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Effect of exercise interventions on the depression of older adults. A meta-analysis

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Existing studies have shown that exercise interventions can reduce depressive symptoms among older adults. This study aimed to propose a set of exercise interventions to reduce the depressive symptoms of older adults aged 65 or over through a systematic analysis of the published studies. The meta-analysis included 28 randomised controlled trials and intervention control trials from 22 previous studies related to the effect of exercise interventions on the depression of older adults. The results were evaluated by calculating standardised mean differences and 95 % confidence intervals. The risk of bias and heterogeneity of the included studies were assessed. Sensitivity and subgroup analyses were carried out to find out sources of heterogeneity further. The results showed that exercise interventions contributed moderately to reducing depression among older adults (standardised mean difference = -0.35; 95% CI = -0.58 to -0.13; P < .01), especially those diagnosed with depression. The most effective interventions were those focussing on aerobic exercises or mind-body exercises of low intensity. Based on the results, interventions between 13 and 24 weeks, more than 3 times per week and shorter than 45 minutes each session are recommended. More research is encouraged to clarify the effect of different exercise interventions on depression among older adults.

KEY WORDS: Exercises interventions, Depression, Older adults, Physical activity.

Introduction

Depression is a mental disorder including symptoms of sadness, slowness in thought, and decline in cognitive activity; it is often accompanied by a series of physical symptoms as well, such as sleep disorders, loss of appe-

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tite, and weight loss (World Health Organization, 2017a). Depression affects about 150 million people worldwide at any moment, and has been a leading cause of disease burden throughout the world (World Health Organization, 2017a). Due to the increased risk of adverse life events, health conditions such as depression are common in older adults (World Health Organization, 2020). The prevalence rate of depression in older adults over 65 years old is conservatively estimated at 10-15% (World Health Organization, 2018). Depression can cause great harm to the physical and mental health of older adults if not treated timely and appropriately (Hu et al., 2012). Aside from the harm to health, depression also results in a substantial economic burden for the patient's family and society (Greenberg et al., 2015). Although geriatric depression has become a severe public health problem, it has not been paid much attention by the public. Compared with younger adults, older adults tend to have substantial depressive symptomatology, without their meeting the diagnostic criteria for a depressive disorder (World Health Organization, 2017b). The recognition rate of geriatric depression is currently low and the treatment is not sufficient. With the increase in the ageing population, this problem is expected to become more prominent.

Exercise and depression are believed to be associated with each other (Mc Dowell et al., 2018). Previous studies have concluded that exercise intervention conducts a positive effect on reducing depressive symptomatology in older adults. For example, Apostolo et al. (2019) found that intervention composed of a cognitive stimulation program and a physical exercise program significantly reduced depressive symptoms among older adults. Another study confirmed that the depressive symptoms of physically fit older adults improved after 10 weeks of functional training (Laredo-Aguilera et al., 2018). Specific kinds of exercise content have been reported to relieve depressive symptoms. Tsang et al. (2006) concluded that eight to 16 weeks of Qigong practice could relieve depression among older adults with chronic physical illness and depression. Chen et al. (2010) confirmed that depression among older adults decreased significantly after six months of silver yoga exercise intervention. However, the reported effect of exercise interventions on reducing depression still differs across studies. A study by Kerse et al. (2010) found no impact of a home-based physical activity program on improving the mood and quality of life of those with depressive symptoms. Lee et al. (2016) showed that exercise intervention did not produce a significant effect on the amelioration of depression symptoms among older adults, although it did lead to an improvement trend in statistical terms. Such variations in study results indicate the necessity for a systematic review of the relevant studies to clarify the relationship between physical exercise and geriatric depression.

Systematic reviews and meta-analyses have been undertaken on the relationship between physical exercise and depression. Arent et al. (2000) carried out a meta-analytic review on the effect of exercise on mood in older adults, but it didn't focus on depression. Mammen and Faulkner (2013) included 30 studies in a systematic review to investigate the effect of physical activity on the occurrence of depression, and concluded that exercise at any intensity level was likely to prevent subsequent depression. Catalan-Matamoros et al. (2016) carried out an umbrella review of meta-analyses to investigate the exercise effect of exercise on depression by including three studies, and recommended that exercise as an essential treatment of older adults with depression. Schuch et al. (2016) included 25 random controlled trails comparing exercise versus control comparison groups, and claimed that exercise was an evidence-based treatment for depression. A systematic review by Hu et al. (2020) included eight studies on depressive symptoms; based on meta-analyses focussing on different age groups, their review indicated that exercise interventions may have a beneficial effect on depressive symptoms. Miller et al. (2020) searched databases through 2018 and included 15 eligible studies in their meta-analysis to compare the effects of three different exercise types in treating depressed older adults. The World Health Organization's publication listing the global recommendations on the health benefits of physical activity divides the recommendations based on three age groups: 5-17 years old, 18-64 years old, and 65 years old and above (World Health Organization, 2010). As for the studies focussing on older adults, Rhyner and Watts (2016) reviewed 41 studies conducted on adults older than 60 years, and found heterogeneity among studies as well as an overall moderate effect size for exercise as a treatment for reducing depressive symptoms. Miller et al. (2020) conducted a systematic review of 15 random controlled trails to compare the effectiveness of three exercise types in clinically depressed older adults, and provided evidence for the antidepressant effect of either aerobic, resistance, or mind-body exercise as an adjunct to prescribed therapy for clinical depression in older populations. A previous sensitivity analysis with participants aged over 65 years of age showed a significant positive effect of physical exercise on healthy ageing, including on reducing depression (Cunningham et al., 2020)Rounded.

Although the overall effect of exercise interventions on reducing depressive symptoms among older adults has been shown in previous research, only a limited number of studies have evaluated how the characteristics of the interventions, such as their content and duration, may affect their efficacy. Moreover, most studies have not evaluated the effect of exercise on depression modified by participants' characteristics, such as the participants' different health

statuses. In addition, although several meta-analyses regarding the effect of exercise interventions on reducing depression have been performed, the studies included in these analyses have had several limitations, including a limited sample and untimely updating of the relevant studies. The present study sought to fill these gaps through a meta-analysis of randomised controlled trials published from data inception to November 2020 on the effect of exercise interventions on depression and depressive symptoms of older adults. It aimed to evaluate the effect of exercise interventions on older adults with depression by analysing data on the aspects of exercise content, intensity of exercise, duration of intervention, weekly frequency, and length of intervention. Moreover, it classified older adults based on their regions and characteristics to compare the effect of exercise interventions on specific segments of older adults.

Methods

Eligibility Criteria

As outlined in the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines (Liberati et al., 2009), the inclusion and exclusion criteria of this meta-analysis were set based on the PICOS (Population, Intervention, Comparison, Outcomes, Study design) model (Table I).

Table I
Inclusion And Exclusion Criteria

		Exclusion Criteria
Population	Older adults aged 65 years or older	Participants aged below 65 years
Intervention	Exercises (e.g. aerobic exercises, resistance training)	Other interventions without exercise (e.g. medical treatment, cognitive training)
Comparison	Non-exercise interventions or no intervention at all in the comparison group	Exercise interventions in the comparison group
Outcomes	Sufficient data of mean ± SD of depression symptoms assessed by the Geriatric Depression Scale (GDS)	Other endpoints
Study design	Randomised controlled trials and intervention control trials	Pre- and post-controlled experiments, reviews, interviews, letters, posters, and book chapters
	Available full text published in journals that were in English	

Literature Retrieval

The Web of Science, PubMed (MEDLINE), ScienceDirect, EBSCO, Engineering Village, SpringerLink, and Google Scholar were searched from the establishment of their database to November 1, 2021. The databases were searched by title or abstract using subject words and free words. Subject words included 'exercise', 'older adults', 'depression', and 'random allocation'. Free words included 'physical activity', 'aged', 'depressive disorder', and 'clinical trial' and other synonyms of subject words. Taking the retrieval strategy used in PubMed as an example, the specific retrieval strategy can be seen below:

#1 exercise[Title/Abstract]

#2 (physical activity [Title/Abstract])) OR (aerobic exercise[Title/Abstract])) OR (exercise training[Title/Abstract])

#3 #1 OR #2

#4 (((older adults[Title/Abstract]) OR (aged[Title/Abstract])) OR (middle-aged[Title/Abstract])) OR (elderly[Title/Abstract])

#5 ((((depression[Title/Abstract]) OR (depressive disorder[Title/Abstract])) OR (depressive symptoms[Title/Abstract])) OR (depressive syndrome[Title/Abstract])) OR (Melancholias[Title/Abstract])

#6 (clinical[tiab] AND trial[tiab]) OR '"clinical trials as topic'"[mesh] OR '"clinical trial'"[pt] OR random*[tiab] OR '"random allocation'"[mesh] OR '"therapeutic use'"[sh]

#7 #3 AND #4 AND #5 AND #6

Study Selection And Data Extraction

According to the inclusion and exclusion criteria listed in Table I, two investigators reviewed the literature and extracted data independently. Some basic data were extracted from each study: name of the first author; year of publication; location; age of participants; participant characteristics; outcomes; content, frequency, duration, and length of the exercise intervention; sample size; and mean and standard deviation of variables in both the control and intervention groups. When there were differences or inconsistencies between the two investigators, they resolved these differences through a discussion with the third investigator.

Bias assessment

Seven aspects (random sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcome assessment, incomplete outcome data, selective reporting, and other biases) were considered in the bias assessment of each included study. Cochrane Review Manager 5.4 was used to perform the bias assessment. Specifically, when a study was assessed to have a low, an unclear, or a high bias risk for a particular aspect, it was marked with a '+', '?', or '–', respectively. Studies marked with 6 to 7 '+' were classified as having a low risk of bias, 4 to 5 '+' as having a moderate risk of bias, and <4 '+' as having a high risk of bias. The assessment of risk of bias was carried out by two investigators independently; the disagreements were resolved through discussions with a third investigator.

Data Calculation And Statistical Analysis

Meta-analysis was Performed Using Stata 16.0 (Stata Corp) and a random-effects model was used. Differences between the control and intervention groups were expressed as the standard mean difference. Standardised mean difference (SMD) and their 95% confidence interval (CIs) were calculated.

$$SMD = \frac{Difference\ in\ mean\ outcome\ between\ groups}{Standard\ deviation\ of\ outcome\ among\ participants}$$

Results

Study Selection Results

The study selection procedure is presented in Figure 1. A total of 7477 related articles were retrieved. By removing the duplicates, 6906 related ar-

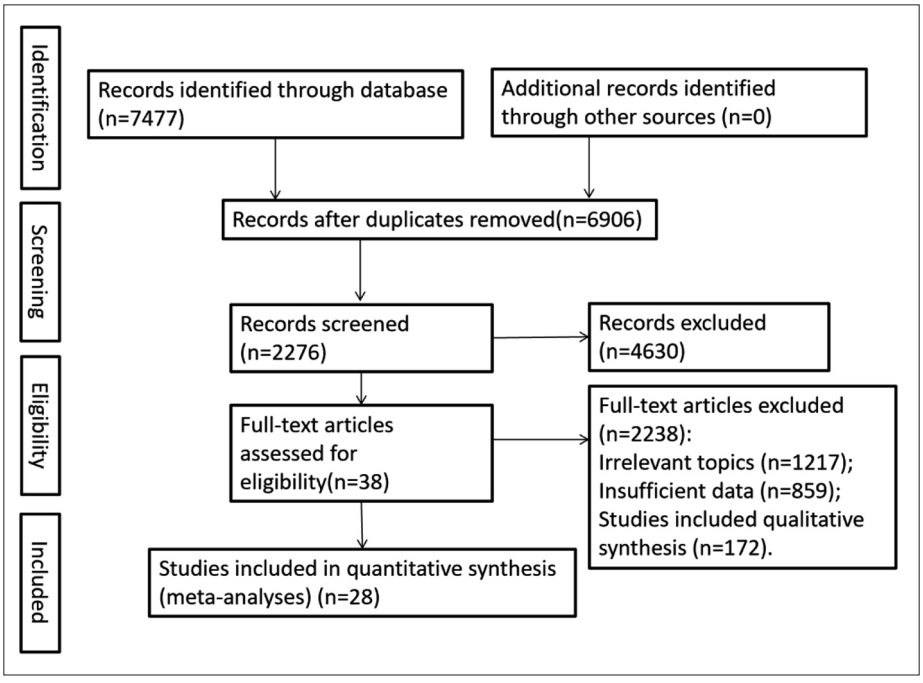

Fig. 1. - Description of the selection procedure for included studies based on PRISMA Guidelines.

ticles were left. The titles and abstracts were screened, leaving 2276 potentially relevant articles that were read in full. From these, 859 studies with insufficient data sets, 1217 studies with irrelevant topics, and 172 studies that were entirely qualitative syntheses were excluded. As a result, 28 studies (randomised controlled trials and intervention control trials) were selected for the meta-analysis.

Study Characteristics

We can observe that the selected 28 articles consisted of 2781 participants from the United States, New Zealand, China, Italy, Brazil, Spain, South Korea, Japan, Sweden, Portugal, Ireland, England, Turkey, and Singapore (see Table II). Intervention programs among these studies varied widely, including content related to aerobics, yoga, Qigong, strength, resistance, balance, and combination training. Each intervention session lasted from 30 to 90 minutes and was conducted 1-5 times per week with total intervention periods between 4 and 48 weeks. Endpoints were outcomes related to depression measured by the Geriatric Depression Scale (GDS), which has versions in different languages. Although various scales are utilised over the world for the assessment of depression, we adopted the Geriatric Depression Scale, which is a scale developed specially for screening depression in older adults. Compared with other depression scales, GDS appears to be a more reliable and sensitive screening scale for elderly populations (Yesavage et al., 1982). Besides, GDS was used commonly across the included studies. We ensured uniformity in this depression assessment standard by including reported outcomes of GDS as one of the inclusion criteria when screening the literature.

Risk Of Bias Within Studies

None of the 22 included studies showed a high risk of bias, with 11 of them showing a moderate risk of bias, and 9 of them showing a low risk of bias. The full results of the assessment of the risk of bias are shown in Figure 2. The percentages of each kind of bias among the included studies are shown in Figure 3.

Meta-analysis Results

Overall, exercise interventions contributed to reducing depression among older adults (SMD = -0.35; $P < .01$) (Figure 4). The result of the

TABLE II
Overview of studies included in this meta-analysis

First Author (year)	Study Location	Sample Size	Age	Participant Characteristics	Intervention Content	Intervention Frequency, times per wk	Intervention Duration, wk	Length of Each Intervention Session, min
Macrae et al. (1996)	United States	I:19 C:12	≥80	Healthier	Aerobic	5	12	30
Kerse et al. (2010)	New Zealand	I:97 C:96	≥75	Depression	Aerobic	3	24	30
Cheng et al. (2012)	Hong Kong, China	I:12 C:12	m=82.5	Depression	Mind-body	3	12	60
Verrusio et al. (2014)	Italy	I:12 C:12	m=75.5	Depression	Aerobic	3	24	60
Ansai and Rebelatto (2015)	Brazil	I:22 C:23	>80	Healthier	Comprehensive	3	16	60
Lare-do-Agui-lera et al. (2018)	Spain	I:20 C:18	>65	Healthier	Comprehensive	3	10	60
Kim et al. (2019)	South Korea	I:11 C:10	67-81	Healthier	Anaerobic	2	24	50-80
C. H. Huang et al. (2020a)	Japan	I:98 C:93	65-85	Healthier	Aerobic	2	26	60
C. H. Huang et al. (2020b)	Japan	I:90 C:93	65-85	Healthier	Anaerobic	3	26	60

(*Continued*) Table II

(*Continued*) Table II

First Author (year)	Study Location	Sample Size	Age	Participant Characteristics	Intervention Content	Intervention Frequency, times per wk	Intervention Duration, wk	Length of Each Intervention Session, min
C. H. Huang et al. (2020c)	Japan	I:96 C:93	65-85	Healthier	Comprehensive	2	26	60
Sohng et al. (2003)	Korea	I:22 C:23	≥65	Healthier	Comprehensive	4	8	30
Tsang et al. (2006)	Hong Kong, China	I:48 C:34	≥65	Depression	Comprehensive	3	16	30-45
Brenes et al. (2007)	United States	I:14 C:12	≥65	Depression	Mind-body	3	16	60
Conradsson et al. (2010)	Sweden	I:91 C:100	≥65	Fragile	Comprehensive	2.5	12	45
Maki et al. (2012)	Japan	I:75 C:75	≥65	Healthier	Comprehensive	1	12	90
T.-T. Huang et al. (2015)	Taiwan, China	I:19 C:20	≥65	Depression	Aerobic	3	12	50
Kamegaya et al. (2014)	Japan	I:26 C:26	≥65	Healthier	Comprehensive	2.5	12	45
Hsu et al. (2016a)	Taiwan, China	I:30 C:30	≥65	Fragile	Mind-body	3	13	40
Hsu et al. (2016b)	Taiwan, China	I:30 C:30	≥65	Fragile	Mind-body	3	26	40
Choi and Sohng (2018)	Korea	I:33 C:30	≥65	Healthier	Mind-body	4	12	30-40

(*Continued*) Table II

(*Continued*) Table II

First Author (year)	Study Location	Sample Size	Age	Participant Characteristics	Intervention Content	Intervention Frequency, times per wk	Intervention Duration, wk	Length of Each Intervention Session, min
Cockayne et al. (2017a)	Ireland and England	I:493 C:517	≥65	Healthier	Anaerobic	3	48	30
Cockayne et al. (2017b)	Ireland and England	I:493 C:517	≥65	Healthier	Anaerobic	3	24	30
Sahin et al. (2018a)	Turkey	I:16 C:16	≥65	Fragile	Anaerobic	3	8	40
Sahin et al. (2018b)	Turkey	I:16 C:16	≥65	Fragile	Anaerobic	3	8	40
Jang et al. (2019)	Korea	I:22 C:22	≥65	Healthier	Mind-body	2	8	60
Apostolo et al. (2019)	Portugal	I:23 C:21	≥65	Fragile	Anaerobic	2	12	30
Ng et al. (2017)	Singapore	I:48 C:50	≥65	Fragile	Anaerobic	2	18	90
Ng et al. (2017)	Singapore	I:48 C:50	≥65	Fragile	Anaerobic	2	24	90

heterogeneity test showed a substantial heterogeneity among all the included studies ($I^2 = 90.1\ \%$, $P < .01$); therefore, a random-effects model was used in this meta-analysis (Figure 4).

The Egger's test ($P = .016$) and asymmetric funnel plot (Figure 5) indicated a significant publication bias. To further investigate the effect of this publication bias, the fifth iteration was performed through the trim and fill method. There was no significant change, indicating that publication bias had little effect and the results were relatively stable. Publication bias may be attributed to several reasons, including the sample size, method of reporting the data, researcher deciding whether or not to submit the results, tendency of journals to reject studies with negative outcomes, and execution of the meta-analyses (Thornton & Lee, 2000).

Sensitivity Analysis

According to the sensitivity analysis, the meta-analysis results did not change significantly as each of the studies was removed one by one (Figure 6), suggesting the reliability of the results despite the heterogeneity of the studies.

Subgroup Analysis

In this meta-analysis, we performed several subgroup analyses based on: geographic region; participants' physical status; and the exercise intervention content, duration, length, frequency, and intensity. As for geographic region, studies were classified into those conducted in Asia, Europe, North America, South America, or Oceania, thereby covering all of the regions in these studies. With regard to participants' physical status, participants of these studies were classified into three categories: depression, which included older adults with depressive symptoms or with a diagnosis of clinical depression according to the original research criteria; fragile, which included older adults with dementia or other kinds of illnesses, and depending on assistance or using a wheelchair for mobilization, conditions that do not affect normal daily activities such as mild cognitive impairment were not included; or healthier, which included older adults capable of walking alone, and without a specific illness or disorder.

In terms of the exercise content, interventions were classified into aerobic, anaerobic, comprehensive, or mind-body exercises based on the definitions stated below. According to the American College of Sports Medicine,

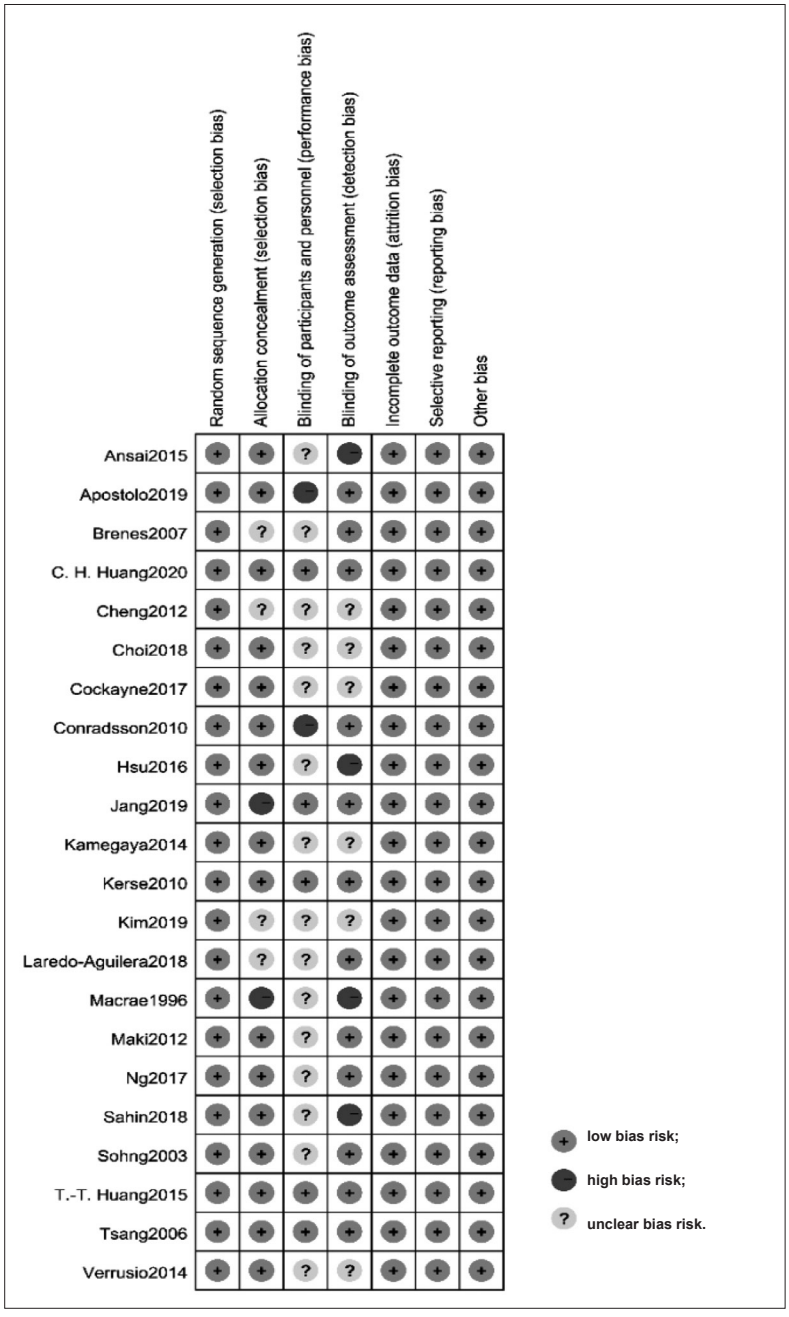

Fig. 2. - Assessment of the risk of bias for included studies.

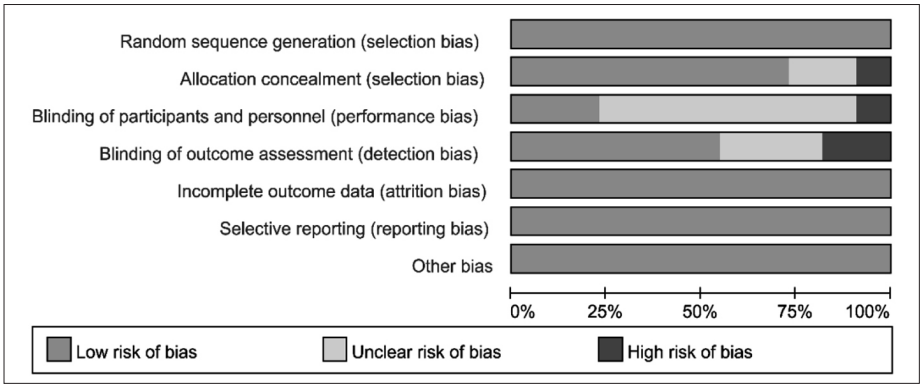

Fig. 3. - Distribution of studies across the bias ranking for each type of bias.

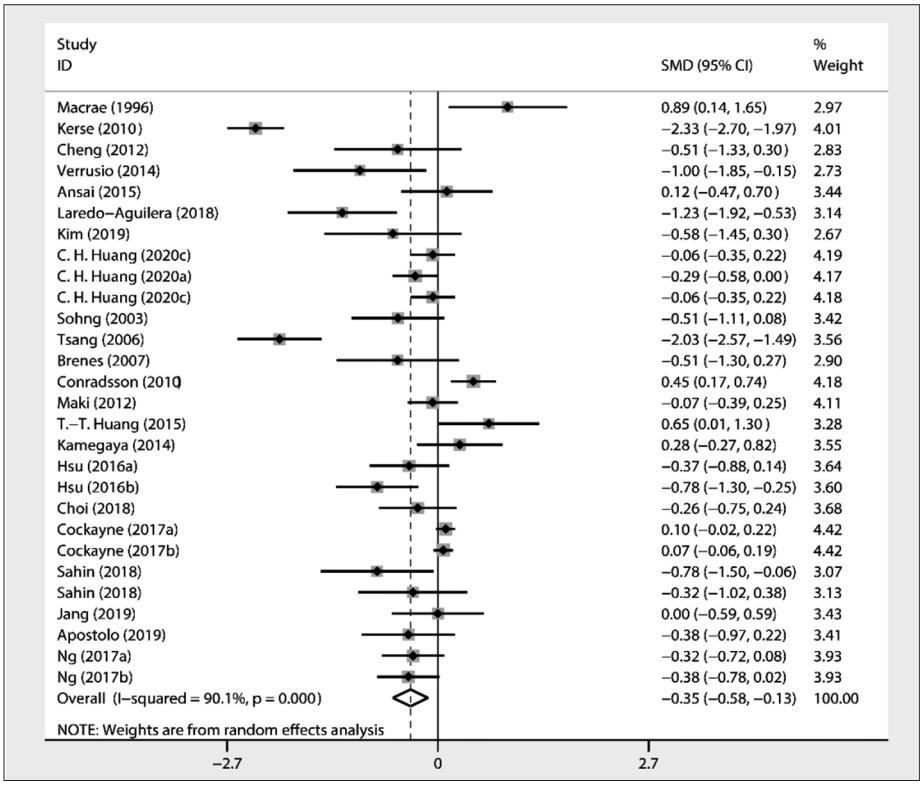

Fig. 4. - Meta-analysis of the effect of exercise interventions on the depression of older adults.
Id, Identification; Smd, Standardised Mean Difference. Risk of publication bias.

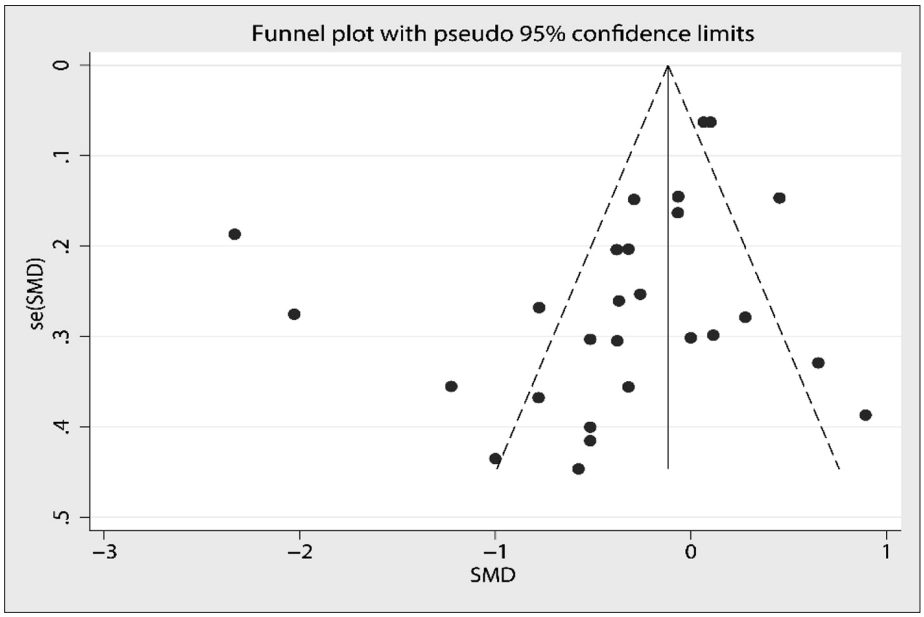

Fig. 5. - Funnel plot.

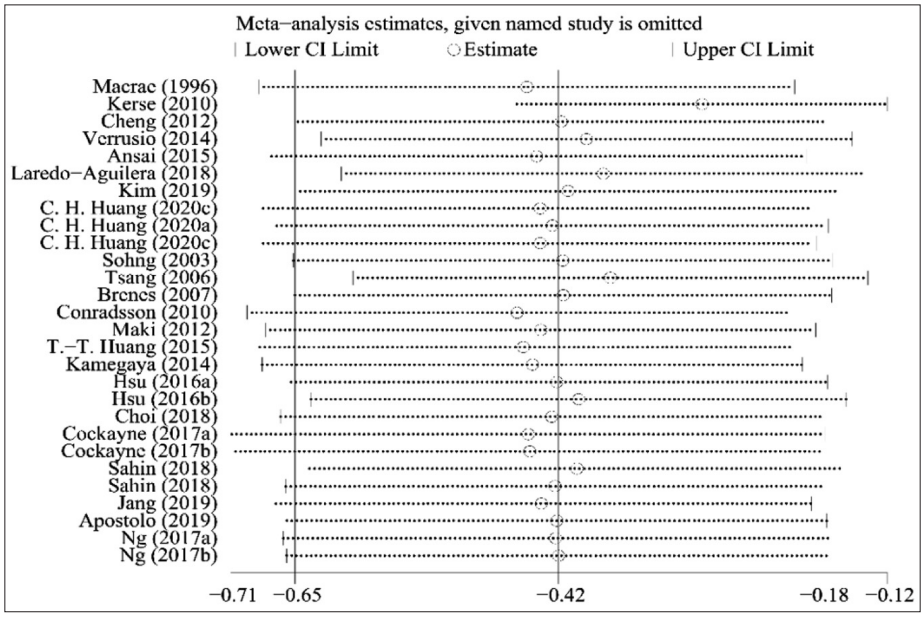

Fig. 6. - Sensitivity analysis.

aerobic exercise refers to activity that uses large muscle groups, is rhythmic, and can be maintained continuously, while anaerobic exercise refers to intense physical activity of a very short duration that does not involve inhaled oxygen as an energy source (Harsh et al., 2017). Accordingly, aerobic exercises in the studies included in this meta-analysis involved uninterrupted and rhythmic activities continued for a long time, such as walking, jogging, swimming, cycling, walking, and aerobics; all these exercises can improve the cardiopulmonary function, such that the entire body's tissues and organs get adequate oxygen and nutrition supply, contributing to the maintenance of the best functional state. Anaerobic exercise refers to static training, which is characterized by a fast rhythm, short time, and easily injured, as seen in the exercises of weightlifting and resistance training. Comprehensive exercises are those that involve components of both aerobic and anaerobic exercises. Mind-body exercises refer to a range of low impact and deliberately slow movements, in addition to breathing, meditation, and progressive relaxation. This exercise mode integrates low-intensity muscular activity with an internally directed focus that encourages a self-contemplative mental state, as seen in the activities of yoga, Tai Chi, and Qigong (Forge & Nursing, 1997).

In terms of the intervention duration, interventions were classified into long duration (>24 weeks), medium duration (13–24 weeks), or short duration (0–12 weeks). As for the length of each intervention session, interventions were classified into long session (>45 minutes) or short session (≤45 minutes). With regard to the intervention frequency, interventions were classified into high frequency (≥3 times per week) and low frequency (<3 times per week). Influenced by subjective factors, researchers could not reach a consensus partition manner for classifying intervention duration, intervention frequency and the length of each session. We have made a relatively appropriate division according to the data of included studies. In terms of the exercise intensity, exercises were classified into low, moderate, and high intensity. Exercise intensity was classified as it had been specifically stated in the original research, or it was decided according to the exercise-related data provided in the original research, including the exercise intensity scale, heart rate, and other related indicators. For example, low intensity exercise included yoga, walking, and Tai Chi.

First, we compared the effects of the exercise interventions on the depression of older adults from different regions. Since only two studies had been conducted in Oceania and South America, and their weight too was relatively small, they were omitted in the subgroup analysis. High heterogeneity was observed among participants in Asia ($I^2 = 67.4\ \%$; $P < .01$) and North America ($I^2 = 71.6\ \%$; $P = .06$). Moreover, substantial heterogeneity

was observed among participants in Europe (I^2 = 87.1 %; P < .01). The largest reduction in depression was observed among participants in Asia (SMD = –0.35; P < .01). (Table III).

Second, we compared the effects of the different exercise interventions on the depression of older adults based on their exercise content. Moderate heterogeneity was observed in the mind-body exercise group (I^2 = 27.5 %; P = .238), high heterogeneity was observed among those receiving anaerobic exercise interventions (I^2 = 70.2 %; P < .01), and substantial heterogeneity was observed among those receiving aerobic (I^2 = 97.3 %; P < .01) or comprehensive exercise interventions (I^2 = 88.3 %; P < .01). Nevertheless, the largest reduction in depression was observed among those who received aerobic exercise interventions (SMD = –0.64; P = .36), followed by those who received mind-body exercises (SMD = –0.44; P < .01). This implies that aerobic and mind-body exercises may be more effective than other exercises in reducing the depressive symptoms of older adults. (Table 3).

Among subgroups based on different intervention duration, high heterogeneity was observed in the subgroup receiving interventions lasting between 0 and 12 weeks (I^2 = 74.2 %; P < .01), while substantial heterogeneity was observed in the subgroup receiving interventions lasting for more than 24 weeks (I^2 = 77.8 %; P < .01) or between 13 and 24 weeks (I^2 = 95.8 %; P < .01). Nevertheless, the largest reduction in depression was observed among those who received interventions lasting between 13 and 24 weeks (SMD = –0.79; P < .01). These results justify further research to assess the potential efficacy of exercise interventions with a duration between 13 and 24 weeks for older adults. (TTable III).

Among subgroups based on the length of each intervention session, high heterogeneity was observed among those receiving interventions lasting more than 45 minutes each session (I^2 =62.2 %; P < .01), while substantial heterogeneity was observed among those receiving interventions lasting 45 minutes or less each session (I^2 = 95.0 %; P < .01). Since the subgroup whose intervention session lasted less than 45 minutes showed greater reduction in depression (SMD = –0.48; P < .01), this session length may be more effective than longer sessions (Table III).

Among subgroups classified based on the frequency of intervention, moderate heterogeneity was observed in the subgroup that received the intervention less than three times per week (I^2 = 66.0 %; P < .01), and substantial heterogeneity was observed in the subgroup that received the intervention three or more times per week (I^2 = 94.0 %; P < .01). Nevertheless, the largest reduction in depression was observed among those who received an intervention three or more times a week (SMD = –0.58; P = .107). These results

TABLE III.
Subgroup Analysis Of The Effect Of Exercise Interventions On The Depression Of Older Adults

Subgroup	N of studies included	Heterogeneity Test			2-Tailed test		
		Heterogeneity statistic	P value	I^2 value, %	SMD (95 % CI)	Value	P value
Region							
North America	3	3.52	P = .061	71.6	-0.04 (-1.05, 0.97)	0.08	P = .939
Asia	16	52.16	P = .000	67.4	-0.35 (-0.55, -0.16)	3.54	P = .000
Europe	8	38.80	P = .000	87.1	-0.20 (-0.50, 0.11)	1.25	P = .326
Exercise content							
Aerobic	5	147.28	P = .000	97.3	-0.64 (-2.01, 0.73)	0.92	P = .358
Anaerobic	9	26.84	P = .000	70.2	-0.23 (-0.43, -0.04)	2.33	P = .020
Mind-body	5	5.52	P = .238	27.5	-0.44 (-0.76, -0.11)	2.65	P = .008
Comprehensive	9	68.22	P = .001	88.3	-0.36 (-0.78, 0.07)	1.66	P = .098
Duration							
≤ 12 wks	13	46.49	P = .000	74.2	-0.20 (-0.50, 0.10)	1.31	P = .191
13–24 wks	10	215.18	P = .000	95.8	-0.79 (-1.43, -0.15)	2.41	P = .016
> 24 wks	5	18.03	P = .001	77.8	-0.18 (-0.43, 0.07)	1.39	P = .165
Length							
≤ 45 mins	14	258.19	P = .000	95.0	-0.48 (-0.88, -0.09)	2.43	P = .015
> 45 mins	14	34.40	P = .001	62.2	-0.30 (-0.51, -0.09)	2.82	P = .005
Frequency							
< 3 times/wk	10	29.41	P = .001	66.0	-0.15 (-0.35, 0.06)	1.42	P = .156
≥ 3 times/wk	18	265.95	P = .000	94.0	-0.58 (-0.96, -0.21)	3.04	P = .002
Intensity							
Low-intensity	9	141.48	P = .000	94.3	-0.78 (-1.50, -0.07)	2.14	P = .032
Moderate-intensity	14	35.17	P = .001	63.0	-0.33 (-0.55, -0.11)	2.99	P = .003
High-intensity	5	7.05	P = .133	43.3	0.12 (-0.01, 0.26)	1.77	P = .077
Health status							
Depression	6	87.16	P = .000	94.3	-1.05 (-2.11, 0.00)	1.96	P = .051
Fragile	8	32.23	P = .000	78.3	-0.38 (-0.74, -0.01)	2.03	P = .042
Healthier	14	36.78	P = .000	64.7	-0.11 (-0.26, 0.04)	1.41	P = .157

indicate the need for further research into the efficacy of interventions that are carried out for no less than three times a week for older adults (Table 3).

Among subgroups classified by the intensity of the intervention, moderate heterogeneity was observed among those receiving high-intensity exercise interventions (I^2 = 43.3 %; P = .133), high heterogeneity was observed

among those receiving moderate-intensity exercise interventions (I^2 = 63.0 %; P < .01), and substantial heterogeneity was observed among those receiving low-intensity exercise interventions (I^2 = 94.3 %; P < .01). Since the low-intensity exercise intervention group showed a larger reduction in depression (SMD = –0.78; P < .01), low-intensity exercises may be more effective and suitable than moderate- or high-intensity exercises for reducing depression among older adults (Table III).

Additionally, we compared the effects of exercise interventions on the depression of older adults with different health statuses. High heterogeneity was observed among the healthier older adults (I^2 = 64.7 %; P < .01). Substantial heterogeneity was observed among the older adults with depression (I^2 = 94.3 %; P < .01) or fragility (I^2 = 78.3 %; P < .01). Nevertheless, the largest reduction in depression was observed among older adults with depression (SMD = –1.05; P = .05), implying that aerobic exercises may be more effective for older adults with depression, rather than those without depression (Table III).

Discussion

This meta-analysis of 22 studies (randomised controlled trials and intervention control trials) suggests that exercise interventions can effectively reduce the depressive symptoms of older adults, especially those who have been formally diagnosed with depression. In particular, our meta-analysis suggests that low-intensity aerobic exercise interventions for reducing depression among older adults should be delivered for 13–24 weeks, no less than three times a week, with each exercise session lasting no more than 45 minutes. The sensitivity analysis showed our results to be robust to the removal of individual studies, with a stable publication bias. The results of this study are consistent with a previous meta-analysis (Rhyner & Watts, 2016), which concluded that exercise interventions produced a moderately significant effect for reducing depressive symptoms in older adults compared to the 'no treatment' or 'comparison treatment' control groups. Rhyner & Watts (2016) observed a greater reduction (SMD = 0.57, 95 % CI 0.36–0.78) in the depressive symptoms of older adults than we did. This can be attributed to the participants included in our study being older than the participants in their study. Compared to the study of Rhyner and Watts (2016), this study includes 20 randomized controlled trials in recent years while all of studies analyzed by Rhyner & Watts (2016) were published before 2013.

Most of the 49 randomised controlled trials and intervention control trials included in these 22 studies reported that exercise interventions ex-

erted a positive influence on reducing depression among older adults. In contrast, 12 of them showed an opposite or neutral effect. The inclusion of different types of exercise interventions across these studies may account for these mixed results. Importantly, we found that almost all the participants included in studies reporting negative or neutral results were relatively healthy older adults, indicating that exercise intervention had a larger effect on individuals with depressive symptoms than on those without these symptoms. To further investigate the heterogeneity and effectiveness of different exercise interventions, several subgroup analyses were performed based on the type of exercises, and their intensity, length, and frequency.

First, subgroup analysis by the type of exercise content showed that aerobic exercises had a better effect on reducing depression than anaerobic or comprehensive exercises; this finding is consistent with previous research by Miller et al. (2020). This result gains more credence upon considering recommendations to promote aerobic exercise training during ageing because of its already recognized benefits on functionality, emotional health, and blood glucose control (Seguin & Nelson, 2003). However, moderate to high intensity aerobic exercises may not be suitable for older adults having multiple comorbidities, as it may limit such individuals' effective participation in exercises (Singh et al., 2005). Thus, exercises such as walking, yoga, and Tai Chi may be better choices for older adults. Nevertheless, whether a particular exercise program is more effective than other types of exercise, and whether characteristics of exercise interventions other than those reviewed in this analysis play a role in reducing depression among older adults remains to be elucidated.

Second, subgroup analysis by the intensity of exercise intervention showed that low-intensity exercises were more effective than moderate- or high-intensity exercises for reducing depression among older adults. In contrast, a study by Singh et al. indicated high- or moderate-intensity exercise to be more effective than low-intensity training (Singh et al., 2005). However, from the perspective of practice, low-intensity aerobic exercise is less difficult, more easily tolerated, and can be practiced daily over an extended period of time (Al Saif & Alsenany, 2015).

Third, subgroup analysis by the length of exercise intervention showed exercise sessions of no more than 45 minutes to be more effective than those lasting beyond 45 minutes; this finding is consistent with that of a previous study, which found shorter resistance exercise training sessions (< 45 min) to result in larger reductions in depressive symptoms than sessions with longer durations (Gordon et al., 2018). The most suitable length of exercise varies from person to person. Considering the typical physical condition of older adults, they might feel more comfortable with exercises that begin with short

durations and progress gradually in their length. According to the subgroup analysis by exercise intervention duration, it showed that 13–24 weeks of exercise intervention was most suitable. When the intervention exceeds 24 weeks, the effect may be weakened with the increase of duration. However, it doesn't imply that exercise lasting longer than 24 weeks would not have more beneficial effects on older adults.

Fourth, subgroup analysis by the frequency of exercise intervention showed exercise programs carried out no less than three times per week to be more effective than programs with lesser frequencies. According to the National Collaboration Centre for Mental Health, supervised exercise three times a week for 10–14 weeks can reduce people's depression level (Health, 2010). Exercises carried out at a moderate frequency, such as three times per week, are considered to be suitable for older adults, as they are safe to carry out and have not resulted in many adverse events during experimental procedures of previous studies (Stout et al., 2017). Such a frequency of exercise intervention is also less likely to result in adverse events while performing the exercises.

A significant conclusion from this study is that exercise interventions had larger effects on older adults with depression than on those without depression. This conclusion is consistent with the finding from Rhyner and Watts's review (2016), which showed greater mean effect sizes for studies including individuals with a diagnosis of depression than for studies not including such individuals. This might be because people with depression can recognize the change in their depressive symptoms more clearly and obviously.

To improve the effectiveness of exercise interventions in relieving depression among older adults, the mechanisms by which exercise relieves depression should be further clarified. Literature has shown that patients with depression may have impairments in neuroprotective and anti-inflammatory T cell responses, suggesting that therapies that boost such T cell responses could be employed with patients having depression (A. H. Miller & Raison, 2016). In addition, inflammatory and oxidative stress markers, such as IL-6 and IL-1B, have been found to contribute to depression (A. H. Miller & Raison, 2016). When patients have higher levels of IL-6, exercise therapy is more effective in curing depression (Lavebratt et al., 2017). In addition, brain-derived neurotrophic factor (BDNF) is also one of the indicators of successful treatment of depression (Polyakova et al., 2015). Exercise can increase the expression of BDNF (Russo-Neustadt et al., 2004), helping bring the level of BDNF back to the original level among patients. Moreover, depression reduces the volume of hippocampus in the human brain (Warner-Schmidt & Duman, 2010), while exercise can increase the volume of hippocampus (Michael et al., 2012). Nevertheless, in order to

enhance the physical function and mental activity of older adults, they must be encouraged to carry out various kinds of exercises if their physical conditions permit them to do so.

Conclusion

Similar to the results of previous studies (Catalan-Matamoros et al., 2016; Chang et al., 2019; Laredo-Aguilera at al., 2018), our research confirmed that physical exercise should be considered as an effective method to reduce depression among older adults. This meta-analysis differs from previous studies and contributes to added value of the meta-analysis in a few important ways. First, we refined the content of exercise interventions based on their duration, intensity, and frequency. As a result, more clear and definite suggestions could be provided according to these subgroup analyses. Second, compared to the previous meta-analyses, the most recent studies were included in this review, possibly contributing to a more comprehensive result. Third, besides the overall effect of exercise intervention on depression, we discussed the mechanisms by which exercise relieves depression. Therefore, these results could be understood and interpreted more accurately, and the effectiveness of exercise intervention could be further improved.

In practice, we provided suggestions for both the clinical treatment of older adults with depression and health promotion by the older adults themselves. From the perspective of clinical treatment, exercise therapy should be emphasized. The efficacy of antidepressant medications is limited, and antidepressants also produce a series of side effects, to which older adults could be more sensitive than younger adults (Hollon et al., 2010). Therefore, exercise intervention could be a possible alternative treatment for depression, and it can be combined with other clinical treatments to relieve depression among older adults. Moreover, the caregivers of older adults could instruct and guide the older adults to adequately adhere to their exercise intervention programs to relieve depression. For the older adults themselves, physical exercise is a key factor to maintain health during ageing (Kekalainen et al., 2018); hence, regular and moderate physical exercise is recommended in their daily life.

Some limitations of this meta-analysis should be addressed. First, a relatively high heterogeneity was found among the included studies, and there remained a high level of heterogeneity within subgroups. Second, immediate post-intervention data were used in this meta-analysis instead of long-term follow-up data. Thus, the long-term effects of exercise interventions on the

depression of older adults could not be demonstrated. Third, some subgroup analyses were not performed due to limited data, such as on age stratification among older adults and gender, since only a few studies reported a clear age range or focussed on segmentation of data based on gender. Fourth, the current subgroups were classified by authors using limited reported information from the original included studies, and there remained the possibility of this reported information being inaccurate. Thus, caution should be adopted when drawing conclusions because of the differences in the exercise definitions. Although GDS is a more reliable and universal screening scale when it comes to elderly populations, there is still limitation to a single measure of depressive symptoms.

Many existing studies included in this analysis were limited in some ways, such as due to a lack of allocation concealment, blinding of outcome assessment, or inadequate control groups; hence, researchers are encouraged to repeat this meta-analysis when more original clinical studies and more valid data become available. Furthermore, in order to determine a more precise impact of exercise interventions on depression among older adults, researchers should carry out more targeted researches; for instance, researches on the effect of exercise interventions on older adults of a specific age range and with different co-morbidities can be undertaken.

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The authors declare no conflict of interest.

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