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Interventions promoting physical activity among obese populations: a meta-analysis considering global effect, long-term maintenance, physical activity indicators and dose characteristics

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Summary

As the benefits that regular physical activity (PA) have on obesity are well known, many interventions promote active lifestyle adoption among obese populations. This meta-analysis aims to determine (i) the global effect that interventions promoting PA among obese populations have on their PA behaviour; (ii) variations in the effect of interventions depending on the PA indicator used; (iii) the programme's dose characteristics and (iv) maintenance of the intervention effects after the intervention has ended. A comprehensive search through databases and review articles was completed. Forty-six studies met the inclusion criteria. Calculations of effect size (Cohen's *d*) and a moderator analysis were conducted. The meta-analysis showed that interventions globally have an impact on the PA behaviour of obese populations ($d = 0.44$; 95% CI = 0.31, 0.57). The moderator analysis revealed that interventions of less than 6 months reported significantly larger effects than longer interventions. Moreover, the interventions had a stronger impact on the number of steps and the PA indexes (i.e. composite scores reflecting PA practice) than on other PA indicators. Finally, the analysis revealed that interventions succeed in maintaining PA behaviour after the intervention is over. However, relatively few studies addressed this issue ($n = 9$). Despite global positive effects, further research is needed to determine the optimal dose for interventions and to evaluate the maintenance of intervention effects.

Keywords: Interventions, meta-analysis, obesity, physical activity.

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Introduction

The prevalence of overweight people (body mass index [BMI] $\geq$ 25 kg m^{-2}) and obesity (BMI $\geq$ 30 kg m^{-2}) worldwide is increasing at such a dramatic rate that is considered to be a global epidemic (1). A total of 1.1 billion adults and 10% of children are now classified as being overweight or obese (2). Obesity has been linked to physical health problems such as hypertension (3), insulin resistance (4), cardiac disorders (5) and some cancers (6). Obesity has also been associated with psychological problems such as decreased self-esteem (7) and depressive symptom development (8). Regular physical activity (PA) represents one of the key elements in the treatment of obesity, along with changes in eating behaviour (9). Considered as an efficient strategy for burning calories, PA plays a key role in compensating for the energy imbalance induced by weight gain and obesity development (10–13). Moreover, in addition to improving psychological well-being and cardiovascular fitness (14,15), PA also plays an important role in the maintenance of weight loss (16). However, despite its positive effects, a sedentary lifestyle and low PA behaviour remain common problems in obese populations (17,18). As a result, numerous intervention studies have been carried out to increase

PA among overweight and obese populations. Despite several reviews and meta-analyses on the efficacy of interventions on weight loss and BMI evolution in obese populations (19–25), obesity prevention in under age and adult populations (26–29) and PA behaviour in healthy populations (30–33), synthetic reviews on the effectiveness of interventions promoting PA among obese populations remain sparse. A recent review (34) reported that interventions were globally effective in increasing the PA level of obese children and adolescents. The present meta-analysis moves beyond this previous synthesis in two different ways. Firstly, whereas the review carried out by Cliff *et al.* (34) only focused on obese children and adolescents, the present work also includes studies carried out on adult participants. As PA is considered to be a cornerstone of obesity treatment for both under age and adult populations (9), it seems relevant to have a synthetic review of the impact of interventions promoting PA in a broader obese population. Secondly, although reports of treatment efficacy from narrative reviews can guide clinical decision making (24), meta-analytical reviews allow for an objective assessment of the overall magnitude of treatment effects (35,36). The present review uses a meta-analytical approach in order to quantify intervention effects on PA in obese populations.

Four specific research questions were addressed. The first one was: what is the overall effect size of interventions on PA behaviour? Such a question is an important step in determining whether or not interventions among obese populations that include PA components globally succeed in enhancing PA. As PA is recognized as being a complex phenomenon to measure (37), interventions promoting an active lifestyle have utilized various direct (e.g. energy expenditure) and/or indirect (e.g. cardiovascular health) indicators to evaluate PA. Differences in sensitivity to the effects of programmes may exist according to the indicator used. Consequently, the second research question was: does the intervention effect vary according to the PA indicator used? As cost-effective treatments are needed to manage the obesity epidemic (38,39), it seems important to test whether or not the 'dose' characteristics of interventions such as implementation duration and number and frequency of sessions have an impact on the programme's effect. Despite the fact that such factors are recognized as playing an important role in the success of obesity treatment (40), less is known about the optimal 'dose' of the intervention for obesity treatment (24). For example, a short programme length or a low session frequency for an intervention could result in fewer possibilities for discussion, learning or support, and thus lead to a lack of interest or concern by the participants and thus reduce the probability of behavioural change. On the other hand, a long programme length or a high session frequency for an intervention could be counterproductive by being perceived as highly constraining and giving a perception of being under pressure to change, which could lead to the development of anxiety, which is recognized as being negatively related to weight management and PA practice enhancement in this population (41). Thus, the third research question was: does the intervention effect vary according to the dose characteristics of the intervention? Finally, given that initial behavioural changes do not ensure long-term maintenance (42) and that maintenance of the intervention effect over time represents one of the most important challenges in obesity treatment (43), the fourth research question was thus: what are the effects of interventions on PA after the interventions have finished?

Methods

Search strategies

A comprehensive investigation was completed using two strategies. Firstly, a search using identified keywords was undertaken in the following databases: Pubmed, Sports Discus, Current Contents and PsycINFO. The identified keywords were as follows:

- Concept 1: obesity, overweight;
- Concept 2: physical activity, exercise;
- Concept 3: intervention, program, treatment, promotion, management.

Secondly, additional searches were carried out on references included in papers, published reviews and meta-analyses on PA promotion and obesity interventions.

Inclusion and exclusion criteria

Articles were included in this meta-analysis if they met the following criteria (i) the sample populations had a BMI $\geq$ 25 kg m^{-2}; (ii) the results were specifically related to an intervention; (iii) the primary component or one of the components of the intervention was to promote PA and (iv) the PA outcome measurements (e.g. duration, energy expenditure) or physical fitness (e.g. cardiovascular fitness) were reported. The studies could be either quasi-experimental (using pre- and post-tests) or randomized controlled trials. The exclusion criteria were (i) descriptive studies; (ii) interventions that specifically targeted populations with diagnosed complications linked to obesity (e.g. metabolic syndrome) or to drug-induced obesity treatment (e.g. Orlistat); (iii) interventions composed only of supervised exercise sessions intended to assess the effect of PA on weight evolution (i.e. without the explicit intent to change behaviour or lifestyle); (iv) interventions that did not report PA indicators other than participation rate in organized sessions and (v) results published in languages other than English.

Data extraction and analyses

In order to answer the four research questions, the data extracted from each study included in this meta-analysis were: sample size, study design, type of PA measure, duration of intervention, number and frequency of sessions and length of follow-up.

Effect sizes were calculated using Cohen's *d* (44) with Comprehensive Meta-Analysis software, Version 2.2.050 (45). For randomized controlled trials, Cohen's *d* represents the mean difference evolution between the intervention and the control group on the outcome during the intervention. For the studies with no control group, Cohen's *d* represents the mean evolution of the outcome between pre- and post-intervention measures (23). Positive effect sizes indicate favourable changes compared to either the control group or baseline mean. Effect sizes of 0.2, 0.5 and 0.8 represent small, medium and large effects, respectively (44). Effect sizes were calculated from data on mean evolution, the number of participants and the pooled standard deviations for each trial. When summary statistics were not reported, data from the significance levels of statistical tests (e.g. *t*- or *F*-values) were used to make an estimation of Cohen's *d* (46). As a complement to Cohen's *d*, 95% confidence intervals (95% CIs) were also reported.

Heterogeneity between the studies was assessed using the omnibus homogeneity test (Q) and the I^2 as indicators. The Q-test indicates whether or not the heterogeneity between trials is statistically significant. The I^2-test (range = 0–100%) indicates the variance between studies as a proportion of the total variance (47). The percentages associated with I^2 are interpreted as low (25%), medium (50%) and high (75%) heterogeneity (48). When heterogeneity was present ($Q < 0.05$, $I^2 \geq 75\%$), the pooled effect size was calculated using a random effects model, otherwise the fixed effects model was used (26). Compared to the fixed effects model, a random effects model assumes a different effect for each study and considers this as an additional source of variation, which leads to wider confidence intervals than with the fixed effects model (48).

Publication bias and outlier identification were tested using a funnel plot (49). Two funnel plots were generated: one for the global effect size of interventions directly post-intervention (i.e. the first research question; see Fig. 2) and one for the effects of the interventions after they ended (i.e. the fourth research question; see Fig. 4). Outliers were also determined by observing the heterogeneity reduction level when the effect size of each intervention was removed (50).

Moderator analysis

Moderator analyses were conducted to test whether or not the effect size varied depending on factors such as the type of PA indicator, the intervention duration, the total number of sessions and session frequency. Continuous moderators were analysed using a univariate meta-regression, and categorical moderators were analysed using a meta-analytical analogue of ANOVA (51). The effect of a continuous or dichotomous moderator was tested using a regression slope (B = unstandardized regression coefficient) or the between-groups heterogeneity statistic (Qb), respectively (52).

Results

Study selection

Figure 1 shows the process of the study selection. A total of 188 references met the search criteria across the four databases. After reviewing the title and abstract, a total of 62 articles were retrieved, and 29 of the 62 studies met the inclusion criteria. The main reasons for exclusion from this meta-analysis were: no appropriate outcome available (e.g. no measurement of PA) and/or the absence of PA promotion in the intervention components. Additional searches from references in prior studies, meta-analyses and reviews found 17 additional studies that were included. As a result, 46 studies met the inclusion criteria and were included in the analysis.

Intervention strategies for increasing physical activity

The programmes varied widely both in their components and in the modality of the interventions. Concerning the components of the interventions, all of the studies used multipronged intervention strategies with information transmission and cognitive–behavioural techniques (e.g. goal setting, self-monitoring) as the main components for improving PA among the participants. Some interventions (e.g. (53–55)) provided supervised exercise sessions, sometimes along with moderate calorie restriction (e.g. (56–58)) in addition to cognitive–behavioural sessions. Other interventions (e.g. (59–61)) used pedometers during the programme as feedback tools for informing and counselling participants about their PA evolution during the programme. Lastly, social environment involvement components such as invitations to sport centres for all the family or direct advice or instructions during sessions for friends or family members about strategies for helping the participants increase their PA were included in some interventions (e.g. (62–64)).

Concerning the modality of the interventions, the programmes used face-to-face (e.g. (61,65,66)), collective (e.g. (53,59,67)) or both types of sessions alternately (e.g. (56,68,69)). For some programmes, telephone calls (e.g. (68,70,71)) were added to motivate and help the participants to adopt active lifestyles, and websites (e.g. (72,73))

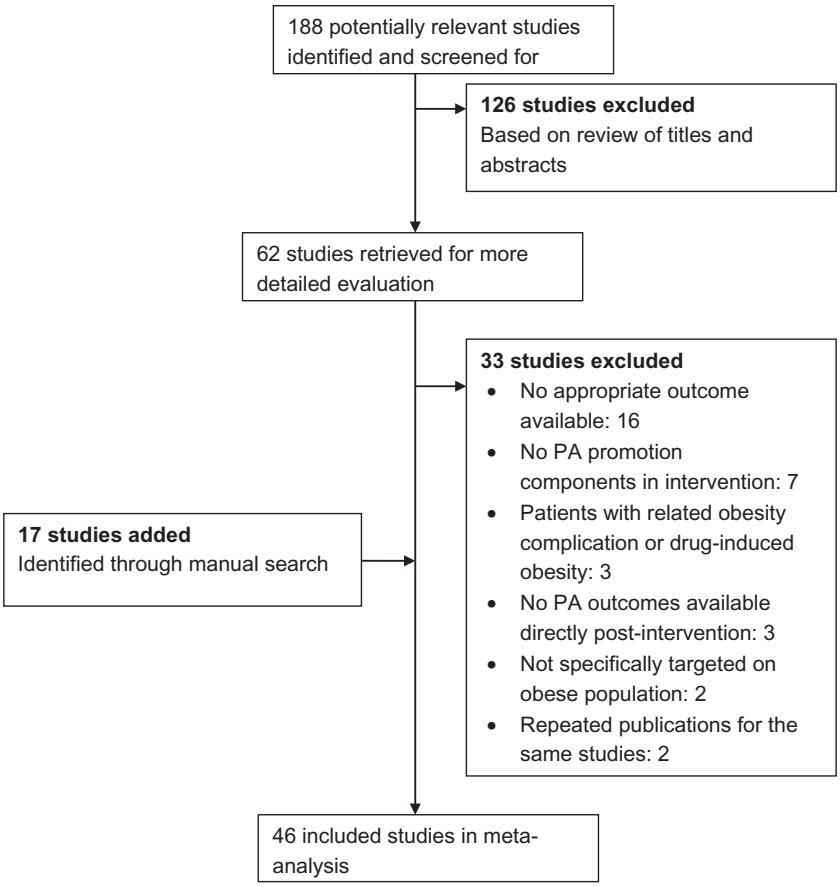

Figure 1 Study selection process. PA, physical activity.

or podcasts (74) were used as media to motivate and help participants adopt active lifestyles.

What is the overall effect size of interventions on physical activity behaviour?

The overall average effect size among the 46 interventions was 0.54 (95% CI = 0.39, 0.69). A considerable heterogeneity level ($Q = 274.03$, $P < 0.001$, $I^2 = 83\%$) was noted. The funnel plot (see Fig. 2) reported the presence of two outliers and thus suggests a small publication bias towards small sample size studies with positive results. The two outliers were studies by Dallow *et al.* (53) ($d = 3.70$; 95% CI = 2.74, 4.66) and Tsiros *et al.* (75) ($d = 2.63$; 95% CI = 1.83, 3.43). These two studies had a substantially larger effect than the other trials and were thus removed from analysis. The overall average effect size among the 44 remaining studies was 0.44 (95% CI = 0.31, 0.57), indicating a significant positive effect of interventions on the participants' PA levels. Figure 3 presents the effect size for each of the 44 studies. Even after exclusion of the outliers, the heterogeneity level remained relatively high ($Q = 139.48$, $P < 0.001$, 76%). More precisely, a total of 21 studies reported positive Cohen's *d* with a lower bound of 95% CI that did not overlap zero, indicating a significant positive effect for these studies. For the 23 other studies, the fact that one of the bounds of the 95% CIs overlapped zero suggested no significant effects of these interventions on PA. As a high heterogeneity was present for the programme effects directly post-intervention, a mixed effects model was used for the moderator analysis.

Does intervention effect vary according to the physical activity indicator used?

The type of PA measurement was tested as a categorical moderator. Six categories were created: energy expenditure, length, number of steps, cardiovascular health, physical test performance and other PA indexes (e.g. Godin Leisure Time Exercise Questionnaire, PACE). Among the 44 studies, 14 had used multiple PA measurements (see Table 1) and thus were represented in several categories. As presented in Table 2, all of the PA indicators were – on average – positively impacted by the interventions. However, the moderator analysis revealed that the type of PA indicator used appeared to be a significant moderator ($Qb = 21.24$, $P < 0.01$). The number of steps ($d = 0.73$; 95% CI = 0.55, 0.9) and the other PA indexes ($d = 0.73$;

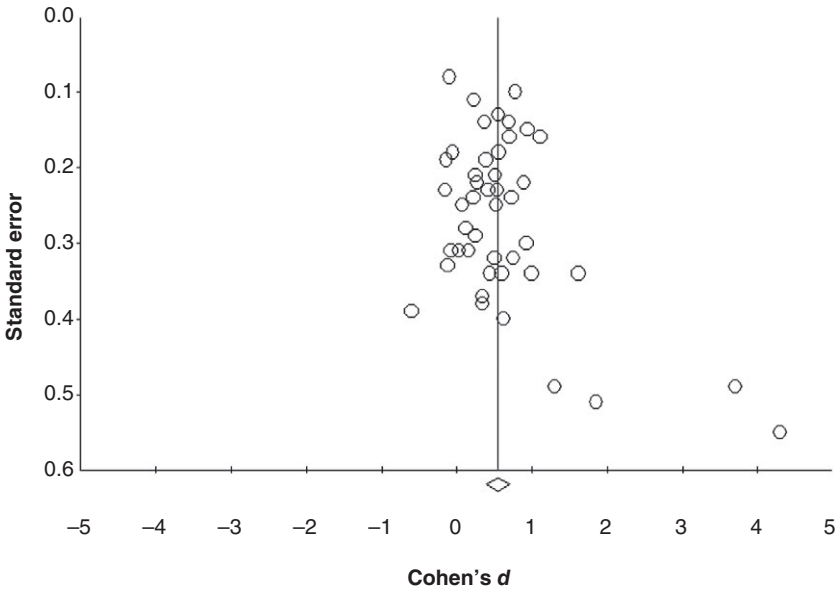

Figure 2 Funnel plot of the 46 studies. Vertical line indicates the random effects summary estimate of Cohen's *d*.

95% CI = 0.4, 1.06) reported stronger effect sizes than energy expenditure ($d = 0.35$; 95% CI = 0.1, 0.79), cardiovascular health ($d = 0.32$; 95% CI = 0.1, 0.53), PA length ($d = 0.3$; 95% CI = 0.13, 0.47) or physical test performance ($d = 0.22$; 95% CI = 0.03, 0.43).

Does the intervention effect vary according to the dose characteristics of the programme?

Three indicators of the intervention dose were tested as moderators of the intervention effect size: intervention duration, the number of sessions and session frequency.

Intervention duration

The duration of the intervention programmes varied greatly (see Table 1), from 3 weeks (58,61) to 24 months (76,77) (M = 6.61 months, SD = 5.57). Firstly, intervention duration was tested as a continuous moderator. As reported in Table 3, the duration of intervention appeared to be a significant negative moderator of intervention effect (B = –0.02, $P < 0.01$). This result indicates that the shorter the intervention period is, the greater the effects are on PA. The intervention duration was also tested as a categorical moderator to identify which length of duration had the strongest effects. Three categories of duration were created: less than 6 months, between 6 and 11 months, and between 12 and 24 months. The results indicated that the categorical moderator analysis (Table 2) also appeared significant (Qb = 13.05, $P < 0.01$). More precisely, this analysis revealed that the programmes carried out for less than 6 months ($d = 0.61$; 95% CI = 0.46, 0.76) had greater effects than the interventions that lasted for a duration of between 6 and 11 months ($d = 0.25$; 95% CI = 0.1, 0.4) and between 12 and 24 months ($d = 0.27$; 95% CI = 0.003, 0.55). In other words, this means that programmes shorter than 6 months have greater effects when compared to longer programmes.

Number and frequency of sessions

The effect of the interventions depending on the total number of sessions and session frequency (i.e. the number of sessions divided by the total duration of treatment in months) was tested via a continuous moderator analysis. The interventions varied widely in both the number (min = 1, max = 75, M = 18.84, SD = 13.5) and the frequency (min = 1, max = 9.33, M = 4.72, SD = 3.93) of sessions (see Table 1). Continuous moderator analysis (Table 3) revealed that neither the number of sessions (B = –0.003, $P > 0.05$) nor the frequency of sessions (B = 0.02, $P > 0.05$) was a significant moderator of intervention effects.

What were the effects of the interventions after the intervention had ended?

Only nine studies reported results concerning the maintenance of the intervention effect on PA after the intervention had ended. Follow-up measures varied from 3 months (78) to 18 months (63) (M = 9 months, SD = 5.19; see Table 1). No outliers appeared in the funnel plot examination (Fig. 4). Heterogeneity levels appeared non-significant among the studies ($I^2 = 70.05\%$, $Q = 26.71$, $P < 0.05$), thus a fixed effects model was used. As presented in Fig. 5, the analysis carried out on the nine studies showed a non-significant post-intervention evolution in the PA level of the participants ($d = 0.05$; 95% CI = –0.12, 0.23). In other

Study name	Sample size	Statistics for each study			
		Std diff in means	Lower limit	Upper limit	Relative limit
Befort *et al.* (2008) (68)	44	–0.075	–0.683	0.533	1.94
Bertozzi *et al.* (2004) (65)	145	0.930	0.342	1.518	1.99
Carels *et al.* (2005) (91)	44	0.600	–0.066	1.266	1.78
Carels *et al.* (2007) (69)	55	0.220	–0.250	0.690	2.35
Carels *et al.* (2008) (92)	51	1.000	0.334	1.666	1.78
Clarke *et al.* (2007) (59)	93	1.110	0.796	1.424	2.85
Cussler *et al.* (2008) (72)	135	–0.140	–0.512	0.232	2.66
Daley *et al.* (2006) (83)	81	0.520	0.030	1.010	2.29
Damschroder *et al.* (2010) (93)	14	0.340	–0.405	1.085	1.59
Davis *et al.* (2007) (62)	94	0.420	–0.031	0871	2.41
Deforche *et al.* (2004) (56)	24	0.250	–0.318	0.818	2.05
Edmunds *et al.* (2007) (80)	49	0.510	0.098	0.922	2.54
Epstein *et al.* (2000) (63)	90	–0.150	–0.601	0.301	2.41
Folta *et al.* (2009) (94)	96	0.730	0.260	1.200	2.35
Fuller *et al.* (1998) (95)	108	0.220	0.250	0.690	2.35
Gillis *et al.* (2007) (96)	27	–0.600	–1.364	0.164	1.55
Golan *et al.* (2006) (97)	37	–0.120	–0.767	0.527	1.83
Goldfield *et al.* (2006) (98)	30	0.340	–0.385	1.065	1.64
Gutin *et al.* (1996) (99)	25	1.850	0.850	2.850	1.11
Hemmingsson *et al.* (2008) (67)	55	0.030	0.578	0.638	1.94
Hughes *et al.* (2008) (100)	134	0.270	–0.161	0.701	2.47
Jeffery *et al.* (1998) (101)	193	0.890	0.459	1.321	2.47
Jensen *et al.* (2004) (66)	26	0.440	–0.226	1.106	1.78
Katzer *et al.* (2008) (102)	222	0.370	0.096	0.644	2.97
Khole-Lehman *et al.* (2007) (60)	91	0.700	0.388	1.014	2.85
Knöpfli *et al.* (2008) (57)	130	0.550	0.295	0.805	3.02
Leermakers *et al.* (1999) (103)	67	0.120	–0.429	0.669	2.11
Logue *et al.* (2005) (76)	665	–0.100	–0.257	0.057	3.26
Maffiuletti *et al.* (2005) (58)	54	0.560	0.207	0.913	2.72
Mascola *et al.* (2009) (70)	26	0.625	–0.159	1.409	1.50
Nemet *et al.* (2005) (81)	24	1.620	0.954	2.286	1.78
Quinn *et al.* (2008) (104)	18	0.155	–0.453	0.763	1.94
Resnicow *et al.* (2005) (71)	123	–0.050	–0.403	0.303	2.72
Richardson *et al.* (2005) (61)	12	1.300	0.340	2.260	1.17
Sacher *et al.* (2010) (64)	116	0.390	0.018	0.762	2.66
Saelens *et al.* (2002) (78)	44	0.500	–0.127	1.127	1.88
Schelling *et al.* (2009) (54)	38	0.750	0.123	1.377	1.88
Silva *et al.* (2010) (55)	239	0.690	0.416	0.964	2.97
Steptoe *et al.* (2000) (105)	505	0.230	0.014	0.446	3.13
Tate *et al.* (2003) (73)	92	0.250	–0.162	0.662	2.54
Teixeira *et al.* (2002) (106)	112	0.940	0.646	1.234	2.91
Turner-McGrievy *et al.* (2009) (74)	78	0.540	0.089	0.991	2.41
Villanova *et al.* (2006) (107)	200	0.780	0.584	0.976	3.18
Wing *et al.* (1998) (77)	154	0.070	–0.420	0.560	2.29
		0.446	0.318	0.575	

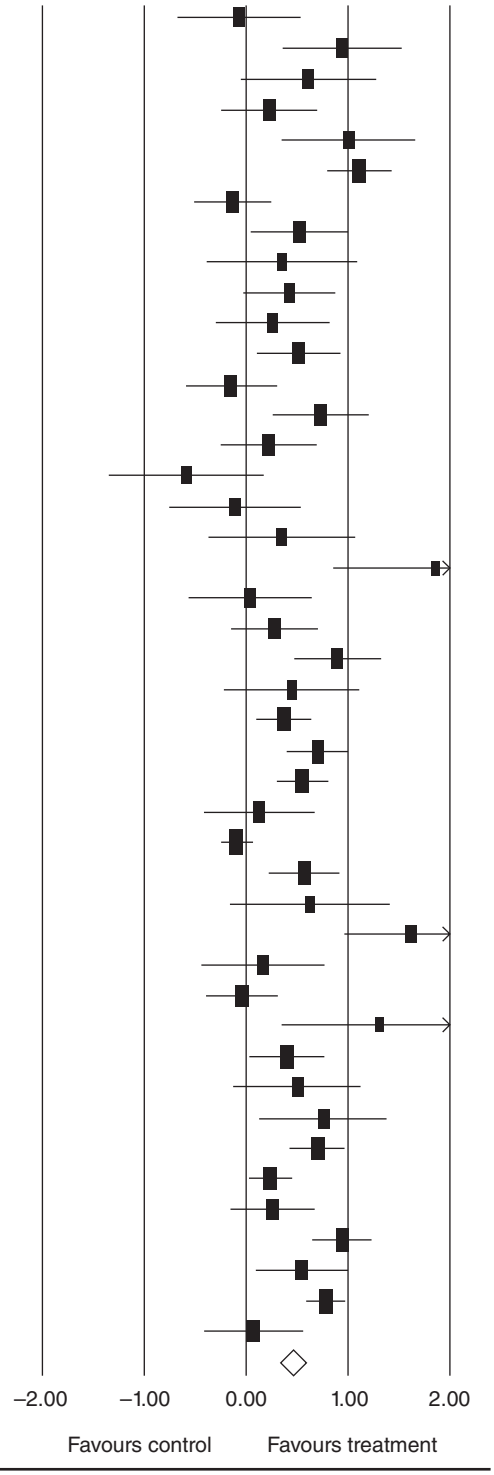

Figure 3 Forest plot with combined results of meta-analysis for interventions' effects on physical activity directly post-intervention ($n = 44$). CI, confidence interval; Std diff, standard difference (Cohen's *d*).

Table 1 General characteristics, physical activity indicator and follow-up length of interventions included in the meta-analysis ($n = 46$)

Study	Sample size	Duration of the intervention (in months)	Number of sessions	Frequency of sessions (per months)	PA indicator						Follow-up after intervention (in months)
					Energy expenditure	Duration	Steps	Cardiovascular health	Physical test	Other PA indexes	
Befort *et al.* (2008) (68)	44	4	12	3	×	×	–	–	–	–	0
Bertozzi *et al.* (2004) (65)	145	7	NR	NA	–	–	–	–	–	×	0
Carels *et al.* (2005) (91)	44	6	24	4	×	–	–	×	×	–	0
Carels *et al.* (2007) (69)	55	4	25	6.25	–	×	–	×	–	–	0
Carels *et al.* (2008) (92)	51	4	22	5.5	×	–	–	–	–	–	0
Clarke *et al.* (2007) (59)	93	2	8	4	×	–	×	–	–	–	0
Cussler *et al.* (2008) (72)	135	16	NA	NA	×	–	–	–	–	–	0
Daley *et al.* (2006) (83)	81	3.5	24	6.85	–	–	–	–	×	×	3.5
Dallow *et al.* (2003) (53)	58	6	24	4	×	–	–	×	–	–	6
Damschroder *et al.* (2010) (93)	14	3	12	4	–	–	×	–	–	–	0
Davis *et al.* (2007) (62)	94	3.75	75	20	–	–	–	–	×	–	0
Deforche *et al.* (2004) (56)	24	10	NA	NA	–	×	–	–	–	–	7.5
Edmunds *et al.* (2007) (80)	49	3	1	0.33	–	–	–	–	–	×	0
Epstein *et al.* (2000) (63)	90	6	22	3.67	–	×	–	–	×	–	18
Folta *et al.* (2009) (94)	96	3	24	8	–	–	×	–	×	–	0
Fuller *et al.* (1998) (95)	108	6	25	4.16	–	×	–	–	–	–	0
Gillis *et al.* (2007) (96)	27	3	12	4	–	–	–	–	×	–	0
Golan *et al.* (2006) (97)	37	6	12	2	–	×	–	–	–	–	0
Goldfield *et al.* (2006) (98)	30	2	16	8	–	×	–	–	–	–	0
Gutin *et al.* (1996) (99)	25	2.5	10	4	×	–	–	–	–	–	0
Hemmingsson *et al.* (2008) (67)	55	4.5	15	3.33	–	–	×	–	–	–	0
Hughes *et al.* (2008) (100)	134	6.5	8	1.23	–	×	–	–	–	–	0
Jeffery *et al.* (1998) (101)	193	18	36	2	×	–	–	–	–	–	0
Jensen *et al.* (2004) (66)	26	3	12	4	–	–	×	–	×	–	0
Katzer *et al.* (2008) (102)	222	12	22	1.83	–	–	–	–	–	×	0
Khole-Lehman *et al.* (2007) (60)	91	2	8	4	–	–	×	–	–	–	0
Knöpfli *et al.* (2008) (57)	130	2	NA	NA	–	–	–	×	×	–	0
Leermakers *et al.* (1999) (103)	67	6	13	2.16	×	–	–	–	–	–	6
Logue *et al.* (2005) (76)	665	24	28	1.16	×	×	–	–	–	–	0
Maffiuletti *et al.* (2005) (58)	54	0.75	NA	NA	–	–	–	×	×	×	12
Mascola *et al.* (2009) (70)	26	4	4	1	–	×	–	×	–	–	0
Nemet *et al.* (2005) (81)	24	3	28	9.33	–	–	–	–	–	×	12
Quinn *et al.* (2008) (104)	18	4	4	1	–	–	–	×	–	–	0
Resnicow *et al.* (2005) (71)	123	6	28	4.66	–	–	–	–	×	–	0
Richardson *et al.* (2005) (61)	12	0.75	4	5.33	–	–	×	–	–	–	0
Sacher *et al.* (2010) (64)	116	6	18	3	–	×	–	–	–	–	0
Saelens *et al.* (2002) (78)	44	4	11	2.75	×	–	–	–	–	–	3
Schelling *et al.* (2009) (54)	38	2	8	4	–	×	–	–	–	–	6
Silva *et al.* (2010) (55)	239	12	30	2.5	–	×	×	–	–	–	0
Steptoe *et al.* (2000) (105)	505	12	NR	NA	–	×	–	–	–	–	0
Tate *et al.* (2003) (73)	92	11	NA	NA	×	–	–	–	–	–	0
Teixeira *et al.* (2002) (106)	112	4	16	4	×	–	–	–	–	–	0
Tsiros *et al.* (2008) (75)	47	5	10	2	–	–	×	–	–	–	0
Turner-McGrievy *et al.* (2009) (74)	78	3	24	8	–	×	–	–	–	–	0
Villanova *et al.* (2006) (107)	200	3	12	4	–	–	×	–	–	–	0
Wing *et al.* (1998) (77)	154	24	48	2	×	–	–	×	×	–	0

NA, not applicable (i.e. web-based and in-patient interventions); NR, not reported; PA, physical activity. × = yes, – = no.

Table 2 Results of categorical moderator analysis for the effects of programmes directly post-intervention ($n = 44$)

Moderator	Number of comparisons	Cohen's *d*	95% CI	Qb
PA indicator				21.46**
Energy expenditure	14	0.35	0.10;0.79	
Length	15	0.30	0.13;0.47	
Number of steps	9	0.73	0.55;0.90	
Cardiovascular health	7	0.32	0.10;0.53	
Physical test performance	11	0.22	0.03;0.43	
Other PA indexes	6	0.73	0.40;1.06	
Intervention duration				13.05**
Less than 6 months	26	0.61	0.46;0.76	
Between 6 and 11 months	11	0.25	0.10;0.40	
Equal or over 12 months	7	0.27	0.003;0.55	

Meta-analytical analogue of ANOVA was used to estimate inter-studies variance for each moderator.
**$P < 0.01$.
95% CI, 95% confidence interval; PA, physical activity; Qb, between-groups heterogeneity statistic.

Table 3 Results of continuous moderator analysis for the effects of programmes directly post-intervention ($n = 44$)

Moderator	Number of comparisons	B
Intervention duration	44	–0.020**
Number of sessions	37	–0.003
Sessions frequency	37	0.025

Univariate meta-regression (method of moments) was used to estimate inter-studies variance for each moderator.
**$P < 0.01$.
B: unstandardized regression coefficient.

words, this result means that between the end of the intervention and the follow-up assessment, the participants' PA levels did not change and thus highlights the fact that interventions have succeeded in maintaining the PA level among participants during this period.

Discussion

The aim of the present meta-analysis was to evaluate the effects of interventions promoting PA among obese populations on their PA behaviour. More precisely, four research questions were addressed concerning (i) the global effect size of interventions; (ii) variations in the intervention effect size depending on the PA indicator used; (iii) variations in intervention effect size depending on the dose characteristics of the interventions (i.e. duration of the intervention, number and frequency of sessions) and (iv) maintenance of the intervention effect once the interventions had ended.

Firstly, the results of this meta-analysis indicate that interventions promoting PA have, on average, an impact on the PA of obese populations. This result is important because it suggests that programmes promoting PA may be an effective strategy for helping obese populations to adopt more active lifestyles. However, the present results suggest a large level of variability in efficacy between interventions. Moreover, the relatively low number of participants in most of the interventions highlights the fact that the study samples were not necessarily representative of obese population. On these different points, the present results corroborate the results of the systematic review carried out by Cliff *et al*. (34), which was limited to obese children and adolescents. However, the present work is, to the best of our knowledge, the first meta-analysis to quantify intervention effects. With a mean effect size of 0.44, we can conclude that interventions promoting PA have a moderate impact on PA in obese populations (44). Future interventions in obesity treatment should thus incorporate PA promotion components to maximize their impact on health indicators (e.g. BMI, weight loss), given that, as presented in the current meta-analysis, successful strategies exist to help this population enhance its current PA practices.

Secondly, our meta-analysis reveals that interventions promoting PA have an impact both on direct (e.g. number of steps) and indirect (e.g. cardiovascular health) PA indicators. However, the moderation analysis indicates that the effect of interventions varies in relation to the PA indicator used. The number of steps and the other PA indexes were most influenced by the programmes, whereas physical test performance was the least influenced. Such results may be explained by differences in sensitivity between the different indicators to capture PA evolution or by the fact that the interventions were more appropriate for having an impact on some indicators than others. It should be noted that the category called 'other PA indexes' grouped questionnaires that evaluated the degree of an individual's involvement in regular PA without making reference to a unit of measurement. The 'PA index' could have been calculated differently between interventions according to the questionnaire used. For example, the Godin Leisure Time Exercise

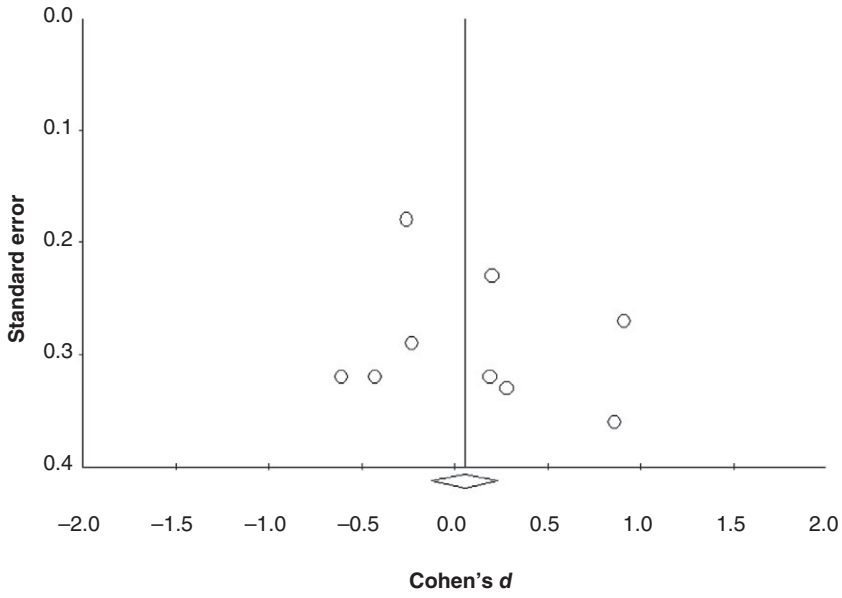

Figure 4 Funnel plot of the nine interventions initially integrated to calculate long-term combined effect size. Vertical line indicates the fixed effects summary estimate of Cohen's *d*.

Study name	Study sample	Statistics for each study				Std diff in means and 95% CI
		Std diff in means	Lower limit	Upper limit	Relative weight	
Daley *et al.* (2006) (83)	81	0.910	0.381	1.439	11.28	
Dallow (2003) (53)	58	0.860	0.154	1.566	6.35	
Deforche (2004) (56)	24	–0.230	–0.798	0.338	9.78	
Esptein (2000) (63)	90	0.200	–0.251	0.651	15.55	
Leermakers (1999) (103)	67	0.190	–0.437	0.817	8.03	
Maffiuletti (2005) (58)	54	–0.260	–0.613	0.093	25.39	
Nemet *et al.* (2005) (81)	24	–0.610	–1.237	0.017	8.03	
Saelens (2002) (78)	44	–0.430	–1.057	0.197	8.03	
Schelling (2009) (54)	38	0.280	–1.367	0.927	7.55	
		0.053	–0.125	0.230		

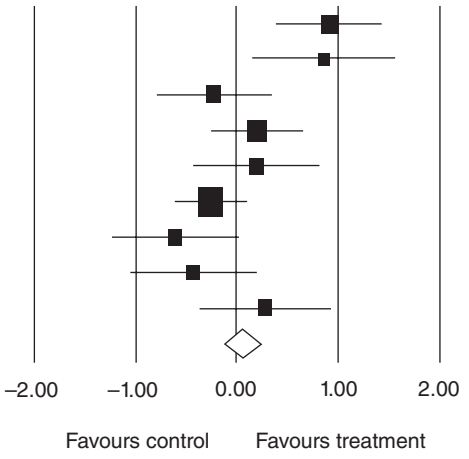

Figure 5 Forest plot with combined results of meta-analysis for interventions' long-term effects on physical activity ($n = 9$). CI, confidence interval; Std diff, standard difference (Cohen's *d*).

Questionnaire (79) used by Edmunds *et al*. (80) and Nemet *et al*. (81) calculates a 'PA index' from the frequency of involvement in strenuous, moderate and light activities, whereas the Physical Activity Questionnaire for Adolescents (82) used by Daley *et al*. (83) calculates a 'PA index' only on the frequency of involvement in different PA activities. As a consequence, the results rating the effects of interventions using this indicator must be taken cautiously, as they use tools that have not exactly measured the same construct. Future investigations should consider the standardization of methods used to calculate a PA index. Finally, because the present results globally highlight the positive impact of interventions on both PA levels and the participants' general state of health, it would seem appropriate for future studies to include both direct (e.g. number of steps, energy expenditure) and indirect PA measurements (e.g. cardiovascular health) in order to assess both intervention efficacy on behaviour evolution as well as consequences of behaviour evolution. Such an approach would help to determine a more precise picture of the intervention effects on PA.

Concerning the third research question, the results reveal that intervention duration may moderate the intervention effect size. Shorter interventions (i.e. less than 6 months) reported a higher effect size than longer ones. Such a result is in line with past work reporting that brief obesity interventions can produce significant change (19,24), but it also seems to contradict previous work demonstrating that long-term obesity management is associated with better outcomes (25,84). The present results could lead to a counterintuitive conclusion that short interventions are the most effective way to increase PA. However, this result must be taken cautiously, because it could be explained by the fact that the post-intervention measurements were not performed at the same time intervals. One can imagine that as studies which included longer programmes measured PA evolution later, it may be possible that at the beginning of the programme, the effects would have been similar to those noted for shorter programmes, but that these effects tended to decrease over time. Similar to the systematic review by Cliff *et al*. (34), the majority of studies included in the present meta-analysis involved relatively short-term interventions (i.e. <6 months). Future research should integrate multiple regular assessments to determine the PA evolution of obese participants during long interventions.

The moderator analysis also reveals the fact that neither the number nor the frequency of sessions moderated intervention effect size. This result highlights the fact that interventions which are more costly in terms of the total number of sessions or the frequency of sessions carried out during an intervention do not appear to be more effective in comparison to interventions that have fewer or a lower frequency of sessions. Of note, the present moderation analyses on the impact of intervention dose on programme efficacy were carried out separately for each dose indicator (i.e. number of sessions, session frequency, intervention duration). However, it may be possible that a suitable frequency or number of sessions in an intervention is linked to intervention duration. For example, it is well recognized that high frequency contact is indispensable for the effectiveness of interventions carried out over a long period (85–87). Future investigations should try to design other types of indicators that consider either the frequency or the total number of sessions with intervention duration in order to enhance knowledge about the most suitable dose rate for interventions.

Finally, concerning the fourth research question, this meta-analysis suggests that the effect generated on PA by these interventions seems to remain stable after the interventions have finished. Combined with the fact that intervention led to a globally significant effect (i.e. the first research question), such a result is encouraging by revealing the fact that interventions have positive effects that can be maintained for at least several months after the intervention has ended. However, because of the high heterogeneity of the follow-up period between the interventions (between 3 and 18 months), as well as the relatively low number of studies that have dealt with this question ($n = 9$), more studies on interventions are clearly needed to confirm the present findings.

Limits and perspectives

Some limitations should be noted regarding the results of this meta-analysis. A first potential limitation is the inclusion of only English language studies. It is possible that studies published in non-English language journals demonstrated different effects. As a second limitation, it was assumed that the limited number of studies that were included in this present meta-analysis ($n = 46$) tended to constrain the analyses that might have identified moderators of success (or failure) of the interventions (88). Additional studies are needed to more clearly identify the moderators of intervention effects. As a third limitation, it should be noted that as studies reporting significant effects of an intervention are more publishable than those that do not find such effects (89), a publication bias cannot be totally excluded (25). As a consequence, the results of the present work about the global positive effect of interventions on PA must be interpreted cautiously.

To conclude, this meta-analysis shows that interventions designed to promote PA in obese populations are globally effective in improving the PA of this population. Short-term interventions reported greater effects than longer ones. The interventions also globally succeeded in maintaining their effects after the intervention had ended, but relatively few studies have assessed this question. At the same time, the intervention effect size varied according to the type of PA indicator used. The other PA indexes and the number of steps were the PA indicators most influenced by the interventions. Finally, the intervention effect was unrelated to the total number and the frequency of sessions. Given these results and the fact that the concept of 'dose' of intervention has yet to be explored and developed for educational treatments (90), it seems that more research is needed in this domain, notably to determine whether or not there is an optimal number or frequency of sessions for a given duration of intervention. Moreover, as maintenance of the treatment effects on health behaviour must be considered a high priority (42,43), researchers and educators should implement interventions with regular assessments throughout the programme and a follow-up period to determine the evolution of a participant's PA behaviour both during and after the programme. The long-term strategies for helping obese patients maintain their PA could lead to the enhanced physical and psychological health of this population. This, in turn, could reduce the estimated costs associated with obesity and its related diseases.

Conflict of Interest Statement

No conflict of interest was declared.

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