Behavior change techniques for increasing physical activity in cancer survivors: a systematic review and meta-analysis of randomized controlled trials

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Purpose: The purpose of this systematic review and meta-analysis is to investigate how physical activity (PA) can be effectively promoted in cancer survivors. The effect of PA-promoting interventions in general, behavior change techniques (BCTs), and further variables as moderators in particular are evaluated.

Methods: This study included randomized controlled trials of lifestyle interventions aiming at an increase in PA that can be carried out independently at home, published by December 2016, for adults diagnosed with cancer after completion of the main treatment. Primary outcomes were subjective and objective measures of PA prior to and immediately after the intervention. Meta-analysis and meta-regression were used to estimate effect sizes (ES) in terms of standardized mean differences, variation between ES in terms of heterogeneity indices (I²), and moderator effects in terms of regression coefficients.

Results: This study included 30 studies containing 45 ES with an overall significant small positive effect size of 0.28 (95% confidence interval = 0.18–0.37) on PA, and I² = 54.29%. The BCTs Prompts, Reduce prompts, Graded tasks, Non-specific reward, and Social reward were significantly related to larger effects, while Information about health consequences and Information about emotional consequences, as well as Social comparison were related to smaller ES. The number of BCTs per intervention did not predict PA effects. Interventions based on the Theory of Planned Behavior were associated with smaller ES, and interventions with a home-based setting component were associated with larger ES. Neither the duration of the intervention nor the methodological quality explained differences in ES.

Conclusion: Certain BCTs were associated with an increase of PA in cancer survivors. Interventions relying on BCTs congruent with (social) learning theory such as using prompts and rewards could be especially successful in this target group. However, large parts of between-study heterogeneity in ES remained unexplained. Further primary studies should directly compare specific BCTs and their combinations.

Keywords: exercise, lifestyle, intervention methods, behavior change, moderator effects, tumor

Background
About 14.1 million new cancer cases and 8.2 million cancer-related deaths were recorded worldwide in 2012.1 A person is defined as a cancer survivor from the moment of cancer diagnosis throughout life.2 Early detection, improved diagnostics, and treatment have resulted in increased survival rates,3,4 leading to almost 32.6 million cancer survivors worldwide with a diagnosis in the previous 5 years.5 Numerous disease- or treatment-related adverse effects, such as secondary cancers, fatigue, or depression, can decrease the length and quality of life.6
In the last two decades it has been demonstrated that physical activity (PA) plays an important role not only in cancer prevention but also during and after cancer treatment.5,7 PA increases physical functioning among cancer survivors and provides physiological and psychological benefits.5–11 It is recommended that cancer survivors should become or stay physically active as soon as possible after diagnosis. They should engage in at least 150 minutes per week of moderately intense or 75 minutes per week of vigorous intense aerobic PA and should perform muscle-strengthening activities at least twice per week.12 Despite this evidence, cancer survivors show low levels of PA13–15 and a decline during cancer treatment without returning to PA levels prior to diagnosis.16,17

Changing behavior from a mainly sedentary to a physically active lifestyle poses a challenge to most people but particularly to those with chronic diseases such as cancer.18,19 PA that is easily performed at home (for example aerobics, walking, biking) is more convenient and accessible for patients and can play an important role in developing an active lifestyle.20

Various interventions have been developed in recent years, aiming at promoting PA in cancer survivors.21–24 Although reviews show beneficial effects in terms of PA increases25–26 and exercise tolerance,24 substantial variance in effect sizes indicates a moderating effect of intervention characteristics such as study design, theoretical foundation, and content.

Regarding study design as a moderator, a recent meta-analysis on PA promoting interventions in different target groups found a strong methodological quality to be related to smaller intervention effects.27 This finding suggests that, by including methodologically weak studies with larger effects in previous meta-analyses, overall effects may potentially have been overestimated.

Theories most commonly used as a basis of behavior change interventions are the Transtheoretical Model (TTM), Social Cognitive Theory (SCT), Health Belief Model, and Theory of Planned Behavior (TPB).28 It is expected that interventions are more effective when built on a theoretical foundation.29 However, studies show ambiguous results.30,31

Examining intervention content as a potential moderator is challenging, since behavior change interventions are usually built out of multiple components. To facilitate consistent classification of intervention content by researchers and clinicians, Michie et al32 developed a taxonomy of behavior change techniques (BCTs) by employing a systematic expert consensus approach.32 A BCT is defined as “an observable, replicable and irreducible component of an intervention designed to alter or redirect causal processes that regulate behavior”.33 The taxonomy of Michie et al33 (BCTT v1) consists of standardized definitions of 93 different BCTs. No consistent matching of BCT definitions from BCTT v1 with theories or theory-based determinants of PA behavior is available yet. Studies that analyzed effective BCTs in interventions to increase PA30,31,34–38 showed equivocal results. Regarding cancer survivors, so far neither the amount of PA nor BCTs were compared between more or less successful trials.24

The purpose of the present review and meta-analysis is to summarize the efficacy of interventions that aim at increasing overall PA that can be carried out independently at home in cancer survivors after completion of main cancer treatment and, particularly, to analyze which BCTs are most effective in this target group. Additional intervention features such as intervention duration, number of applied BCTs, and theoretical foundation as well as patient characteristics are analyzed as possible moderators of treatment effects.

**Methods**

To ensure correct proceedings along the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA), a PRISMA checklist was created and PRISMA review guidelines were followed (Figure S1).39 Every study and intervention feature was extracted by two reviewers independently and ambiguity in this process was resolved by consulting with a third reviewer. Since only published results were analyzed and no individual data gathered, no ethical approval was obtained.

**Search strategy**

The electronic database MEDLINE was searched for articles from the earliest possible year to December 2016. The search strategy included medical subheadings and text word terms in different combinations, for example: neoplasms, cancer survivor, exercise, PA, physical fitness, muscle strength, health promotion, health education, behavior therapy, and randomized controlled trial (RCT). The complete search strategy is shown in Figure S2. Additionally, reference lists of retrieved articles and published reviews and meta-analyses on PA interventions in cancer survivors were screened.

**Study inclusion criteria**

For eligibility, studies had to meet the following conditions:

1. Type of study: RCT. Exclusion: RCT-pilot study subsequently evaluated in a main study.
2. Type of participants: Adult patients (18 years of age or older) diagnosed with cancer. Exclusion: Current active
treatment (except hormonal treatment) or end-of-life-care patients.
3. Type of intervention: Lifestyle intervention aiming at an increase in PA behavior including exercise intervention and multicomponent program focusing on PA and further lifestyle factors; interventions that aim at increasing PA that can be easily carried out independently at home. Exclusion: Interventions aiming at PA that requires professional guidance, specific equipment or facilities (eg, fitness machines).
4. Type of control group: Usual care or wait-list control group.
5. Type of outcome measure: PA (self-reported or objectively measured) prior to and immediately after the intervention. PA is defined as any bodily movement produced by skeletal muscles resulting in energy expenditure.

Follow-up measurements were not taken into account, since these were reported only for a subset of interventions and were of varying duration. Only full-text articles written in English and German were included. To identify studies meeting the inclusion criteria, titles and/or abstracts of studies retrieved with the search strategy were screened. The full texts of these studies were retrieved and assessed for eligibility.

Data extraction
Extracted information of study details included author, year, research question, the country where the study was carried out, recruitment source, inclusion and exclusion criteria, study design, and description of the control group (CG) vs intervention group (IG). Regarding participant characteristics, cancer type, age, gender, and time since diagnosis or treatment were extracted. Furthermore, the following intervention details were recorded: name, frequency and total duration of the intervention, setting, type of delivery, theoretical basis, and BCTs used. Regarding PA outcome, the method of measuring PA, the number of participants randomly assigned and assessed, as well as the PA level were extracted.

Coding of methodological quality
Methodological quality was assessed according to the Effective Public Health Practice Project Quality Assessment Tool for Quantitative Studies (EPHPP-Tool). The tool consists of questions to help with assessing the quality concerning the six criteria selection bias, study design, confounders, blinding, data collection methods, as well as withdrawals and dropouts, which are combined to a global rating of methodological quality. Additionally, intervention integrity and statistical analyses (including intention-to-treat approach) are evaluated.

Coding of behavior change techniques
The BCT taxonomy v1 was used to identify and code the BCTs reported in each IG. The most comprehensive published description of the intervention content (eg, from study protocols) was used. Coding was carried out by MG and EF independently after completing the BCT taxonomy v1 Online Training using the given BCT definitions and coding rules. BCTs were coded as present or absent, and only the BCTs exclusively applied in the IG were extracted. After coding the first interventions, definitions and coding rules were discussed and additional coding rules established to interpret ambiguities. To quantify intercoder agreement, Cohen’s kappa was calculated for BCTs and studies (Table S1) based on the semi-final coding after this discussion. Prevalence-adjusted bias-adjusted kappa (PABAK) values are additionally reported. These are kappa values adjusted for a potential bias by the overall proportion of “yes”-responses as well as by differences in this proportion between the coders. Remaining disagreements in coding were then solved by discussion and consulting with a third reviewer (AE).

Data synthesis (meta-analysis and meta-regression)
Since the majority of studies reported means and standard deviations (SD or equivalents) as outcome and only a few studies reported change scores, Hedge’s g was computed as an effect size from the PA scores immediately after the intervention. Since only RCTs were included, possible baseline differences between groups should be random. For calculating SDs from other measures, formulae from the Cochrane Handbook were used.

Effect sizes and variances were calculated within the package “metafor” for the Software R and, where effect sizes had to be calculated from F-values, P-values or proportions, these calculations were performed with the package “compute.es”, using conversion formulas from Cooper et al. If required, SDs of PA outcomes following the intervention were estimated by regressing the log SDs on the log means following the Cochrane Handbook.

Available objective and self-reported measures were included, since both measure slightly different aspects of PA behavior and are only moderately correlated. Within-study dependencies of effect sizes were accounted for.

For studies that provided multiple self-report measures, only one effect size regarding these measures was included.
Scores of total moderate to vigorous physical activity were prioritized over scores solely including low-intensity activities or those limited to only moderate or vigorous intensity activities. Overall PA was preferred over measures of sport or exercise, and measures related to total volume (ie, combining intensity, frequency, and duration) were favored over the duration of PA. Validated self-report instruments were given priority. One study did not report any measure of PA volume or frequency, but instead gave a “relative treatment effect” and the corresponding SD for both groups. This study was included in the meta-analysis, since this outcome measure seemed directly related to overall PA, and sensitivity analysis excluding this study did not change our results meaningfully.

For studies which included different treatment conditions compared to the same CG, dependencies between effect sizes were also taken into account in the models.

Within-study covariances were estimated following Gleiser and Olkin51 and Pustejovsky52 for multiple outcomes, multiple treatment conditions, or both. In cases without a reported correlation, the estimation of covariances was based on a correlation between self-reported and objective outcomes of r=0.51, as reported for cancer survivors. Significance tests comparing the duration of interventions ranged from one-time recommendation (zero months) to 12 months (M=12, SD=3.6–73.1), and an overall percentage of females of M=74.14% (Md=90.93, SD=35.25, range=0%–100%). Most samples were survivors of breast cancer (k=13 trials) or mixed types of cancer (k=11). The majority of trials were from the US (k=19) and mostly used standard care as control comparison (k=21, eight wait-list control, and one not stated).

The duration of interventions ranged from one-time recommendation (zero months) to 12 months (M=4.26, Md=3, SD=2.87), and treatment took place at home (k=16), at different treatment facilities (k=4) or both combined (k=10). Study characteristics are depicted in Table 1.

Methodological quality
Results of the methodological quality assessment are presented in Figure 2 (for details see also Table S2). Overall, nine of the 30 studies were rated as methodologically strong, 16 as moderate, and five as weak. Regarding patient selection bias, many of the studies were rated weak (k=18), while the remaining were rated moderate. Confounders were controlled for in most of the studies (k=26). For blinding, only two of the studies were ranked strong. In the remaining studies, the blinding process was either not explained, the outcome assessors were aware of the exposure status of the participant, or the participants were aware of the research question. Reliable and valid outcome measures were used in most of the studies (k=26). Regarding drop-outs, 21 studies had a rate of less than 20%, and were, therefore, rated as strong. Nine studies had 60%–79% drop-outs, and one study did not report on drop-outs. Half of the studies (k=15) reported a sample-size calculation. Many of the studies had small sample sizes, suggesting difficulties in providing adequate statistical power to detect between-group differences, even if they were pres-
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Intention-to-treat analyses were used in 20 studies. The remaining studies used either per-protocol analysis (k=7) or analyses were not explained (k=3).

Regarding intervention integrity (ie, the degree to which an intervention is implemented as intended), three studies reported that more than 80% of participants of the IG received the intervention, in two studies 60%–79% of participants received the intervention, while the remaining 25 studies did not communicate the information. Four studies measured the consistency of the intervention (ie, if all individuals receive the same intervention). Unfortunately, 26 studies did not report on the consistency of the intervention.
| Reference                                      | Cancer type            | Sample size (n) | Control group | Age (mean years) | Gender (women) | Time since diagnosis (mean years) | Intervention | Setting | Duration (weeks) | Types of PA | Intervention provided by | Theory  |
|-----------------------------------------------|------------------------|-----------------|---------------|------------------|----------------|-----------------------------------|--------------|---------|------------------|------------|------------------------|---------|
| Bantum et al, 2014                            | Diverse               | 352             | WL            | 51.0             | 82.1%          | 1.8                               | Six sessions, web-based educational material | Home-based | 6                  | MVPA       | Trained peer facilitators | —       |
| Basen-Engquist et al, 2006                    | Breast                 | 60              | SC            | 55.1             | 100%           | 3.2                               | 21 Group sessions, educational material | Facility-based | 24                 | MVPA       | —                      | SCT, TTM |
| Bennett et al, 2007                           | Breast, others         | 56              | SC            | 57.8             | 89.3%          | 3.5                               | Four counseling sessions (three phone sessions) | Home-based | 24                 | Moderate intensity | Exercise specialist | MI       |
| Bloom et al, 2008                             | Breast                 | 404             | WL            | —                | 100%           | —                                 | Three workshops | Facility-based | 12                  | Stretching, walking, others | Social support | —       |
| Carmack Taylor et al, 2004, 2006               | Prostate               | 134             | SC            | 69.2             | 0%             | —                                 | 21 Group sessions, educational material | Facility-based | 24                 | Moderate intensity | Group facilitator | SCT, TTM |
| Culos-Reed et al, 2010                        | Prostate               | 100             | WL            | 67.4             | 0%             | —                                 | 16 Group sessions, tailored exercise program | Combined | 16                 | Walking, light resistance training | Exercise specialist | ToPB     |
| Demark-Wahnefried et al, 2003 and 2007;       | Breast, prostate       | 543             | SC            | 57.0             | 56.4%          | —                                 | Tailored educational material (two workbooks), eight newsletters | Home-based | 40                 | MVPA       | Mail-based material | SCT, TTM |
| Hatchett et al, 2013                          | Breast                 | 85              | WL            | —                | 100%           | —                                 | Eight emails, access to e-counselor | Home-based | 12                 | MVPA       | Exercise specialist | SCT     |
| Hébert et al, 2012                            | Prostate               | 54              | WL            | 70.4             | 0%             | —                                 | One individual session, 13 group sessions, progress phone calls | Combined | 24                 | MVPA       | —                      | —       |
| Ibelt et al, 2011; Høybye et al, 2008          | Breast, prostate, colorectal | 507             | SC            | 61.0             | 35.3%          | 1.2                               | Retreat with lectures, patient group work, training, access to counselor | Facility-based | 1                  | —          | Medical doctor, others | —       |

(Continued)
### Table 1 (Continued)

| Reference                        | Cancer type       | Sample size (n) | Control group | Age (mean years) | Gender (women) | Time since diagnosis (mean years) | Intervention Components | Setting | Duration (weeks) | Types of PA | Intervention provided by | Theory |
|----------------------------------|-------------------|-----------------|---------------|------------------|----------------|-----------------------------------|-------------------------|---------|-----------------|-------------|--------------------------|--------|
| Irwin et al, 2008b⁷               | Breast            | 75              | SC            | 55.8             | 100%           | 3.5                               | Three supervised group training sessions and two home-based training sessions per week, educational material | Combined             | 24               | Walking, others | Medical doctor, others | —      |
| James et al, 2011 and 2015⁶⁵⁷⁰   | Diverse           | 133             | WL            | 57.2             | 77.4%          | 3.5                               | Six group sessions, home-based training program, educational material | Combined             | 8                | Resistance training, MVPA | Exercise specialist, others | SCT    |
| Kim et al, 2011⁷¹                 | Breast            | 45              | —             | 45.6             | 100%           | 1.1                               | 12 Tailored phone sessions, educational material | Home-based           | 12               | Moderate intensity | Nurses | TTM                     |
| Lahart et al, 2016⁵²             | Breast            | 80              | SC            | 53.6             | 100%           | 0.7                               | One individual session, three phone sessions, educational material | Home-based           | 24               | MVPA               | Researcher | MI                      |
| Ligibel et al, 2012⁷³             | Breast, colorectal| 121             | SC            | 54.3             | 92.6%          | —                                 | Ten phone sessions, educational material | Home-based           | 16               | Moderate intensity | Behavioral counselor | SCT    |
| Livingston et al, 2011 and 2015⁵⁷⁵| Prostate          | 147             | SC            | 65.6             | 0%             | 0.5a                              | One individual session, 24 supervised training sessions, unsupervised training | Combined             | 12               | MVPA, resistance training, others | Exercise specialist | SCT    |
| Matthews et al, 2007⁷⁶           | Breast            | 36              | SC            | 54.1             | 100%           | 0.8                               | One counseling visit, five phone sessions | Home-based           | 12               | Walking            | Health counselor | SCT                  |
| Reference                        | Cancer type           | Sample size (n) | Control group | Age (mean years) | Gender (women) | Time since diagnosis (mean years) | Intervention | Setting | Duration (weeks) | Types of PA | Intervention provided by | Theory |
|---------------------------------|-----------------------|-----------------|---------------|------------------|----------------|-----------------------------------|--------------|---------|------------------|-------------|------------------------|--------|
| Morey et al., 2009; Demark-Wahnefried et al., 2012; Snyder et al., 2009 | Breast, prostate, colorectal | 641 | WL | 73.1 | 54.5% | — | Tailored educational material (workbook), newsletters, 15 phone sessions, eight automated phone prompts | Home-based | 48 | Resistance training, mVPA | Health counselor | SCT, TTM |
| Park et al., 2015<sup>c</sup> | Breast, colorectal | 162 | SC | 51.8 | 87.2% | 1.9 | Exercise recommendation or exercise recommendation plus educational material, and pedometer<sup>d</sup> | Home-based | 4 | Moderate intensity | Exercise specialist | — |
| Pinto et al., 2005 and 2008<sup>e</sup> | Breast | 86 | SC (+ phone calls) | 53.1 | 100% | 1.8 | One individual session, 15 phone sessions, mailed educational material, and feedback | Combined | 12 | Moderate intensity (eg, biking) | Researcher | SCT, TTM |
| Pinto et al., 2013<sup>f</sup> | Breast | 192 | SC (+ phone calls) | 60.0 | 100% | 3.0 | One individual session, 11 phone sessions, mailed educational material, and feedback | Combined | 12 | Moderate intensity aerobic (eg, biking) | Researcher | SCT, TTM |
| Pinto et al., 2013<sup>g</sup> | Colorectal | 46 | SC (+ phone calls) | 57.6 | 56.5% | 3.0 | One individual session, 15 phone sessions, mailed educational material, and feedback | Home-based | 12 | Moderate intensity aerobic (eg, biking) | Researcher | SCT, TTM |
| Rabin et al., 2016<sup>h</sup> | Diverse | 35 | WL | 33.6 | 82.9% | 2.5 | One individual session, 15 phone sessions, access to monitored online peer forum | Home-based | 12 | Moderate intensity aerobic | Researcher | SCT, TTM |
## Table 1 (Continued)

| Reference                          | Cancer type | Sample size (n) | Control group | Cancer type | Sample size (n) | Control group | Age (mean years) | Gender (women) | Time since diagnosis (mean years) | Intervention Theory | Components | Setting | Duration (weeks) | Types of PA | Intervention provided by |
|------------------------------------|-------------|----------------|---------------|-------------|----------------|---------------|------------------|----------------|-------------------------------|---------------------|------------|---------|-----------------|-------------|------------------------|
| Rau et al, 2009                    | Diverse     | 118            | SC (+ phone calls) | 56.4        | 38.5%         | Three phone sessions | Home-based | 24 | MVPa              | —                   | TTM, MI                     |
| Reif et al, 2010 and 2013          | Breast, others | 261           | SC             | 57.7        | 71.7%         | Eight group sessions, educational material | Combined | 24 | —                | Nurse, others | Self-management |
| Rogers et al, 2012 and 2015         | Breast      | 222            | SC             | 54.4        | 100%          | Six discussion group sessions, 12 supervised exercise sessions, home-based training, three counseling sessions | Combined | 12 | Moderate-intensity (eg, walking) | Exercise specialist, others | SCT |
| Sheppard et al, 2016               | Breast      | 31             | SC             | 54.7        | 100%          | Six group sessions with supervised training and education, 12 phone sessions | Facility-based | 12 | Moderate intensity (walking) | Exercise specialist, others | TPB, SCT, MI |
| Short et al, 2012, 2013, and 2015   | Breast      | 330            | SC             | 55.0        | 100%          | Three tailored newsletters or targeted PA guidebook | Home-based | 12 | Moderate intensity (aerobic, resistance training) | Mail-based | SCT, TPB |
| Vallance et al, 2007 and 2008       | Breast      | 377            | SC             | 58.0        | 100%          | PA recommendation plus PA guidebook or plus pedometer and step calendar or plus both | Home-based | 12 | MVPa              | Print-based | TPB |
| von Gruenigen et al, 2012           | Uterine     | 75             | SC             | 58.0        | 100%          | 16 group sessions, three counseling visits, PA guidebook, newsletters, phone sessions, emails | Combined | 48 | Moderate intensity (eg, walking) | Physician, others | SCT |

Notes: *Time since treatment. *Theory mentioned as basis of intervention. For several intervention groups.
Abbreviations: MI, Motivational Interviewing; MVPa, moderate to vigorous physical activity; PA, physical activity; SC, standard care; SCT, Social Cognitive Theory; TPB, Theory of Planned Behavior; TTM, Transtheoretical Model of Behavior Change; WL, wait-list control group; —, not reported.
Behavior change technique coding

Overall, 41 of the 93 BCTs were coded at least once in the semi-final and 37 in the final coding. For the individual BCTs, based on the semi-final coding, Cohen’s kappa ranged from 0.30 (BCT Reduce prompts) to 1.0, with the exception of four BCTs that were coded only once or twice by one reviewer but not the other, resulting in $\kappa=0$. Including these values, mean $\kappa$ was 0.76 and reflects substantial agreement.97 PABAK values ranged from 0.65–1.0 (M=0.93) for the different BCTs. Regarding the different trials, Cohen’s $\kappa$ ranged from 0.67–1.0 (M=0.91) and PABAK from 0.74–1.0 (M=0.94) (see Table S1). Overall, a substantial agreement could be reached.

The included interventions used an average of 10.44 BCTs (Md=11, SD=4.44), ranging from 1–17. The BCTs most commonly used were Goal setting (behavior) and Social support (unspecified) (in k=27 IGs), followed by Problem solving and Self-monitoring of behavior (k=26), Instructions on how to perform the behavior (k=24), Behavioral practice/rehearsal (k=23), and Adding objects to the environment (k=21, often related to the use of pedometers).

Overall meta-analysis

The meta-analysis included k=45 effect sizes (34 for self-reported, 11 for objective PA outcomes) within 30 trials. All trials used self-reported PA as an outcome and eight trials (effect sizes from 10 IGs) additionally used objectively measured PA. Raw means and SDs for the PA outcomes immediately after the intervention were extracted for 33 effects. The SD had to be estimated in eight studies (10 comparisons overall). For the prediction of SDs from log means the values $R^2=0.946$ for the IG and $R^2=0.918$ for the CG were detected. The estimated SDs were controlled for plausibility. In two cases the effect size was estimated based on available data, comparing group proportions by converting effect sizes to the standardized mean difference.

The funnel plot (Figure S3) and regression of effect size on sampling variance ($\beta=3.65$, $t_{(44)}=2.273$, $P=0.031$) indicated a significant asymmetry in the distribution of standard errors related to observed study outcomes mainly caused by small studies with particularly large effect sizes. The estimated pooled effect size may, therefore, be slightly overestimated. However, with a fail-safe N (number of unpublished studies with nonsignificant findings that would have to exist for the overall effect to become insignificant) of 1,859 for a probability of error of alpha=5%, an overall positive effect seems likely.

The model resulted in an overall estimated effect size in terms of standardized mean difference of $g=0.276$ (95% CI=0.183–0.369 based on robust variance estimation), indicating a significant effect in favor of the IG ($P<0.001$; Figure 3). There was significant heterogeneity of effect sizes ($Q_{(df=44)}=94.081$, $P<0.001$), with $\tau^2=0.048$ (95% CI=0.013–0.132) for subjective outcomes and $\tau^2=0.007$ (95% CI=0.000–0.097) for objective outcomes, respectively. About 54.29% of the total variation in effect sizes was estimated to be caused by heterogeneity of true effects ($I^2$). On average, effect sizes for self-reported PA were higher than for objective outcomes ($g=0.316$ as compared to 0.182, $F_{(1,28)}=4.642$, $P=0.040$).

Meta-regression of PA outcomes on behavior change techniques and other potential moderators

Results of multivariate mixed effects models on BCTs

Number of BCTs

Figure 4 shows predicted and observed effect sizes of the included studies in relation to the number of BCTs used in the analyzed interventions. Effect sizes did not increase meaningfully with the number of BCTs per intervention (estimated increase per additional BCT, $\beta=0.005$, 95% CI=–0.007–0.017, $P=0.408$).

Moderator effects of specific BCTs

Of the final 37 BCTs exclusively applied in an IG, 27 were coded as being present for at least five effect sizes and were, therefore, analyzed as possible moderators in the meta-regression models for self-reported and objectively measured PA outcomes (see Table 2). The BCTs Prompts/cues, Reduce prompts/cues, Graded tasks, Nonspecific reward, and Social reward were significantly related to larger effect sizes, while...
Information about health consequences and Information about emotional consequences as well as Social comparison were used in interventions with smaller treatment effects (P<0.05). The largest differences in effect sizes associated with the use of specific BCTs were comparable in size to the magnitude of the overall effect. With a borderline significant trend, the potential moderator Self-monitoring of behavior was associated with larger effect sizes and the moderators Discrepancy between current behavior and goal and Information about social and environmental consequences with smaller effect sizes (P<0.10).

None of these individually tested BCTs reduced the unexplained heterogeneity in effects to a nonsignificant level. Overall, the amount of heterogeneity explained by the mentioned BCTs was higher for objective than for self-reported outcomes, although the heterogeneity estimates were rather imprecise due to the small number of effect sizes for objective outcomes.

Of the seven mentioned BCTs coded most often (see “BCT coding” above), only Self-monitoring of behavior had a trend to significance while the other six BCTs were clearly not significant.

Further study characteristics analyzed as potential moderators

Intervention features

Theories that were mentioned as the foundation of interventions were analyzed as further potential moderators concerning an increase in PA (see Table 3). Some interventions referred to more than one theory so that frequently mentioned theories were coded binary as absent or present.
Table 2 Results of simple meta-regression analyses with BCTs and further study characteristics as predictors of 45 effect sizes from physical activity interventions

| Moderator | k   | β         | 95% CI          | Percentage reduction in heterogeneity (I²) |
|-----------|-----|-----------|-----------------|------------------------------------------|
| **Single BCT*** |     |           |                 |                                          |
| 1.1 Goal setting | 37  | -0.050    | (-0.160, 0.059) | 0.00%                                    |
| 1.2 Problem solving | 35  | 0.015     | (-0.065, 0.095) | 0.00%                                    |
| 1.3 Goal setting outcome | 6   | 0.082     | (-0.207, 0.372) | 0.17%                                    |
| 1.4 Action planning | 24  | -0.034    | (-0.147, 0.079) | 0.00%                                    |
| 1.5 Review behavior goal(s) | 14  | 0.090     | (-0.098, 0.278) | 0.61%                                    |
| 1.6 Discrepancy between current behavior and goal | 6   | -0.084*   | (-0.174, 0.007) | 1.17%                                    |
| 2.2 Feedback on behavior | 16  | 0.042     | (-0.087, 0.171) | 0.31%                                    |
| 2.3 Self-monitoring of behavior | 34  | 0.085*    | (-0.031, 0.182) | 5.15%                                    |
| 3.1 Social support (unspecified) | 37  | 0.011     | (-0.089, 0.110) | 0.18%                                    |
| 3.2 Social support (practical) | 5   | -0.018    | (-0.170, 0.134) | 0.20%                                    |
| 4.1 Instruction on how to perform the behavior | 34  | -0.029    | (-0.137, 0.079) | 0.00%                                    |
| 5.1 Information about health consequences | 11  | -0.093*   | (-0.183, -0.002) | 1.92%                                    |
| 5.3 Information about social and environmental consequences | 22  | -0.092*   | (-0.199, 0.015) | 1.16%                                    |
| 5.6 Information about emotional consequences | 7   | -0.097*   | (-0.184, -0.010) | 0.92%                                    |
| 6.1 Demonstration of the behavior | 19  | -0.004    | (-0.120, 0.111) | 0.02%                                    |
| 6.2 Social comparison | 9   | -0.143*** | (-0.203, -0.083) | 1.83%                                    |
| 7.1 Prompts/cues | 9   | 0.170**   | (0.003, 0.336)  | 1.75%                                    |
| 7.3 Reduce prompts/cues | 11  | 0.224*    | (0.045, 0.404)  | 7.92%                                    |
| 8.1 Behavioral practice/rehearsal | 32  | -0.105    | (-0.236, 0.026) | 1.46%                                    |
| 8.7 Graded tasks | 20  | 0.203***  | (0.057, 0.348)  | 4.33%                                    |
| 9.1 Credible source | 6   | -0.014    | (-0.092, 0.065) | 0.01%                                    |
| 9.2 Pros and cons | 6   | -0.002    | (-0.043, 0.399) | 0.12%                                    |
| 10.3 Nonspecific reward | 10  | 0.322***  | (0.140, 0.504)  | 11.41%                                   |
| 10.4 Social reward | 12  | 0.274**   | (0.098, 0.450)  | 5.92%                                    |
| 10.9 Self-reward | 6   | 0.325     | (-0.231, 0.881) | 2.06%                                    |
| 12.3 Avoidance/reducing exposure to cues for the behavior | 6   | 0.220     | (-0.107, 0.546) | 1.95%                                    |
| 12.5 Adding objects to the environment | 28  | 0.077     | (-0.039, 0.193) | 1.87%                                    |

| Number of BCTs |     |           |                 |                                          |
|---------------|-----|-----------|-----------------|                                          |
| Overall number of BCTs uniquely applied in IG | 45  | 0.005     | (-0.007, 0.017) | 1.29%                                    |
| Number of BCTs applied from the group of those significantly associated with larger treatment effects| 45  | 0.066***  | (0.032, 0.101)  | 8.59%                                    |
| Number of BCTs applied from the group of those significantly associated with smaller treatment effects| 45  | -0.042*** | (-0.064, -0.021) | 1.87%                                    |

Notes: *Only results for BCTs involved in ≥5 effects sizes (or used in ≥5 IGs) are reported; †compared to the model without moderator; ‡BCTs 7.1, 7.3, 8.7, 10.3, 10.4; §BCTs 5.3, 5.6, 6.2. *P≤0.10, †P≤0.05, ‡P≤0.01, §§P≤0.001 (based on robust estimation). k, number of interventions where a specific BCT was present; β, estimated meta-regression coefficient for the comparison of effect size with BCT present vs absent; I², percentage of residual heterogeneity, test for residual heterogeneity was significant (P<0.001) for all BCTs.

Abbreviations: BCT, Behavior Change Technique; CI, confidence interval; IG, intervention group.

for each study. The most frequently used theories were Social Cognitive Theory (SCT, in 25 IGs), the Transtheoretical Model (TTM, in 11), and Theory of Planned Behavior (TPB, in 7), whereas seven interventions used other theories and for eight interventions no theoretical foundation was mentioned. Interventions based on the SCT reported slightly but not significantly larger effect sizes. No difference was found for interventions based on the TTM. Interventions based on the TPB revealed significantly smaller effects (P<0.001). No significant moderating effects were found for interventions that did not mention a theoretical foundation or those that were based on other theories when compared to the remaining interventions.

Effect sizes varied with the setting of the intervention (P<0.001). Interventions that included a home-based training component seemed more effective than those that only took place at facilities like clinics or gyms, and those that combined both settings showed the largest effect sizes.

The duration of the intervention did not explain differences in effect sizes. However, effect sizes for longer...
interventions had a tendency to be smaller (mean effect size = 0.30 for duration < 3 months, 0.36 for 3 months, and 0.19 for > 3 months; F(2, 27) = 1.452, P = 0.252).

Study characteristics
Methodological quality had no significant effect on effect size (see Table 3). Particularly, studies with lower quality did not result in larger effect sizes. Studies published more currently reported slightly larger effect sizes with an estimated increase per year of β = 0.016 (P < 0.10). Effects for trials with a wait-list CG did not differ meaningfully from those with a standard care comparison.

Patient characteristics
Effect sizes had a tendency to be smaller in studies with older participants, with an estimated decrease in effect size of β = 0.016 per year of mean age of the study population (P < 0.10). No differential effects were found for cancer survivors with different types of cancer, neither did the proportion of females vs males have a significant effect on outcomes.

Discussion
Within this meta-analysis, treatment effects from 30 RCTs on interventions for cancer survivors following acute treatment and aiming at an increase in PA which can be carried out independently at home were analyzed. The results show an overall significant positive effect (Hedge’s g = 0.28; 95% CI = 0.18–0.37) after the end of treatment, which is in line with the magnitude of effect sizes of other meta-analyses for PA interventions in cancer patients and survivors. Therefore, the effect is of small magnitude in terms of established rules and typical for studies in this field.

Behavior change techniques
Our results show that some specific BCTs were associated with larger effects on PA increases. Namely, including...
prompts or cues to perform PA behavior (eg, adding a pedometer to a workbook as a behavioral cue) or employing intermittent telephone calls as prompts and gradually decreasing such prompts (or the frequency/intensity of interventions) over time were significantly associated with larger PA increases. The same was true for setting graded tasks that increase in difficulty (eg, increasing the frequency and/or duration of exercise sessions from week to week was a common strategy or progressing to more demanding exercises) and for delivering different kinds of rewards for effort or progress toward PA behavior (eg, immediate reinforcement via positive automated messaging for participants who attained their personal exercise goal, praise for achievement of goals, or progress toward goal). In general, interventions using a larger number of these specific BCTs showed larger PA increases.

In contrast, BCTs including information about the consequences of PA behavior in terms of health benefits or positive emotional effects were used in less successful interventions. Likewise, social comparison, ie, to draw attention to the performance of others compared to the patient her/himself, or emphasizing discrepancies between PA goals and actual behavior was associated with smaller intervention effects in our analysis. Combinations of more than two of these BCTs were associated with smaller PA increases.

In contrast, the overall number of BCTs used in an intervention had no significant impact on the achieved PA increase immediately after the intervention compared to standard care or wait-list controls in our study. This result is in line with meta-regressions that included BCTs to increase PA behavior in adults with obesity or diabetes. In contrast, Samdal et al found more BCTs associated with larger intervention effects in overweight or obese adults.

Overall, results on the effectiveness of specific BCTs for increasing PA do not show a consistent pattern, and our analysis is only partly consistent with previous research. Rewards were associated with greater success, in line with other studies on healthy adults of the general population as well as older adults. However, a negative effect was found for Graded tasks in one study, while others found a positive effect of graded tasks only on long-term but not on immediate success. On the other hand, BCTs similar to Social comparison, which was associated with lower effect sizes in our study, showed a positive PA effect in healthy adults, but a negative effect in a meta-analysis on older adults. In terms of Information on consequences of the behavior, we obtained a negative association with effect size, whereas others found no effect. None of the compared studies endorses the positive effects we found in relation to Prompts and cues.

Several authors came to the conclusion that a combination of BCTs fostering self-regulation, ie, Self-monitoring, Goal setting, Feedback on performance, and Reviewing goals are especially promising in increasing PA in different populations. Of these only Self-monitoring showed a marginally significant effect in our study, while no effects were found for other self-regulatory BCTs. One reason could be that cancer survivors as a specific target group react differentially to certain BCTs than other groups. This conclusion is backed by the results of French et al, who found these techniques were not successful in older adults in contrast to younger populations. A similar mechanism could apply to Social comparison. Social comparison might be more important for younger people than for cancer survivors or the elderly, and, thus, might not be as effective when applied as BCT in these target groups.

In addition to potential target group effects, reasons for the differences observed may lie in different taxonomies used for coding of BCTs (ie, CALO-RE taxonomy vs BCTT v1) or in the challenge of adequate translation of intervention methods into practical application, as well as the varying numbers of included studies.

In our analysis, the most frequently used BCTs, including some of the self-regulatory techniques mentioned above, were not associated with a more successful PA increase. In other reviews and meta-analyses on different target groups, these or similarly defined BCTs were shown to be associated with larger PA effects (ie, Instructions on how to perform behavior, Problem solving, Goal setting, Behavioral practice).

One possible explanation for this finding may be that some of these BCTs were used in too many interventions to enable meaningful comparisons in our analysis. Further studies should specifically test intervention effects of such frequently employed BCTs in different target groups alone and in combination with other techniques.

**Further moderators**

Overall, results on the use of specific theories in PA interventions are equivocal. Most studies did not find differences between specific theories reported as the basis of PA interventions or the use of theory in general.

Interventions that were described as based on the TPB showed lower effect sizes. Husebo et al, on the other hand, reported that constructs of the TPB (ie, intention, perceived behavioral control) were weakly but significantly associated
with better exercise adherence in eight studies with cancer patients and survivors. The most frequently stated theory in our analysis was SCT and interventions based on SCT reported slightly but not significantly larger effect sizes. While some of the identified BCTs directly match SCT constructs (like Setting graded tasks to increase self-efficacy), other techniques fitting into the SCT framework (like Role modeling) were not associated with better success.

While the authors of the present study could not identify a cluster of BCTs that completely matches one specific theory of behavior change, BCTs that proved advantageous in our study seem mostly congruent with principles of (social) learning theory, ie, rewards, including sense of achievement and situational cues which are faded out gradually and may promote habit building. In contrast, those BCTs relying on knowledge and rational decision making (ie, setting goals, providing information, problem solving) seemed less successful in increasing PA in cancer survivors. The latter is consistent with smaller effect sizes for TPB-based interventions which often rely on information and rationality.

However, in many cases it remains unclear how exactly theory is implemented in interventions. An explicit methodology for linking BCTs to theories is currently being developed and will help to clarify relations between BCTs, mechanisms of action, and other variables such as modes of delivery, populations, settings, and types of behavior. Further research should establish whether the results of the present study can be replicated for cancer survivors compared to other groups, since this would have theoretical implications for planning interventions for this target group.

In terms of intervention duration, we did not find a meaningful effect on PA increase. A study by Bernard et al even reports a shorter duration of theory-based interventions designed to promote PA, ie, less than 14 weeks, to be associated with larger treatment effects in different target groups. Although not significant, our results point in the same direction with the lowest effect sizes for those interventions longer than 3 months. These findings underline that duration alone may not be the best measure of overall intervention intensity and that, in fact, more complex or longer interventions do not necessarily lead to greater success.

Methodological quality of included studies was also not associated with the magnitude of intervention effects indicating that the results are not contorted by differences in study quality. In contrast, two recent studies reported significant moderator effects suggesting overestimation of the efficacy of PA interventions due to methodological weaknesses. Both of these studies employed the Cochrane tool for assessing risk of bias, while the present study used the EPHPP-Tool. As Armijo-Olivo et al demonstrated, ratings using the EPHPP-Tool may differ from those resulting from the Cochrane tool. This may explain the diverging results. However, it was also found that the EPHPP tool seems superior in terms of interrater reliability.

**Strengths and limitations**

This is the first study that systematically analyzed the associations of BCTs with PA increases in cancer survivors after treatment employing a current BCT taxonomy, where two coders evaluated studies independently, arriving at good interrater reliabilities. Furthermore, self-reported as well as objectively measured PA outcomes were included while adjusting the analysis for intratrial correlations.

Some limitations must also be taken into account. As our search was limited to MEDLINE, missing studies may lead to publication bias. However, we also accounted for reference lists of other current reviews and meta-analyses. Although the overall methodological quality of trials was not related to effect sizes, only a subset implemented an intention-to-treat analysis or reported on intervention integrity. As these criteria are not included in the overall quality rating, they may have biased the results.

Our meta-analysis is limited to outcomes measured directly after completion of interventions. Effects of specific BCTs might differ between immediate and long-term outcomes, as recently shown by Samdal et al. Further research on long-term effects is, therefore, desirable.

Eight trials added an objectively measured PA outcome to a self-report measure. Since these trials contained more effect size information than those relying only on self-report measures, this may have influenced our results. However, including all available information by using a multivariate model and adjusting for dependencies between outcomes seemed more appropriate than including only information on self-reported measures. The overall effect size was similar to other studies on cancer survivors. Due to the limited amount of data on objective outcomes, it was not suitable to distinguish the results of meta-regression models by subjective vs objective outcome.

Peters et al described limitations of analyzing effectiveness of BCTs by meta-analytical techniques. Within the included studies, BCTs may not have been transferred to intervention strategies effectively or may not have been adapted to target groups and contexts adequately. A prerequisite for finding an effect of BCTs in a meta-regression is the exclusive use of a BCT in the IG, but not in the CG. Since
most of the included interventions only provided a very short
description of the “standard care,” it was impossible to code
and, therefore, detect BCTs for the CG accurately.

Effects of different BCTs may have confounded each
other or may have been confounded by other study charac-
teristics such as the overall number of BCTs applied in an
intervention. Due to a large number of analyzed potential
moderators compared to the limited number of included stud-
ies, calculation of more complex models allowing analyses
of confounding effects were not possible.

Since some BCTs were often used in combination in the
same studies (see Table S3) we adjusted for within-study
dependencies of effect sizes and show “dose-response”
relations for the use of those BCTs associated with effect
sizes, but we cannot rule out that trial characteristics other
than these BCTs were responsible for differences in PA
effects. Furthermore, many BCTs were tested as moderators
in separate models without adjustment for multiple testing.

Furthermore, some BCTs were used in very many or very
few interventions, reducing the power of tests for moderator
effects of these BCTs. A nonsignificant effect may not be
interpreted as a proof of lack of effectiveness. The results
are, therefore, exploratory and do not allow definite or causal
conclusions.

We found some BCT definitions and coding rules not
being clearly outlined and, therefore, added more specific
coding rules, attaining good intercoder reliabilities after-
wards. Others report similar issues.100 Cradock et al36 also
developed extensive additional coding rules, which we
included in our discussion process.

Notwithstanding these limitations, meta-analyzing the
effectiveness of BCTs for increasing PA in cancer survivors
and comparing the results to other target groups can be seen as
one constituent of further developing theory-based interven-
tions aimed at health behavior change in this target group.103

Conclusions
A growing body of evidence shows the positive effects of PA
in cancer survivors. Thus, identifying the relevant characteris-
tics of interventions is of great importance. The present meta-
analysis shows significant effects for interventions aiming at
an increase in PA that can be carried out independently by
cancer survivors. The magnitude of PA increase seems neither
to depend on the duration of the intervention nor on the num-
ber of BCTs used, but certain techniques were associated with
significantly larger or smaller PA-increasing effects. Inter-
ventions relying on BCTs congruent with (social) learning
theory, such as using prompts and rewards and setting graded
tasks, could be especially successful in this target group.
However, large parts of between-study heterogeneity in effect
sizes remained unexplained by single moderator variables.
Other factors than those studied here may impact on the suc-
cess of PA interventions in cancer survivors, or synergistic
effects of moderators may exist that can only be revealed in
more complex analyses which require larger meta-studies.

To strengthen validity, the results should be replicated and
in addition be complemented by the analysis of long-term
effects and direct comparisons to other target groups. Further
primary studies should directly test and compare specific
BCTs and their combinations. Coding instruments should
be more precise with an extension of definitions and anchor
examples for different interventions goals.

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