

Effective Behavior Change Techniques in Asthma Self-care Interventions: Systematic Review and Meta-Regression

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Abstract

Objectives: To update previous systematic reviews of interventions targeting asthma self-care in adults with asthma. To use meta-regression to examine the association between the use of specific behavior change techniques and intervention effectiveness.

Methods: Electronic bibliographies were searched systematically to identify randomized controlled trials of interventions targeting asthma self-care. Intervention content was coded using a published taxonomy of behavior change techniques. For trials with a low-to-moderate risk of bias, study outcomes were pooled using random effects meta-analysis. Associations between intervention content and effect size were explored using meta-regression.

Results: Meta-analysis of 38 trials (7883 patients) showed that interventions targeting asthma self-care reduced symptoms (Standardized mean difference (SMD))=-0.38;(-0.52,-0.24)) and unscheduled health care use (Odds ratio (OR))=0.71;(0.56 to 0.90)) and increased adherence to preventive medication (OR=2.55;(2.11 to 3.10)). Meta-regression analyses found that ‘active involvement of participants’ was associated with a reduction in unscheduled health care use (OR=0.50 vs. 0.79). Inclusion of ‘stress management’ techniques was associated with an increase in asthma symptoms (SMD= 0.01vs. -0.44). Existing recommendations about the ‘optimal’ content of asthma self-care interventions were tested, but were not supported by the data.

Conclusions: Interventions targeting asthma self-care are effective. Active involvement of participants is associated with increased intervention effectiveness, but the use of stress management techniques may be counter-productive. Taxonomy based systematic reviews using meta-regression have potential for identifying techniques associated with increased effectiveness in behavioral interventions.

Keywords: asthma self-care, behavior change techniques, taxonomy, systematic review

Introduction

An estimated 300 million people worldwide suffer from asthma, with 250,000 annual deaths attributed to the disease (World Health Organization, 2007). Despite the existence of effective treatments, morbidity associated with asthma remains high. In the United States, asthma accounts for approximately 1.8 million hospital visits and 500,000 hospitalizations each year (Akinbarni, Moorman, & Lui, 2011). The annual economic cost of asthma is estimated to be \$56 billion with indirect costs such as lost productivity estimated at \$5 billion (American Lung Association 2012). Results of a large survey of 7,768 adults with asthma (Rabe et al., 2004) suggest that the majority of patients with asthma experience regular asthma symptoms that restrict their general activities and ability to work. It has been suggested that poor self-care is responsible for many asthma exacerbations and symptoms (Global Initiative for Asthma, (GINA) 2009) and for as many as 75% of hospital admissions (Blainey, Beale, Lomas, & Partridge, 1994).

Systematic reviews have found that interventions targeting asthma self-care can reduce asthma symptoms and unscheduled health care use, and result in improved patient reported quality of life (Gibson, Powell, Coughlan, et al., 2002; Powell & Gibson, 2002; Smith, Mugford, Holland, Noble, & Harrison, 2007; Tapp, Lasserson, & Rowe, 2007; Yorke, Flemming, & Shulldham, 2006). Consequently, asthma self-care education is recommended in asthma treatment guidelines and programs are widespread in the US (American Lung Association, 2012; GINA, 2011) and other countries. However, these reviews also show considerable statistical heterogeneity in outcome effects across different studies. Hence, there is a need for research to go a step further and explore how the content of an intervention can influence its effectiveness (Abraham & Michie, 2008; Abraham, Kelly, West, & Michie, 2009).

In asthma self-care interventions, patients may be taught how to respond to exacerbations of asthma, to avoid environmental asthma triggers, to manage stress associated with symptoms of asthma, to communicate better with health professionals, or to use medication correctly (Clark et al., 1991). In our review, we use the following definition of asthma self-care:

“Types of processes or strategies the patient must employ to achieve a degree of control over the impact of the disease. These range from identification of impending problems through symptom recognition, to obtaining optimum health care through effective interaction with providers, to consciously reducing the psychological burden of the illness by managing emotions” (Clark et al., 1991).

Existing systematic reviews have explored the effectiveness of; ‘limited information only interventions’ (Gibson, Powell, Wilson, et al., 2002 2002) , ‘education interventions’ (Tapp, et al., 2007), ‘psychological interventions’ (Yorke, et al., 2006), psycho-educational ‘interventions’ (Smith, et al. 2007), ‘self-management education and regular practitioner review’ (Gibson, Powell, Coughlan, et al., 2002; Powell & Gibson, 2002), and ‘primary care-based clinics’ (Jones, Fay, & Ram-Felix, 2002) for improving asthma control. However, the terms that are used to describe the interventions (psycho-education, education, limited information etc) overlap considerably. The systematic review of Gibson, Powell, Coughlan, et al., (2002) explored variations in the effectiveness of different asthma self-care interventions. Based on narrative description, the results suggested that the most effective interventions include a combination of four behavior change techniques, i.e. ‘education’, ‘self-monitoring of asthma symptoms’, ‘incorporation of a written self-management plan’, and ‘arrangements for regular follow-up /review’. Interventions that included all four of these behavior change techniques were described

as ‘optimal’. However, the ‘optimal’ interventions identified varied in effectiveness, as well as in terms of other features, such as their content, setting, intensity, and delivery provider.

Furthermore, many of the interventions included more than just the four optimal techniques. It is therefore still not clear which behavior change techniques should be incorporated in interventions targeting asthma self-care to maximize their effectiveness in reducing asthma morbidity.

Meta-regression is a statistical technique that is capable of identifying predictors of effect size from the characteristics of individual trials (Thompson & Higgins, 2002). The use of meta-regression for exploring the mechanisms of change in complex interventions is increasing (Dombrowski, et al., 2012; Michie, Abraham, Whittington, McAteer, & Gupta, 2009), but has not yet been applied to asthma self-care interventions. A published and validated taxonomy of behavior change techniques has been used as the basis for meta-regression studies that relate intervention content to intervention effectiveness (Abraham & Michie, 2008). This taxonomy includes definitions of twenty six commonly used behavior change techniques, thus providing a framework for coding the content of published interventions.

Aims and objectives

The aims of our review were to a) update previous systematic reviews of interventions targeting asthma self-care in adults with asthma and b) to explore the association between the use of specific behavior change techniques and change in asthma morbidity, (symptoms) unscheduled health care use, and adherence to preventative asthma medication.

Methods

This review was conducted and reported in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) statement (Moher, Liberati, Tetzlaff, &

Altman, 2009). The PRISMA flowchart is presented in online resource 1.

Search strategy

Using the search engine ‘Dialogue DataStar’, the Cochrane Central Register of Controlled Trials (CENTRAL), EMBASE, CINAHL, MEDLINE, Psych Info and the Clinical trials register (ClinicalTrials.gov) were searched to identify trials that were published between January 1998 to October 2012. Search terms followed the population, intervention, comparator, outcome and study design (PICOS) principal, and were adapted for each database. To identify trials that were published before 1998, the reference lists of all included studies, and three existing systematic reviews of interventions targeting asthma self-care (Gibson, Powell, Wilson, et al., 2002; Gibson, Powell, Coughlan, et al., 2002; Smith, et al., 2007) were hand searched. Search terms for Medline are presented in online resource 2.

Study Selection

Two reviewers (SD, CG) independently reviewed titles and abstracts of trials that were retrieved using our search strategy. Potentially eligible articles were retrieved in full and checked further for eligibility. Studies were included on the basis of the following criteria:

Study type: Randomized controlled trials of interventions targeting at least one of four guideline-recommended (American Lung Association, 2012; British Thoracic Society, 2008; GINA, 2011; National Heart Lung and Blood Institute, 2007) asthma self-care behaviors were considered for inclusion. The targeted self-care behaviors were: adherence to preventive asthma medication, trigger avoidance, appropriate help seeking *and* stress management.

Population: Participants aged 18 or above with a diagnosis of asthma. Trials that targeted both children (participants under the age of 18 years) and adults were only considered if more than 50% of the sample were adult.

Intervention and control: Interventions targeting asthma self-care behavior were eligible for inclusion if the intervention description contained one or more behavior change technique from the taxonomy of behavior change techniques developed by Abraham and Michie (2008). Behavior change techniques were only coded as ‘present’ if the patients in the control condition did not receive the behavior change technique. Studies were eligible if the control arms included information-only, a different / less intensive intervention or usual care.

Outcomes: Asthma symptoms and healthcare use were used as proxies for change in asthma self-care behaviours. Studies were therefore included if they reported one or more of the following outcomes: (1) Asthma symptoms; (2) unscheduled health care use associated with asthma management; (3) adherence to preventive asthma medication. Data on outcomes obtained using validated and objective (as opposed to self-report) measures were extracted for the meta-analysis if a choice was available.

Quality assessment

Study quality was independently assessed by two authors (CG, SD) using the Cochrane Collaboration risk of bias assessment tool (Higgins & Green, 2011). The methodological domains considered when assessing the quality of the studies were: sequence generation; allocation concealment; blinding of patients, personnel and outcome assessors; incomplete outcome data; imbalance between groups at baseline; selective outcome reporting; and other sources of bias. Using the Cochrane risk of bias assessment tool (Higgins & Green, 2011), each trial was rated as having a high, low, or unclear risk of bias for each domain. Trials were categorized as having low risk of bias if they were considered to have low potential for bias in three *critical* domains (i.e. allocation concealment, incomplete outcome data, and imbalance between groups at baseline). Studies were categorized as having high risk of bias if they were

judged to have a high potential for bias in one or more of the critical domains. Studies with a high risk of bias were excluded from the analyses. Authors of published trial reports were contacted and asked to clarify any ambiguities.

Data extraction

Data were extracted by one reviewer (SD) and checked by another (CG) and any disagreements were resolved by discussion. Data were extracted on the following features of trials: severity of asthma (mild, moderate, severe); setting of intervention (primary, secondary, community); mode of intervention delivery (face to face, self-delivered (e.g. written, internet-based)); number of intervention sessions (categorized for the regression analysis as <4 or ≥ 4); total contact time (categorized for the regression analysis as <5 hours or ≥ 5 hours); intervention provider (nurse, general practitioner etc); follow-up period (categorized for the regression analysis as 3, 6, 9, 12, or greater than 12 months); and theory underpinning the intervention.

As the intervention description needed to be sufficient to allow coding of intervention content, trials with poor intervention description were excluded from the meta-regression analyses. The quality of intervention descriptions was rated independently by two authors on five features: the presence of recognizable behavior change techniques in the intervention, quality of description of behavior change techniques, length of published description, completeness of intervention description, and the confidence with which the coder felt that the description of the intervention matched the intervention that was being evaluated. Based on the results of that procedure, the descriptions of the content of interventions were categorized as good, sufficient, or poor. Authors were contacted and asked to clarify any ambiguities. Any disagreements between reviewers in terms of study quality or quality of intervention descriptions were resolved by discussion.

The content of each intervention was coded independently by two reviewers in accordance with the taxonomy of behavior change techniques developed by Abraham and Michie (2008). Each intervention description was coded as ‘including’ or ‘not including’ each of the 26 behavior change techniques defined in the taxonomy. A further 11 behavior change techniques, that were not included in Abraham and Michie (2008) taxonomy of behavior change techniques, were identified whilst assessing the content of the interventions and were also coded. Definitions of each of the techniques included in our review are available online (online resource 3).

In line with previous taxonomy-based reviews (Dombrowski, et al., 2012; Michie, et al., 2009), interventions were coded as being ‘consistent’ or ‘not consistent’ with Social Cognitive Theory, (Bandura, 1977) and consistent or not consistent with Control Theory (Carver & Scheier, 1982). We also coded interventions that were consistent or not consistent with the ‘optimal’ content for asthma self-care interventions defined by Gibson, Powell, Coughlan, et al. (2002). To be considered consistent with Social Cognitive Theory, the intervention needed to include the following behavior change techniques (i) provide information on consequences, (ii) prompt intention formation, (iii) prompt barrier identification, (iv) provide general encouragement, (v) set graded tasks, (vi) provide instruction, (vii) model/ demonstrate the behavior. In order to be considered to be consistent with Control Theory the intervention needed to include the following behavior change techniques (i) prompt specific goal setting, (ii) prompt self-monitoring of behavior (iii) prompt review of behavior goals, OR provide feedback on performance. In order to be considered to be coded as an ‘optimal’ intervention, the intervention needed to include (i) provide general information OR provide instruction, (ii) prompt specific

goal setting OR intention formation, (iii) prompt self-monitoring of behavior (iv) prompt review of behavioral goals OR use follow-up prompts OR provide feedback on performance.

Data Analysis

Kappa statistics were calculated to provide an estimate of the level of agreement between the two reviewers regarding the identification of the 37 behavior change techniques reported in intervention descriptions. For binary outcomes odds ratios (OR) with 95% confidence intervals were calculated. Given the variation in asthma symptoms scales used across studies, continuous data on asthma symptoms was expressed as standardized mean differences (SMD) and 95% confidence intervals.

Meta-analysis: Given the heterogeneity in intervention content, we decided in advance to pool data using a random effects meta-analysis (Higgins & Green, 2011). Statistical heterogeneity was assessed using the χ^2 test and the I^2 statistic. In order to maximize the total number of studies available for the analysis, binary and continuous data were pooled using the generic inverse variance method. This procedure, described in the Cochrane Handbook for Systematic Reviews (Higgins & Green, 2011), involves converting standardized mean differences into odds ratios so they could be combined with odds ratio calculated directly from binary outcomes.

Meta-regression analyses: Nine trial features (i.e. severity of asthma, setting of intervention, mode of delivery, number of intervention sessions, total contact time, intervention provider, follow-up period, theoretical underpinning, total number of behavior change techniques and trial quality) and the presence or absence of each behavior change technique were defined as covariates. Univariate meta-regression was used to assess the association between each covariate and each outcome (symptoms of asthma, unscheduled health care use, and adherence to

preventive asthma medication). To ensure statistical power, analyses were restricted to situations where a minimum of four trials was available in each category. To assess the amount of heterogeneity explained by each covariate, we compared the baseline heterogeneity variance obtained from an empty regression model with the heterogeneity variance reported by the ‘metareg’ command in STATA.

The univariate association between outcomes and the inclusion in interventions of clusters of behavior change techniques consistent with the central features of either Control Theory, Social Cognitive Theory or Gibson, Powell, Coughlan, et al.’s (2002) cluster of ‘optimal’ intervention components (see above) was also assessed. A funnel plot was generated and the Egger test was used to assess the degree of funnel plot asymmetry (Egger, Smith, Schneider, & Minder, 1997). Analyses were conducted using the Review Manager (RevMan) software, V5.1 and STATA v.10.

Results

The initial search identified 3282 articles excluding duplicates. A total of 2349 were excluded on the basis of abstract and title. Of the 223 full papers retrieved, 164 were excluded on the grounds of eligibility or quality and 21 were excluded on ground of inadequate intervention description. Consequently, 38 trials (involving 7883 participants) were eligible for analysis (Fig. 1).

Insert figure 1 here

Quality

Of the trials retrieved in full, 95 were considered to have a high risk of bias and were therefore excluded. An overview of the quality of the trials is available online (online resource 4).

Description of included trials

The year of publication of trial reports ranged from 1993 to 2012. The mean (range) number of patients per trial was 207 (22 to 808). Eleven trials included patients with a particular level of asthma severity (e.g. mild, moderate or severe asthma), fourteen trials included patients of all severities and severity was not reported in thirteen trials. Twenty four trials were undertaken in primary care and twelve in secondary care (setting was not reported in two instances).

Interventions were delivered individually (30), in groups (1), in a combination of group and individual sessions (5) or were self administered (2). The number of sessions over which interventions were delivered ranged from 1 to 26. It was possible to extract data on the total contact time between health care providers and patients (in hours) for 27 of the 38 trials. This ranged from 0.1 to 10 hours. Intervention providers included patient educators (4); pharmacists (4); nurses (11); General practitioners (2); researchers (7); physiotherapists (1); not reported (3); no delivery provider (self-delivery via internet or other formats) (2) telephone (1) combination (3). The length of follow-up ranged from 2 to 18 months (median 12 months). Nine interventions reported a theoretical basis: Social Learning Theory (or Social Cognitive Theory) (6); Protection Motivation Theory (1); Self Determination Theory (1); Self-Efficacy Theory (1). In 26 trials, intervention patients were compared with patients receiving usual care. In the remaining 12 trials, interventions were compared with less comprehensive interventions (seven of which were information only). Details of the included studies and their intervention characteristics are included online (online resources 5 and 6).

Intervention Content

Information on the content of interventions is presented in online resource 6. The number of techniques included in each intervention ranged from 1-30 (mean 12.4, SD 5.9). The most common behavioral techniques were; self-monitoring (30), instruction (27), goal setting (26) and

inhaler technique (24). Four of the behavior change techniques included in Abraham and Michie's (2008) taxonomy of behavior change techniques (provide information about others' approval, agree behavioral contract, prompt identification as a role model and prompt self talk) were not included as part of any of the interventions examined.

The 11 additional behavior change techniques we identified were (i) providing feedback on inhaler technique (n=24), (ii) instruction in breathing control techniques (n=3), (iii) training in social communication skills (n=3), (iv) individual tailoring of information or of intervention content (n=9), (v) addressing medication concerns (n=7), (vi) active involvement of participants (n=10), (vii) cognitive behavior therapy (n=3), (viii) medication optimization (n=11), (iv) efficacy building (n=1), (x) use of active learning techniques (n=11), and (xi) developing illness models (n=4) (i.e. improving understanding of the illness' identity, cause, controllability, consequences and timeline). Definitions of these eleven techniques are provided online (Online resource 3).

Five of 38 interventions included all of the behavior change techniques associated with Control Theory (Carver & Scheier, 1982). No intervention included all the behavior change techniques associated with Social Cognitive Theory (Bandura, 1977). In light of this, the five interventions that used four or more behavior change techniques coherent with Social Cognitive Theory were considered as being consistent with Social Cognitive Theory. Fourteen interventions were considered to be 'optimal' as defined by Gibson, Powell, Coughlan, et al., (2002) (as above).

Inter-rater reliability

Kappa statistics indicated good levels of agreement (≥ 0.7) as specified by Landis and Koch (1977) for the initial identification of 22 behavior change techniques, and moderate levels of

agreement for 6 behavior change techniques ($0.4 \leq \text{Kappa} < 0.7$). Agreement for the identification of six behavior change techniques (provide general information, provide information on the consequences of not performing the behavior, prompt intention formation, prompt barrier identification, model or demonstrate the behavior, and use follow-up prompts) was considered to be poor ($\text{Kappa} < 0.4$). Initial discrepancies were resolved by agreement between the two coders.

Results of meta-analyses

Symptoms: Twenty seven randomized controlled trials provided data on asthma symptoms. The meta-analysis (Fig.2) identified a statistically significant reduction in asthma symptoms for intervention group participants compared to controls (SMD=-0.38, 95% CI: -0.52, to -0.24). There was substantial statistical heterogeneity between trials in effect size ($I^2 = 75\%$, $P=0.00$) and the Egger test revealed significant asymmetry in the funnel plot ($p=0.00$).

Insert figure 2 here

Unscheduled health care use: Twenty three trials provided data on unscheduled health care use. The meta-analysis (Fig.3) showed a significant reduction in health care use for intervention group participants compared with controls; OR 0.71 (95% CI; 0.56 to 0.90). There was substantial statistical heterogeneity in effect size between trials ($I^2 = 59\%$, $p=0.00$) and the Egger test revealed significant asymmetry in the funnel plots ($p=0.00$).

Insert figure 3 here

Adherence to medication: Sixteen trials provided data on adherence to preventive asthma medication. The meta-analysis (Fig.4) showed a significant increase in adherence to preventive medication for intervention group participants compared with controls; OR 2.55 (95% CI; 2.11, to 3.10). Heterogeneity was not statistically significant ($I^2 = 4\%$, $p=0.4$) and the Egger test

revealed no significant asymmetry in the funnel plots.

Insert figure 4 here

Meta-regression analyses

Tables showing the results of the meta-regression analyses are provided online (online resources 7-12).

Symptoms of asthma: There were no statistically significant associations ($p > 0.05$) between patient-reported asthma symptoms and any of the following intervention characteristics: Intervention setting, risk of bias, or the specified use of a behavioral theory (online resource 7). There was insufficient data to assess the association between symptoms of asthma and contact time, intervention delivery mode, length of follow-up, number of sessions, or intervention provider.

Twenty one behavior change techniques were regressed against asthma symptoms (online resource 8). The inclusion of the technique ‘stress management’ was significantly associated with the effect of interventions on symptoms of asthma. The four interventions that included stress management were *less* effective for reducing symptoms of asthma than the 23 interventions that did not include this technique (SMD=0.01(95%CI; -0.08, 0.10) vs. (SMD=-0.44 (95%CI; -0.57, -0.31)). No significant associations between the inclusion of any other BCTs and asthma symptoms were found. However, the association between the inclusion of the technique ‘providing feedback’ and symptoms of asthma was approaching significance, with the eight interventions that included the technique being less effective than the 19 that did not (SMD= -0.19 (95%CI; -0.40, 0.01) vs. SMD -0.46 (-0.62, -0.30) $p=0.07$). The use of techniques consistent with Social Cognitive Theory or Control Theory or the use of the four ‘optimal’

techniques identified by Gibson, Powell, Coughlan, et al. (2002) were not significantly associated with symptoms of asthma.

Unscheduled health care use: There were no statistically significant associations ($p > 0.05$) between unscheduled health care use and any of the following intervention characteristics: Intervention setting, or risk of bias (online resource 9). There was insufficient data to assess the association between symptoms of asthma and contact time, intervention delivery mode, length of follow-up, number of sessions, or intervention provider. However, the relationship between use of a behavioral theory and unscheduled healthcare use was approaching significance ($p = 0.5$). The seven interventions that specified the use of a behavioral theory were more effective for reducing unscheduled healthcare use than the 16 that did not ($OR = 0.66$ (95% CI; 0.43, 1.01) vs. $OR = 0.73$ (95% CI; 0.54, 0.97), $p = 0.05$).

Sixteen behavior change techniques were regressed against unscheduled health care use (online resource 10). ‘Active involvement of participants’ was the only behavior change technique significantly associated with unscheduled health care use. The six trials that included active involvement of participants were considerably more effective for reducing unscheduled health care use than the 17 trials that did not include this technique ($OR = 0.50$ (95% CI; 0.28, 0.90)) vs. ($OR = 0.79$ (95% CI; 0.62, 1.01)). No significant associations between the inclusion of any other BCTs and symptoms were found, however, the association between inclusion of the technique ‘medication concerns’ and unscheduled healthcare use was approaching significance. The seven interventions that included the technique ‘medication concerns’ being more effective than the 16 interventions that did not ($OR = 0.44$ (95% CI; 0.25, 0.77) vs. $OR = 0.84$ (95% CI; 0.65, 1.08) $p = 0.05$). Interventions in which the four ‘optimal’ techniques specified by Gibson, Powell, Coughlan, et al. (2002), and techniques associated with Control Theory were used were not

significantly more effective for reducing unscheduled health care use than those that did not include these techniques.

Adherence to medication: There were no statistically significant associations ($p > 0.05$) between adherence to medication and any of the following intervention characteristics: Intervention setting, risk of bias, or the specified use of a behavioral theory (online resource 11). There was insufficient data to assess the association between symptoms of asthma and contact time, intervention delivery mode, length of follow-up, number of sessions, or intervention provider.

Fifteen behavior change techniques were regressed against adherence to preventive asthma medication (online resource 12). No significant association between any of the behavior change techniques and adherence to preventive asthma medication was found. Interventions in which the four ‘optimal’ techniques specified by Gibson, Powell, Coughlan, et al. (2002), and techniques consistent with Control Theory or Social Cognitive Theory were used were not significantly more effective for improving adherence to preventative medication for asthma than those that did not include these techniques.

Discussion

The results of the meta-analyses show that interventions targeting asthma self-care are effective for improving asthma symptoms, reducing unscheduled health care use for exacerbations of asthma and improving adherence to preventive asthma medication. The results of our meta-analysis support the existing body of literature that has found interventions targeting asthma self-care to be effective for improving asthma symptoms, lung function, unscheduled health care and adherence to preventative asthma medication (Devine, 1996; Gibson, Powell, Coughlan, et al., 2002; Smith et al., 2007; Tolle & Ram, 2004).

The results of the meta-regression analyses suggest that inclusion of ‘active involvement of participants’ may increase the effectiveness of interventions targeting asthma self-care for reducing unscheduled health care use. Inclusion of techniques targeting ‘stress management’ was associated with a reduction in intervention effects on asthma symptoms. No significant associations were found between other behavior change techniques or trial features and either symptoms of asthma, unscheduled health care use or medication adherence. Of importance, the inclusion in interventions of the set of behavior change techniques identified in a previous systematic review as being ‘optimal’ (Gibson, Powell, Coughlan, et al., 2002) did not appear to be associated with increased effectiveness for any of the three outcomes assessed in our review.

Our findings on active involvement of participants are consistent with previous research which has suggested that interventions in which health care providers encourage patients to be actively involved in the consultation / decision making process are likely to be effective for changing behavior (Lewin, Skea, Entwistle, Zwarenstein, & Dick, 2001; Stevenson, Cox, Britten, & Dundar, 2004; Tang, Funnell, Brown, & Kurlander, 2010). However, in the trials examined here, often very little information was provided on the techniques used to actively involve participants (e.g. this might include the use of person-centered counseling techniques or encouragement to self-identify learning goals or ways to overcome barriers to behavior change). Further research is needed to explore the range of strategies that can be used to encourage patients to be more actively involved in interventions targeting asthma self-care, and the extent to which these influence intervention effectiveness.

That stress management techniques were associated with reduced effectiveness is also consistent with prior research, although the evidence base on this topic is mixed. A previous systematic review failed to find a significant benefit of interventions targeting stress management

for individuals with asthma (Huntley, White, & Ernst, 2002). However, it has been suggested that the effectiveness of interventions targeting stress management may be diluted if they are not targeted towards patients who are prone to stress induced hyperventilation (Thomas, McKinley, Freeman, Foy, Prodger, & Price, 2003). It is also possible that interventions in which health care providers largely focus on stress management included fewer (possibly more beneficial) behavior change techniques.

Strengths and limitations of the review

Strengths of the review: Our review augments previous reviews of asthma self-care interventions in a number of ways. Only high quality RCTs trials were included in our analyses. Therefore our findings may be considered to be more robust than data from previous systematic reviews. It is worth noting that, as we excluded 95 trials on the basis of methodological quality, the potential for these lower quality trials to introduce bias into the findings would have been high. The content of each intervention included in our review was independently coded by two researchers using a previously published, validated taxonomy of 26 behavior change techniques (Abraham & Michie, 2008).

Previous reviewers who have attempted to categorize the content of interventions targeting asthma self-care have done so using imprecise umbrella terms such as ‘psycho-social’ and ‘educational.’ In such reviews considerable variation in the content of supposedly ‘similar’ interventions was evident (Smith et al., 2007). Because we excluded trials with poor intervention descriptions and used a validated coding taxonomy, we can be confident that our coding represented the content of interventions reasonably well.

As a result of the coding process, the authors became aware of a number of techniques that appeared to be unique to asthma self-care interventions. In some cases, these techniques

could be seen as specific examples of taxonomy defined techniques (for example feedback on inhaler technique is a specific example of ‘providing feedback’). In other cases, the techniques were distinct from the techniques in the taxonomy, although may be considered as delivery techniques rather than behaviour change techniques per se (e.g. individual tailoring, patient involvement). Nevertheless, such techniques may be an important element of intervention content that, as the results here indicate, may contribute significantly to intervention effectiveness. Whilst the identification of these techniques has not been previously validated, we provide kappa statistics that show that agreement for the presence or absence of these techniques in intervention descriptions was good.

Limitations: A potential explanation for the lack of statistically significant associations observed in this study may be a lack of statistical power. The number of trials needed to detect significant associations in meta-regression is dependent on many factors (the sample size of each trial, the variance in the covariates both between and within trials) (Simmonds & Higgins, 2007). To our knowledge, no formal calculations for sample size in meta-regressions are available, although it has been suggested that no less than ten trials per variable should be used when performing a meta-regression analysis (Higgins & Green, 2011). Researchers undertaking meta-regressions have tended to accept this suggestion (Dombrowski, et al., 2012; Michie, et al., 2009; West, Walia, Hyder, Shahab, & Michie, 2010). In limiting our analyses to univariate models we were able to meet this requirement. In excluding studies of poor quality, we are confident that every attempt has been made to minimize bias, and increase the trustworthiness of our results. Whilst this strategy also reduced the statistical power of our meta-regression analyses, we feel that lowering the quality threshold would risk introducing bias into the analyses.

Limiting our analyses to univariate meta-regression models also prevented us from being able to examine the potential for confounding by other covariates. It also meant that we had to run a large number of univariate analyses, thus increasing the likelihood of finding significant associations by chance. The Egger test revealed significant funnel plot asymmetry for two of the three outcomes, suggesting that publication bias or other selection bias is a possibility. However, this could also reflect a number of other factors, including the significant heterogeneity that was evident in the results of the studies.

Implications for practice: The results of our review have a number of implications for practice. First, our review supports and extends (through a focus on high quality evidence) the findings of previous reviews on the effectiveness of asthma self-care interventions. Such interventions should therefore be offered to patients who have poorly controlled asthma. In this study, active patient involvement was defined as “*Encouraging the participant to be actively involved in the intervention processes (such as getting motivated, planning actions, monitoring progress and problem-solving). Active involvement requires the participant to generate (as opposed to being a passive recipient of) information or ideas. This might include encouraging participants to take the lead in prioritizing and setting goals, and in identifying problems and solutions. This would also include the use throughout the intervention of empathy-building techniques within a person-centered counseling framework or the explicit use of empowerment or shared decision-making techniques*”. The results of our regression analyses suggest that the effectiveness of such interventions would be maximized if health care providers encourage patients to be actively involved in the intervention.

The results also suggest that the inclusion of stress-management techniques may dilute the effectiveness of interventions and so health care providers should ensure that inclusion of

such techniques is targeted to people for whom stress or hyperventilation causes problems with asthma self-care or symptom control. They should also ensure that the inclusion of such techniques does not interfere with or distract from making changes in other self-care behaviors. Incorporating techniques from Social Cognitive Theory into interventions targeting asthma self-care may also increase the effectiveness of the intervention.

We tentatively suggest that the inclusion of the techniques addressing medication concerns (defined as: “*any techniques designed to explore and address concerns associated with a the use of medication for asthma*” and providing patients with feedback (defined as “*providing data about recorded behavior or evaluating performance in relation to a set standard or others’ performance*”) could increase the effectiveness of the interventions. However, the associations between these techniques and outcomes were only approaching significance, and require future research before conclusions can be drawn.

Guidelines for the management of asthma cite the review by Gibson, Powell, Coughlan, et al., (2002) when recommending that interventions should include education, self-monitoring of asthma symptoms, action planning and a regular follow-up review (American Lung Association, 2012; GINA, 2011). Gibson et al.’s identification of optimal techniques is based on a simple descriptive analysis of the characteristics of successful interventions in a systematic review. However, our attempt to validate the usefulness of these techniques statistically and based on high quality evidence, with a reliable coding frame found no evidence to support the idea that this cluster of intervention components is optimal for improving asthma outcomes. Although we would not recommend removal of these techniques from asthma guidelines (as interventions using them are still effective), the results of our research suggest that other content (e.g., active involvement of participants) may be equally important.

Implications for research: Our research shows that it is possible to identify effective components of interventions using a taxonomy of behavior change techniques. Further work that applies the taxonomy to self-management interventions for other conditions, where there is large variation in intervention effectiveness (Newman, Steed & Mulligan, 2004) may therefore be useful.

More high quality trials of different approaches to asthma self-care intervention are needed. In-trial process evaluations are needed to examine in more detail the role of active involvement of participants and other intervention techniques in promoting better asthma self-care. To facilitate future meta-analyses of this type, scientific journals should insist on the publication of intervention descriptions that are sufficiently detailed to categorize the intervention using available taxonomies and to replicate the intervention. Describing interventions in sufficient detail to allow replication is a fundamental premise in all other sciences, so it is puzzling that this has not yet been widely adopted in the field of health behavior intervention.

Conclusions

This study is the first empirical examination to apply a taxonomy of behavior change techniques to identify components in asthma self-care interventions that are associated with increased effectiveness. We have provided preliminary evidence that asthma self-care interventions that actively involve patients and that use techniques related to social cognitive theory may be more effective for reducing unscheduled health care use than interventions in which patients are less actively engaged. The inclusion of stress management techniques may dilute the effectiveness of asthma self-care interventions. Taxonomy based systematic reviews using meta-regression have potential for identifying techniques associated with increased effectiveness in complex

behavioral interventions. However, in applying this approach, statistical power, trial quality and quality of intervention descriptions are important methodological considerations.

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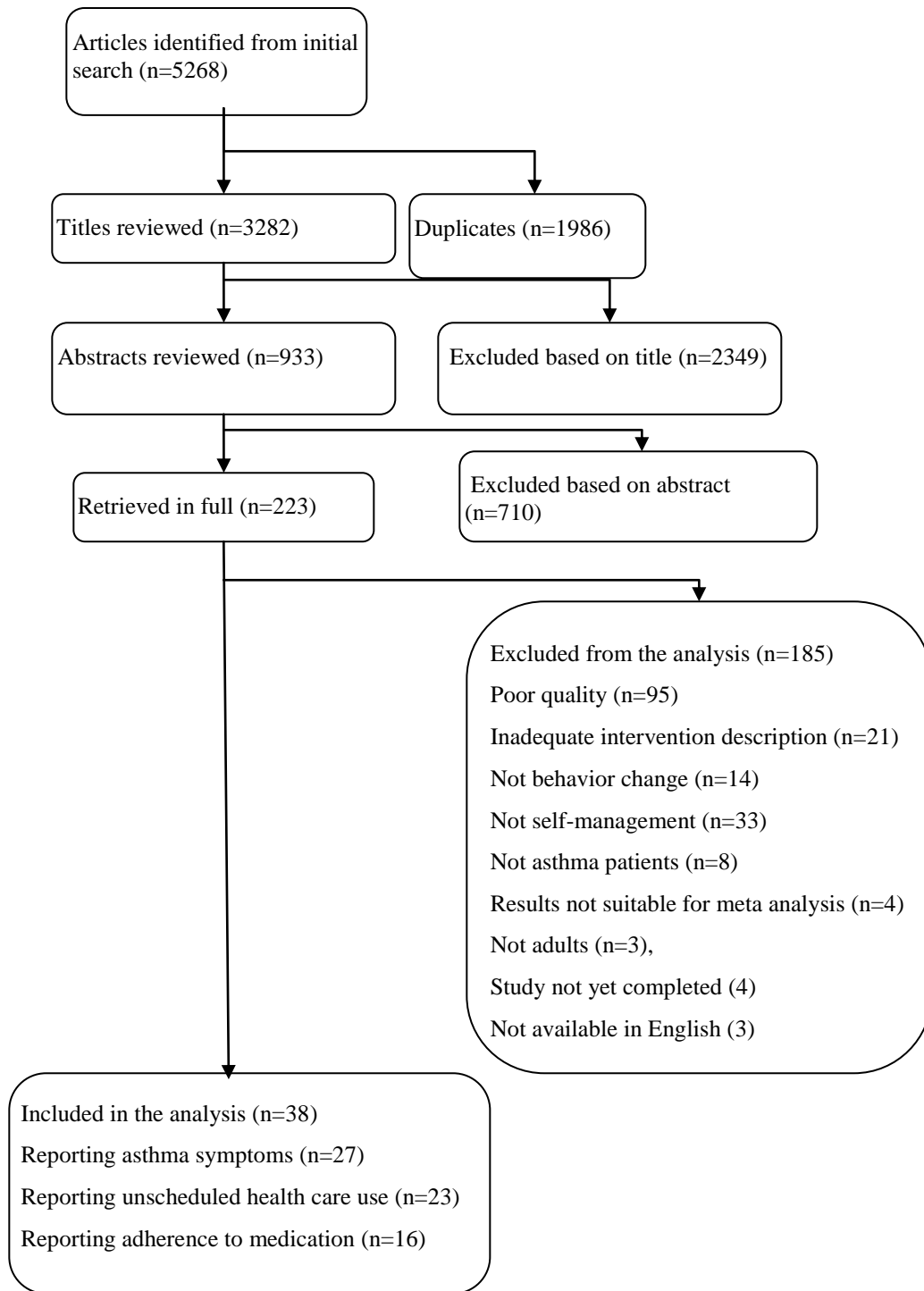
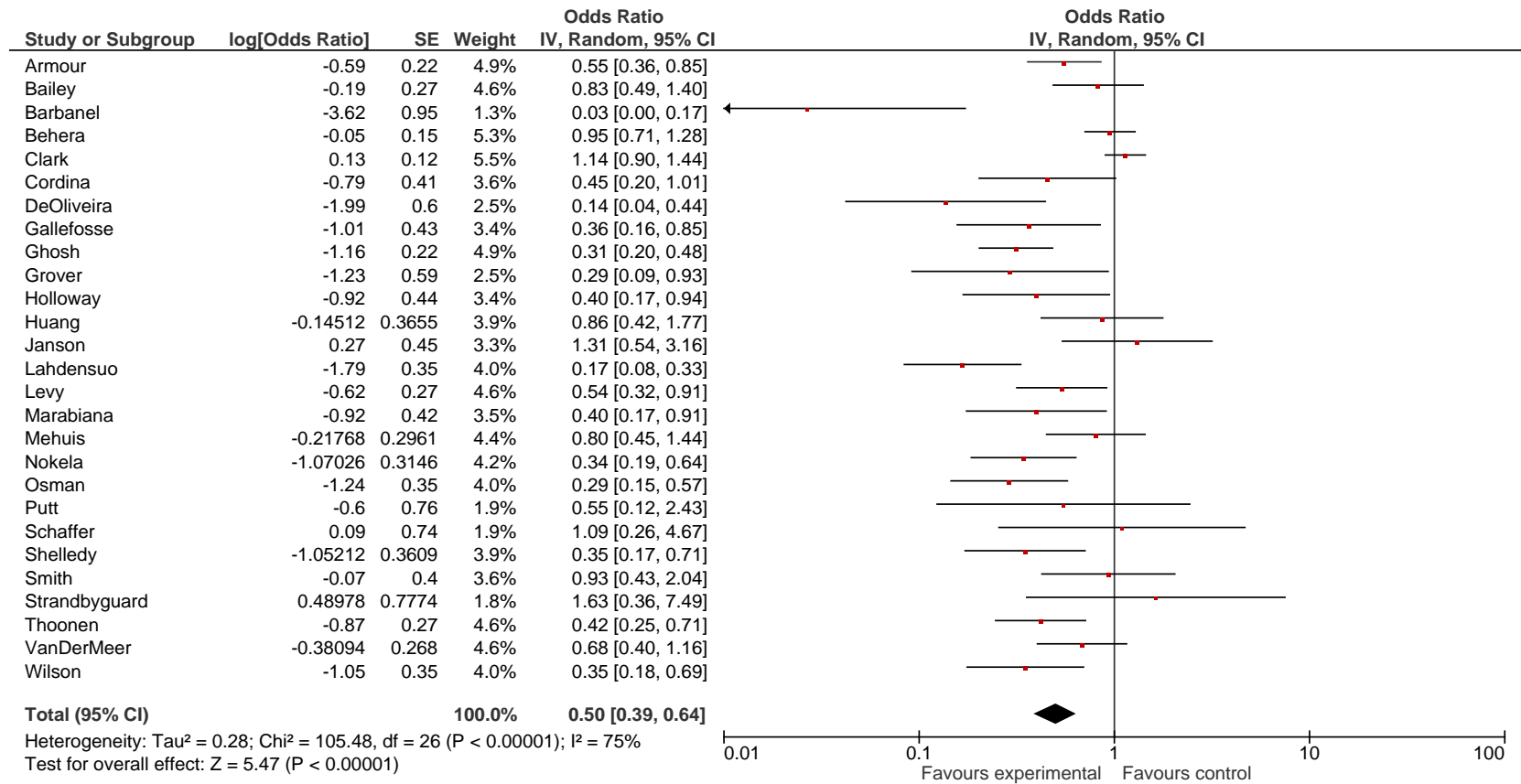


Figure 1

Flow chart of study identification process

**Figure 2**

Meta-analysis of intervention versus control for reducing symptoms of asthma. As data was pooled using Generic Inverse, results are presented as an OR. This was later converted into an SMD.

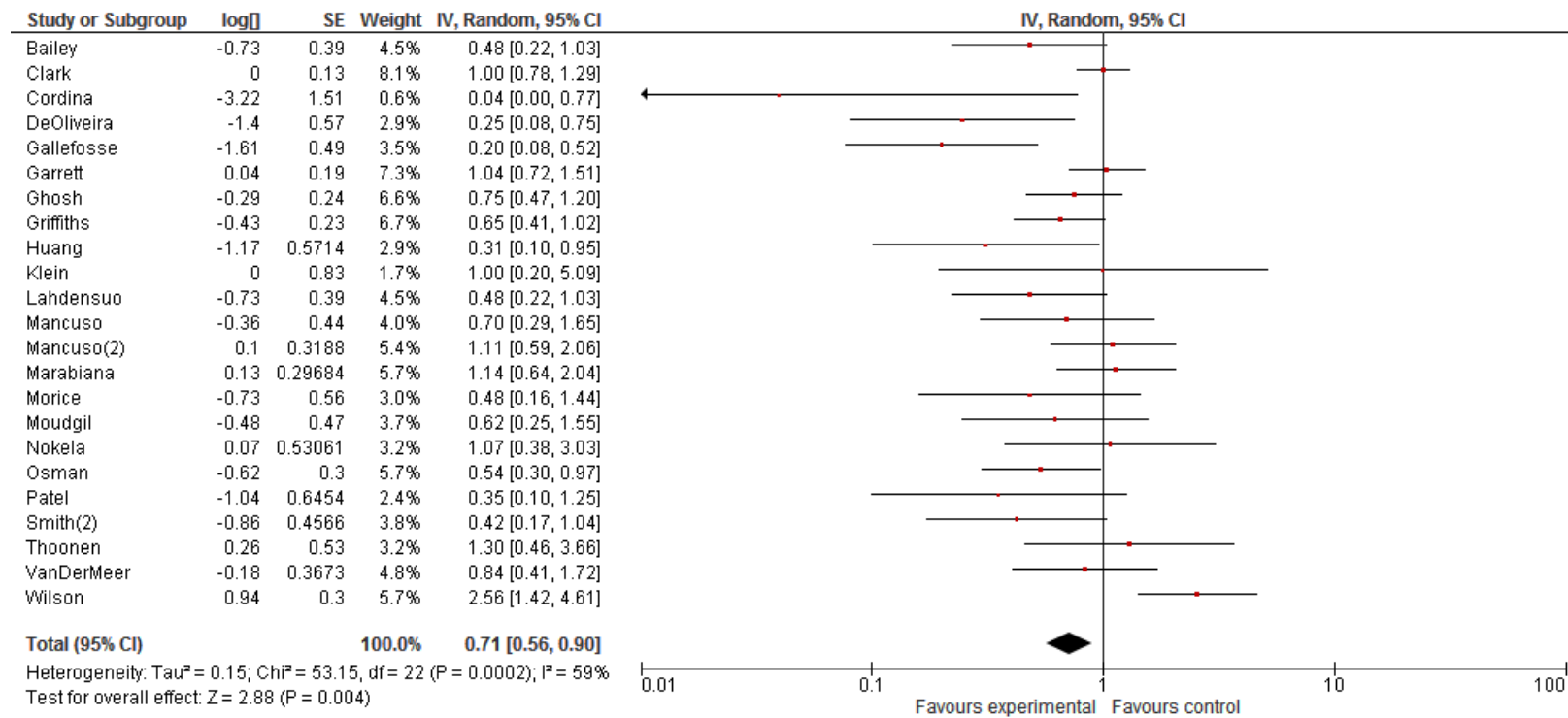


Figure 3

Meta-analysis of intervention versus control for reducing unscheduled health care use for asthma

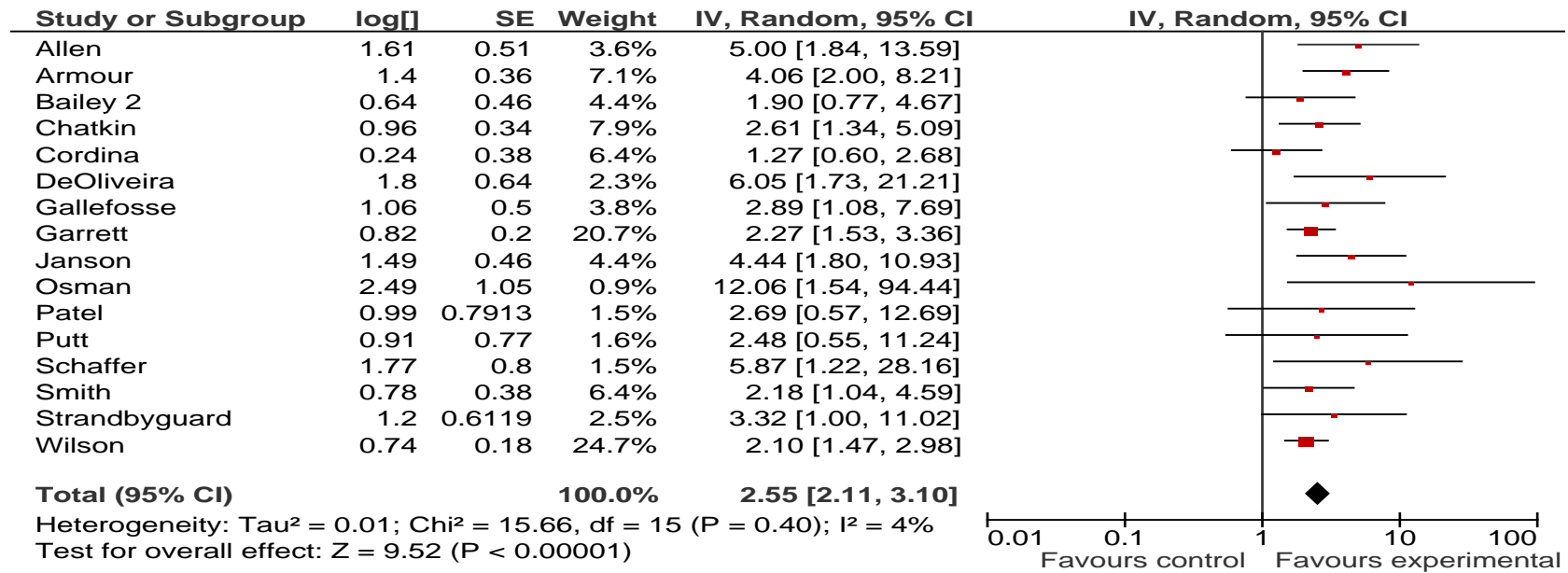


Figure 4

Meta-analysis of intervention versus control for improving adherence to medication

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Supplementary online material**Online resource 1****The PRISMA statement**

TITLE		<i>Page (in manuscript)</i>
<i>Title</i>	<i>Identify the report as a systematic review, meta-analysis, or both.</i>	<i>1</i>
ABSTRACT		
<i>Structured summary</i>	<i>Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.</i>	<i>2</i>
INTRODUCTION		
<i>Rationale</i>	<i>Describe the rationale for the review in the context of what is already known.</i>	<i>4,5</i>
<i>Objectives</i>	<i>Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).</i>	<i>6</i>
METHODS		
<i>Protocol and registration</i>	<i>Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.</i>	
<i>Eligibility criteria</i>	<i>Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.</i>	<i>6,7</i>
<i>Information sources</i>	<i>Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.</i>	<i>6</i>

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<i>Search</i>	<i>Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.</i>	<i>Online resource 2</i>
<i>Study selection</i>	<i>State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).</i>	<i>6,7</i>
<i>Data collection process</i>	<i>Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.</i>	<i>8, 9</i>
<i>Data items</i>	<i>List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.</i>	<i>8,9</i>
<i>Risk of bias in individual studies</i>	<i>Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.</i>	<i>7</i>
<i>Summary measures</i>	<i>State the principal summary measures (e.g., risk ratio, difference in means).</i>	<i>10</i>
<i>Synthesis of results</i>	<i>Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I^2) for each meta-analysis.</i>	<i>10</i>
<i>Risk of bias across studies</i>	<i>Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).</i>	<i>7,8</i>
<i>Additional analyses</i>	<i>Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.</i>	<i>10,11</i>
RESULTS		
<i>Study selection</i>	<i>Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.</i>	<i>12, Fig.1</i>

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<i>Study characteristics</i>	<i>For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.</i>	<i>Online resources 5,6</i>
<i>Risk of bias within studies</i>	<i>Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).</i>	<i>11 (online resource 4)</i>
<i>Results of individual studies</i>	<i>For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.</i>	<i>Fig 2,3 4</i>
<i>Synthesis of results</i>	<i>Present results of each meta-analysis done, including confidence intervals and measures of consistency.</i>	<i>14, 15</i>
<i>Risk of bias across studies</i>	<i>Present results of any assessment of risk of bias across studies (see Item 15).</i>	<i>11</i>
<i>Additional analysis</i>	<i>Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).</i>	<i>15-17</i>
DISCUSSION		
<i>Summary of evidence</i>	<i>Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., health care providers, users, and policy makers).</i>	<i>18,19, 22</i>
<i>Limitations</i>	<i>Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).</i>	<i>20-21</i>
<i>Conclusions</i>	<i>Provide a general interpretation of the results in the context of other evidence, and implications for future research.</i>	<i>17, 18,21-23</i>
FUNDING		
<i>Funding</i>	<i>Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.</i>	<i>24</i>

From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and

Meta-Analyses: The PRISMA Statement. PLoS Med 6(6): e1000097. doi:10.1371/journal.pmed1000097

Online resource 2

Search strategy (adapted for Medline)

1. ASTHMA\$.TI,AB.
2. ASTHMA#.W..DE.
3. (1 OR 2).TI,AB.
4. (SELF ADJ CARE OR SELF-CARE).TI,AB.
5. (SELF ADJ MANAGE\$ OR SELF-MANAGE\$).TI,AB.
6. (SELF ADJ MONITOR\$ OR SELF-MONITOR\$).TI,AB.
7. (SELF ADJ REGULAT\$ OR SELF-REGULAT\$).TI,AB.
8. (SELF ADJ TREAT\$ OR SELF-TREAT\$).TI,AB.
9. (INDIVIDUAL ADJ MANAGE\$).TI,AB.
10. (CARE ADJ PLAN\$3).TI,AB.
11. ACTION ADJ PLAN\$3
12. ADHERE\$.TI,AB.
13. COMPLIAN\$.TI,AB.
14. CONCORD\$.TI,AB.
15. (MEDICAT\$ NEXT TAK\$).TI,AB.
16. (SELF NEXT MEDICAT\$).TI,AB.
17. (COGNITIVE NEXT BEHAVIOUR\$).TI,AB.
18. (COGNITIVE NEXT BEHAVIOR\$).TI,AB.
19. (TRIGGER NEXT AVOID\$).TI,AB.
20. (SOCIAL NEXT SUPPORT\$).TI,AB.
21. COUNSEL\$.TI,AB.
22. (PSYCHOLOGICAL NEXT THERAP\$).TI,AB.

23. EDUCAT\$.TI,AB.
24. TRAIN\$3.TI,AB.
25. INSTRUCT\$.TI,AB.
26. (EMOTION\$ NEXT CONTROL\$).TI,AB.
27. (EMOTION\$ NEXT MANAG\$).TI,AB.
28. (EMOTION\$ NEXT REGULAT\$).TI,AB.
29. (STRESS NEXT CONTROL\$).TI,AB.
30. (STRESS NEXT MANAG\$).TI,AB.
31. (STRESS NEXT REGULAT\$).TI,AB.
32. RELAX\$.TI,AB.
33. (LAY ADJ LED OR LAY-LED).TI,AB.
34. (PATIENT ADJ LED OR PATIENT-LED).TI,AB.
35. EXPERT NEXT PATIENT.TI,AB.
36. HEALTHY-PEOPLE-PROGRAMS.DE.
37. SELF-ADMINISTRATION.DE.
38. SELF-CARE.MJ.
39. SELF-ADMINISTRATION.MJ.
40. BEHAVIOR-THERAPY.MJ. OR COGNITIVE-THERAPY.MJ.
41. CONSUMER-HEALTH-INFORMATION.MJ.
42. PATIENT-EDUCATION-AS-TOPIC.MJ.
43. (4 OR 5 OR 6 OR 7 OR 8 OR 9 OR 10 OR 11 OR 12 OR 13 OR 14 OR 15 OR 16 OR 17 OR 18 OR 19 OR 20 OR 21 OR 22 OR 23 OR 24 OR 25 OR 26 OR 27 OR 28 OR 29 OR 30 OR 31 OR 32 OR 33 OR 34 OR 35 OR 36 OR 37 OR 38 OR 39 OR 40 OR 41 OR 42).TI,AB.

44. RANDOMIZED-CONTROLLED-TRIALS-AS-TOPIC#.DE.
45. PT=RANDOMIZED-CONTROLLED-TRIAL
46. (RANDOM\$ OR PLACEBO\$).TI,AB,KW,SH.
47. (SINGLE OR DOUBLE OR TRIPLE).TI,KW,SH,AB. AND (BLIND\$2 OR MASK\$2).TI,KW,SH,AB.
48. 44 OR 45 OR 46 OR 47
49. 3 AND 43 AND 48
50. 49

Online resource 3

Behavior change techniques included in the review

Behavior change technique included in Abraham and Michie's taxonomy of behavior change techniques	Definition
Provide general information about behavior health link	General information about behavioral risk, e.g. susceptibility to poor health outcomes or mortality risk in relation to the behavior.
Provide information on consequences	Information about the benefits and costs of action or inaction, focusing on what will happen if the person does/does not perform the behavior.
Provide information on others' approval	Information about what others think about the person's behavior and whether others will approve or disapprove of any proposed behavior change.
Prompt intention formation	Encouraging the person to decide to act or set a general goal, e.g. to make a behavioral resolution such as 'I will take more exercise next week'.
Prompt barrier identification	Identify barriers to performing the behavior and plan ways of overcoming them.
Provide general encouragement	Praising or rewarding the person for effort or performance without this being contingent on specified behaviors or standards of performance.
Set graded tasks	Set easy tasks, and increase difficulty until target behavior

	is performed.
Provide instruction	Telling the person how to perform a behavior and/ or preparatory behaviors.
Model/demonstrate behavior	An expert shows the person how to correctly perform a behavior, e.g. in class or on video.
Prompt specific goal setting	Involves detailed planning of what the person will do including a definition of the behavior specifying frequency, intensity or duration as well as specification of at least one context, i.e. where, when, how or with whom.
Prompt review of behavioral goals	Review and/or reconsideration of previously set goals or intentions.
Prompt self-monitoring of behavior	The person is asked to keep a record of specified behavior/s (e.g. in a diary).
Provide feedback on performance	Providing data about recorded behavior or evaluating performance in relation to a set standard or others' performance. Person received feedback.
Provide contingent rewards	Praise, encouragement or material rewards that are be explicitly linked to the achievement of specified behaviors.
Teach to use prompts/cues	Teach the person to identify environmental cues which can be used to remind them to perform a behavior, including times of day, contexts or elements of contexts.
Agree behavioral contract	Agreement (e.g., signing) of a contract specifying behavior to be performed so that there is a written record of the person's resolution witnessed by another.

Prompt practice	Prompt the person to rehearse and repeat the behavior or preparatory behaviors.
Use follow-up prompts	Contacting the person again after the main part of the intervention is complete.
Provide opportunities for social comparison	Facilitate observation of non-expert others' performance e.g. in a group class or using video or case study.
Plan social support	Prompting consideration of how others' could change their behavior to offer the person help or (instrumental) social support, including 'buddy' systems – and/or providing social support.
Prompt identification as role model	Indicating how the person may be an example to others and influencing their behavior or providing an opportunity for the person to set a good example.
Prompt self talk	Encourage use self-instruction and self-encouragement (aloud or silently) to support action.
Relapse prevention	Following initial change, help identify situations likely to result in re-adopting risk behaviors or failure to maintain new behaviors and help the person plan to avoid or manage these situations.
Stress management	May involve a variety of specific techniques (e.g. progressive relaxation) which do not target the behavior but seek to reduce anxiety and stress.
Motivational interviewing	Prompting the person to provide self-motivating statements and evaluations of their own behavior to minimise

	resistance to change.
Time management	Helping the person make time for the behavior (e.g. to fit it into a daily schedule).
Behavior change technique identified during our review	Definition
Feedback on inhaler technique	Check and provide feedback about the way in which asthma medication is inhaled
Breathing management	Techniques aiming to teach participants how to specifically control or prevent hyperventilation when they experience an exacerbation of asthma
Social communication skills	Any techniques aiming to improve the participants' ability to communicate with health care providers (including assertiveness training)
Individual tailoring	The content of the information and of the intervention is based on an assessment of the individuals' needs
Identify and address medication concerns	Any techniques designed to explore and address concerns associated with a the use of medication for asthma
Active involvement of participants	Encouraging the participant to be actively involved in the intervention processes (such as getting motivated, planning actions, monitoring progress and problem-solving). Active involvement requires the participant to generate (as opposed to being a passive recipient of) information or ideas. This might include encouraging

	<p>participants to take the lead in prioritizing and setting goals, and in identifying problems and solutions. This would also include the use throughout the intervention of empathy-building techniques within a person-centered counseling framework or the explicit use of empowerment or shared decision-making techniques.</p>
Cognitive behavioral therapy	<p>Identification and restructuring of persistent negative thoughts and beliefs about one's self (including about having asthma) and one's relationship to others</p>
Medication optimization	<p>Assessing and increasing or decreasing dose of medication based on assessments of lung function / symptoms</p>
Efficacy building	<p>Techniques aiming to increase the participants' efficacy (e.g. exploring past successes, setting up an experiment to try out the behavior).</p>
Active learning	<p>Use of active learning techniques (e.g. group discussion, problem-based learning, role-play, workbooks) as opposed to didactic information giving. Differs from 'active involvement of patients' in that it focuses on attempting to teach participants specific information content that is pre-specified by the health care provider, rather than encouraging the participants to take control of or responsibility for their asthma self-care.</p>
Assessing and addressing illness understanding	<p>Developing patients understanding of their condition in terms of its Causes, Consequences, Cure /Control,</p>

Identity, and Timeline.

Online resource 4**Overview of the quality of trials included in the review**

Study	Sequence generation	Concealment	Blinding	withdrawal	Balance at baseline	Receipt	Risk of bias
Allen	Unclear	Unclear	High	Low	Unclear	Unclear	Unclear
Armour	Low	Unclear	High	Unclear	Unclear	Unclear	Unclear
Bailey	Low	Low	High	Low	Low	Unclear	Unclear
Barbanel	Unclear	Low	High	Low	Unclear	Unclear	Low
Behera	Unclear	Unclear	High	Low	Low	Unclear	Low
Chatkin	Unclear	Unclear	High	Unclear	Low	Unclear	Unclear
Clark	Unclear	Unclear	High	Low	Low	Unclear	Unclear
Cordina	Unclear	Unclear	High	Unclear	Low	Unclear	Unclear
De Oliveira	Unclear	Low	High	Low	Low	Unclear	Unclear
Gallefoss	Unclear	Unclear	High	Low	Unclear	Unclear	Unclear
Garrett	Unclear	Unclear	Low	Low	Low	Unclear	Unclear
Ghosh	Unclear	Unclear	High	Unclear	Low	Low	Unclear
Griffiths	Low	Low	Low	Low	Low	Unclear	Low
Grover	Low	Unclear	High	Low	Unclear	Unclear	Low
Holloway	Low	Low	High	Low	Unclear	Unclear	Unclear
Huang	Low	Low	Low	Low	Low	Unclear	Low
Janson	Unclear	Low	High	Low	Low	Unclear	Unclear
Klein	Unclear	Low	High	Low	Low	Unclear	Unclear
Lahdensuo	Low	Low	High	Low	Low	Unclear	Unclear
Levy	Low	Unclear	High	Unclear	Unclear	Unclear	Low
Mancuso	Low	Low	High	Unclear	Low	Unclear	Unclear
Mancuso (2)	Low	Low	High	Unclear	Low	Unclear	Unclear

Effective change techniques in asthma self-care interventions

Study	Sequence generation	Concealment	Blinding	withdrawal	Balance at baseline	Receipt	Risk of bias
Marabini	Unclear	Unclear	High	Low	Low	Unclear	Low
Mehuys	Low	Low	High	Low	Low	Unclear	Unclear
Morice	Unclear	Unclear	High	Low	Low	Unclear	Unclear
Moudgil	Low	Low	High	Low	Unclear	Unclear	Unclear
Nokela	Low	Unclear	Low	Low	Low	Unclear	Unclear
Osman	Unclear	Low	High	Low	Low	Unclear	Low
Patel	Unclear	Low	Low	Low	Low	Unclear	Low
Putt	Unclear	Low	High	Low	Unclear	Unclear	Low
Schaffer	Low	Unclear	Unclear	Low	Low	Unclear	Unclear
Shelledy	Low	Unclear	Low	Low	Low	Unclear	Unclear
Smith	Low	Low	High	Low	Unclear	Unclear	Unclear
Strandbyguard	Low	Low	High	Low	Low	Unclear	Low
2010							
Thoonen	Unclear	Unclear	High	Low	Unclear	Unclear	Low
Van der Meer	Low	Low	High	Low	Low	Unclear	Low
Wilson	Unclear	Unclear	High	Low	Low	Unclear	Unclear

Online resource 5

Characteristics of included studies

Study	Participants	Intervention	Comparator	Outcomes	Risk of bias
Allen 1994	% male: 50 Asthma severity: not reported N randomized: 115 intervention: 58 control: 58 N analyzed: 92 intervention, 47 control: 45	Setting: secondary care Mode of delivery: group Delivery provider: patient educator Number of sessions: 4 Total duration in hours: 10 Length of follow-up (months): 12 Reported use of theory: yes	Usual care - peak flow and medication diary were kept	Adherence	Unclear
Armour 1998	% male: 35 Asthma severity: mainly severe N randomized: 396 intervention: 191 control: 205 N analyzed: 349 intervention: 165 control: 184	Setting: primary care Mode of delivery: individual Delivery provider: pharmacist Number of sessions: 4 Total duration in hours: not reported Length of follow-up (months): 6 Reported use of theory: No	Usual care	Symptoms Adherence	Unclear
Bailey 1996	% male: 30 Asthma severity: moderate to	Setting: secondary care Mode of delivery: individual and group	Usual care	Symptoms UHCU	Unclear

Study	Participants	Intervention	Comparator	Outcomes	Risk of bias
	severe N randomized: 236 intervention: 78 control: 78 N analyzed: 236 intervention: 78 control: 76	Delivery provider: patient educator Number of sessions: 1-2 Total duration in hours: 2 Length of follow-up (months): 12 Reported use of theory: Yes		Adherence	
Barbanel 2007	% male: 45 Asthma severity: not reported N randomized: 24 Intervention: 12 control: 12 N analyzed: 23 Intervention: 11 control: 12	Setting: primary care Mode of delivery: individual Delivery provider: pharmacist Number of sessions: 1 Total duration in hours: 1 Length of follow-up (months): 3 Reported use of theory: No	Usual pharmacist care	Symptoms	Low
Behera 2002	% male: 56 Asthma severity: not reported N randomized: 523 Intervention: 260 control: 263 N analyzed: 523	Setting: secondary care Mode of delivery: not reported Delivery provider: self Number of sessions: not reported Total duration in hours: not reported Length of follow-up (months): 12	Education but no self-care manual	Symptoms	Low

Study	Participants	Intervention	Comparator	Outcomes	Risk of bias
	Intervention: 260 control: 263	Reported use of theory: No			
Chatkin 2004	% male: 26 Asthma severity: moderate to severe N randomized: 278 Intervention: 131 control: 140 N analyzed: not reported	Setting: primary care Mode of delivery: individual Delivery provider: nurse Number of sessions: 12 Total duration in hours: not reported Length of follow-up (months) 3 Reported use of theory: No	Usual care	Adherence	Unclear
Clark 2005	% male: 0 Asthma severity: mild N randomized: 808 Intervention: 424 control: 384 Total completed: 608 Intervention: 311 control: 297	Setting: primary care Mode of delivery: individual Delivery provider: patient educator Number of sessions: 4 Total duration in hours: 2 Length of follow-up (months): 12 Reported use of theory: Yes	Usual care including conventional education	Symptoms UHCU	Unclear
Cordina 1993	% male: 50 Asthma severity: not reported N randomized: 152 Intervention: 86	Setting: primary care Mode of delivery: individual Delivery provider: pharmacist Number of sessions: not reported	Usual care	Symptoms UHCU Adherence	Unclear

Study	Participants	Intervention	Comparator	Outcomes	Risk of bias
	control: 66 N analyzed: 119 Intervention: 64 control: 55	Total duration in hours: not reported Length of follow-up (months): 12 Reported use of theory: No			
De Oliveira 1999	% male: 11 Asthma severity: moderate to severe N randomized: 53 Intervention: 26 control: 22 N analyzed: 42 Intervention: 21 control: 16	Setting: secondary care Mode of delivery: individual Delivery provider: nurse Number of sessions: 6 Total duration in hours: 6 Length of follow-up (months): 6 Reported use of theory: No	Usual care	Symptoms UHCU Adherence	Unclear
Gallefoss 1999; 2000; 2001	% male: 29 Asthma severity: not reported N randomized: 78 Intervention: 39 control: 39 N analyzed: 71 Intervention: 32 control: 39	Setting: primary care Mode of delivery: individual and group Delivery provider: nurse Number of sessions: 4 Total duration in hours: 5 Length of follow-up (months): 12 Reported use of theory: No	Usual care	Symptoms UHCU Adherence	Unclear

Study	Participants	Intervention	Comparator	Outcomes	Risk of bias
Garrett 1994	% male: 42	Setting: primary care	Usual care	UHCU Adherence	Unclear
	Asthma severity: not reported	Mode of delivery: individual			
	N randomized: 500	Delivery provider: not reported			
	Intervention: 249	Number of sessions: not reported			
	control: 251	Total duration in hours: not reported			
	N analyzed: 446	Length of follow-up (months): not reported			
	Intervention: 249 control: 249	Reported use of theory: No			
Ghosh 1998	% male: 41	Setting: secondary care	Usual care	Symptoms UHCU	Unclear
	Asthma severity: severe	Mode of delivery: individual and group			
	N randomized: 303	Delivery provider: researcher			
	Intervention: 153	Number of sessions: 4			
	control: 150	Total duration in hours: 8			
	N analyzed: 276	Length of follow-up (months): 12			
	Intervention: 140 Control: 136	Reported use of theory: Yes			
Griffiths 2004	% male: 50	Setting: primary care	Control practices received a visit promoting standard asthma guidelines;	UHCU	Low
	Asthma severity: mild	Mode of delivery: individual			
	N randomized: 324	Delivery provider: nurse			
	Intervention: 175	Number of sessions: 1			
	control: 149	Total duration in hours: not reported			

Study	Participants	Intervention	Comparator	Outcomes	Risk of bias
	N analyzed: 324 Intervention: 175 control: 149	Length of follow-up (months): 12 Reported use of theory: No	control patients were checked for inhaler technique.		
Grover 2002	% male: Not reported Asthma severity: severe N randomized: 40 Intervention: 20 control: 20 N analyzed: 40 Intervention: 20 control: 20	Setting: primary care Mode of delivery: individual Delivery provider: Number of sessions: 10 Total duration in hours: 10 Length of follow-up (months): 2 Reported use of theory: No	Less intensive intervention	Symptoms	Low
Holloway 2007	% male: 18 Asthma severity: not reported N randomized: 85 Intervention: 39 control: 49 N analyzed: 72	Setting: primary care Mode of delivery: individual Delivery provider: physiologist Number of sessions: 5 Total duration in hours: 5 Length of follow-up (months): 12 Reported use of theory: No	Usual care	Symptoms	Unclear
Huang 2009	% male: 72 Asthma severity: range N randomized: 173	Setting: secondary care Mode of delivery: telephone Delivery provider: nurse	Usual care	Symptoms HCU	Low

Study	Participants	Intervention	Comparator	Outcomes	Risk of bias
	Intervention: 57 Control: 58 N analyzed: 99 Intervention: 50 Control: 49	Number of sessions: 26 Total duration in hours: Not stated Length of follow-up (months): 6 Reported use of theory: No			
Janson 2003	% male: 45 Asthma severity: mild to moderate N randomized: 65 Intervention: 33 control: 32 N analyzed: 65 Intervention: 33 control: 32	Setting: primary care Mode of delivery: individual Delivery provider: nurse Number of sessions: 1 Total duration in hours: 0.5 Length of follow-up (months): 2 Reported use of theory: No	Symptom monitoring only	Symptoms Adherence	Unclear
Klein 2001	% male: 45 Asthma severity: mild to moderate N randomized: 245 Intervention: 123 control: 122 N analyzed: not reported	Setting: primary care Mode of delivery: individual and group Delivery provider: nurse Number of sessions: 3 Total duration in hours: not reported Length of follow-up (months): 12 Reported use of theory: No	Self-management education only	UHCU	Unclear
Lahdensuo 1996;	% male: 37	Setting: primary care	Not specified	Symptoms	Unclear

Study	Participants	Intervention	Comparator	Outcomes	Risk of bias
1998	Asthma severity: mild to moderate N randomized: 122 Intervention: 60 control: 62 N analyzed: 116 Intervention: 56 control: 59	Mode of delivery: individual Delivery provider: nurse Number of sessions: 1 Total duration in hours: 2.5 Length of follow-up (months): 12 Reported use of theory: No		UHCU	
Levy 2000	% male: 38% Asthma severity: Not reported N randomized: 211 Intervention: 103 control: 108 N analyzed: 197 Intervention: 99 control: 98	Setting: secondary care Mode of delivery: individual Delivery provider: nurse Number of sessions: 3 Total duration in hours: 2 Length of follow-up (months): 12 Reported use of theory: No	Usual care	Symptoms	Low
Mancuso 2010	% male: 83 Asthma severity: moderate N randomized: 180 Intervention: 90 control: 90 N analyzed: 18	Setting: primary care Mode of delivery: face to face and phone Delivery provider: Non medical Number of sessions: 13 Total duration in hours: 3.5	Education only	Symptoms HCU	Unclear

Study	Participants	Intervention	Comparator	Outcomes	Risk of bias
	Intervention: 90 control: 90	Length of follow-up (months): 5 Reported use of theory: Yes			
Mancuso 2011	% male: 42 Asthma severity: 12.5 on Severity of asthma scale N randomized: 296 Intervention: 148 control: 148 N analyzed: 281 Intervention: 141 control: 140	Setting: secondary care Mode of delivery: face to face plus telephone Delivery provider: study personnel Number of sessions: 9 Total duration in hours: 1.5 Length of follow-up (months): 4 Reported use of theory: Yes	Less intensive intervention	HCU	Unclear
Marabini 2002	% male: 46 Asthma severity: not reported N randomized: 77 Intervention: 37 control: 40 N analyzed: 69 Intervention: 37 control: 32	Setting: primary care Mode of delivery: individual and group Delivery provider: GP Number of sessions: 3 Total duration in hours: 6 Length of follow-up (months): 3 Reported use of theory: No	Usual care	Symptoms UHCU	Low
Mehuys 2008	% male: 47 Asthma severity: not reported	Setting: primary care Mode of delivery: individual	Usual care	Symptoms	Unclear

Study	Participants	Intervention	Comparator	Outcomes	Risk of bias
	N randomized: 201 Intervention: 107 control: 94 N analyzed: 150 Intervention: 80 control: 70	Delivery provider: pharmacist Number of sessions: 3 Total duration in hours: not reported Length of follow-up (months): 6 Reported use of theory: No			
Morice 2001	% male: 39 Asthma severity: severe N randomized: 80 Intervention: 40 control: 40 N analyzed: 65 Intervention: 35 control: 30	Setting: secondary care Mode of delivery: individual Delivery provider: nurse Number of sessions: 2 Total duration in hours: 1 Length of follow-up (months): 18 Reported use of theory: No	Usual care	UHCU	Unclear
Moudgil 2000	% male: 51 Asthma severity: mild to severe N randomized: 689 Intervention: 343 control: 346 N analyzed: 593 Intervention: 304	Setting: primary care Mode of delivery: individual Delivery provider: researcher Number of sessions: 3 Total duration in hours: 2 Length of follow-up (months): 12 Reported use of theory: No	Usual care	UHCU	Unclear

Study	Participants	Intervention	Comparator	Outcomes	Risk of bias
	control: 289				
Nokela 2010	% male: 30.5 Asthma severity: not reported N randomized: 168 Intervention: 77 control: 91 N analyzed: 141 Intervention: 77 control: 64	Setting: primary care Mode of delivery: individual face to face Delivery provider: usual practice provider Number of sessions: 1 Total duration in hours: not reported Length of follow-up (months): 3 Reported use of theory: No	Usual care	Symptoms UHCU	Low
Osman 1994;2002	% male: 34 Asthma severity: severe N randomized: 280 Intervention: 135 control: 145 N analyzed: 226 Intervention: 108 control: 118	Setting: secondary care Mode of delivery: individual Delivery provider: nurse Number of sessions: 2 Total duration in hours: 1 Length of follow-up (months): 12 Reported use of theory: No	Usual care	Symptoms UHCU Adherence	Low
Patel 2009	% male: 35 Asthma severity: not reported N randomized: 52	Setting: unclear Mode of delivery: telephone Delivery provider: Non clinical	Control participants completed a	UHCU Adherence	Un clear

Study	Participants	Intervention	Comparator	Outcomes	Risk of bias
	Intervention: 26 control: 26 N analyzed: 48 Intervention: 25 control: 23	Number of sessions: 2 Total duration in hours: 0.2 Length of follow-up (months): 12 Reported use of theory: No	questionnaire		
Putt 2003	% male: 47 Asthma severity: mild to moderate N randomized: 23 Intervention: 12 control: 11 N analyzed: not reported intervention, control:	Setting: primary care Mode of delivery: individual Delivery provider: researcher Number of sessions: 6 Total duration in hours: 6 Length of follow-up (months): 6 Reported use of theory: No	Waiting list control	Symptoms Adherence	Low
Schaffer 2004	% male: 32 Asthma severity: mild to moderate N randomized: 46 Intervention: 23 control: 23 N analyzed: 46 Intervention: 23 control: 23	Setting: primary care Mode of delivery: self Delivery provider: video Number of sessions: 1 Total duration in hours: 0.5 Length of follow-up (months): 6 Reported use of theory: No	Usual care	Symptoms Adherence	Unclear
Shelledy 2009	% male: 16	Setting: secondary care	Usual care	Symptoms	Unclear

Study	Participants	Intervention	Comparator	Outcomes	Risk of bias
	Asthma severity: not reported N randomized: 166 Intervention: 49 control: 61 N analyzed: 105 Intervention: 46 control: 59	Mode of delivery: face to face individual Delivery provider: nurses Number of sessions: 5 Total duration in hours: 7.5 Length of follow-up (months): 6 Reported use of theory: No		UHCU	
Smith 2005	% male: 27 Asthma severity: severe N randomized: 92 Intervention: 47 control: 45 N analyzed: 84 Intervention: 42 control: 42	Setting: primary care Mode of delivery: individual Delivery provider: nurse Number of sessions: 4 Total duration in hours: 5.5 Length of follow-up (months): 12 Reported use of theory: Yes	Usual care	Symptoms UHCU	Unclear
Smith 2008	% male: 44 Asthma severity: not reported N randomized: 146 Intervention: 78 control: 68 N analyzed: 142	Setting: secondary care Mode of delivery: face to face individual Delivery provider: researcher Number of sessions: 1 Total duration in hours: 0.1	Same content as intervention participants in a standardized format	UHCU	Unclear

Study	Participants	Intervention	Comparator	Outcomes	Risk of bias
	Intervention: 76 control: 66	Length of follow-up (months): 4 Reported use of theory: Yes			
Strandbygaard 2010	% male: 54% Asthma severity: Range N randomized: 22 Intervention: 11 control: 11 N analyzed: 22 Intervention: 11 control: 11	Setting: Primary care Mode of delivery: Text Delivery provider: Text Number of sessions: 1 plus one daily text Total duration in hours: not reported Length of follow-up (months): 3 Reported use of theory: No	Usual care	Symptoms Adherence	Low
Thoonen 1999; 2003	% male: 38 Asthma severity: mild to moderate N randomized: 214 Intervention: 110 control: 104 N analyzed: 193 Intervention: 98 control: 95	Setting: primary care Mode of delivery: individual Delivery provider: GP Number of sessions: 4 Total duration in hours: 1 Length of follow-up (months): 6 Reported use of theory: No	Usual care	Symptoms Adherence	Low
Van der Meer 2009	% male: 30 Asthma severity: Range N randomized: 200	Setting: not reported Mode of delivery: face to face plus internet	Usual care	Symptoms UHCU Adherence	Low

Study	Participants	Intervention	Comparator	Outcomes	Risk of bias
	Intervention: 101 control: 99 N analyzed: 183 Intervention: 91 control: 92	Delivery provider: nurse (and internet) Number of sessions: 2 Total duration in hours: 1.5 Length of follow-up (months): 12 Reported use of theory: No			
Wilson 1993	% male: Not reported Asthma severity: Range N randomized: 235 Intervention: 81 control: 71 N analyzed: 235 Intervention: 81 control: 71 (NB: 83 participants were randomized to a third intervention arm)	Setting: primary care Mode of delivery: face to face Delivery provider: nurse educator Number of sessions: 3-5 Total duration in hours: 0.45 Length of follow-up (months): 12 Reported use of theory: Yes	Usual care	Symptoms UHCUs Adherence	Unclear

Online resources 6

Inclusion in trials of taxonomy defined behavior change techniques in interventions

Reference	Cognitive Behavioral Therapy (CBT) Components and Outcomes																																						
	General information	Consequences	Intention formation	Barrier ID	Encouragement	Graded tasks	Instruction	Modeling	Goal setting	Review of goal	Self-monitoring	General feedback	Inhaler technique	Rewards	Cues	Prompt Practice	Follow-up	Social Comparison	Social support	Relapse prevention	Stress management	Breathing management	Motivational interviewing	Time management	Communication Skills	Tailoring	Medication concerns	Patient Involvement	Cognitive Behavior Therapy	Medication optimization	Efficacy building	Active learning	Changing illness model	Optimal	Control theory	Social cognitive theory	Total		
Allen (1995)	✓		✓	✓			✓	✓			✓	✓	✓		✓	✓		✓	✓	✓					✓				✓				✓		✓		✓	16	
Armour (2007)	✓			✓			✓		✓	✓	✓		✓				✓									✓		✓			✓					✓	✓		11
Bailey (1999)	✓			✓			✓		✓		✓	✓	✓			✓	✓	✓	✓		✓		✓		✓		✓	✓					✓		✓	✓			16
Barbanel (2003)	✓						✓		✓		✓		✓				✓																		✓				6
Behera (2006)	✓						✓		✓		✓		✓		✓						✓												✓						8
Chatkin (2006)																	✓													✓									2
Clark (2007)			✓	✓	✓	✓	✓	✓		✓	✓	✓		✓			✓				✓					✓	✓						✓		✓		✓		15

Reference	General information	Consequences	Intention formation	Barrier ID	Encouragement	Graded tasks	Instruction	Modeling	Goal setting	Review of goal	Self-monitoring	General feedback	Inhaler technique	Rewards	Cues	Prompt Practice	Follow-up	Social Comparison	Social support	Relapse prevention	Stress management	Breathing management	Motivational interviewing	Time management	Communication Skills	Tailoring	Medication concerns	Patient Involvement	Cognitive Behavior Therapy	Medication optimization	Efficacy building	Active learning	Changing illness model	Optimal	Control theory	Social cognitive theory	Total		
Cordina (2001)	✓			✓			✓				✓	✓	✓		✓												✓			✓							9		
de Oliveira (1999)	✓	✓		✓			✓		✓	✓	✓		✓		✓			✓											✓		✓			✓	✓			13	
Gallefoss (1999; 2000; 2001)	✓	✓		✓			✓		✓		✓		✓				✓	✓				✓					✓	✓	✓	✓				✓	✓				15
Garrett (1994)	✓			✓			✓		✓		✓		✓				✓		✓											✓				✓				10	
Ghosh (1998)	✓	✓					✓		✓		✓				✓	✓		✓	✓														✓					10	
Griffiths (2004)	✓						✓		✓		✓						✓	✓								✓								✓				7	
Grover (2002)				✓						✓			✓			✓			✓					✓	✓	✓			✓										9
Holloway (2007)							✓	✓	✓		✓				✓	✓						✓		✓									✓					9	
Huang (2009)				✓			✓		✓		✓						✓		✓							✓	✓			✓					✓				9

Effective change techniques in asthma self-care interventions

Reference	General information	Consequences	Intention formation	Barrier ID	Encouragement	Graded tasks	Instruction	Modeling	Goal setting	Review of goal	Self-monitoring	General feedback	Inhaler technique	Rewards	Cues	Prompt Practice	Follow-up	Social Comparison	Social support	Relapse prevention	Stress management	Breathing management	Motivational interviewing	Time management	Communication Skills	Tailoring	Medication concerns	Patient Involvement	Cognitive Behavior Therapy	Medication optimization	Efficacy building	Active learning	Changing illness model	Optimal	Control theory	Social cognitive theory	Total	
Janson (2003)	✓						✓	✓	✓			✓	✓			✓																✓					8	
Klein (2001)									✓		✓				✓																							3
Lahdensuo (1996; 1998)							✓		✓		✓											✓																4
Levy (2000)	✓						✓		✓		✓		✓		✓															✓								7
Mancuso (2010)		✓						✓	✓	✓							✓	✓															✓					7
Mancuso (2011)							✓	✓	✓				✓			✓	✓	✓															✓					8
Marabini (2002)									✓		✓		✓		✓			✓	✓									✓		✓								8
Mehuys (2007)	✓	✓		✓								✓	✓													✓												6
Morice (2001)	✓	✓		✓			✓		✓		✓		✓		✓				✓					✓				✓										11

Effective change techniques in asthma self-care interventions

Reference	General information	Consequences	Intention formation	Barrier ID	Encouragement	Graded tasks	Instruction	Modeling	Goal setting	Review of goal	Self-monitoring	General feedback	Inhaler technique	Rewards	Cues	Prompt Practice	Follow-up	Social Comparison	Social support	Relapse prevention	Stress management	Breathing management	Motivational interviewing	Time management	Communication Skills	Tailoring	Medication concerns	Patient Involvement	Cognitive Behavior Therapy	Medication optimization	Efficacy building	Active learning	Changing illness model	Optimal	Control theory	Social cognitive theory	Total	
Moudgil (2000)	✓	✓					✓		✓		✓		✓		✓															✓							8	
Nokela (2010)	✓	✓									✓																											3
Osman (2002; 1994)	✓			✓			✓		✓		✓	✓			✓												✓								✓	✓		8
Patel (2010)			✓		✓						✓																											3
Putt (2003)	✓	✓	✓	✓							✓		✓		✓						✓							✓					✓	✓				11
Schaffer (2004)	✓	✓	✓	✓			✓				✓		✓		✓			✓																			✓	9
Shelledy (2009)	✓						✓	✓	✓		✓		✓			✓												✓		✓			✓					10
Smith (2005)	✓		✓	✓	✓	✓	✓		✓	✓	✓	✓	✓		✓				✓	✓				✓				✓				✓			✓	✓	✓	17
Smith (2008)				✓																							✓	✓										3

Effective change techniques in asthma self-care interventions

Reference	General information	Consequences	Intention formation	Barrier ID	Encouragement	Graded tasks	Instruction	Modeling	Goal setting	Review of goal	Self-monitoring	General feedback	Inhaler technique	Rewards	Cues	Prompt Practice	Follow-up	Social Comparison	Social support	Relapse prevention	Stress management	Breathing management	Motivational interviewing	Time management	Communication Skills	Tailoring	Medication concerns	Patient Involvement	Cognitive Behavior Therapy	Medication optimization	Efficacy building	Active learning	Changing illness model	Optimal	Control theory	Social cognitive theory		
Straadbyguard (2010)																	✓																					1
Thoonen (1999; 2003)	✓						✓		✓		✓	✓	✓		✓		✓									✓				✓				✓	✓			10
Van de Meer (2010)	✓	✓					✓		✓		✓		✓		✓			✓								✓		✓				✓						11
Wilson (1993)	✓	✓	✓	✓			✓		✓		✓		✓		✓		✓																	✓		✓		10
Total	25	12	7	18	3	2	27	7	26	6	30	9	24	1	19	8	14	11	9	2	4	3	1	4	3	9	7	10	3	11	1	11	4	11	6	5		

Each behavior change technique is described in detail in online resource

Online resource 7**Meta-regression analyses of associations between trial features and asthma symptoms**

Trial feature		N	SMD (CI)	P	Diff tau ²
Setting	Primary	7	-0.25 (-0.59, 0.08)	0.45	0%
	Secondary	20	-0.41 (-0.56, -0.27)		
Risk of bias	Low	11	-0.33 (-0.59, -0.08)	0.48	0%
	Moderate	16	-0.39 (-0.56, -0.22)		
Theoretical basis	Yes	5	-0.32 (-0.56, -0.08)	0.34	0%
	No	22	-0.41 (-0.59, -0.24)		
Optimal	Yes	11	-0.12 (-0.47, 0.21)	0.84	0%
	No	16	-0.41 (-0.56, -0.28)		
Control Theory	Yes	6	-0.39 (-0.62, -0.16)	0.82	0%
	No	21	-0.37 (-0.53, -0.21)		
Social Cognitive theory	Yes	4	-0.40 (-0.64, -0.17)	0.14	0%
	No	23	-0.37 (-0.53, -0.20)		

Online resource 8**Meta-regression analyses of associations between BCTs and asthma symptoms**

	N with / without BCT	SMD (CI) With BCT	SMD (CI) Without BCT	P	Diff Tau ²
Significant associations					
Stress management	4/23	0.01 (-0.08, 0.10)	-0.44 (-0.57, -0.31)	0.01	82%
Non significant associations					
BCT					
General info	20/7	-0.36 (-0.72, 0.01)	-0.38 (-0.51, -0.24)	0.81	0%
Consequences	9/18	-0.45 (-0.64, -0.26)	-0.33 (-0.50, -0.18)	0.44	19%
Intention formation	5/22	-0.15 (-0.45, 0.15)	-0.42 (-0.56, -0.28)	0.15	29%
Barrier identification	1/13	-0.30 (0.49, -0.13)	-0.44 (-0.64, -0.23)	0.39	2%
Instruction	21/6	-0.38 (-0.54, -0.22)	-0.37 (-0.61, -0.12)	0.90	0%
Modeling	4/23	-0.41 (-0.54, -0.27)	-0.19 (-0.57, 0.18)	0.25	24%
Goal setting	19/8	-0.42 (-0.57, -0.27)	-0.22 (-0.49, 0.02)	0.22	17%
Review of goal	5/22	-0.31 (-0.66, 0.02)	-0.39 (-0.53, -0.25)	0.60	13%
Self-monitoring	23/4	-0.10 (-0.44, 0.23)	-0.41 (-0.56, -0.27)	0.16	0%

Effective change techniques in asthma self-care interventions

	N with / without BCT	SMD (CI) With BCT	SMD (CI) Without BCT	P	Diff Tau ²
Feedback	8/19	-0.19 (-0.40, 0.01)	-0.46 (-0.62, -0.30)	0.07	15%
Inhaler technique	19/8	-0.33 (-0.47, -0.20)	-0.41 (-0.74, -0.08)	0.70	0%
Cues	14/13	-0.40 (-0.56, -0.24)	-0.36 (-0.54, -0.12)	0.67	0%
Prompt practice	6/21	-0.39 (-0.66, -0.12)	-0.38 (-0.53, -0.22)	0.94	0%
Follow-up	9/18	-0.31 (-0.56, -0.07)	-0.41 (-0.57, -0.25)	0.50	3%
Comparison	7/20	-0.42 (-0.66, -0.18)	-0.36 (-0.51, -0.20)	0.69	2%
Social support	6/21	-0.32 (-0.57, -0.07)	-0.39 (-0.56, -0.23)	0.69	0%
Tailoring	8/19	-0.24 (-0.44, -0.05)	-0.44 (-0.61, -0.26)	0.24	13%
Medication concerns	6/21	-0.26 (-0.53, 0.00)	-0.41 (-0.56, -0.26)	0.35	17%
Active involvement	6/21	-0.39 (-0.57, -0.22)	-0.37 (-0.53, -0.19)	0.70	0%
Medication optimization	8/19	-0.41 (-0.56, -0.27)	-0.35 (-0.53, -0.17)	0.54	5%
Active learning	8/19	-0.28 (-0.51, -0.05)	-0.42 (-0.56, -0.28)	0.34	37%

Online resource 9**Meta-regression analyses of associations between trial features and unscheduled health care use**

Trial feature		N	OR (CI)	P	Diff tau ²
Non significant associations					
Setting	Primary	7	0.69 (0.53, 0.89)	0.21	0%
	Secondary	16	0.68 (0.50, 0.92)		
Theory	Yes	7	0.66 (0.43, 1.01)	0.05	30%
	No	16	0.73 (0.54, 0.97)		
Risk of bias	Low	9	0.88 (0.70, 1.12)	0.89	0%
	Moderate	14	0.62 (0.44, 0.88)		
Optimal	Yes	10	0.83 (0.55, 1.25)	0.91	0%
	No	13	0.64 (0.49, 0.85)		
Control theory	Yes	4	0.98 (0.77, 1.24)	0.34	15%
	No	19	0.66 (0.50, 0.87)		

Online resource 10**Meta-regression analyses of BCTs associated with unscheduled health care use**

BCT	N with / without BCT	OR (CI) With BCT	OR (CI) Without BCT	P	Diff Tau ²
Significant associations					
Active patient involvement	6/17	0.50 (0.28, 0.90)	0.79 (0.62, 1.01)	0.03	53%
Non significant associations BCT					
General info	14/9	0.69 (0.49, 0.97)	0.76 (0.56, 1.03)	0.94	0%
Consequences	9/14	0.68 (0.41, 1.14)	0.73 (0.57, 0.94)	0.66	0%
Barrier identification	10/13	0.60 (0.38, 0.94)	0.76 (0.62, 0.93)	0.58	0%
Instruction	17/6	0.70 (0.53, 0.92)	0.78 (0.53, 1.15)	0.92	0%
Goal setting	18/5	0.78 (0.62, 0.98)	0.40 (0.20, 0.81)	0.76	0%
General feedback	5/18	0.69, (0.41, 1.17)	0.71 (0.54, 0.93)	0.94	0%
Feedback on inhaler technique	12/11	0.74 (0.49, 1.12)	0.69 (0.54, 0.86)	0.69	0%
Cues	12/11	0.83 (0.58, 1.18)	0.61 (0.44, 0.83)	0.39	0%
Follow-up	10/13	0.82 (0.58, 1.16)	0.63 (0.49, 0.82)	0.08	0%
Social comparison	9/14	0.66 (0.48, 0.91)	0.75 (0.54, 1.04)	0.56	0%
Social support	6/17	0.76 (0.54, 1.06)	0.69 (0.51, 0.94)	0.69	0%

Effective change techniques in asthma self-care interventions

BCT	N with / without BCT	OR (CI) With BCT	OR (CI) Without BCT	P	Diff Tau ²
Individual tailoring	6/17	0.66 (0.42, 1.03)	0.72 (0.54, 0.97)	0.73	0%
Medication concerns	7/16	0.44 (0.25, 0.77)	0.84 (0.65, 1.08)	0.05	0%
Medication optimization	7/16	0.67 (0.40, 1.12)	0.71 (0.54, 0.94)	0.57	0%
Active learning techniques	7/16	0.78 (0.59, 1.04)	0.67 (0.48, 0.95)	0.52	0%

Online resource 11**Meta-regression analyses of associations between trial features and adherence to preventative asthma medication**

Trial feature		N	OR (CI)	P	Diff tau ²
Theory	Yes	4	2.55 (1.47, 2.98)	0.33	0%
	No	12	2.57 (2.11, 3.12)		
Risk of bias	Low	5	2.67 (1.56, 4.56)	0.61	95%
	Unclear	11	2.50 (2.03, 3.08)		
Optimal interventions	Yes	9	2.64 (1.47, 2.98)	0.96	0%
	No	7	2.51 (2.01, 3.13)		
Social Cognitive Theory	Yes	4	2.24 (1.34, 3.73)	0.70	0%
	No	12	2.70 (2.16, 3.36)		
Control theory	Yes	5	2.64 (1.40, 4.98)	0.29	63%
	No	11	2.56 (2.09, 3.13)		

Online resource 12**Meta-regression of associations between BCTs associated with adherence to preventative asthma medication**

	N with / without BCT	OR (CI) With BCT	OR (CI) Without BCT	P	Diff Tau ²
Non significant associations					
BCT					
Consequences	5/11	2.43 (1.77, 3.34)	2.64 (2.04, 3.41)	0.89	0%
Intention formation	6/10	2.38 (1.79, 3.17)	2.73 (2.04, 3.64)	0.71	0%
Barrier identification	12/4	2.54 (1.98, 3.25)	3.13 (1.96, 4.99)	0.37	0%
Instruction	12/4	2.67 (2.06, 3.48)	2.72 (1.63, 4.55)	0.84	0%
Goal setting	9/7	2.60 (2.04, 3.32)	2.58 (1.78, 3.84)	0.97	0%
Feedback	6/10	2.70 (1.60, 4.57)	2.53 (2.05, 3.13)	0.85	0%
Inhaler technique	12/4	2.55 (2.02, 3.22)	3.03 (1.79, 5.14)	0.51	0%
Cues	9/7	2.47 (1.82, 3.35)	3.07 (2.19, 4.29)	0.19	0%
Follow-up	7/9	2.39 (1.93, 2.96)	3.16 (2.03, 4.92)	0.38	0%
Comparison	5/11	3.47 (2.14, 5.61)	2.40 (1.96, 2.93)	0.18	0%

Effective change techniques in asthma self-care interventions

	N with / without BCT	OR (CI) With BCT	OR (CI) Without BCT	P	Diff Tau ²
Support	4/12	2.38 (1.75, 3.24)	2.76 (2.10, 3.63)	0.60	0%
Medication concerns	4/12	2.16 (1.13, 4.15)	2.63 (2.16, 3.21)	0.28	45%
Active involvement of participants	5/11	3.18 (2.11, 4.80)	2.45 (1.93, 3.11)	0.24	96%
Medication optimization	5/11	2.56 (1.71, 3.84)	2.58 (2.01, 3.29)	0.72	0%
Active learning	4/12	2.46 (2.01, 3.02)	3.31 (1.88, 5.83)	0.35	0%