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Effective Techniques in Healthy Eating and Physical Activity Interventions: A Meta-Regression

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Objective: Meta-analyses of behavior change (BC) interventions typically find large heterogeneity in effectiveness and small effects. This study aimed to assess the effectiveness of active BC interventions designed to promote physical activity and healthy eating and investigate whether theoretically specified BC techniques improve outcome. ***Design:*** Interventions, evaluated in experimental or quasi-experimental studies, using behavioral and/or cognitive techniques to increase physical activity and healthy eating in adults, were systematically reviewed. Intervention content was reliably classified into 26 BC techniques and the effects of individual techniques, and of a theoretically derived combination of self-regulation techniques, were assessed using meta-regression. ***Main Outcome Measures:*** Valid outcomes of physical activity and healthy eating. ***Results:*** The 122 evaluations ($N = 44{,}747$) produced an overall pooled effect size of 0.31 (95% confidence interval = 0.26 to 0.36, $I^2 = 69\%$). The technique, "self-monitoring," explained the greatest amount of among-study heterogeneity (13%). Interventions that combined self-monitoring with at least one other technique derived from control theory were significantly more effective than the other interventions (0.42 vs. 0.26). ***Conclusion:*** Classifying interventions according to component techniques and theoretically derived technique combinations and conducting meta-regression enabled identification of effective components of interventions designed to increase physical activity and healthy eating.

Keywords: physical activity, healthy eating, behavior change, self-regulation, meta-regression

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Interventions designed to change health-related behaviors generally include many components and typically produce small effects in meta-analyses, but with large heterogeneity in effectiveness (e.g., Dishman & Buckworth, 1996; Grimshaw et al., 2004; National Institute for Health & Clinical Excellence, 2007). This limits the potential for understanding *how* intervention content relates to effectiveness and, consequently, the inferences that can be drawn regarding optimal design and the content of future behavior change interventions. Recent guidance has called for new methods to evaluate the effects of "complex" interventions (Craig et al., 2008). This study aimed to assess the utility of classifying the content of behavior change interventions into component techniques and applying meta-regression to identify effective individual techniques and theoretically derived combinations of techniques.

To address this aim, we focused on interventions designed to increase physical activity and healthy eating because these are key change targets in the context of the growing obesity epidemic, one of the most serious health risk factors in both the developed and developing world (World Health Organisation, 2002). We further focused on active interventions that engaged participants in the process of behavior change, rather than passive interventions such as simply providing information or advice (Department of Health, 2004). Self-management approaches, involving people in their own change, have had considerable success among those with long-term illnesses (Lorig, Ritter, & Plant, 2005), and can also

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initiate change (Bandura, 2000; Gupta, 2005). Active interventions have also been found to be more effective than passive interventions in other areas (Albarracín et al., 2005) and, because of the sustained behavior changes necessary to translate dietary and physical activity into health benefits, self-regulatory processes are likely to be central to health-enhancing change, recommending active engagement of participants. Yet, despite the potential of active, self-management approaches, there is little guidance on which techniques are important to effectiveness.

Two methodological advances have enhanced our capacity to learn from intervention evaluations. First, reliable methods of specifying component techniques (e.g., Abraham & Michie, 2008) and, second, use of meta-analysis and meta-regression to identify the effects of individual techniques, and combinations of techniques, across studies (e.g., Albarracín et al., 2005). In the current study we combined these tools in an investigation of effective change techniques included in healthy eating and physical activity interventions.

Repeated calls have been made for precise specification of what makes one behavior change intervention more effective than another and how this can be understood theoretically (e.g., Rothman, 2004). In the current study, we used a reliable taxonomy of 26 techniques to identify intervention content. Reliability checks have shown that independent coders can reliably judge whether or not published intervention descriptions in papers or manuals indicated inclusion of each technique (Abraham & Michie, 2008).

If we are to understand, not only what works, but how interventions work, it is necessary to understand the causal mechanisms hypothesized to explain intervention effects (Michie & Abraham, 2004; Michie, Johnston, Francis, Hardeman & Eccles, 2008). Interventions have been found to be more effective if they involve techniques that behavior change theory predicts would act synergistically (Albaraccin et al., 2005). Carver and Scheier's (1981, 1982) control theory specifies action control processes underpinning behavioral regulation. The theory proposes that setting goals, monitoring behavior, receiving feedback, and reviewing relevant goals in the light of feedback are central to self-management and behavioral control. Therefore, while we examined which of 26 change techniques would be most strongly associated with intervention effectiveness, we hypothesized that interventions that included five self-regulation techniques derived from control theory would be more effective than other techniques. These were prompt intention formation, prompt specific goal setting, provide feedback on performance, prompt self-monitoring of behavior, and prompt review of behavioral goals. These techniques may act additively or synergistically; the number of studies required to detect the latter is substantially greater than the former.

Previous studies have employed meta-analysis to assess whether the presence or absence of particular techniques is associated with effectiveness. For example, Albarracín et al. (2005) showed that 10 techniques (e.g., provision of factual information and attitudinal arguments) could be reliably identified in published descriptions of interventions designed to promote condom use, and that inclusion of some of these (e.g., provision of attitudinal arguments) was associated with greater effectiveness, while inclusion of others (e.g., threat-inducing arguments) was not. Noar, Benac, and Harris (2007) showed that eight targeted theoretical constructs could be reliably identified in reports of tailored print interventions designed to promote health behaviors, and that inclusion of some of these constructs (e.g., attitudes, self-efficacy) was associated with greater effectiveness. Two (social norms and behavioral intentions) were not associated with effectiveness and one (perceived susceptibility) was associated with decreased effectiveness. Despite the impressive scope of these meta-analytic reviews, they have shortcomings. First, only 10 distinct techniques and eight constructs, respectively, were considered. The need for more comprehensive categorization of intervention content is evidenced from reviews of interventions in other behavioral domains (e.g., Webb & Sheeran, 2006). In addition, Albaraccín et al. used within-group change over time as the criterion of effectiveness as opposed to behavior change observed in an intervention group relative to changes observed in a matched no-intervention control. This allows inclusion of many more datasets but is a less rigorous criterion of effectiveness because the benefits of controlling for techniques within the control conditions are lost. In addition, both these reviews used meta-analysis and/or univariate regression rather than multivariate meta-regression to synthesize the evidence. While meta-analysis provides a technique for combining data from separate studies to arrive at pooled effect size estimates, meta-regression provides a means of assessing both single and multiple predictors of effect size from variables derived from individual studies, while weighting the regression so that precision of study results is properly accounted for (Sutton & Higgins, 2008).

The present systematic review applied a reliable taxonomy of behavior change techniques and meta-regression to analyze the effect of individual intervention techniques and the effect of combining five theoretically derived self-regulation techniques.

Method

Search Strategy and Results

We searched MEDLINE, EMBASE, PsycINFO, the Cochrane library (Cochrane Central Controlled Trials Register and the Health Technology Assessment database), AMED (Allied and Complementary Medicine Database), and HMIC (Health Management Information Consortium) databases between 1990 and 2008 for peer-reviewed journal articles written in English. Three search filters were used, one for interventions targeting physical activity/ healthy eating, one for study design, and one to exclude those with chronic diseases. Studies were also sought from experts in the field, identified by the British Psychological Society's Division of Health Psychology experts list.

Inclusion criteria specified interventions that recruited adults' (18 years or over) to increase their levels of physical activity or healthy eating, used experimental or quasi-experimental designs (that is, controlled trials and interrupted time series designs), and had outcome measures that were objective, standardized, or validated self-report measures. Inclusion criteria also specified that interventions had to use cognitive or behavioral change strategies so that, for example, interventions consisting only of the provision of information were excluded. The following were excluded: interventions aimed at pregnant or recently postnatal women; amateur or professional athletes; those already engaged in another intervention such as dietary, slimming, or fitness programs; and interventions targeting those not living in the free-population or those exclusively targeting participants with physical or mental health problems. Studies targeting the general population, with a small proportion exhibiting physical or mental health problems, were included if members of that subset were assessed as being healthy enough to participate by a physician.

This strategy identified 34,769 references (physical activity [PA] = 13,870; healthy eating [HE] = 20,899). After excluding duplicates, 28,440 references remained (PA = 10,859, including 22 papers recommended by experts in the field; HE = 17,581). In a sample of 300 titles screened independently by two reviewers, there was 100% agreement on inclusion/exclusion. One thousand forty-one studies identified as potentially relevant were further screened by abstract to assess suitability for inclusion (PA = 472; HE = 569). One hundred abstracts were screened independently by two reviewers, with 85% agreement on inclusion. Disagreements were resolved through discussion and consulting a third reviewer and where uncertainty remained the full paper was examined. After screening by abstract, full text papers were obtained for 295 articles (PA = 156; HE = 139). Where there was insufficient statistical or intervention information ($N = 17$), authors were contacted (35% responded). Detailed evaluation according to the inclusion criteria resulted in a final set of 139 studies. Of these, 38 were excluded from the meta-analysis (see supplementary material, Table S1), leaving 101 papers reporting 122 evaluations (PA = 69; HE = 53).

Data Extraction

In evaluations of PA interventions reporting multiple outcome measures, the most general or comprehensive measure was selected (e.g., exercise level, energy expenditure). For studies of healthy eating, measures of good and/or poor diet were extracted. There was a significant correlation ($r = .91$, $p < .001$) between the "good diet" and "poor diet" measures, consequently, an average effect size from each study was used for the meta-analysis.[1] For studies reporting more than one measure of fat intake, total fat intake (grams per day or % energy from fat) was preferred over saturated fat intake or kcal consumption, because a certain kcal consumption may reflect a more or less healthy diet. For studies reporting the percentage of participants consuming five fruit or vegetable servings per day in addition to the number of fruit and vegetable servings per day, the latter was selected.

Effect sizes were indexed as the standardized mean difference (the difference between two means divided by their pooled standard deviation) with Hedge's correction for small sample size (Hedges & Olkin, 1985). For studies that reported continuous data, the effect size was computed from means and *SD*s (adjusted for baseline differences if reported), or, if these data were not reported, from the sample size and p value from an appropriate between-groups t- or F test. For studies that only reported dichotomous data, the log odds ratio was converted into a standardized mean difference using meta-analysis software. For cluster randomized, controlled trials, where the study had used an appropriate analysis to account for the effect of clustering, the results of the analysis were used to estimate the effect size. Where the analysis did not properly take account of clustering, we calculated an effective sample size using the following formula: N (effective) $= (k \times m)/(1+ (m - 1) * \text{ICC}$, where k indicates the number of clusters; m, the number of observations per cluster; and ICC, the intracluster correlation coefficient (Shojania et al., 2006). We imputed unreported ICCs based on an empirically derived value of 0.05 (Elley, Kerse, Arroll, & Robinson, 2003; Elley, Kerse, Chondros, & Robinson, 2005). When results were reported only as significant, $p = .05$ was assumed, and when only as nonsignificant, $p = .50$ was assumed. Where data were reported from multiple time points, outcomes, or evaluations, an average effect size was used (we explored the effect of doing this using a series of subgroup analyses, but found little difference between subgroups; data not reported but available from the authors). Where there were two interventions compared in one study and both met the inclusion criteria, we chose the intervention with the greatest effect (because we were exploring determinants of effectiveness). Where a single study reported both PA and HE outcomes, both were entered into the analysis as if from separate evaluations, but group sample sizes were halved when calculating the standard error of the effect size. This avoids double counting participants and underestimating the variance associated with each effect size.

Coding of Study Characteristics

The following information was extracted from each study: (a) bibliographic information, (b) location (setting, country), (c) type of behavior targeted by intervention (physical activity, health eating or both), (d) participant information (general description, age, gender, sample size, whether sedentary/low active/obese/at risk of cardiovascular disease or not, whether disadvantaged/from a low income group or not), (e) intervention information (techniques used, use of multiple sessions, duration of intervention, format of delivery, source of delivery, theoretical background), methodological information (attrition, outcomes, how outcome was validated, length of follow-up, study design), and (f) effect size information (mean, *SD*, statistic type, value of statistic, p value, direction of effect, number of responders).

In addition, each intervention was coded for inclusion (or not) of each of 26 behavior change techniques. These were (T1) provide information on behavior–health link, (T2) provide information on consequences, (T3) provide information about others' approval, (T4) prompt intention formation, (T5) prompt barrier identification, (T6) provide general encouragement, (T7) set graded tasks, (T8) provide instruction, (T9) model/ demonstrate the behavior, (T10) prompt specific goal setting, (T11) prompt review of behavioral goals, (T12) prompt self-monitoring of behavior, (T13) provide feedback on performance, (T14) provide contingent rewards, (T15) teach to use prompts/cues, (T16) agree a behavioral contract, (T17) prompt practice, (T18) use of follow-up prompts, (T19) provide opportunities for social comparison, (T20) plan social support/social change, (T21) prompt identification as role model/ position advocate, (T22) prompt self talk, (T23) relapse prevention, (T24) stress management, (T25) motivational interviewing and (T26) time management. Interrater reliability checks on identification of techniques was conducted by the first two authors on the first 29 papers reporting PA intervention evaluations and the first 22 papers reporting HE interventions (i.e., 51 of 71 included papers, 72%). Modal and mean kappa values and average percentage of disagreements were, respectively, 0.79, 0.80, and 8.2% for

[1] For an initial set of 18 studies that reported both good and poor diet measures.

PA evaluations and 0.81, 0.82, and 6.7% for HE evaluations, suggesting high reliability. Disagreements were resolved through discussion. The coding manual is available from the first two authors (Abraham & Michie, 2008).

Data Synthesis and Analytic Strategy

Analyses and computations were conducted using Comprehensive Meta Analysis software, Version 2.2.040 (Borenstein, Hedges, Higgins, & Rothstein, 2005) and Stata Version 9.2 (StataCorp, 2007). Using the revised metareg command in Stata, we conducted random effects meta-analysis and random effects meta-regression with restricted maximum likelihood estimation and the improved variance estimator of Knapp and Hartung (2003). Meta-regression is ". . . a combination of meta-analytic principles (of combining results from multiple studies with due attention to within-study precision and among-study variation) with regression ideas (of predicting study effects using study-level covariates)" (Sutton & Higgins, 2008, p. 629). In our analysis, the regression coefficients (β) are the estimated increase in the effect size per unit increase in the covariate(s). Positive effect sizes indicate that the intervention had a better outcome than the control group.

A random effects model (DerSimonian & Laird, 1986) was used in the analyses to incorporate the assumption that the different studies are estimating different, yet related, treatment effects. In addition, the random effects model was used to incorporate heterogeneity beyond that explained by the explanatory variable(s) included in the meta-regression. Where the meta-regression suggested the presence of a potentially important covariate, we used subgroup analyses to further investigate the data. To counter the high risk of false-positive results in the univariate meta-regressions because of among-study heterogeneity and the large number of covariates, we used the Higgins and Thompson (2004) Monte Carlo permutation test (10,000 permutations) to calculate p values adjusted for multiple testing (implemented using the revised metareg command in Stata).

To examine statistical heterogeneity in the meta-analysis, both the Q statistic and I^2 (Higgins & Thompson, 2002) were used as well as a visual inspection of the forest plots. I^2 describes the ". . . percentage of total variation across studies that is due to heterogeneity rather than chance" (Higgins, Thompson, Deeks, & Altman, 2003). Based on suggestions made by Higgins et al. (2003), we interpreted an I^2 of over 75% as high heterogeneity and over 50% as moderate.

We used random effects univariate meta-regression models to examine whether any of the following intervention characteristics were associated with intervention effectiveness: target behavior (coded as physical activity or healthy eating); number of intervention techniques, duration of intervention (weeks); source of delivery (coded as medically trained health professional nonmedically trained health professional or nonhealth professional); format of delivery (coded as individual, group, or mixed); country (coded as United Kingdom, other European, United States, or other); treatment setting (coded as community, primary care, or workplace); total number of techniques; use of multiple sessions (coded as yes or no); time of outcome measurement (coded as immediate or follow-up); target population: disadvantaged/low income (yes, no); target population: sedentary/low active/obese/at risk of cardiovascular disease (yes, no); target population: women only (yes, no).

Random effects univariate meta-regression models were also used to examine the association between the 26 individual behavior change techniques and intervention effectiveness. To be included in the analysis, each technique was required to be evaluated by at least four separate studies. We then created a multivariate meta-regression model including all study characteristics and behavior change techniques that were shown in the univariate models to have a meaningful association (i.e., $\beta > .10$ for dichotomous variables) with effect size.

To examine how much of the heterogeneity was accounted for by the covariates(s) included in each model, we used the adjusted R^2 produced by the revised metareg command in Stata. The adjusted R^2 is calculated by comparing the baseline value of the heterogeneity variance (τ_a^2) obtained from the empty regression model with the heterogeneity variance from the meta-regression (τ_b^2) after the covariate(s) were added, using the following formula: $100\% \times ([\tau_a^2 - \tau_b^2]/\tau_a^2)$.

Sensitivity analyses were used to explore the effect of removing: a) studies which were not randomized at the individual participant level; b) studies not randomized or for which assumptions about statistical significance were made, and c) studies with results classified as outliers, determined by the Sample-Adjusted Meta-Analytic Deviancy (SAMD) Statistic (Huffcut & Arthur, 1995).

We assessed the possibility of publication bias using the Stata metabias command. Where there was evidence of significant asymmetry in the funnel plot (as judged by the Begg and Mazumdar adjusted rank correlation test) (Begg & Mazumdar, 1994), we used the Stata metatrim command to perform the Duval and Tweedie nonparametric "trim and fill" method (Duval & Tweedie, 2000). This method was used to examine the impact of the missing studies by adjusting the meta-analysis to take into account the theoretically missing studies.

Analysis of Theoretically Derived Self-Regulation Techniques

The ideal comparison would be that of interventions that include all five self-regulation techniques (T4, T10, T11, T12, and T13) without additional techniques compared with interventions that include none of the self-regulation techniques. In the absence of sufficient data for this, a comparison was made that best approximates it, given the available data. In addition, we examined the additive (rather than synergistic) effects by conducting both univariate and multivariate meta-regressions. For the univariate meta-regression, the number of theoretically derived self-regulation techniques used by each evaluation was entered into the model. For the multivariate meta-regression, we added all five individual techniques into the model to examine the unique association between each technique and intervention effectiveness.

Results

Description of Interventions

One hundred and one papers reporting 122 evaluations were included in the meta-analysis (see Table 1 and online supplementary material, Table S2). Fifty-one evaluations targeted physical activity only, 35 targeted healthy eating only and 18 targeted both. Table 1 shows that the majority of studies evaluated a multifaceted

Table 1
Effectiveness and Behavior Change Techniques by Target Behavior and Study

Study[a]	*N*	*d*	*SE*	Techniques[b]
Physical activity				
Aldana et al., 2005	337	0.61	0.16	1, 2, 4, 6, 8, 9, 18
Anderson et al., 2006	133	0.75	0.23	4, 10, 12
Arao et al., 2007	128	0.51	0.26	4, 11, 12, 13, 20
Ash et al. 2006	55	0.66	0.28	23
Babazono et al., 2007	87	0.89	0.32	4, 8, 11, 14
Baker et al., 2008	79	0.74	0.23	2, 5, 7, 8, 12, 13
Bennett et al., 2008	72	0.16	0.23	4, 5, 6, 8, 11, 12, 13, 25
Blissmer et al., 2002	78	0.40	0.23	2, 5, 8, 10, 14, 15, 20, 21, 23
Bolognesi et al., 2006	96	0.53	0.21	1, 2, 5, 6, 10, 12, 16, 18, 23
Bull et al., 1999	570	0.18	0.10	2, 5, 13
Calfas et al., 1996	212	0.19	0.14	2, 4, 5, 10, 13, 18, 20, 23
Calfas et al., 2000 (W)	177	0.00	0.15	2, 5, 6, 8, 9, 17, 18, 19, 20, 22, 23, 26
Calfas et al., 2000 (M)	144	−0.17	0.17	
Campbell et al., 2002	538	0.12	0.24	1, 2, 4, 8, 9, 13, 19, 20
De Cocker et al., 2008	82	−0.06	0.22	1, 7, 8, 12, 13
Dinger et al., 2007	56	0.54	0.27	2, 4, 5, 8, 10, 11, 12, 13, 14, 15
Dzator et al., 2004	90	0.19	0.30	1, 2, 4, 8
Elbel et al., 2003	118	0.15	0.22	2, 4, 5, 6, 8, 19, 23, 26
Elley et al., 2003	750	0.25	0.07	4, 6, 18, 25
Elliot et al., 2004	23	0.90	0.68	1, 2, 4, 6, 8, 11, 13, 14, 18, 20, 23, 25
Elliot et al., 2007	315	0.44	0.25	1, 2, 4, 6, 8, 11, 13, 14, 18, 20, 23, 25
Fahrenwald et al., 2004	44	1.28	0.33	2, 5, 10, 11, 12, 15, 17, 18, 19, 20, 21
Green et al., 2002	181	0.41	0.16	4, 5, 8, 12, 20, 25
Halbert et al., 2000	299	0.23	0.12	2, 4, 5, 7, 10, 11, 12, 18, 20
Hardcastle et al., 2008	334	0.22	0.16	2, 4, 5, 25
Harland et al., 1999	309	0.49	0.16	2, 4, 11, 25
Hivert et al., 2007	115	0.22	0.26	2, 4, 5, 12
Huddy et al., 1995	111	0.50	0.26	1, 2, 4, 5, 10, 16
Hurling et al., 2007	77	0.36	0.25	4, 5, 6, 8, 12, 13
Hyman et al., 2007	185	0.03	0.23	12, 13, 25
Inoue et al., 2003	84	0.57	0.15	8, 10, 12, 14, 15, 16, 17, 18, 19, 20, 22, 23
King et al., 2008	37	0.98	0.17	1, 4, 5, 8, 12, 13
Kinmonth et al., 2008	218	0.02	0.34	2, 10, 11, 12, 13, 14, 18, 20, 23
Lawton et al., 2008	1089	0.30	0.12	2, 4, 5, 6, 13, 25
Little et al., 2004	72	0.52	0.07	1, 2, 4, 8, 10, 16
Loughlan et al., 1997	104	0.43	0.24	2, 4, 5, 8, 10, 18, 20
Marcus et al., 1997	44	0.20	0.20	2, 4, 8, 10, 14, 18
Marcus et al., 2007	159	0.54	0.15	4, 6, 8, 13, 19
Marshall et al., 2003	462	0.25	0.16	2, 5, 6, 8, 10, 14, 20
Marshall et al., 2004	719	−0.01	0.11	2, 5, 6, 8, 10, 14, 20
Martinson et al., 2008	986	0.17	0.09	2, 4, 5, 6, 12, 13, 15, 20, 23
Mayer et al., 1994	1548	0.17	0.07	2, 4, 8, 13, 14, 16, 18
McAuley et al., 1994	114	0.52	0.07	1, 2, 6, 7, 8, 9, 12, 13, 17, 19, 20
Merom et al., 2007	246	−0.01	0.19	4, 8, 11, 12, 13
Miller et al., 2002	390	0.31	0.13	2, 5, 18, 19, 20
Newton et al., 2004	18	0.46	0.17	12
Nichols et al., 2000	58	0.40	0.46	2, 4, 9, 17, 18, 19, 22, 23, 26
Nies et al., 2003	137	0.34	0.26	2, 5, 7, 10, 20, 23, 26
Nies et al., 2006	173	0.10	0.17	2, 4, 23
Norris et al., 2000	812	0.02	0.15	2, 4, 5, 6, 8, 10, 16, 18, 20, 23
Peterson et al., 1999	359	0.45	0.08	1, 4, 23
Peterson et al., 2005	42	0.18	0.11	8, 10, 12, 14, 20
Poston et al., 2001	237	0.02	0.36	1, 2, 6, 7, 8, 9, 12, 13, 17, 19, 20
Purath et al., 2004	271	0.45	0.05	1, 4, 16, 18
Resnicow et al., 2005	535	0.22	0.14	1, 2, 5, 6, 8, 15, 16, 25
Rodearmel et al., 2006	81	0.52	0.38	4, 7, 12, 15
Rosamond et al., 2000	515	−0.07	0.14	4, 6, 8, 14, 15, 18
Schneider et al., 2004	16	0.44	0.10	4, 5, 7, 8, 9, 12, 17, 18
Speck et al., 2001	49	0.45	0.48	12
Spittaels et al., 2007	257	−0.01	0.29	2, 8, 13

Table 1 (*continued*)

Study[a]	*N*	*d*	*SE*	Techniques[b]
Stevens et al., 1998	714	0.59	0.12	1, 4, 11, 12, 13, 18
Stewart et al., 1997	89	0.59	0.09	1, 2, 4, 5, 12, 18
Tate et al., 2001	62	−0.14	0.25	4, 6, 12, 13, 14, 15, 20, 24
Tate et al., 2006	110	0.27	0.28	4, 5, 11, 12, 13
Vandelanotte et al., 2005	393	0.31	0.15	2, 8, 13
Winett et al., 2007	620	0.23	0.12	7, 8, 13, 14, 19
Wing et al., 2006	190	0.10	0.20	1, 12, 14, 17
Writing Group for the ACT Research Group, 2001 (W)	228	0.40	0.14	1, 2, 4, 5, 6, 7, 8, 12, 13, 14, 18, 19
Writing Group for the ACT Research Group, 2001 (M)	297	0.08	0.19	
Healthy eating				
Ahluwalia et al., 2007	173	0.47	0.16	2, 8, 13
Aldana et al., 2005	331	0.46	0.16	1, 2, 4, 6, 8, 9, 18
Anderson et al., 2001	221	0.44	0.14	8, 10, 12, 13
Arao et al., 2007	135	0.05	0.25	4, 11, 12, 13, 20
Armitage, 2004	264	0.34	0.12	10
Armitage, 2007	82	0.40	0.22	10
Babazono et al, 2007	87	0.49	0.43	4, 8, 11, 14
Beresford et al., 1997	1853	0.15	0.05	4, 18
Brug et al., 1996	352	0.04	0.11	1, 2, 5, 6, 8, 13
Brug et al., 1998	435	0.33	0.10	1, 2, 5, 6, 8, 13
Burke et al., 2003	64	0.28	0.25	1, 2, 5, 6, 8, 9, 12, 13, 17, 19, 20, 23, 24, 26
Campbell et al., 1994	258	0.22	0.13	1, 2, 4, 5, 8, 13, 15, 23
Campbell et al., 1999	377	0.03	0.10	2, 4, 8, 13
Campbell et al., 2002	538	0.09	0.24	1, 2, 4, 8, 9, 13, 19, 20
Campbell et al., 2004	306	−0.08	0.12	1, 13
Carpenter et al., 2004	61	0.82	0.26	1, 2, 4, 5, 7, 12, 13, 14, 15, 20, 23, 24, 26
de Bourdeaudhuij et al., 2000 (W)	35	0.71	0.34	4, 8, 13
de Bourdeaudhuij et al., 2000 (M)	35	0.24	0.33	
de bourdeaudhuij et al., 2007	213	0.56	0.25	2, 8, 13
de Noojier et al., 2006	293	0.06	0.15	4, 10
Delichatsios et al., 2001a	298	0.28	0.12	2, 4, 8, 13
Delichatsios et al., 2001b	504	0.35	0.09	1, 4, 8, 10, 13, 25
Dzator et al., 2004	90	0.53	0.30	1, 2, 4, 8
Elder et al., 2005	214	0.14	0.14	4, 5, 8, 12, 15
Elliot et al., 2004	23	0.42	0.65	1, 2, 4, 6, 8, 11, 13, 14, 18, 20, 23, 25
Elliot et al., 2007	315	0.57	0.26	1, 2, 4, 6, 8, 11, 13, 14, 18, 20, 23, 25
Emmons et al., 1999	2054	0.13	0.04	6, 13, 19, 20
Fuller et al., 1998	50	1.28	0.32	4, 7, 8, 12, 14, 15, 16
Hardcastle et al., 2008	334	−0.12	0.16	2, 4, 5, 25
Havas et al., 1998	3122	0.11	0.18	4, 5, 8, 14, 15, 20
Hivert et al., 2007	115	0.01	0.04	2, 4, 5, 12
Insull et al., 1990	264	1.90	0.22	4, 8, 12, 13, 18
Kellar et al., 2005	218	0.34	0.15	4, 10
Kristal et al., 1992	1050	0.40	0.14	2, 8, 13, 18
Kristal et al., 2000	1205	0.28	0.07	2, 4, 6, 7, 8, 13
Kroeze et al., 2008	278	0.23	0.06	1, 5, 8, 13, 19
Mayer et al., 1994	1548	0.10	0.06	2, 4, 8, 13, 14, 16, 18
Oenema et al., 2005	301	0.13	0.07	4, 8, 10, 13, 19
Paineau et al., 2008	673	0.40	0.11	8, 13
Raats et al., 1999	113	0.22	0.12	12, 13
Resnicow et al., 2001	576	0.36	0.19	1, 2, 5, 6, 8, 15, 16
Resnicow et al., 2005	535	0.25	0.18	1, 2, 5, 6, 8, 15, 16, 25
Reuter et al., 2008	115	0.51	0.18	10
Rodearmel et al., 2006	81	0.52	0.25	4, 7, 12, 15
Rosamond et al., 2000	515	0.34	0.14	4, 6, 8, 14, 15, 18
Steptoe et al., 2003	271	0.28	0.13	1, 2
Stevens et al., 2002	616	0.39	0.08	4, 5, 7, 8, 10, 11, 12, 13, 18, 23, 25

(*table continues*)

Table 1 (*continued*)

Study[a]	N	d	SE	Techniques[b]
Tate et al., 2001	62	−0.12	0.26	4, 6, 12, 13, 14, 15, 20, 24
Tate et al., 2006	106	0.72	0.25	4, 5, 11, 12, 13
Tilley et al., 1999	3477	0.56	0.27	4, 6, 12, 13, 14, 15, 20
Vandelanotte et al., 2005	371	0.84	0.22	2, 8, 13
Winett et al., 2007	620	0.45	0.17	7, 8, 13, 14, 19
Wing et al., 2006	190	0.10	0.11	1, 12, 14, 17

[a] 18 studies (Aldana et al., 2005; Arao et al., 2007; Babazono et al., 2007; Campbell et al., 2002; Dzator et al., 2004; Elliot et al., 2004; Elliot et al., 2007; Hardcastle et al., 2008; Hivert et al., 2007; Mayer et al., 1994; Resnicow et al., 2005; Rodearmel et al., 2006; Rosamond et al., 2000; Tate et al., 2001; Tate, Jackvony, & Wing, 2006; Vandelanotte, De Bourdeaudhuij, Sallis, Spittaels, & Brug, 2005; Winett et al., 2007; Wing, Tate, Gorin, Raynor, Fava, 2006) reported both physical activity and healthy eating outcomes and so were entered into the meta-analysis as if they were separate evaluations. To avoid double counting participants (and underestimating the variance associated with each effect size), we calculated the *SE* of each study effect size using half the sample size. In addition, three studies (Calfas et al., 2000; Writing Group for the ACT Research Group, 2001; de Bourdeaudhuij et al., 2000) reported data for men and women separately, and therefore, were entered into the meta-analysis as if they were separate evaluations without adjustment of sample size. [b] Techniques: 1 = Provide information on behavior-health link, 2 = Provide information on consequences, 3 = Provide information about others' approval, 4 = Prompt intention formation, 5 = Prompt barrier identification, 6 = Provide general encouragement, 7 = Set graded tasks, 8 = Provide instruction, 9 = Model/demonstrate the behavior, 10 = Prompt specific goal setting, 11 = Prompt review of behavioral goals, 12 = Prompt self-monitoring of behavior, 13 = Provide feedback on performance, 14 = Provide contingent rewards, 15 = Teach to use prompts/cues, 16 = Agree 2 behavioral contract, 17 = Prompt practice, 18 = Use of follow up prompts, 19 = Provide opportunities for social comparison, 20 = Plan social support/social change, 21 = Prompt identification as role model/position advocate, 22 = Prompt self talk, 23 = Relapse prevention, 24 = Stress management, 25 = Motivational interviewing, 26 = Time management, M = men, W = women.

intervention, using more than one behavior change technique. Of a possible 26 behavior change techniques, the overall average per intervention was 6.0 ($SD = 3.1$) (online supplementary, Table S3). Two techniques were used in less than four evaluations ("provide information about others' approval" and "prompt identification as role model/position advocate"). In most evaluations, the intervention was compared with a no treatment or treatment-as-usual control, while a small number of evaluations used an active control. Overall, the mean number of techniques in the control groups was 0.8 ($SD = 1.3$).

The duration of interventions varied greatly, ranging from receipt of a single session to two and a half years ($M = 24.9$ weeks, $SD = 29.1$) (online supplementary material, Table S3). Overall, in 16% of the evaluations the treatment was brief (<1 day), in 9% it was less than 1 month, in 34% it was between 1 and 5 months, in 22% it was between 6 and 11 months, and in 20% it was 12 or more months long. Overall, in 84% of evaluations, multiple sessions were used to deliver the intervention, and the majority (59%) assessed the outcome at follow-up, which ranged from 1 week to 36 months' postbaseline assessment. In 13% of evaluations, the intervention was delivered by a clinically trained health professional (defined as someone qualified to provide direct patient care), in 28% delivery was by a nonclinically trained health professional (e.g., health educators or exercise facilitators), and in 59% a nonprofessional delivered the intervention. Format of intervention delivery was "individuals" in 62% of evaluations, "groups" in 17%, and both individuals and groups in 20%. In 55% of evaluations, the setting was the community, in 25% primary care and in 20% the workplace. Studies were conducted in Australasia (10%), Canada (2%), United Kingdom (11%), another European country (11%), the United States (61%), or Japan (4%). In 7% of evaluations, the target population was disadvantaged/low-income groups, in 34% it was sedentary/low active, obese, or individuals at risk of cardiovascular disease, and in 21% it was women.

Effect of the Interventions (Evaluations of Physical Activity and Healthy Eating Combined)

Overall effect. Pooling the data across the 122 evaluations ($N = 44{,}747$) using a random-effects model produced an overall effect size of 0.31 (95% confidence interval [CI] = 0.26 to 0.36), indicating that participants receiving behavior change interventions reported significantly better outcomes than those in control conditions. Examination of the I^2 suggested moderate levels of heterogeneity ($I^2 = 69\%$; $Q = 393$, $p < .001$) (online supplementary material, Table S4, Model 0). Sensitivity analyses excluding studies defined as outliers, nonrandomized studies or other studies for which assumptions were made had little effect on either the overall effect size or heterogeneity.[2]

Moderating variables. To explore the reason for heterogeneity across evaluations, we used meta-regression to examine 10 intervention characteristics (e.g., target behavior, duration of intervention, target population) and the 26 behavior change techniques (see online supplementary material, Table S4 and S5, Models 1 to 33). Initially, potential moderators were entered into univariate models to determine the size of the association and the percentage of among-study heterogeneity (adjusted R^2) explained by the covariate. The results indicated that most variables explained very little of the heterogeneity, with 'prompt self-monitoring of behavior' (T12) explaining the greatest amount (13%; see Model 21). A subgroup analysis indicated that the 46 evaluations ($N = 11{,}019$) that used the technique produced a pooled effect size of 0.41 (95% CI = 0.29 to 0.52) compared with the remaining 76 evaluations ($N = 33{,}728$), which produced a pooled effect size of 0.26 (95% CI = 0.21 to 0.30). We then developed a multivariate model, entering only those covariates that had a meaningful association with effect size (see online supplementary material, Table S6).

[2] Havas et al. (1998); Insull et al. (1990); Vandelanotte et al. (2005).

However, the model explained less heterogeneity (11%) than the single technique involving self-monitoring.

Separate Effect of Physical Activity and Healthy Eating

Across all evaluations, there was no evidence from the univariate meta-regression that the target behavior (physical activity or healthy eating) accounted for any of the among-study heterogeneity (Model 1). Subgroup analyses by behavior showed similar effect sizes; for the 69 PA evaluations (N = 18,330), the overall effect size was 0.32 (95% CI = 0.26 to 0.38), while for the 53 HE evaluations (N = 26,417), the overall effect size was 0.31 (95% CI = 0.23 to 0.39). Moreover, within each subgroup, there was notable heterogeneity, I^2 = 58% (PA), 73% (HE).

Theoretically Derived Self-Regulation Techniques

Overall, 60% of the evaluations prompted intention formation, 50% provided feedback on performance, 38% prompted self-monitoring of behavior, 22% prompted specific goal setting, and 16% prompted review of behavioral goals. Only two evaluations used all five of the self-regulation techniques derived from control theory (PA = 1; HE = 1), nine evaluations used four of the techniques (PA = 7; HE = 2), 19 used three techniques (PA = 10; HE = 9), 41 used two techniques (PA = 25; HE = 16), 42 used one technique (PA = 21; HE = 21), and nine used none of the five self-regulation techniques (PA = 5; HE = 4).

Entering the number of theoretically derived self-regulation techniques used by each evaluation into a univariate meta-regression model accounted for 9% of the among-study heterogeneity (Online supplementary material, Table S7, Model 35). Entering all five techniques into a multivariate model also accounted for 9% of the among-study heterogeneity (online supplementary material, Table S7, Model 37), and indicated that the strongest covariate was ‘prompt self-monitoring of behavior’ (T12).

Given that in both the univariate and the multivariate model, self-monitoring was the most important technique, we dummy coded a new variable (self-monitoring plus) to examine the impact of combining self-monitoring with any of the other four self-regulatory techniques. The meta-regression indicated that 17% of the heterogeneity was accounted for by this covariate. A subgroup analysis showed that the 42 evaluations (N = 10,572) that used ‘self-monitoring plus’ produced a pooled effect size of 0.42 (95% CI = 0.30 to 0.54) compared with the remaining 80 evaluations (N = 34,175) that produced a pooled effect size of 0.26 (95% CI = 0.21 to 0.30) (online supplementary material, Table S7, Model 36). Sensitivity analyses suggested that these results were robust to the presence of outliers.

To evaluate whether the ‘self-monitoring plus’ effect was consistent in both PA and HE interventions, we repeated the analysis within each subgroup of studies. For the 29 PA evaluations (N = 5,108) that used ‘self-monitoring plus’ the overall effect size was 0.38 (95% CI = 0.27 to 0.49) compared with the remaining 40 evaluations (N = 13,222) that produced a pooled effect size of 0.27 (95% CI = 0.21 to 0.34). For the 13 HE evaluations (N = 5,464) that used ‘self-monitoring plus’ the overall effect size was 0.54 (95% CI = 0.21 to 0.86), while the remaining 40 evaluations (N = 20,953) produced a pooled effect size of 0.24 (95% CI = 0.18 to 0.29).

Discussion

This systematic review of interventions designed to promote physical activity and/or healthy eating used a novel approach to classifying intervention content according to change techniques and theoretically derived technique combinations (Abraham & Michie, 2008). Use of meta-analysis and meta-regression showed that specification of intervention content clarified which interventions were most likely to be effective. Those including self-monitoring and at least one of four other self regulatory techniques derived from control theory (Carver & Scheier, 1981, 1982) were significantly more effective than interventions not including these techniques, both in interventions designed to promote physical activity and healthy eating. Thus our hypothesis that inclusion of the five techniques derived from control theory (i.e., prompt intention formation, prompt specific goal setting, provide feedback on performance, prompt self-monitoring of behavior, and prompt review of behavioral goals) was partially supported.

We identified 122 evaluations of interventions which actively involve adults living in the community in cognition and behavior change sessions and were evaluated using an experimental or quasi-experimental design. We found that such interventions are effective with effect sizes of 0.32 and 0.31 for physical activity and healthy eating interventions, respectively. These are small effect sizes (Cohen, 1992) in the typical range for psychological interventions (Hunter & Schmidt, 1990). Our results show that the behavioral target and many design characteristics (duration, person delivering the intervention, delivery format [e.g., individual vs. group], setting [e.g., workplace or community settings], use of multiple sessions, time to follow-up, target population) did not distinguish between effective and ineffective interventions. Moreover, the number of behavior change techniques included did not increase effectiveness. This may be because intervention quality and fidelity of delivery may be compromised by a large number of techniques. By contrast, intervention content was associated with intervention effectiveness.

Moderator analysis, using both univariate and multivariate meta-regression, revealed that the number of theoretically derived self-regulation techniques, and in particular, self-monitoring of behavior was associated with improved effectiveness. The interpretation of this effect is supported by the finding that combining self-monitoring with the other theoretically predicted techniques enhances its effect. Interventions combining self-monitoring with one or more of four other hypothesized self-regulation techniques were significantly more effective than interventions not including self-monitoring and one other self-regulatory technique (pooled effect sizes for healthy eating: 0.54 vs. 0.24; physical activity: 0.38 vs. 0.27; all interventions: 0.42 vs. 0.26). Unfortunately, we were unable to reliably compare interventions that combined all five of our hypothesized self-regulatory technique set with those that did not because only two studies included all five. Nonetheless, these data strongly suggest that inclusion of self-monitoring in combination with other self-regulation behavior change techniques is likely to enhance the effectiveness of interventions designed to promote healthy eating and physical activity.

It would be desirable to test our hypothesis on a larger set of intervention studies, since the model may be overdetermined, given the ratio of techniques to studies. However, at present, this would mean relaxing the methodological rigor by which we selected evaluations, i.e., including only experimental or quasi-experimental designs. Sensitivity analysis suggests that our findings are robust, e.g., it is possible that the magnitude of the intervention effects were overestimated because of publication bias, indicated by asymmetry in the funnel plot (see Figure S1 in the online supplementary materials). However, using the "trim and fill" method (Duval & Tweedie, 2000) to adjust the meta-analysis to incorporate the theoretically missing studies, the overall pooled effect size did not substantially change. In addition, excluding both nonrandomized studies and studies for which we had to make assumptions when calculating effect sizes (e.g., studies reporting nonsignificant effects were assumed to have an effect size of 0.50) did not substantially change the results. This suggests that our sample of intervention evaluations is representative of the population of such evaluations using rigorous evaluation methods.

Our analyses do not illuminate determinants of a large proportion of unaccounted variance in effect size heterogeneity but we have shown that a series of study characteristics that might be expected to affect effectiveness do not account for this heterogeneity. It is likely that combinations of characteristics and behavior change techniques may interact to account for this heterogeneity. However, the number of studies in the available literature does not allow us to reliably explore these potential effects.

In conclusion, our analyses offer clear support for including self-monitoring of behavior as well as prompting intention formation, prompting specific goal setting, providing feedback on performance, and prompting review of behavioral goals in interventions designed to promote healthy eating and physical activity. The implications of these analyses need to be tested experimentally with study designs of interventions which do, and do not include, sets of behavior change techniques theoretically predicted to effect change (e.g., the set of five intervention techniques based on Carver and Scheier's [1981; 1982] control theory). This will advance both the design of more effective interventions and theory development.

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