to the interpretation of the results and data analysis; D.G.B., contributed to the design of the study and interpretation of the results. All authors contributed to the manuscript writing. All authors have read and approved the final version of the manuscripts.

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Competing interests

The authors declare no competing interests.

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Article 4

Marques, A., Gaspar de Matos, M., Henriques-Neto, D., Peralta, M., Gouveia, E. G., Tesler, R., Martins, J., & Gomez Baya, D. (2020). Grip strength and depression symptoms among middle-age and older adults. *Mayo Clinic Proceedings, 95*(10), 2134-2143. DOI: 10.1016/j.mayocp.2020.02.035

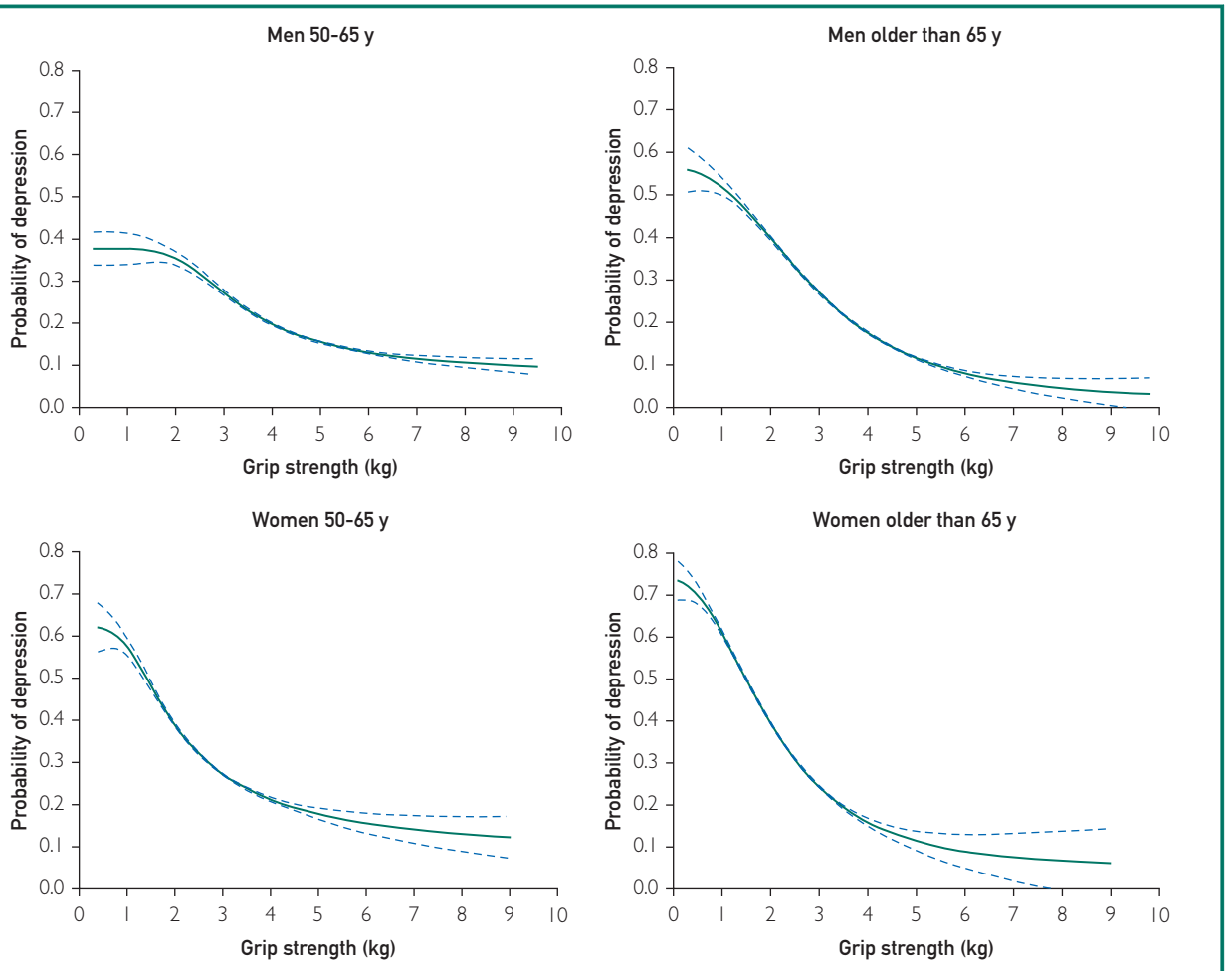

FIGURE 2. Spline curves and 95% CIs for the relationship between grip strength and the probability of depression by sex and age.

analyzed. We found that higher grip strength is significantly associated with having lower odds of depression. In particular, among men and women, those with higher grip strength were less likely to have depression symptoms than those with the lowest grip strength.

Although women and older adults are more prone to have depression symptoms than men,[24] grip strength, an important indicator of musculoskeletal function, seemed to have the same effect on depression regardless of sex or age. In this study, people with higher grip strength had significantly fewer depression symptoms relative to those with less grip strength. Depressive symptoms remained associated with reduced grip strength in adjusted models independent of sex and age. This is consistent with previous studies from other countries. In Japan and Korea, lower grip strength was associated with depressive symptoms in both cross-sectional and longitudinal analysis, regardless of sex, suggesting that muscular strength may prevent depression.[4,5] In studies carried out in Brazil and the United States, decreasing muscular strength was also significantly associated with depression.[25,26]

These results reinforce the importance of promoting muscular strength among older people. Physical activity recommendations suggest that older people should engage in muscle-strengthening activities that involve major muscle groups 2 or more days a week.[27] This is particularly important for

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Article 5

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Review

The Effect of Muscular Strength on Depression Symptoms in Adults: A Systematic Review and Meta-Analysis

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Abstract: The aim was to systematically review the relationship between muscular strength (MS) and depression symptoms (DS) among adults, and conduct a meta-analysis to determine the pooled odds ratio (OR) for the relationship between MS and DS. The strategies employed in this systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines. Studies published up to December 2019 were systematically identified by searching in the PubMed, Scopus, and Web of Science electronic databases. Inclusion criteria were: (1) cross-sectional, longitudinal and intervention studies; (2) outcomes included depression or DS; (3) participants were adults and older adults; and (4) the articles were published in English, French, Portuguese, or Spanish. A total of 21 studies were included in the review, totalling 87,508 adults aged ≥18 years, from 26 countries. The systematic review findings suggest that MS has a positive effect on reducing DS. Meta-analysis findings indicate that MS is inversely and significantly related to DS 0.85 (95% CI: 0.80, 0.89). Interventions aiming to improve MS have the potential to promote mental health and prevent depression. Thus, public health professionals could use MS assessment and improvement as a strategy to promote mental health and prevent depression.

Keywords: anxiety; mental health; handgrip; fitness

1. Introduction

Depression is a mental health disorder affecting more than 300 million adults around the world [1]. It is the largest contributor to worldwide disability, and leads to almost one million suicide deaths annually [1]. The most common treatment for depression includes pharmacotherapy and psychotherapy [2,3], which, in the long term, can be expensive and costly for health care systems due to the prevalence of the disorder [4]. In order to address the health problem of depression that affects

so many people around the world and to effectively allocate health care spending, it is important to identify additional and effective treatment options.

Regular physical activity increases physical fitness, which is related to a decreased risk of all-cause mortality in healthy people [5]. Physical fitness is a multi-component construct, including cardiorespiratory fitness, muscular fitness, flexibility, balance, and speed. There is longitudinal evidence that cardiorespiratory fitness, a component of physical fitness, is related to depression, preventing it or having a treatment effect [6,7]. Muscular strength is a component of muscular fitness that defines how much strength an individual can voluntarily produce by contracting muscles, and has been associated with a lower risk of mortality in the adult population [8]. Two types of contractions exist: isometric, when the length of the muscle remains the same; and isotonic, when the length of the muscle changes, which can be eccentric or concentric. The most common tests to assess muscular strength are the handgrip strength and the isometric knee extension, which are related to overall strength [9,10]. Both cardiorespiratory fitness and muscular strength are in part genetically determined and in part a result of physical activity and exercise participation. Thus, it is plausible that greater muscular strength also has a positive effect on depression. However, the effect of muscular strength on mental health and depression symptoms is still not clear. Some studies have shown that decreased muscular strength is related to depression [11], while other studies did not find a significant association [12,13].

Muscular strength is positively related to physical function [14]. This is particularly important because a better physical function is significantly associated with less depressive symptoms [15,16]. Moreover, muscular strength is associated with physical activity and exercise habits [17], which are known to be negatively associated with depression symptoms [18,19]. In this line, the possible effects of muscular strength on depression may be mediated by physical activity, which can partly explain this association. Taking into account the significant association between physical activity and the risk of mental illness, it can be hypothesised that better muscular strength may also have a positive effect on reducing or preventing depression. Therefore, a systematic review was conducted, aiming to review the literature regarding the relationship between muscular strength and depression symptoms among adults. Furthermore, a meta-analysis of selected studies was conducted to determine the pooled odds ratio for the relationship between muscular strength and depression symptoms.

2. Materials and Methods

The strategies employed in this systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines [20].

2.1. Data Sources and Searches

Studies published up to the 31st of December 2019 were systematically identified by searching in the PubMed, Scopus, and Web of Science electronic databases. The search was performed using the following combination of terms: Handgrip, Hand-Grip or "Hand Strength" or "Grip Strength" or "Muscular Strength" or "Muscular Fitness" or "Muscular Train*" and depression or depressive or "Mental Health" or anxiety or "Psychological Functioning". Retrieved titles and abstracts were assessed for eligibility for inclusion by two authors. Duplicate entries were removed. Relevant articles were retrieved for a full read. The same two authors reviewed the text of potential studies, and decisions to include or exclude studies in the review were made by consensus.

2.2. Study Selection

Articles published up to December 2019 were eligible for inclusion. Specific criteria were: (1) design criterion: cross-sectional, longitudinal and interventional studies; (2) outcome measure criterion: studies were included if the outcomes included depression; (3) participants: adults and older adults; (4) language criterion: articles published in English, French, Portuguese, or Spanish; and (5) exclusion criterion: articles were excluded if they did not meet inclusion criteria or did not include findings related to the inclusion criteria. Published conference proceedings, conference abstracts, and theses or studies

including animals were also excluded. Finally, studies focusing on general mental health, anxiety, and mood were excluded because they preclude concluding the isolated effect of muscular strength on depression.

2.3. Data Extraction and Quality Assessment

The following information was extracted from each study: author's name and year of publication, study design, country, sample characteristics (number of participants, sex, age), the instrument for assessing the depression symptoms, the instrument for assessing muscular strength, main results, and study quality. For the intervention studies, the following were extracted: duration of intervention, description of the program, intensity, duration, and frequency. For longitudinal studies, the time of follow-up was also extracted. The methodological quality of the studies was assessed using the Quality Assessment Tool for Quantitative Studies. It is a 19-item checklist, assessing methodological domains: selection bias, study design, confounders, blinding, data-collection methods, withdrawals and dropouts, intervention integrity, and analyses. A global rating was determined based on the scores of each component. Two researchers rated the studies in each domain, as well as the overall quality of each study. Discrepancies were resolved by consensus.

2.4. Data Synthesis and Analysis

This review analysed the relationship between muscular strength and depression. The details for each study are presented consistently. Data from all studies were pooled using Review Manager 5.3. For the five clinical trial studies, the instruments used to assess the muscular strength or the depression symptoms were different among the studies. From the 16 observational studies, the data from 9 were used for meta-analysis [11,21–28]. The seven studies not included were eliminated based on the heterogeneity of the association measure between muscular strength and depression symptoms. Two reported the comparison between the effect of high vs. low muscular strength on depression [29,30]; two reported the muscular strength difference between depressed vs. not depressed cases, and the other three reported results stratified by weight status or quartiles of muscular strength [31]. The homogeneity of the odds ratio of the studies included in the meta-analysis was assessed using I^2 statistics. Values of ≥50% were considered substantial heterogeneity [32]. As there was significant heterogeneity, a random effects model was used to calculate the pooled odds ratio. Sensitivity analyses were carried out by successively omitting one study at each turn. A Forest plot was performed to showcase each included study log-odds, odds ratio (95% confidence interval (CI)), standard error and weight as lines, and the pooled odds ratio from all studies as a diamond.

3. Results

3.1. Literature Search

The primary search in the databases yielded 782 citations. After excluding the duplicates (n = 359), the title and abstract of 423 articles were screened. Of these, 378 citations were discarded after reviewing the title and the abstract because it was clear that they did not contain an assessment of muscular strength and depression symptoms. After having read the full text of the remaining 45 citations, 24 were discarded, either because they did not have depression symptoms as the outcome variable (n = 15), were not focused on muscular strength (n = 4), were not empirical studies (n = 3), or were written in a language other than English, French, Portuguese, or Spanish (n = 2). The flow diagram is presented in Figure 1.

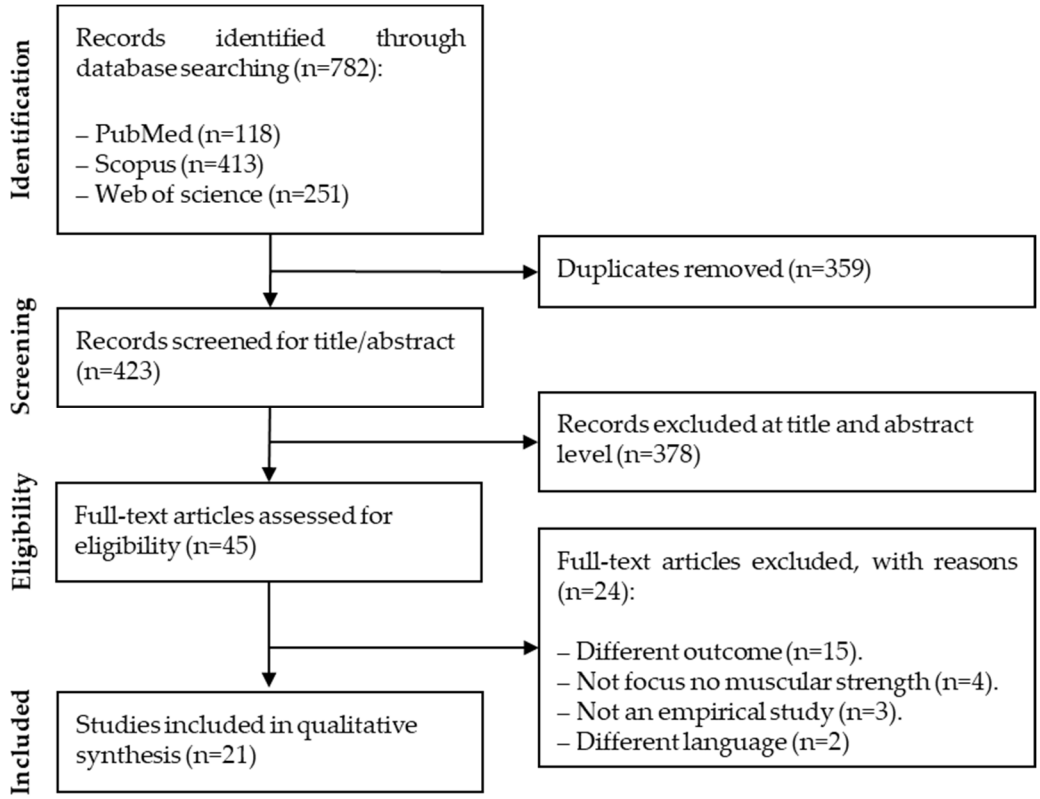

Figure 1. Flow diagram of the study selection.

3.2. Study Characteristics

Table 1 presents the studies' characteristics. A total of 21 studies were included in the review, totalling 87,508 adults aged ≥18 years, from 26 countries. Most studies were cross-sectional (n = 12), five were clinical trials, and four were prospective studies. Five studies were performed in South Korea, two in Brazil, two in Spain, two in the United States, and the others were performed in Australia, Belgium, China, Denmark, Finland, Ireland, Japan, Turkey, and the United Kingdom. One study was performed in six countries (China, Ghana, India, Mexico, Russia, South Africa). The Geriatric Depression Scale, Patient Health Questionnaire, and the Beck Depression Inventory were the most used scales to assess the depression symptoms (each scale in four studies). The other scales used were the Center for Epidemiologic Studies Depression Scale, EuroQol Five-Dimension Questionnaire, Hamilton Depression Rating Scale Hopkins' Symptom Checklist, Mental Health Inventory, and Psychosis Evaluation Tool for Common Use by Caregivers. Seven studies were considered to be of weak methodological quality, seven of moderate quality, and the other seven of strong quality.

Table 1. Studies' characteristics.

Author, Year	Study Design	Country and Sample's Characteristics	Depression Measure	Muscular Strength Measure	Main Results	Study Quality
Krogh et al., 2009	Clinical trial	Denmark n = 165, 122 women, age range = 18–55, mean age 38.9 ± 9.46; strength training (n = 55); aerobic training (n = 55); relaxation training (n = 55).	Hamilton Depression Rating Scale (HAM-D17)	Knee extension; Chest press; Leg press	(Ø) At 4 months, the mean change in the HAM-D17 score was –1.3 (−3.7–1.2; p = 0.3) for the strength group vs. the relaxation group. At 12 months, the mean differences in the HAM-D17 score were −0.2 (−2.7–2.3) for the strength group vs. the relaxation group. Findings do not support a biologically mediated effect of strength exercise on symptom severity in depressed patients.	Strong
Suija et al., 2013	Prospective	Finland n = 5497, 51% women, age = 31 (all participants were born in 1966).	Hopkins' Symptom Checklist (HSCL-25)	Trunk extension test; Hand dynamometer	(+) Depressive symptoms were most common among males and females in the lowest quintile group of the trunk extension test and among the males in the lowest quintile group of the handgrip strength compared to the middle quintile group.	Strong
Vancampfort et al., 2013	Cross-sectional	Belgium n = 120; schizophrenia: n = 80, mean age 36.8 ± 10.0; control: n = 40, mean age 37.1 ± 10.3.	Psychosis Evaluation Tool for Common use by Caregivers (PECC)	Standing broad jump; Sit-ups; Handgrip strength	(+) Standing broad jump (−0.35, $p < 0.01$), handgrip strength (−0.28, $p < 0.01$) and sit-ups (−0.33, $p < 0.01$) were inversely associated to depressive symptoms. Low physical fitness was associated with depressive symptoms.	Moderate
Aidar et al., 2014	Clinical trial	Brazil Control group: n = 24, 6 men, mean age = 51.7 ± 0.8 Experimental group: n = 13, 9 men, mean age = 52.5 ± 7.7.	Beck Depression Inventory (BDI)	Squat; Bench press; Horizontal leg press; Military press; Abdominal crunch; Front lat pull-downs; Lunges	(+) There were significant differences in all indicators of depression between the experimental group and the control group after completing 12 weeks of training. A negative correlation between the strength gains as determined with the one-repetition maximum test and the levels of depression was found.	Weak
Fukumori, 2015	Prospective	Japan n = 4314, 58.5% women, age range 40–79, mean age 66.3 ± 9.0.	Mental Health Inventory (MHI-5)	Digital dynamometer (Takei Scientific Instruments Co., Ltd.)	(+) Men and women with lower handgrip strength had higher odds of having depressive symptoms at baseline. Lower handgrip strength was associated with the longitudinal development of depressive symptoms after 1 year (odds ratio (OR) = 1.13, 95%CI = 1.01, 1.27).	Strong
Sener et al., 2016	Clinical trial	Turkey n = 79; experimental group: n = 39 women with fibromyalgia; mean age 42 ± 10.3 years; control group: n = 40 women; mean age 38.3 ± 8.4 years.	Beck Depression Inventory (BDI)	Digital Grip Dynamometer (T.K.K.5401)	(+) In the fibromyalgia group, right and left handgrip strength were moderately negatively correlated with depression scores (r = 0.263 p = 0.025; r = 0.233 p = 0.048). Low muscle strength increased depression and anxiety symptomatology in patients with fibromyalgia.	Moderate
Soriano-Maldonado et al., 2016	Cross-sectional	Spain n = 444 were included in the analysis; mean age 52.0 ± 8.0 years.	Beck Depression Inventory II (BDI II)	Digital Grip Dynamometer (T.K.K. 5101)	(+) The odds of severe symptoms of depression were 4.8% (95% CI: 8.2% to 1.2%; p = 0.010) lower for each additional kilogram in the handgrip test among women with fibromyalgia.	Weak
Gopinath et al., 2017	Cross-sectional	Australia n = 947 men and women; aged ≥65 years.	Center for Epidemiologic Studies Depression Scale (CES-D-10)	Jamar hand dynamometer (Sammons Preston Inc.)	(Ø) Handgrip strength was not associated with depressive symptoms and quality of life.	Weak
Wu et al., 2017	Cross-sectional	China n = 1046, 486 men, 560 women, aged ≥60.	Geriatric Depression Scale (GDS)	Dynamometer (EH101; CAMRY, Guangdong)	(+) Men and women in the lower quartile for muscle strength had a significantly higher risk for depressive symptoms compared with those in the fourth quartile. Muscle strength are inversely associated with depressive symptoms in elderly Chinese.	Weak

Table 1. *Cont.*

Author, Year	Study Design	Country and Sample's Characteristics	Depression Measure	Muscular Strength Measure	Main Results	Study Quality
Brooks et al., 2018	Cross-sectional	USA *n* = 3421 community-dwelling, non-institutionalized adults; 1660 men, 1761 women; aged ≥60 years, mean age was 69.9 ± 6.9 years.	Patient Health Questionnaire (PHQ-9)	Dynamometer	(+) Depression was significantly associated with reduced handgrip strength in older adults.	Weak
Lee, 2018	Cross-sectional	South Korea *n* = 4810, 2167 men, 2643 women; mean age 50.9 ± 16.7 years.	Depressive mood was assessed using one question: 'During the past year, did you ever feel so sad or hopeless for 2 weeks or more in a row that you stopped performing usual activities?	Digital Grip Dynamometer (T.K.K.5401)	(+) Handgrip strength was negatively associated with depressive mood (OR = 0.82, 95% CI: 0.69–0.99) and suicidal ideation (OR = 0.73, 95% CI: 0.54–0.99). In a sex-specific relationship, handgrip strength was negatively associated with depressive mood and suicidal ideation among women (OR = 0.71, 95% CI: 0.55–0.93) but not men.	Moderate
Lee et al., 2018	Cross-sectional	South Korea *n* = 4298, 1860 men, 2438 women; age range (19–80 years); subjects were divided into three groups (young adult (19–39 years), middle aged (40–59 years), and elderly (60–80 years).	Patient Health Questionnaire (PHQ-9)	Digital Grip Dynamometer (T.K.K.5401)	(+) Handgrip strength was inversely associated with the PHQ-9 score. The odds ratios of depression symptoms were statistically significant for the participants in the first and second quartile of handgrip strength compared to those with the highest quartile. There was about a 50% mediation effect of EQ5D in the relationship between handgrip strength and depression.	Moderate
McDowell et al., 2018	Prospective	Ireland *n* = 4505, 2544 men, 1961 women; aged ≥50 years.	EuroQol Five-Dimension Questionnaire (EQ5D)	Baseline hydraulic dynamometer	(+) In the total sample, the middle- and high-strength tertiles were significantly associated with 31.5% (p = 0.04) and 34.1% (p = 0.02) reduced odds of developing depression, respectively. The interaction between sex and strength was not statistically significant.	Strong
Smith et al., 2018	Cross-sectional	USA *n* = 2812, 1380 men, 1432 women, mean age 68.9 ± 0.3 and 69.5 ± 0.3	Center for Epidemiological Studies Depression Scale (CES-D)	Takei Digital Grip Strength Dynamometer	(+) Women with moderate to major depressive symptoms had 1.60 kg (95% CI: 0.91 to 2.30) lower handgrip strength compared to women with minimal or no depressive symptoms. No association was observed in men. Obese men (-3.72 kg, 95% CI:−7.00, −0.43) and women (−1.83 kg, 95% CI:−2.87, −0.78) with moderate to severe depressive symptoms had lower handgrip strength.	Moderate
Ashdown-Franks et al., 2019	Cross-sectional	China, Ghana, India Mexico, Russia, South Africa *n* = 34,129, China 13,175, Ghana 4305, India 6560, Mexico 2313, Russia 3938, South Africa 3838; mean age 62.4 ± 16 years	Patient Health Questionnaire (PHQ-9)	Smedley Handgrip Dynamometer	(+) Individuals with weak handgrip strength had a higher prevalence of depression than those without (8.8% vs. 3.8%; $p < 0.001$). In all countries, weak handgrip strength was associated with a 1.45 (95% CI:1.12–1.88) times higher odds for depression, although some between country differences were noted (particularly in Ghana). Age and sex-stratified analysis showed similar results.	Strong
Han et al., 2019	Cross-sectional	South Korea *n* = 3169, 1451 men, 1718 women; aged 59–69 years, mean age 55 ± 6.25 years.	Patient Health Questionnaire (PHQ-9)	Digital Grip Dynamometer (T.K.K.5401)	(+) Older adults in the lowest tertile of handgrip strength measures were more likely to have experienced depressive symptoms compared to those in the highest tertile.	Moderate

Table 1. *Cont.*

Author, Year	Study Design	Country and Sample's Characteristics	Depression Measure	Muscular Strength Measure	Main Results	Study Quality
Kim et al., 2019	Clinical trial	South Korea *n* = 21 women, aged 67–81 years, mean age 76.40 ± 3.27 years; control group (*n* = 10; mean age 76.40 ± 3.27 years) and intervention group (*n* = 11, mean age 76.10 ± 3.85 years).	Korean version of the Short form of the Geriatric Depression Scale (SGDS-K)	The exercise program was 3 times/week for 24 weeks. Part I from 1–4 weeks, Part II from 5–8 weeks, Part III from 9–15 weeks, and advanced long-term training from 16 to 24 weeks. The exercise program consists of warm-up (for 10 min), main exercise (for 30–60 min) and warm-down (for 10 min).	(Ø) In neurotransmitter factor, serotonin, dopamine, epinephrine, and norepinephrine were significantly decreased in the strength exercise group but not for the control group. There were no significant differences for both the strength exercise group and control group.	Weak
Laredo-Aguilera et al., 2019	Cross-sectional	Spain *n* = 38 active women, aged >65 years, mean age 72.29 ± 5.21 years.	Spanish version of the Short form of the Geriatric Depression Scale (SGDS-S)	Digital Grip Dynamometer (T.K.K. 5101)	(+) The group with a higher handgrip strength result had a better total score for depression. Significant and negative correlations were found between the handgrip strength and depression.	Weak
Moraes et al., 2019	Clinical trial	Brazil *n* = 27 older adults with major depressive disorder; aerobic training (*n* = 9, 1 man and 8 women, aged 60–78; 70.88 ± 5.94 years), strength training (*n* = 9, 8 men, 1 woman, aged 60–81; 72.89 ± 7.06 years), control group (*n* = 7, 2 men and 5 women, aged 61–77; 69.28 ± 5.28 years).	Hamilton Depression Rating Scale (HAM-D), and Beck Depression Inventory (BDI)	The 1-repetition maximum test was applied. The scale of perception of effort from 6 to 20 was used to quantify the subject's effort during activity.	(+) The aerobic training and strength training intervention groups showed significant reductions in depressive symptoms from pre to post intervention when compared to the control group.	Moderate
Park et al., 2019	Prospective	South Korea *n* = 13,901, 5996 men, 7905 women; aged > 60 year, mean age 69.54 ± 7.06 years.	Korean version of the Short form of the Geriatric Depression Scale (SGDS-K)	Handgrip Dynamometer (TANITA No. 6103, Tokyo)	(+) Individuals with depression only and individuals with low handgrip strength plus depression had significantly higher risks of all-cause mortality. Men and women with higher handgrip strength had significantly lower depression scores.	Strong
Smith et al., 2019	Cross-sectional	United Kingdom *n* = 3741 community-dwelling, 1257 men, 2484 women; aged 54–89 years, mean age 68.4 years.	Center for Epidemiologic Studies Depression scale (CES-D8)	Hand-held dynamometer	(+) Grip strength was negatively associated with depressive symptoms, when the analysis was adjusted for sex and age. When fully adjusted, the association remained significant but was weaker.	Strong

3.3. Principal Findings

The description of the studies reporting the relationship between muscular strength and depression symptoms is presented in Table 1. The results from two clinical trials [33,34] and one observational study [13] were inconsistent. A relationship between muscular strength and depressive symptoms was not observed. However, in one study, the neurotransmitter factors, such as serotonin, dopamine, epinephrine, and norepinephrine significantly decreased in the strength exercise group but not for the control group [33]. From the other clinical trial studies, the muscular strength decreased the depression symptomatology [35–37]. Results demonstrated significant differences in all indicators of depression after completing 12 weeks of training [35], that low muscle strength increased depression symptomatology in patients with fibromyalgia [37], and that strength training intervention significantly decreased depressive symptoms [36]. The other observational studies showed that independently of sex, age, and country, depression symptoms were significantly associated with a reduced handgrip strength [11,21,22,24,27–30,38–40]. Furthermore, adults in the lower tertile or quartile for muscle strength had a significantly higher risk for depressive symptoms compared with those in the third tertile or fourth quartile [23,25,26,31].

3.4. Meta-Analysis

Figure 2 shows the forest plot of the odds ratio and 95% CI of each study and the odds ratio of the random effects model. A moderate heterogeneity among studies was detected (I^2 =55%; χ^2 = 17.96, df = 8; p = 0.02). Based on nine observational studies [11,21–28], including 62,831 cases, the presence of depression symptoms was negatively associated with muscular strength. The pooled odds ratio from the random-effects model was 0.85 (95% CI: 0.80, 0.89).

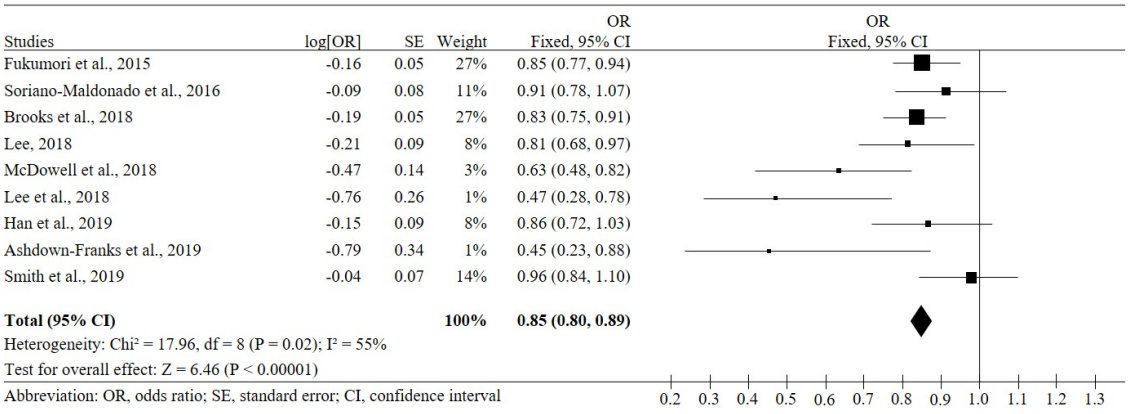

Figure 2. Pooled odds of the association between muscular strength and depression symptoms.

4. Discussion

This study sought to review the relationship between muscular strength and depressive symptoms in adults and older adults. Findings suggest that increased muscular fitness may have a beneficial effect on depression symptoms. Furthermore, the meta-analysis findings indicate that muscular fitness is inversely and significantly related to depression symptoms among adults and older adults. This is of importance because depression is the greatest non-communicable disease contributing to the loss of health [1] and it is associated with comorbidity [41], a higher risk of suicide [42], and premature mortality [43].

Muscular strength is recognized as an important health indicator, mainly because it is associated with a lower risk of mortality in the adult and older adults population, regardless of age [8]. Moreover, it is independently associated with cardiometabolic risk and metabolic syndrome in adults and older adults [44,45]. Specifically among older adults, muscular fitness is associated with sarcopenia [46], functional limitations and disabilities [47]. Thus, it is considered a useful marker of frailty in the

older adult population [48]. In this systematic review and meta-analysis, muscular fitness was also found to be inversely associated with depressive symptoms. Several mechanisms may explain the observed inverse association between muscular strength and depression symptoms. One possible mechanism is the relationship between muscular strength and sarcopenia [46], functional limitations and disabilities [47]. The relation between muscular strength and these health outcomes may transfer to depression by increased disability, as people with lower muscular strength are less independent and have more difficulties performing activities of daily living [49], which is linked to depression symptoms [50,51]. Moreover, muscular strength is also associated with frailty and health-related quality of life [52]. Another possible explanation is the release of cytokines and myokines into the circulatory systems in response to muscle contraction. It is suggested that myokines might protect against the risk of depression [53]. Furthermore, older adults' inflammatory profile is associated with frailty and sarcopenia, which can increase the risk of depression [54–56].

When examining the association between muscular strength and depression, one must consider the potential mediating role of physical activity. Physical activity, most notably muscle-strengthening activity, is known to be the most important modifiable factor related to muscular strength; therefore, higher muscular strength levels are likely to be related to greater physical activity levels [17]. Furthermore, muscular strength and physical activity share most of the mechanisms through which they may affect depression symptoms. Nevertheless, physical fitness mirrors both participation in physical activity and the state of physiological systems, being suggested that because of that the relationship between physical fitness and health outcomes may be stronger than the relationship between physical activity and those same health outcomes [57]. Moreover, changes in fitness due to participation in physical activity are not immediate and may take weeks to be measurable. Some of the studies included in this review controlled the analysis for physical activity participation and still concluded that muscular strength was associated with depression, independently of physical activity [21,23–25,27]. The mediating role of physical activity in the relationship between muscular strength and depression symptoms has not been explored yet, and thus, future research should investigate how much of this relationship is mediated by physical activity.

Depression has one of the greatest disease burdens in several countries worldwide [42]. It is usually treated using pharmacotherapy and psychotherapy [2,3], but both treatment options are expensive and increase the health costs for health care systems [4]. To address this public health problem and possibly reduce the present and future burden of the disease, different strategies are needed. The association between the muscular strength and depression symptoms observed in this review indicates that promoting muscular fitness through physical activity and exercise might be used as a potential strategy to fight depression. Furthermore, a recent systematic review and meta-analysis revealed that resistance training had a moderately positive effect on disability and function in older adults with or at risk of disability [58]. This is important because disability and function are related to depression. Moreover, measures of muscular strength, such as handgrip, could be used as one of several indicators of depression, or for the development of depression symptoms, and its assessment could be promoted in the primary health care systems, as it is already suggested to be for mortality [8]. The early detection and prevention of depression symptoms, and mental health promotion in the health care systems, may lead to healthier populations and reduced health care costs. Moreover, improving muscular fitness would not only promote mental health but also promote cardiometabolic health and the quality of life [45,52,58].

To our knowledge, this is the first systematic review to investigate associations, between muscular fitness and depression symptoms in adults and older adults, using a meta-analysis to determine the pooled odds ratio for the relationship between muscular strength and depression symptoms. Nevertheless, these systematic review and meta-analysis findings should be taken in light of some limitations that must be acknowledged. Most studies used handgrip strength as a measure of muscular strength, while other studies used different measures. This leads to heterogeneity in the muscular strength outcome. Even though the studies were assessed according to their methodological quality,

they were not weighed or ranked according to it for the systematic review. Thus, the findings from studies with weaker quality and smaller sample sizes were given no less importance than the findings from studies with strong research designs and larger sample sizes. Furthermore, most included studies were cross-sectional and therefore associations of the temporal direction cannot be certainly assessed. Search terms were selected to identify articles that associate muscular strength and depression. Nonetheless, some articles were eventually left out, because in the title or abstract, they did not have a term that could be associated with muscular strength or depression.

5. Conclusions

Muscular strength is inversely and significantly related to depression symptoms among adults and older adults. This may be partially explained by physical activity, but also by the associations between muscular fitness and functional limitations and disabilities, as well as frailty and health-related quality of life, which in turn are related to depression symptoms. Interventions aiming to improve muscular fitness have the potential to promote mental health and prevent depression. Thus, public health professionals could use muscular strength assessment and improvement as a strategy to promote mental health and prevent depression. These findings are of the utmost importance for public policies where the strength of the connection between physical and mental factors, in the promotion of mental health and well-being, is not always duly considered.

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Article 6

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Article

Active Commuting and Depression Symptoms in Adults: A Systematic Review

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Abstract: Physical activity (PA) is suggested to have a protective effect against depression. One way of engaging in PA is through active commuting. This review summarises the literature regarding the relationship between active commuting and depression among adults and older adults. A systematic review of studies published up to December 2019, performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis guidelines, was conducted using three databases (PubMed, Scopus, and Web of Science). A total of seven articles were identified as relevant. The results from these studies were inconsistent. Only two presented a significant relationship between active commuting and depression symptoms. In those two studies, switching to more active modes of travel and walking long distances were negatively related to the likelihood of developing new depressive symptoms. In the other five studies, no significant association between active travel or active commuting and depression was found. The relationship between active commuting and depression symptoms in adults is not clear. More studies on this topic are necessary in order to understand if active commuting can be used as a public health strategy to tackle mental health issues such as depression.

Keywords: active travel; walking; cycling; mental health

1. Introduction

Depression is a mental health problem that affects more than 300 million adults worldwide [1]. The prevalence of depression has been rising globally, and it was projected to be the second-largest cause for the burden of disease by 2020 [2]. Depression is already the greatest non-communicable disease contributing to the loss of health [1], due to its association with comorbidities [3], risk of suicide [4], and premature mortality [5]. Most cases of depression are treated using pharmacotherapy and psychotherapy [6,7]. However, both types of therapies are expensive and increase health costs for health care systems [8].

Physical activity (PA) is suggested to have a protective effect against depression and a positive effect on the treatment of depression in non-clinical and clinical populations, regardless of sex and

age [9,10]. As non-pharmacology therapy, PA does not show drug side effects such as weight gain, insomnia, dry mouth, or withdrawal symptoms [11]. On the contrary, besides the positive benefits on depression, it is also associated with positive public health gains such as physical performance and cardiovascular improvements [11].

PA can be performed in several contexts, including sports activities, occupational context, leisure-time activities, domestic activities, and in active commuting. For some adults, walking or cycling while commuting to work or to other places seems to be important for enhancing their daily levels of PA [12,13], because is likely to be sustained when incorporated into people's daily routine [14]. As a result, active commuting has been related to health and wellbeing improvement [15,16] and associated with fewer transport-related carbon emissions [17]. Thus, it can be expected that commuting actively might also be related to depression symptoms. However, so far, there is no clear evidence of the relationship between active travel or active commuting and depression symptoms. Therefore, the purpose of this study was to review the literature regarding the relationship between PA in active commuting and depression among adults and older adults.

2. Materials and Methods

This systematic review was performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines [18].

2.1. Inclusion Criteria

Articles that presented a relationship between active travel and active commuting and depression symptoms published in peer-reviewed journals up to December 2019 were eligible for inclusion. Eligibility criteria included the following: (1) cross-sectional, prospective, and cohort studies (study design criterion); (2) outcomes included depression or depressive symptoms (outcome measure criterion); (3) active travel or active commuting (relationship criterion); (4) adults and older adults (participants criterion); (5) articles published in English, Portuguese, or Spanish (language criterion); and (6) articles that did not meet the inclusion criteria or did not include findings related to the inclusion criteria were excluded (exclusion criteria).

2.2. Search Strategy

Studies published up to December 2019 were identified by searching in electronic databases. The search was undertaken in the PubMed, Scopus, and Web of Science databases. Articles that assessed the relationship between active travel or active commuting and depression were included in this review. The search was performed using the following combination of terms: travel* OR transport* OR commute* OR cycle OR cycling OR bicycle* OR bike* OR walk* OR/AND depress* OR mental health OR psychological health OR anxiety OR psychological function*. Search terms were defined previously and used in each database to identify articles for review. Two reviewers (A.M. and M.P.) independently screened titles and abstracts to identify studies that met the inclusion criteria. Duplicate articles were removed. Relevant articles were retrieved for a full read. Two authors (A.M. and M.P.) reviewed the full text of potential studies, and decisions to include or exclude studies in the review were made by consensus. Disagreements were solved by consensus and, when necessary, a third reviewer served as a judge (D.H.-N. or D.F.).

2.3. Data Extraction and Harmonisation

Based on PRISMA [18], a data extraction form was developed. The following information was extracted from each article: authors' name and year of publication; study design; country; sample characteristics (number of participants, sex, and age); the instrument for assessing depression symptoms; the instrument for assessing active travel or active commuting; main results; and study quality. The extraction was performed by one author (A.M.), and coding was verified by two authors (M.P. and D.H.-N.).

2.4. Study Quality and Risk of Bias

Study methodological quality was assessed using a checklist criteria from the Quality Assessment Tool for Quantitative Studies [19]. The checklist comprises 19 items, assessing eight methodological domains: selection bias, study design, confounders, blinding, data collection methods, withdrawals and dropouts, intervention integrity, and analyses. Each section is classified as strong, moderate, and with weak methodological quality. Then, a global rating is determined based on the scores of each component. Two researchers rated the articles (M.P. and D.F.) in each domain and the studies' overall quality. Discrepancies were resolved by consensus.

2.5. Synthesis of Results

This review analysed the relationship between active travel or active commuting and depression. The details for each study, including design, participant characteristics and sample size, measures, main results, and study quality, are presented in a consistent manner.

3. Results

3.1. Search Results

Figure 1 presents the flow citation through the systematic review process. The systematic search yielded 3938 publications. After excluding the duplicates (n = 2246), the title and abstract of 1692 articles were screened. After eliminating 1606 articles at the title and abstract level, 86 articles remained and were subsequently read. From the 86 articles, 35 were eliminated for having a different outcome, 40 were eliminated because they were not focused on active travel or active commuting, three were eliminated for not being empirical studies, and one was deleted because it was written in Mandarin. Thus, seven articles were identified as relevant.

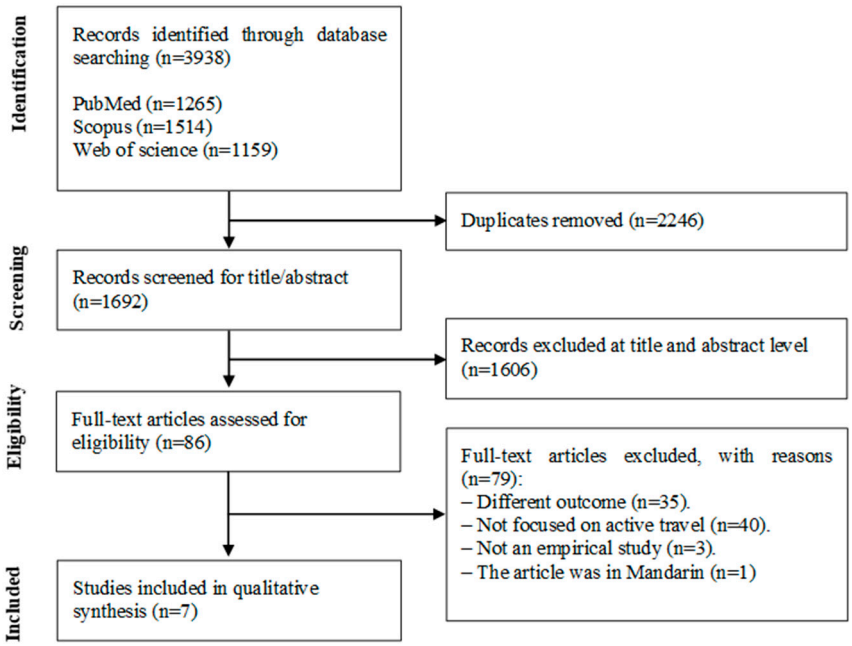

Figure 1. Flow diagram of study selection.

3.2. Study Characteristics

Table 1 presents the studies' characteristics. From the seven articles, five had prospective designs and two had cross-sectional designs. In total, all studies combined included 47,300 adults aged over 18 years. Geographically, two were performed in the United States; two in Japan; one in Canada; one in the United Kingdom; and one in several Latin American countries (Argentina, Bolivia, Brazil,

Colombia, Ecuador, México, Panamá, Peru, Uruguay, and Venezuela). The Center for Epidemiologic Studies Depression Scale (CES-D) was the most used scale to assess depression symptoms (in five articles). In most articles, the walking distance was self-reported and included leisure time and active commuting. The seven studies were considered of moderate quality.

The older study included in the systematic review was published in 2010, and it examined the effect of walking on incident depressive symptoms in Japanese-American older men with and without chronic disease [20]. The authors used a cohort of men from Hawaii born between 1900 and 1919. Several rounds of examinations were performed; the seventh (which was used in the study) was in 1999–2000. The CES-D 11 scale was used to screen for depressive symptoms, and walking activity was self-reported. It was found that older men, without chronic diseases, in the intermediate (odds ratio (OR) = 0.52, 95% confidence interval (CI): 0.32–0.83) and highest (OR = 0.61, 95% CI: 0.39–0.97) walking groups had significantly lower odds of developing eight-year incident depressive symptoms.

Posteriorly, using a one-year follow-up longitudinal survey, Kai et al. [21] examined the prospective association of walking to work with depressive symptoms among 634 Japanese workers. Depression symptoms were screened by the CES-D scale, and walking activity was self-reported. The authors reported that baseline mean walking to work time was 29.2 ± 18.0 min per day. Walking to work tertiles were calculated; mean values of the low, medium, and high walking to work time tertiles were 13.8 ± 7.0, 29.6 ± 1.9, and 49.7 ± 16.1, respectively. No significant association was found between the depressive symptoms and tertiles of walking to work duration.

In an effort to determine whether walking or depressive symptoms were the stronger predictor of each other, Julien et al. [22] examined the longitudinal associations between walking and depressive symptoms in a population-based sample of 498 Canadian urban-dwelling older adults. Four repeated measures over a five-year period were performed. The geriatric depression scale was used to assess depressive symptoms, and walking was self-reported. Although depressive symptoms predicted walking frequency, walking frequency did not predict depressive symptoms at subsequent time points.

Later, a cross-sectional study based on the National Survey of American Life investigated the odds of having depressive symptoms accordingly to walking frequency in 2978 African-American adults [23]. Walking was measured by self-reported frequency, and depressive symptoms were measured with modified versions of the CES-D scale. In this study, women who reported walking often presented lower odds for depressive symptoms than women who reported never walking (OR = 0.56, 95% CI: 0.38–0.82); however, no significant results were found for men.

In the same year, Kuwahara et al. [24] published a cohort study of 29,082 Japanese workers, examining the prospective associations of physical activity during commuting with the risk of depressive symptoms. During a mean follow-up of 4.7 years, 6177 adults developed depressive symptoms. Physical activity and depressive symptoms (similar to the CES-D scale) were assessed by a self-reported questionnaire. The hazard ratio (HR) for individuals who stand or walk during work was 0.86 (95% CI: 0.81–0.92) compared with sedentary workers. However, walking to and from work was not found to be associated with the risk of depressive symptoms.

More recently, Knott et al. [25] examined whether changes in commute mode were associated with differences in the severity of depressive symptoms in 5474 working adults from the United Kingdom in a population-base prospective cohort study (mean follow-up, 4.65 years). Mode, frequency, and distance of commuting to work were self-reported. The severity of depressive symptoms was assessed using the two-item Patient Health Questionnaire. Baseline asymptomatic adults who altered from inactive to active commuting to work reported less severe symptoms at follow-up than those who remained inactive ($\beta = -0.10$, 95% CI: −0.20–0.00). However, among baseline symptomatic adults, longer trips for work were associated with worse symptoms at follow-up ($\beta = 0.64$, 95% CI: 0.13–1.16).

The most recent study examined the cross-sectional associations between commute patterns and mental health in 5438 adults using survey data from 11 Latin American cities [26]. Commuting was self-reported, and depression was measured using the CES-D scale. No association was found between non-motorised modes of travel and depression.

Table 1. Characteristics of the studies.

Author, Year	Study Design	Sample and Country	Depression Measure	Active Commuting Measure	Observations	Main Results	Methodological Quality
Smith et al., 2010	Prospective cohort.	*n* = 3196 Japanese-American men who were involved in the Honolulu Heart Program aged 71–93 years; mean age 77 years. United States.	Center for Epidemiologic Studies Depression Scale (CES-D 11)	Participants reported how many city blocks they walked each day. Blocks were converted into miles using 12 blocks per mile as a conversion factor. This assessment was developed from the Harvard Alumni Survey.	Walking distance included leisure-time and active commuting.	Those who walked more had significantly lower rates of prevalent depressive symptoms in cross-sectional analyses. Elderly men, without chronic diseases, who walked longer distances per day were less likely to develop new depressive symptoms over eight years of follow-up.	Moderate
Kai et al., 2011	Prospective (1-year follow-up).	*n* = 634: 536 men, 98 women aged 20–60 years; 36.7 ± 9.2 years. Japan.	Center for Epidemiologic Studies Depression Scale (CES-D)	The duration of leisure-time physical activity and commuting by walking were measured using a self-report questionnaire.	Walking distance included leisure-time physical activity and commuting to work.	The adjusted odds ratio (OR) of depressive symptoms in the highest tertile of leisure-time physical activity was 50% lower (OR = 0.50, 95% CI: 0.26–0.97) than those in the lowest tertile. In contrast, no significant association was found between the risk of depressive symptoms and duration of commuting by walking.	Moderate
Julien et al., 2013	Prospective (5-years follow-up). VoisiNuAge Study.	*n* = 498: 236 men, 262 women aged 68–84 years (74.86 ± 4.18 men and 74.90 ± 3.97 women). Canada.	Geriatric Depression Scale (GDS)	Physical Activity Scale for the Elderly (PASE).	Walking distance included leisure-time and active commuting.	Depressive symptoms predicted walking frequency (higher depressive symptoms were related to fewer walking days), but walking frequency did not predict depressive symptoms at subsequent time points.	Moderate
Torres at el., 2015	Cross-sectional. National Survey of American Life (NSAL).	*n* = 2978: 1903 men, 1075 women aged ≥18 years. United states.	Center for Epidemiologic Studies Depression Scale (CES-D)	Walking was measured with responses to one question from the Americans' Changing Lives questionnaire.	Walking distance included leisure-time and active commuting.	Women who reported often walking had lower odds for depressive symptoms than women who reported never walking (OR = 0.56, 95% CI: 0.38–0.82). Walking frequency was not related to depressive symptoms in men.	Moderate

Table 1. *Cont.*

Author, Year	Study Design	Sample and Country	Depression Measure	Active Commuting Measure	Observations	Main Results	Methodological Quality
Kuwahara et al., 2015	Prospective (5-year follow-up). Japan Epidemiology Collaboration on Occupational Health (J-ECOH) Study.	*n* = 29,082 workers: 24,676 men, 4406 women aged 20–64 years; mean age 42.7 years. Japan.	Epidemiologic Studies Depression Scale (CES-D), Self-Rating Depression Scale (SDS)	Participants were asked whether they regularly engaged in any physical activity during leisure. Duration of walking to and from work was self-reported and categorised as <20minutes, 20–40 min, and ≥ 40 min.	It assessed leisure-time physical activity, physical activity at work, and active commuting.	Leisure exercise showed a U-shaped association with the risk of depressive symptoms. Walking to and from work was not associated with depressive symptoms.	Moderate
Knott et al., 2018	Population-based prospective cohort. UK Biobank.	*n* = 5474, aged 37–73 years. United Kingdom.	Patient Health Questionnaire (PHQ-2)	Participants reported the frequency of trips from home to work (trips/week); the distance travelled (miles); and the mode of transport used ("car or motor vehicle" (hereafter "car" for simplicity), "public transport", and "walk" and/or "cycle").	Paper was focused on modes of travel to work.	Participants who were asymptomatic at baseline and switched to more active modes of commuting tended to report a lower severity of symptoms at follow-up than those who continued to travel inactively (β = −0.10, 95% CI: −0.20–0.00). Among commuters who were symptomatic at baseline, longer journeys were associated with worse symptoms at follow-up (β = 0.64, 95% CI: 0.13–1.16). Shifting from exclusive car use towards more active commuting may help prevent and attenuate depressive symptoms in working adults.	Moderate
Wang et al., 2019	Cross-sectional. La Encuesta CAF 2016.	*n* = 5438. Argentina, Bolivia, Brazil, Colombia, Ecuador, México, Panamá, Peru, Uruguay, and Venezuela.	Center for Epidemiologic Studies Depression Scale (CES-D)	Participants reported commuting time during a "normal day", uncongested commuting time, and travel mode commonly used for the commute.	Different modes of travel were assessed.	Every 10 more minutes of commuting time is associated with a 0.5% (p = 0.011) higher probability of screening positively for depression. There were not found any significant associations between non-motorised modes of travel and depression.	Moderate

4. Discussion

This review summarises studies, published up to December 2019, which met the defined criteria. Seven studies were systematically reviewed to address the relationship between active commuting and depression symptoms. In general, although some studies demonstrate that active commuting might be negatively related to depression symptoms, the evidence suggests that the active commuting and depression relationship is unclear.

From the seven studies screened, only two presented a significant relationship between active commuting and depression symptoms. In those two studies [20,25], switching to more active modes of travel and walking long distances were negatively related to the likelihood of developing new depressive symptoms. When examining the effect of walking on incident depressive symptoms in older men, Smith et al. [20] observed that those who walked more had lower rates of prevalent depressive symptoms and that those with chronic diseases who walked longer distances per day were less likely to develop eight-year incident depressive symptoms. Furthermore, the authors suggested that there seems to be a threshold effect in the protective effect of walking on the development of incident depressive symptoms, as few differences were found between the intermediate and high walking groups. This finding is of importance, especially for older adults who have more difficulties in engaging in high volumes of physical activity. More recently, using data from the UK Biobank, a study investigated whether changes in commute mode were associated with differences in the severity of depressive symptoms [25]. It was found that adults who altered from inactive to active commuting to work reported less severe symptoms at follow-up than those who remained inactive. This suggests that commuting behaviours change matters, and thus, active commuting may be used as an intervention strategy to prevent the development of depressive symptoms. Previous investigations in physical activity have shown that, for health purposes, present behaviours may be more important than past behaviours [27]. Active travel offers a suitable way of integrating PA into daily life, and those who use active modes of commuting have higher levels of PA [12,13]. As a result, people who often use more active ways to travel might have better health status [15–17]. Hypothetically, it means that active commuting can also have a protective effect on depression symptomology or reduce depression symptoms [9,10]. However, different types of PA have different effects on mental health status.

Among adults, there is evidence that leisure-time PA is more related to mental health problems, and specifically to depression, than other forms of PA [28–30]. In five out of seven articles, a significant relationship between active commuting and depression symptoms was not found [21–24,26]. Cross-sectional evidence from two studies showed that the association between active commuting and depression is not consistent. In one study, performed among Latin American adults, it was found that non-motorised modes of travel were not associated with depression [26]. On the other hand, a study among African-American adults reported that, while women who reported walking often presented a lower probability for depressive symptoms than women who reported never walking, the same pattern was not observed in men [23]. In order to prevent an increase in depressive symptoms, physical activity may need to improve fitness [31]. However, walking in many cases is probably not performed at a high enough intensity to improve fitness. This difference between sexes may be due to a large percentage of African-American women being obese and, thus, having lower exercise capacity [23]. This can lead to walking being a more intense physical activity among African-American women compared to African-American men. The other three studies had a longitudinal design and, in general, concluded that walking was not associated with depressive symptoms at follow-up [21,22,24]. In a one-year follow-up longitudinal survey performed among Japanese workers, it was found that depressive symptoms were not associated with tertiles of walking to work durations [21]. Similarly, in a cohort study with a mean follow-up of 4.7 years also among Japanese workers, walking to and from work was not related to the risk of depressive symptoms [24]. Lastly, a study among Canadian older adults verified that, while depressive symptoms predicted walking frequency at subsequent time points, walking frequency did not predict depressive symptoms [22]. The lack of a significant relationship between active commuting and depression symptoms in these articles are in agreement

with previous studies among men and women, which showed that walking distance was not related to depression symptoms [32–34]. For those who use an active mode of transportation, transit connectivity matters more for mental health than active travel [26,34]. Furthermore, there is a difference between walking and cycling as a mode of active transportation. Most studies focus on walking as a way of active transportation. Those who usually walk as an active mode of transportation undertake at a lower intensity than cycling [34,35]. This is of particular importance, because PA intensity is a determinant of health. Thus, perhaps in some studies, the level of PA intensity while walking was too low to cause effects on mental health and depression symptoms.

Inconsistent findings identified in this systematic review can be a reflection of the different methodologies used and the different geographical areas and social contexts examined. Measures of active commuting widely varied from study to study, although all were self-reported. Some studies focused on volume [20,21,24], others on frequency [22,23]; one study focused only on the mode of commuting [26] and another one examined the transition from non-active commuting to active commuting [25]. The type of active commuting also differed among studies. Most investigated only walking [20–24], while two studies investigated active commuting without specifying the type [25,26]. Additionally, the context of the commuting was different among studies. Three studies referred to commuting to and from work [21,24,25]. The others did not specify the context of commuting. Due to this, comparability among studies is very limited. Regarding physical activity and active commuting volume and frequency are important information. Results may differ based on these variables. Although some studies examined volume or frequency, they used different time frames. Studies rarely consider both volume and frequency together. Another important aspect for comparability of the results is the type of active commuting, mainly because different types of commuting (e.g., walking versus cycling) have different intensities and volumes associated to them. Future studies should include frequency and volume and be as specific as possible when analysing active commuting. Preferably, similar methods should be used among studies to improve comparability. In addition to the studies being undertaken in different geographic areas and using different ways to measure active transport, it is important to mention that different scales were used to assess symptoms of depression. The use of different scales between the articles may also have contributed to the inconsistency of the results that were observed.

The social and built environment is an important factor to be considered in mental health. The neighbourhood socioeconomic level and built-environment characteristics are associated with a higher probability of screening positively for depression [36]. Walking or cycling in some built-environments can contribute to the development of depression symptoms [26,36]. Furthermore, for some people, active transportation is the only mode of transportation, because they do not have a car or access to mass transit options. In these cases, an active mode of transportation is not an option, it is a mandatory condition. As a result, transport exclusion is associated with social exclusion, which might increment potential mental health problems such as depression [37].

These study review findings should be considered in light of some limitations. Firstly, in all screened articles, the information on commuting and depression was self-reported, which may be subject to bias. Moreover, self-reported PA may have led to overestimates of total PA. Secondly, several articles do not make a clear distinction between active transport as a form of displacement and active transport as a form of leisure (e.g., walking for leisure). This lack of distinction precludes a more rigorous analysis of the relationship between active transport and depression symptoms. Thirdly, some studies were focused on specific populations, such as Japanese-American older men in Hawaii, African-American adults, or workers. This may compromise the generalisability of the results to the general population. Finally, two studies were cross-sectional, which makes it impossible to infer causality. Finally, search terms were selected to identify articles that associate active transportation and depression symptoms. Nevertheless, several articles were subsequently excluded, because neither the title nor abstract contained terms that could be associated with active travel or active commuting.

5. Conclusions

This systematic review shows that the relationship between active commuting and depression symptoms in adults and older adults is inconsistent. Overall, out of seven studies, only two found beneficial effects of active commuting on depression symptoms. Active commuting improves daily PA levels, which is known to be related to depression symptoms. Thus, hypothetically, active commuting could be related to depression. However, five studies did not find a significant relationship between active commuting and depression symptoms. More studies on this topic are necessary in order to understand if active commuting can be used as a public health strategy to tackle mental health problems such as depression. Future studies should include frequency and volume and be as specific as possible when analysing active commuting. Preferably, similar methods should be used among studies to improve comparability. Furthermore, future studies should be more specific regarding the context of commuting.

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