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Assessing and exploring self-enacted behavior change techniques: frequency, structure, and relevance for physical activity and healthy eating

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Abstract
Self-enactable behavior change techniques (Knittle et al., 2020), are active components of interventions that individuals can also employ on their own. The study explored the frequency of self-enactable behavior change techniques (SE-BCTs) usage, their psychometric structure, and their association with physical activity and healthy nutrition. To evaluate SE-BCTs, Abraham & Michie's (2008) 26-BCT taxonomy was translated into a SE-BCT questionnaire and administered to 504 participants via a web survey. Participants reported self-enacted goals in physical activity (PA) and healthy nutrition (NUT), along with their importance, difficulty, and progress. Physical activity and healthy eating questionnaires served as indicators of successful behavior change. Using Bayesian statistics, we found variations in the usage intensity of SE-BCTs. Similarities and differences emerged between PA and NUT domains. For example, "time management" was commonly used in both, while "information seeking" was more prevalent in NUT. For some SE-BCTs, weak evidence emerged for gender differences and age effects. SE-BCTs formed clusters similar to BCTs, supported by Bayesian psychometric network analyses. Tests for potential preconditions and consequences of SE-BCTs revealed moderate-to-strong support for positive relations with goal importance, and strong support for positive relationships of SE-BCTs with behavior change. Moreover, PA was best predicted by a combination of the SE-BCTs "time management" plus "detailed plans," whereas for NUT, a complex pattern of six SE-BCTs was the best-fitting predictive model. We discuss the potential of SE-BCTs for promoting physical activity and healthy eating add what is still needed to make them work efficiently.

Keywords Behavior change techniques · Physical activity · Nutrition · Bayesian statistics

The risk of premature death from non-communicable diseases is significantly increased by physical inactivity and unhealthy eating (WHO, 2022; Lee et al., 2012; GBD 2017 Diet Collaborators, 2019; Schwingshackl et al., 2018), which emphasizes the assertion that "behavior matters" (Fisher et al., 2011) when it comes to health. This logic also applies in reverse: The key to reducing premature deaths and improving health lies in changing behaviors, such as increasing physical activity and eating a healthier diet (Nitschke et al., 2022; Pescatello et al., 2021). For this reason, research on health promotion has devoted considerable effort into developing a wealth of interventions that help people to adopt and maintain healthy behaviors. This is accompanied by high quality standards regarding the theoretical foundation of existing interventions, as well as high levels of sophistication of the methods used to implement them (Davidson et al., 2020). What this research has in common is that behavior change is to be initiated through *interventions*, i.e. behavioral strategies that are provided from outside (e.g. by researchers or health care providers). Here, participants are asked to apply specific *behavior change techniques* (*BCTs*, defined as the active ingredient of interventions (Michie & Johnston, 2013), such as self-monitoring and action planning to promote, for example, physical activity and healthy

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eating (Compernolle et al., 2019; Peng et al., 2022; Raber et al., 2021).

Interventions for behavior change, however, have the disadvantage that they are expensive (Cortaredona et al., 2017), and still commonly reach only a relatively small proportion of individuals (Zamboni et al., 2019). Approaches and attempts to scale up interventions to promote physical activity (Reis et al., 2016) and healthy eating (Sutherland et al., 2022) are encouraging. Despite their success, however, the magnitude of the problem remains challenging: For example, as reported in the WHO's Global Status Health Report on Physical Activity (WHO, 2022), 27.5% of the world population and a concerning number of 81% of boys and girls aged between 11–17 are not sufficiently physically active. An estimated 2 billion people worldwide are overweight or obese, largely due to an unhealthy diet. For instance, in 2022, 37 million children under the age of 5 and over 390 million children and adolescents aged 5–19 years were overweight (WHO, 2024). It is obvious that with elaborate interventions, only a fraction of those affected can be reached and that we thus have not yet achieved what is needed to combat the pandemic of physical inactivity and unhealthy diet. It would be more cost-effective and scalable if the resources for behavior change didn't need to be provided externally (by interventions) but instead, people employed positive and successful strategies on their own. This is also a central idea that underlies the Compendium for Self-Enact*able* Techniques to Change Behavior (Knittle et al., 2020). In a complex multi-step multi-methods approach, the authors identified BCTs that individuals can self-enact (self-enact*able*). Existing taxonomies of BCTs (e.g., Abraham & Michie, 2008; Kok et al., 2016; Michie et al., 2013) were integrated using group discussions, and additional techniques from the applied literature were incorporated. Instructive examples were generated to enhance the ease of self-enactment. The acceptability of self-enactable BCTs was evaluated through qualitative interviews with members of the public, and experts in intervention development assessed the usefulness, consistency, and simplicity of self- enactable BCTs' definitions and descriptions. A final group discussion resulted in a compendium including 123 self-enactable BCTs, such as "agenda mapping", "information seeking", "goal setting", "action planning", "reviewing one's goals", "self-monitoring", "information about others' approval"," social comparison", "looking for experts demonstrating behavior", "prayer", and "using prompts and cues" (see https://osf.io/g6c8r/?view_only=957a269b9d3242c4af72f483e299aaa6) for list of self-enact*able* BCTs). Additional explanations on how to use the compendium are provided. The compendium can be used by intervention developers and is also suitable for self-application due to its simplified language, detailed explanations, and examples. In summary, the Compendium for self-enactable techniques aims to identify BCTs that can be performed without external support and make these accessible and applicable with the help of recommendations and specific instructions for intervention developers and individuals who want to autonomously change their behavior. It offers information and could thus be understood as a low-threshold and cost-effective intervention.

In the current study, our objective is to enhance the understanding of self-enact*able* BCTs by assessing which are utilized naturally, that is self-enact*ed*, without any external intervention or provision of information, and how often they are employed. We further refer to self-enact*ed* BCTs as *SE-BCTs*. The existence of naturally occurring SE-BCTs can be indirectly inferred: If 42.5% of people from high-income Western are insufficiently physically active (Guthold et al., 2020) and thereby contributing to the pandemic of physical inactivity, that also means that 57.5% manage to be sufficiently active. The latter individuals seem to be natural experts in adopting and maintaining a healthy lifestyle, which could, among other things, be due to their *self-enacted* behavior change techniques.

Assessing self-enacted behavior change techniques

To explore SE-BCTs, a suitable assessment tool has to be developed. One possible way to measure SE-BCTs would be to rephrase the 123 self-enact*able* BCTs from the Compendium (Knittle et al., 2020) into items that individuals can use to indicate whether and how frequently they employ them in their lives. The shorter and thus more research-pragmatic variant proposed here, is based on a selection of SE-BCTs that is aligned with a classic 26-BCT taxonomy (Abraham & Michie, 2008). Since this taxonomy is also one of the foundations of the self-enact*able* BCT Compendium (Knittle et al., 2020), it is not surprising that there is a significant overlap in content. Abraham and Michie´s (2008) taxonomy is based on a theory-driven multistep process that began with compiling existing lists of discrete BCTs used in health behavior interventions (Conn et al., 2002, Hardeman et al., 2000), was continued through pilot studies, expert discussions, and culminated in the development of BCT definitions and a coding manual. The resulting BCTs were mapped to theoretical backgrounds such as Theory of Planned Behavior (Aijzen, 1991), and Control Theory (Carver & Scheier, 1982). Abraham and Michie's (2008) sophisticated approach distinguished between 26 different categories of BCTs (other approaches to clustering behavior change techniques followed, e.g., Michie et al., 2013, 2015). The 26 categories are shown in the left column of Table 1.

Table 1 Definitions of 26 behavior change techniques (columns 1 and 2, adapted from Abraham & Michie, 2008, p.283), and items of the SE-BCT-questionnaire (column 3)

	BCTs	Definition	SE-BCT item
1	Provide information about behavior health link.	General information about behavioral risk, for example, susceptibility to poor health outcomes or mortality risk in relation to the behavior	I search for information about the relationship between PA/NUT and health (e.g. on the Internet, physician).
2	Provide information on consequences.	Information about the benefits and costs of action or inaction, focusing on what will happen if the person does or does not perform the behavior	I weigh the benefits and costs of PA/NUT in terms of health outcomes.
3	Provide information about others' approval.	Information about what others think about the person's behavior and whether others will approve or disapprove of any proposed behavior change	I consider whether or not other people like my changed PA/NUT behavior.
4	Prompt intention formation.	Encouraging the person to decide to act or sei a general goal, for example, to make a behavioral resolution such as "I will take more exercise next week'	I explicitly stated my desire to PA/NUT as a goal (e.g., "I want to exercise more," "I will exercise next week")/(e.g., "I want to eat more fruit and vegetables"; "I avoid convenience food").
5	Prompt barrier identification.	Identify barriers to performing the behavior and plan ways of overcoming them	I identify obstacles that interfere with my PA/NUT behavior and look for solutions to overcome them.
6	Provide general encouragement.	Praising or rewarding the person for effort or performance without this being contingent on specified behaviors or Standards of performance	I encourage myself to exert effort for my goal (e.g., encouragement, reward).
7	Set graded tasks.	Set easy tasks, and increase difficulty until target behavior is performed.	I start with easy tasks and increase the difficulty until I reach my PA/NUT goal.
8	Provide instruction.	Telling the person how to perform a behavior and/or preparatory behaviors	I look for information on how to best perform the PA/NUT behavior (e.g., on the Internet, from friends).
9	Model or demonstrate the behavior.	An expert shows the person how to correctly perform a behavior, for example, in class or on video	I am looking for experts (coaches, videos) to show me how to properly perform the PA/NUT behavior.
10	Prompt specific goal setting.	Involves detailed planning of what the person will do, including a definition of the behavior specifying frequency, intensity, or duration and specification of at least one context, that is, where, when, how, or with whom	I make detailed plans for my PA/NUT behavior (e.g., where, when, how, and with whom).
11	Prompt review of behavioral goals.	Review and/or reconsideration of previously set goals or intentions	I review and rethink my set PA/NUT goal (e.g., Does it fit me? Is it realistic?).
12	Prompt self-monitoring of behavior.	Review and/or reconsideration of previously set goals or intentions	I document my PA/NUT behavior (e.g. diary, weekly log).
13	Provide feedback on performance.	Providing data about recorded behavior or evaluating performance in relation to a set standard or others' performance, i.e., the person received feedback on their behavior.	I match my actual PA/NUT behavior with my set goals and use this as feedback.
14	Provide contingent rewards.	Praise, encouragement, or material rewards that are explicitly linked to the achievement of specified behaviors	I reward myself for achieving specific behavioral and subgoals (e.g., going to the movies for regular exercise participation)(/e.g., going to the movies for regular healthy eating).
15	Teach to use prompts or cues.	Teach the person to identify environmental cues that can be used to remind them to perform a behavior, including times of day or elements of contexts	I use cues from my environment to remind me to do PA/NUT (e.g., fixed time, reminders).
16	Agree on 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	I make my PA/NUT goal public and binding (e.g., tell my partner or friends; write it down).
17	Prompt practice.	Prompt the person to rehearse and repeat the behavior or preparatory behaviors	I practice and repeat behaviors that bring me closer to my PA/NUT goal.
18	Use follow-up prompts.	Contacting the person again after the main part of the intervention is complete	I take precautions to remind myself to perform the PA/NUT behavior in the future (e.g., automatic reminders, other reminders).
19	Provide opportunities for social comparison.	Facilitate observation of nonexpert others' performance for example, in a group class or using video or case study	I seek opportunities to compare myself with others in my PA/NUT behavior.

Table 1 (continued)

	BCTs	Definition	SE-BCT item
20	Plan social support or social change.	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	I look for social support to achieve my PA/NUT goal (e.g., How can others support me?).
21	Prompt identification as a role model.	lndicating how the person may be an example to others and influencence their behavior or provide an opportunity for the person to set a good example.	I try to be a role model for others with my PA/NUT behavior and to positively influence their behavior.
22	Prompt self-talk.	Encourage use of self-instruction and self-encouragement (aloud or silently) to support action.	I use self-instructions to motivate me to achieve my PA/NUT goal (e.g., mental encouragement, concrete instructions).
23	Relapse prevention.	Following initial change, help identify situations likely to result in readopting risk behaviors or failure to maintain new behaviors and help the person plan to avoid or manage these situations	I identify situations in which I could fall back into a sedentary behavior / unhealthy eating behavior and try to avoid them.
24	Stress management.	May involve a variety of specific techniques (e.g., progressive relaxation) that do not target the behavior but seek to reduce anxiety and stress.	I specifically try to regulate stress (e.g., progressive muscle relaxation).
25	Motivational interviewing	Prompting the person to provide self-motivating statements and evaluations of their own behavior to minimize resistance to change	I use self-motivating statements to minimize possible inner resistance to the PA/NUT goal (e.g., "I can do it", "Come on now, pull yourself together").
26	Time management	Helping the person make time for the behavior (e.g., to fit it into a daily schedule)	I plan my time so that my PA/NUT fits into everyday life.

SE-BCTs were formulated to highlight the self-enacted application of the strategies, contrasting them from externally applied BCTs

PA stands for sport and physical activity, NUT stands for nutrition

A complete version of the SE-BCT questionnaire for PA and NUT (instructions, items, response scale) can be found on OSF (https://osf.io/g6c8r/?view_only=957a269b9d3242c4af72f483e299aaa6)

This and other taxonomies (Kok et al., 2016; Michie et al., 2013) have set the stage for taking higher-level perspectives – at a *meta-level* s– to adequately assess the effectiveness of intervention techniques (e.g., Pescatello et al., 2021). For example, in the domains of physical activity and diet, a meta-review showed that the BCT intervention "*self-monitoring*" best improves health behavior change and health outcomes (Suls et al., 2020). This confirms a previous meta-regression based on Abraham & Michie's (2008) 26-item taxonomy for BCT, showing that *self-monitoring* plus at least one other *technique from control theory* (Carver & Scheier, 1982), e.g., setting goals, receiving feedback, and reviewing relevant goals in light of feedback, were significantly more effective than other interventions (Michie et al., 2009). As outlined in the methods section, we used Abraham and Michie´s (2008) taxonomy as a basis for developing a SE-BCTs assessment tool.

Aims of the present research

The aims of this research are to introduce a tool to assess SE-BCTs and to explore the use of SE-BCTs by addressing several fundamental questions. Firstly, we investigate which SE-BCTs are used to what extent and whether their usage differs in the domains of physical activity and nutrition. We have chosen these behavioral domains due to their significantly positive health impacts (PA: Saqib et al., 2020, Singh et al., 2023; NUT: Taylor et al., 2023, Xu et al., 2021). While previous studies examining the efficiency of BCTs combine PA and healthy nutrition in their analyses and interpretation (Hankonen et al., 2015; Michie et al., 2009; Samdal et al., 2017), we consider these behavioral domains separately. This approach allows us to determine whether strategies usage and efficiency differ in the domains of PA and NUT, and enables us to infer whether a stronger tailoring of BCTs to different target behaviors might be beneficial (Black et al., 2019).

Secondly, we examine whether SE-BCT usage varies across ages and genders. We examined gender differences to gain insights into addressing the gender gap in physical activity (women being less active than men; The Lancet Public Health, 2019) and healthy nutrition (men consuming less healthy diets than women; Wardle et al., 2004). Additionally, we explored age differences in SE-BCT use to understand the challenges related to physical activity decline with age (Kleinke et al., 2020) and to investigate age-related variations in dietary patterns (e.g., lower energy intakes, higher consumption of vegetables and fruits; Drewnowski & Shultz, 2001). Identifying SE-BCTs that are highly effective for PA or nutrition behaviors but underutilized by specific genders or age groups could be particularly considered in gender-tailored or age-tailored interventions.

Another aspect of our exploration concerns how SE-BCTs interrelate. To this end, we investigate the Bayesian psychometric network they form, aiming to visually inspect

whether SE-BCTs cluster similarly to traditional BCTs (Michie et al., 2015).

Furthermore, our study includes initial analyses on the external validity of SE-BCTs. Specifically, we examine their association with variables that serve as theoretically plausible antecedents and consequences of SE-BCT use. As antecedents, we analyze the importance and difficulty of self-set goals. Behavior change techniques are strategies employed when actions are not smoothly executed or intrinsically motivated, and are mobilized when overcoming obstacles in goal pursuit (Achtziger & Gollwitzer, 2010; Schwarzer, 2008). This is particularly relevant for goals perceived as difficult. Additionally, our validity testing explores relationships between SE-BCT use and potential indicators of successful health behavior. We hypothesize positive correlations between SE-BCTs and progress in self-set goals, physical activity, and healthy eating. Furthermore, we aim to identify the most effective behavior change strategies or combinations thereof by testing SE-BCT combinations as predictors of successful behavior change (Michie et al., 2009; Vetrovsky et al., 2022).

Methods

Participants and procedure

504 participants (203 indicated to be female, 297 to be male, and 4 chose the diverse category) with a mean age of 40.02 years ($SD = 11.36$) were recruited from Amazon's website Mechanical Turk (MTurk; requirements: ≥ 100 HITs, approval rate ≥ 90%, US citizenship). Participants received $2 for completing the web-based questionnaire (LimeSurvey: An open source survey tool. URL http://www.limesurvey.org), which was accessible for a two-week time frame in August and September 2022. The sample size was not determined statistically (e.g., via power analysis) but was limited by the available financial resources for participant compensation.

Participants were first informed that the study is about health behavior change in the domains of physical activity (PA) and healthy nutrition (NUT) and subsequently gave their informed consent. The study was divided into a PA and a NUT section, and participants worked on these two sections in counterbalanced order. The order of items was constant for both questionnaires. Participants initially indicated whether they were pursuing a corresponding goal, that is, a PA goal or a NUT goal, and were prompted to specify this goal in case they answered in the affirmative. Of the 504 subjects, 311 reported pursuing a PA goal (e.g., increase number of gym visits) and 340 declared pursuing a NUT goal (e.g., eating more fruit and vegetables; for details, see supplemental material in OSF, https://osf.io/g6c8r/?view_only=957a269b9d3242c4af72f483e299aaa6). Forty-six subjects from these groups reported pursuing both goals, and completed the following questionnaires for both behavioral domains. Participants then rated their specified goal in terms of its importance, its difficulty, and the progress already made toward its attainment. This was followed by PA- and NUT-specific versions of a newly developed SE-BCT tool, and participants specified any additional strategies they might use. They then completed the International Physical Activity Questionnaire (IPAQ) (Craig et al., 2003) in the PA section and the Eating Style Questionnaire (König et al., 2018; Renner et al., 1996) in the NUT section, respectively. Only participants with a PA or NUT goal answered the corresponding questions, and skipped the section otherwise. As the answer format for all questionnaires, forced answering (FA) was applied to decrease the amount of missing data (for a critical discussion, see Sischka et al., 2022). Other questionnaires were used, but are not reported on further as they are not related to the present research question (for details see study material in OSF). The study was conducted in accordance with the Declaration of Helsinki. It is not subject to a separate IRB assessment per the guidelines of the ethics committee of the authors institution.

Measures

Participants were asked whether they were pursuing a *PA or NUT goal* ("Are you pursuing a sport or physical activity goal / nutrition goal?"). If this was answered in the affirmative, participants were prompted to enter their goal in a free response field. Participants then rated *goal importance* ("It is important to me to pursue my PA/NUT goal") and *goal difficulty* ("Implementing my PA/NUT goal is difficult") with one item each, and *goal progress* (e.g., "I have made a great deal of progress concerning my PA/NUT goal"; recoded: "I've hardly made any progress in the attempt of advancing in my PA/NUT goal") with two items (all items were adapted from Brunstein, 1993) using a 7-point rating scale (1: don´t agree with statement at al – 7: I fully agree with the statement). The two items pertaining to goal progress were averaged into an average score.

To develop a comprehensive self-enacted behavior change technique questionnaire (SE-BCTsQ), we converted the 26 behavior change techniques of Abraham and Michie´s (2008) taxonomy (left column of Table 1) into items that represent BCTs as a behavioral strategy that people self-enact proactively to change health behaviors. For example, we reformulated the instruction for the intervention "Provide individual with information" to "I search for information". For each of the resulting 26 items, people then indicate the extent to which they use this strategy to attain their goals in the physical activity and the healthy nutrition

domain, respectively. This "translation" of the 26 BCTs into 26 SE-BCTs items was carried out by the two authors based on the BCT descriptions by Abraham and Michie (2008) (middle column of Table 1), and by consulting the SE-BCT Compendium (Knittle et al., 2020). The items were further discussed and refined in a course with graduate students regarding their alignment with BCT definitions and the clarity of the items. The resulting 26 *SE-BCT*s items for both behavior domains are shown in the right column in Table 1.

We used two versions of the SE-BCTsQ tailored to the PA and to the NUT domain, respectively (e.g., "I search for information about the relationship between sport and physical activity/healthy eating and health", "I use cues from my environment to remind me to follow my sport and physical activity/healthy eating goal"). The instructions for filling in the questionnaires read: "The table describes strategies that people often use to change their sport and physical activity behavior (/nutrition behavior). Please indicate how much you use these strategies for your sport and physical activity (/nutrition). Participants indicated their agreement with the statements using a 7-point rating scale (anchors: 1: I don´t agree with the statement at all, 4: I partly agree with the statement, 7: I fully agree with the statement). The analysis focuses on each strategy in the SE-BCT inventory individually, which is complemented by an analysis of a mean score across all SE-BCTs. *Additional behavior change techniques* could be listed in a free response field ("Further strategies I use to achieve my sports / physical activity goal: _____"). This list of items is displayed in Additional File 1.

To assess *physical activity* behavior, the International Physical Activity Questionnaire (IPAQ, Craig et al., 2003) was used. Participants were asked how many days per week they spent with walking, with moderate physical activity (such as carrying light loads or riding a bicycle at ordinary speed), and with vigorous activity (such as aerobics, running, or fast cycling) for at least 10 min without interruption. Participants also indicated how much time they spent on average with each of these three intensity levels. Further, we calculated an overall MET value (further abbreviated PA-MET) per week by aggregating the values for walking, moderate PA, and vigorous PA (MET = 3.3 * walking minutes * walking days + 4* moderate minutes * moderate days + 8* vigorous minutes * days). To assess *healthy nutrition* behavior, we used the *Eating Style Questionnaire* that was developed by Renner et al. (1996) and revised by König et al. (2018). The current German version (https://www.psychologie.uni-konstanz.de/en/working-group-renner/research/questionnaires-and-scales/health-psychology-scales/healthy-eating-style-questionnaire, retrieved August 15, 2022) was translated into English by the first author and reviewed by the co-author (neither of whom are native English speakers). Participants indicated their agreement to 12 statements (e.g., "I do not eat fast food", reverse coded: "I eat a lot of meat or sausage") using a 7-point item scale (1: do not agree at all – 7: fully agree).

Statistical analyses

In need of a better understanding of SE-BCTs, we start with describing their characteristics, for example whether participants agreed to some SE-BCTs more strongly than to others (average scores) and how broadly they are dispersed among participants (standard deviations). Because our study is exploratory in nature and we only have little prior knowledge of the structure of SE-BCTs, their usage by participants, and their relations to goal characteristics or health behavior, we further used a Bayesian approach (Wagenmakers et al., 2018) to investigate relationships and differences (i.e., Bayesian t-tests and regressions). We report the Bayes factor that quantifies the relative predictive performance of two rivaling hypotheses (Wagenmakers et al., 2016) referred to as the null-hypothesis (H0: no differences/relationships) and the alternative hypothesis (H1: significant differences/relationships). We specifically report the BF10, which expresses the likelihood of the alternative-hypothesis divided by the likelihood of the null hypothesis. In brief, BF10 index the evidence for H1 over H0 (i.e., larger values of BF10 indicate stronger support for H1 relative to H0). To classify the strength of evidence that different Bayes Factors provide, we refer to Jeffreys (1939) and Van Doorn et al. (2021) and describe a BF10 of 3 or less as "weak evidence", of 3–10 as "moderate evidence", and a BF greater than 10 as "strong evidence" in favor of the alternative hypothesis. We conducted Shapiro Wilks' Test to test whether variables are normally-distributed and applied Bayesian non-parametric tests to test for differences (Bayesian paired sample t-tests / Wilcoxon signed rank r, Bayesian Independent Sample t-tests / Mann-Whitney test), and relationships (Bayesian correlation, Kendall's tau rather than Pearson) when normal distribution was not given.

To take the multivariate nature of our data into account, we relied on psychometric network analysis and modeling (Golino & Eskamp, 2017). Network psychometrics is a new approach in psychological research that interprets multivariate data in terms of a network, with nodes representing individual variables (here, the 26 SE-BCT strategies) and edges representing the strengths of the statistical association between nodes (here, the conditional dependence between the 26 SE-BCT strategies) (Borsboom et al., 2021). To avoid limitations of frequentist psychometric network approaches (i.e., concerns about robustness of networks uncertainty]), we used *Bayesian* network psychometric analysis that directly addresses sources of network uncertainties (by quantifying structure uncertainty, by obtaining

evidence for edge inclusion or exclusion, and by parameter precision) (Huth et al., 2023). We used the Bayesian Psychometric Network approach implemented in JASP (Huth et al., 2023), which uses the functionality of the R-package BDgraph (Mohammadi, & Wit, 2019). We chose "ggm" (Gaussian graphical model for continuous data) as the estimation method. To quantify the structure uncertainty, we chose the "Posterior Structure Probability" and the "Posterior Complexity Plot" options in JASP (see Additional File 2, part A). Evidence for edge inclusion or exclusion is displayed in a table that contains the posterior inclusion probabilities for each edge in the network (Additional File 2, part B). To determine the parameter precision we displayed the weight tables showing the posterior means of the model parameters (Additional File 2, part C). Following conventions in the literature on psychometric networks, the three centrality indices *degree centrality* (sum of direct edges each node has), *closeness* (considers the indirect paths between variables; nodes with a high closeness score have the shortest distances to all other nodes), and b*etweenness centrality* (relative number of shortest paths passing through a specific node) were determined to characterize the centrality of each SE-BCT item in the network (Bringmann et al., 2019) (Additional File 2, part D). To specify the number of iterations for the Markov Chain Monte Carlo sampling procedure (MCMC; used in BDgraph), we chose 10,000 iterations. We used the default prior options in JASP (edge inclusion probability: 0.5., initial configuration prior edge inclusion: empty, degrees of freedom of G-Wishart prior: 3).

Taken together, Bayesian network analysis allows us to characterize the relationship between individual SE-BCTs in a psychometric network. We used the JASP network plots and use them in the following to interpret the visual representation of the estimates (Fig. 1).

We further visually inspected whether SE-BCTs were clustered similarly as BCTs. In Michie's et al.´s (2015) approach, BCTs were assigned to theory-driven clusters on the basis of expert ratings (p. 21–23). Because the 26 SE-BCTs refer to Michie et al.´s clusters "goals" (SE-BCTs 4, 10, 11, 13, 23, 26), "social influence" (SE-BCTs 3, 16, 19, 20, 21), "knowledge" (SE-BCTs 1, 2, 8, 9), "environmental context" (SE-BCTs 15, 18), "behavioral regulation" (SE-BCTs 5, 12), "skills" (SE-BCTs 7, 17), "emotions" (SE-BCT 24), and "reinforcement" (SE-BCT 14) (assignment of SE-BCTs to Mitchie et al´s clusters by authors), we color-coded them accordingly in the networks for physical activity and healthy nutrition. One cluster that is not covered by Michie et al.´ is self-motivation (SE-BCTs 6, 22, 25), which is coded in an additional color in the network. This approach allows to compare the structure of SE-BCTs directly with the structure already established for BCTs. For all analyses we used JASP (JASP Team, 2022).

Results

To what extent people use SE-BCTs in the PA and NUT domain and does usage in the domains differ? Means and standard deviations of all SE-BCTs are displayed in Table 2. Mean values of SE-BCTs are additionally illustrated as points in Fig. 2.

The least used strategy was to *consider other's approval* (SE-BCT 3) in both the PA ($M = 2.8$, $SD = 2.0$) and the NUT domain ($M = 3.0$, $SD = 1.9$). In the PA domain, subjects were most strongly inclined to use *time management* as a strategy (SE-BCT 26; $M = 5.7$, $SD = 1.4$), while *practicing and repeating goal-directed behaviors* was most pronounced in the NUT domain (SE-BCT 17; $M = 5.5$, $SD = 1.4$). The mean score across all SE-BCTs for PA was $M = 4.5$ ($SD = 1.2$) and for NUT $M = 4.5$ ($SD = 1.1$), indicating a generally strong propensity to engage in the various SE-BCTs. Interestingly, Cronbach's alpha was high with 0.938 for PA and 0.940 for NUT, which suggests that the SE-BCT inventory reliable measures people's use of behavior change techniques. To examine differences between SE-BCTs in the PA versus NUT domain on the item level, we applied non-parametric Bayesian paired-sample t-tests for tests as none of the variables was normally-distributed (see Additional File 3 in OSF).

As displayed in Table 2, strong evidence for differences between PA and NUT was found for SE-BCTs 1, 7, 8, 17, 21, and 23, and moderate evidence for SE-BCTs 2, 11, and 20. With the exception of SE-BCT 7 (gradually increasing difficulty), participants scored higher in the NUT domain than in the PA domain.

Does SE-BCT usage differ between age and gender? To test for gender differences in use of SE-BCTs, we calculated Bayesian t-tests for independent samples. The tests only included the categories "female" and "male" because the number of subjects in category "diverse" was too small ($n = 4$; means and standard deviations for all three categories and further details on analyses are displayed in Additional File 4). As summarized in Table 2, men were more strongly inclined than women to explicitly *form a an intention* (SE-BCT 4) in the PA domain and reported to *take information about others' approval* more strongly into account than women (SE-BCT3) in the NUT domain. Regarding age, non-parametric Bayesian correlation revealed weak evidence for negative relationships with the tendency to *reward oneself* (SE-BCT 14) in the PA domain and with the tendency to *consider others' approval* (SE-BCT 3), to *engage in self-monitoring* (SE-BCT 12), and *reward oneself* (SE-BCT 14) in the NUT domain.

How do the BCTs relate to each other in a psychometric network? And do they cluster in a similar way as BCTs? The psychometric networks of PA and NUT in Fig. 1 reveal

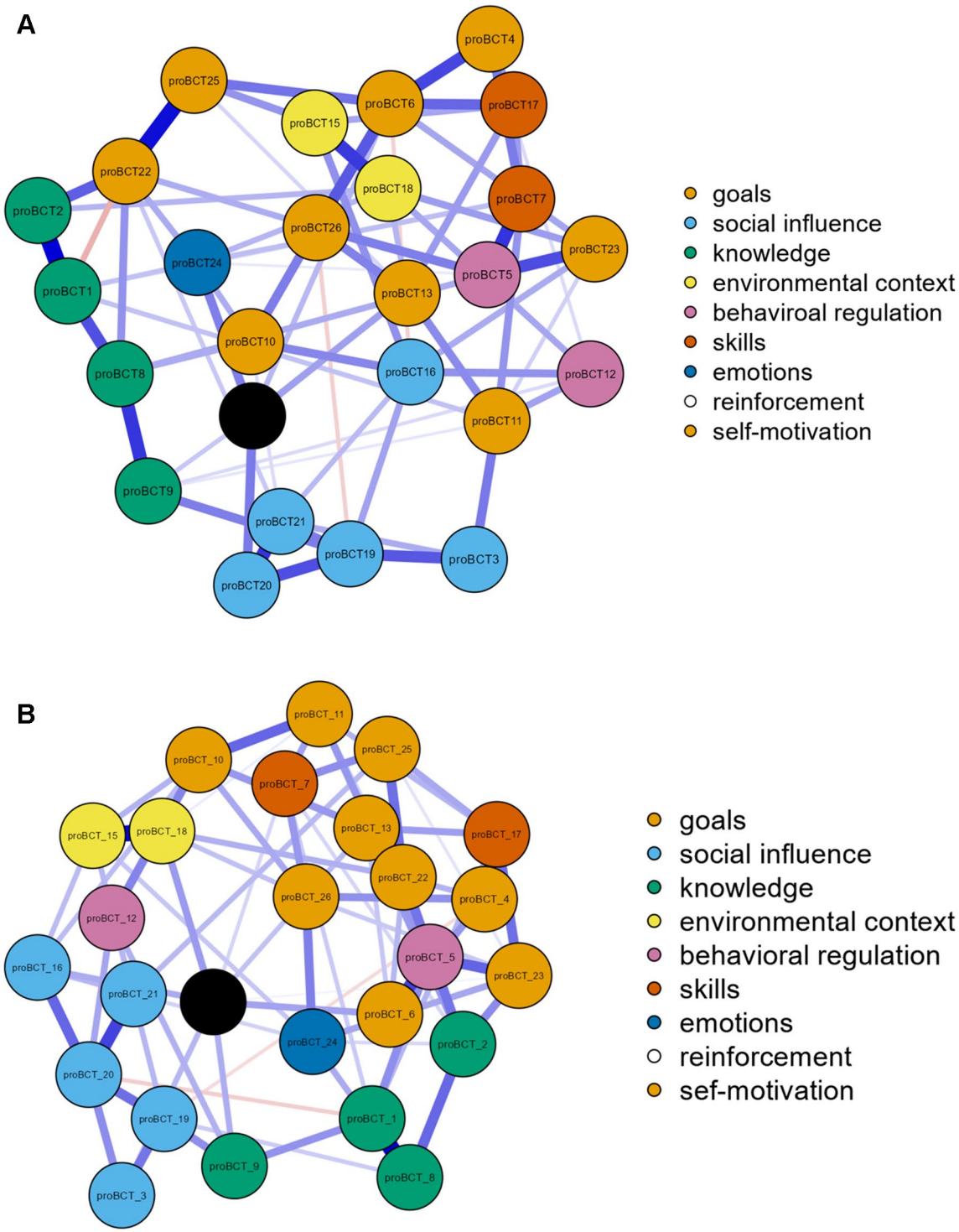

Fig. 1 Results of Bayesian network analyses for SE-BCT-PA and SE-BCT-NUT. Note. The colored markings (colorblind node palette) correspond to the assignments to the domains identified by Michie et al. (2015, p. 20–21) using the theory-driven method (TDF). The node filled in black is SE-BCT14 (rewarding myself), which is the only assigned to Michie´s category "reinforcement"

several strong connections between some SE-BCTs, and SE-BCTs belonging to the same cluster according to Michie et al. (2015) are typically located close to each other. This applies to SE-BCTs that involve the "social environment" (cluster in Michie et al.´s [33] BCT classification, see blue edges) such as *consider other people´s approval* (SE-BCT3), *social comparison* (SE-BCT 19), *social support* (SE-BCT 20) and *being a role model* (SE-BCT 21), and in the NUT

Table 2 Summary of descriptive statistics of SE-BCTs in the domains of physical activity and sport (PA) and health eating (nutrition: NUT), gender differences, correlations with age and differences between PA and NUT. SE-BCTs with the lowest and highest scores for PA and NUT, respectively, are underlined. Differences and relationships for which weak, moderate and strong evidence were found are highlighted in bold letters. (for details on tests for sex differences and correlations see Supplemental table 3)

Physical activity (PA)					Nutrition (NUT)					Differences PA - NUT		
	M	*SD*	Gender differences[1]	Correlations with age		*M*	*SD*	Gender differences[1]	Correlations with age	BF10	W	Rhat
SE-BCT_PA	4.488	1.165	no	no	SE-BCT_NUT	4.543	1.144	no	no	0.236	10257.000	1.001
SE-BCT_1_PA	4.453	1.914	no	no	SE-BCT_1_NUT	4.976	1.741	no	no	**25.948**	3328.000	1.003
SE-BCT_2_PA	5.064	1.735	no	no	SE-BCT_2_NUT	5.365	1.488	no	no	**7.327**	2153.000	1.001
SE-BCT_3_PA	*2.788*	2.008	no	no	*SE-BCT_3_NUT*	*2.956*	1.943	**M > F**	**negative***	0.171	2692.000	1.000
SE-BCT_4_PA	5.347	1.664	**M > F**	no	SE-BCT_4_NUT	5.412	1.563	no	no	0.083	4578.000	1.000
SE-BCT_5_PA	5.280	1.464	no	no	SE-BCT_5_NUT	5.450	1.344	no	no	0.358	2960.500	1.001
SE-BCT_6_PA	5.514	1.402	no	no	SE-BCT_6_NUT	5.244	1.580	no	no	0.155	3926.000	1.000
SE-BCT_7_PA	5.412	1.495	no	no	SE-BCT_7_NUT	4.982	1.681	no	no	**95.253**	6817.000	1.000
SE-BCT_8_PA	4.646	1.929	no	no	SE-BCT_8_NUT	5.244	1.657	no	no	**685.338**	2908.500	1.003
SE-BCT_9_PA	3.659	2.140	no	no	SE-BCT_9_NUT	3.703	2.023	no	no	0.096	4652.000	1.000
SE-BCT_10_PA	4.421	1.882	no	no	SE-BCT_10_NUT	4.318	1.824	no	no	0.077	6138.500	1.000
SE-BCT_11_PA	4.463	1.812	no	no	SE-BCT_11_NUT	4.862	1.695	no	no	**5.717**	3786.500	1.002
SE-BCT_12_PA	3.923	2.286	no	no	SE-BCT_12_NUT	3.568	2.327	no	**negative***	0.311	5094.000	1.000
SE-BCT_13_PA	4.662	1.781	no	no	SE-BCT_13_NUT	4.762	1.765	no	no	0.254	4083.000	1.001
SE-BCT_14_PA	4.203	1.963	no	**negative***	SE-BCT_14_NUT	4.215	1.941	no	**negative***	0.076	3749.500	1.000
SE-BCT_15_PA	4.376	1.832	no	no	SE-BCT_15_NUT	4.024	1.894	no	no	1.475	5519.000	1.000
SE-BCT_16_PA	3.608	2.146	no	no	SE-BCT_16_NUT	3.768	2.111	no	no	0.162	3074.000	1.001
SE-BCT_17_PA	5.277	1.554	no	no	*SE-BCT_17_NUT*	*5.485*	1.394	no	no	**11.628**	2518.000	1.003
SE-BCT_18_PA	4.392	2.005	no	no	SE-BCT_18_NUT	4.338	1.961	no	no	0.099	4075.500	1.000
SE-BCT_19_PA	3.418	2.194	no	no	SE-BCT_19_NUT	3.465	2.066	no	no	0.117	3230.500	1.000
SE-BCT_20_PA	3.344	2.087	no	no	SE-BCT_20_NUT	3.476	2.056	no	no	**5.780**	2635.000	1.001
SE-BCT_21_PA	3.402	2.109	no	no	SE-BCT_21_NUT	3.668	2.131	no	no	**11.323**	2594.000	1.000
SE-BCT_22_PA	4.907	1.727	no	no	SE-BCT_22_NUT	5.029	1.592	no	no	0.357	3553.500	1.000
SE-BCT_23_PA	4.830	1.723	no	no	SE-BCT_23_NUT	5.262	1.542	no	no	**54.939**	2565.500	1.003
SE-BCT_24_PA	4.643	1.881	no	no	SE-BCT_24_NUT	4.550	1.837	no	no	0.270	4868.500	1.000
SE-BCT_25_PA	4.990	1.802	no	no	SE-BCT_25_NUT	4.782	1.763	no	no	0.233	4031.000	1.001
SE-BCT_26_PA	*5.675*	1.401	no	no	SE-BCT_26_NUT	5.209	1.631	no	no	1.450	4587.500	1.001

Note. SE-BCT_PA: $n = 311$. SE-BCT_NUT: $n = 340$

All variables ranged from 1–7

[1] M: male, F: female

[1]* weak evidence for relationship (BF10: 0–3), ** moderate evidence (BF10: 3–10), *** strong evidence (BF10: >10)

+ BF10 in bold: "strong evidence" for alternative hypothesis (differences) according to Jeffreys (1939)

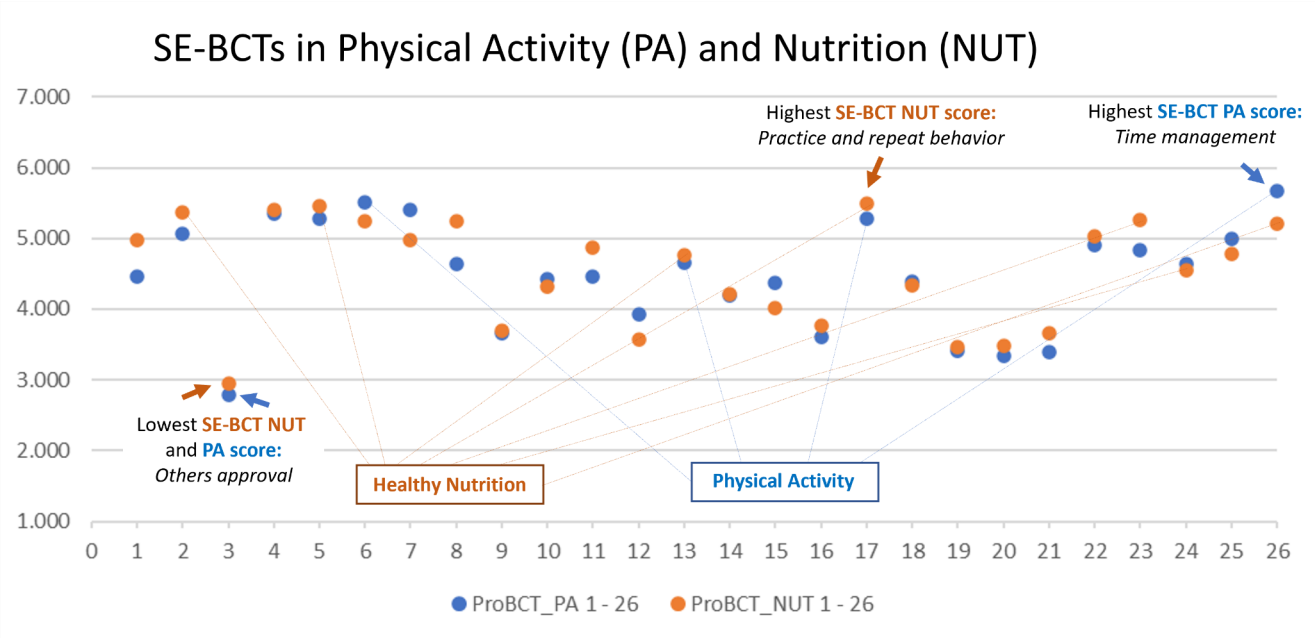

Fig. 2 Illustration of SE-BCT scores (for SE-BCT wording see Table 1), and correlations with Healthy Nutrition and Physical Activity (PA-MET). Lines indicate correlations of SE-BCTs to corresponding health behavior questionnaire. For clarity, only correlations of r > .2 are stated.

network also *social contracts* (SE-BCT 16). This also applies to SE-BCTs that relate to "knowledge" (see green edges) such as *search for information* (SE-BCT 1), *weighing pros and cons of behavior according to health outcomes* (SE-BCT 2), *looking for information* (SE-BCT 8), and *looking for experts* (SE-BCT9). Also the SE-BCTS pertaining to the "environmental context" (see yellow edges) *using cues to remind on behavior* and *reminding myself to perform behavior* are strongly linked. Further, the "goal"- SE-BCTs (orange edges) *matching behavior with goal* (SE-BCT 13) and *planning time* (SE-BCT 26), as well as the "self-motivation" SE-BCTs *self-instructions* (SE-BCT 22) and *self-motivating statements* (SE-BCT 25) are strongly related in the PA and NUT domain. Also *identifying and removing obstacles* (SE-BCT 5, Michie´s BCT cluster: "behavioral regulation") and *identifying fall backs and avoiding them* (SE-BCT 23, Michie´s cluster: "goals") have strong edges in the PA and NUT domains. There are, however several noteworthy differences between the PA and NUT networks. For example, in the PA network *set graded tasks* (SE-BCT 7) and *practicing and repeating behavior* (SE-BCT 17) are directly related, while in the NUT network they are only connected indirectly to each other via *matching behavior with goals* (SE-BCT 13). Another example is the direct relationship between *identifying obstacles and removing them* (SE-BCT 5) and *encouraging myself to exert effort* (SE-BCT 6) in the NUT network that are indirectly linked (via *planning time*, SE-BCT26) in the PA network. In Additional File 2, part D we report the centrality indices betweenness, closeness, strength, and the expected influence (normalized centrality measures).

Is the use of SE-BCTs related to importance and difficulty of PA and NUT goals? To test our hypothesis according to which SE-BCTs positively correlate with difficulty and importance of one's self-set goal, we calculated non-parametric Bayesian correlation coefficients, which are displayed in Table 3.

In the PA domain, moderate-to-strong evidence for positive relationships between thirteen SE-BCTs and goal importance were found (e.g., correlations > 0.20 for *intention formation*, SE-BCT4, and *self-encouragement*, SE-BCT 6). In contrast, only one strategy (*time management*; SE-BCT 26) was correlated with goal difficulty, and this correlation was negative and thus opposite to the hypothesized direction: The more difficult the goal, the less willing people are to plan time for this goal so that it fits in their everyday life. Also in the NUT domain, relationships between SE-BCTs and goal importance were stronger than for SE-BCTs and goal difficulty. Again, *time management* (SE-BCT26) was negatively related to goal difficulty, and in addition a negative relationship was found for *practicing and repeating nutrition behavior* (SE-BCT 17) and a positive relationship with *trying be a role model for nutrition behavior* (SE-BCT 21). Strong evidence for positive relationships with goal importance was found for 19 SE-BCTs with, for example, correlations above 0.35 for SE-BCTs 2, 5, 6, 17, and 23. Across both behavioral domains, it appears that (with few exceptions) the same SE-BCTs are related to goal importance (SE-BCTs 1, 2, 4–8, 10, 17, 23, 25, 26),

Table 3 Bayesian correlations (Kendall´s Tau) between SE-BCTs and difficulty and importance of self-set goals. Strong evidence for relationships ($BF_{10} > 10$) are highlighted in bold

PA	Goal difficulty		Goal importance		NUT	Goal difficulty		Goal importance	
	K´s Tau	BF_{10}	K´s Tau	BF_{10}		K´s Tau	BF_{10}	K´s Tau	BF_{10}
SE-BCT_PA	0.000	0.080	**0.106****	2.314	SE-BCT_NUT	−0.003	0.071	**0.221*****	7.72e+6
SE-BCT_1	0.032	0.109	**0.118****	5.112	SE-BCT_1	−0.043	0.141	**0.284*****	1.13e+12
SE-BCT_2	0.046	0.151	**0.179*****	1172.542	SE-BCT_2	−0.063	0.321	**0.365*****	5.06e+20
SE-BCT_3	0.016	0.086	−0.042	0.134	SE-BCT_3	0.044	0.147	−0.087*	1.223
SE-BCT_4	0.037	0.119	**.230*****	613737.5	SE-BCT_4	0.000	0.071	**0.299*****	3.53e+13
SE-BCT_5	0.035	0.115	**0.185*****	2520.858	SE-BCT_5	−0.024	0.088	**0.415*****	1.06e+27
SE-BCT_6	−0.079	0.505	**.247*****	6.224e+6	SE-BCT_6	0.066	0.072	**0.365*****	4.29e+20
SE-BCT_7	−0.008	0.081	**0.181*****	1442.744	SE-BCT_7	0.021	0.084	**0.198*****	18285.14
SE-BCT_8	0.026	0.097	**0.169*****	385.462	SE-BCT_8	−0.018	0.080	**0.298*****	2.60e+13
SE-BCT_9	0.101*	1.633	0.036	0.119	SE-BCT_9	0.010	0.074	0.069	0.437
SE-BCT_10	0.038	0.124	**0.134*****	16.678	SE-BCT_10	−0.050	0.182	**0.177*****	9599.988
SE-BCT_11	0.061	0.246	0.108*	2.677	SE-BCT_11	0.063	0.317	**0.196*****	146548.1
SE-BCT_12	−0.040	0.129	0.087	0.754	SE-BCT_12	−0.014	0.077	0.089*	1.371
SE-BCT_13	−0.037	0.127	0.127	9.958	SE-BCT_13	−0.018	0.080	**0.242*****	2.64e+8
SE-BCT_14	0.022	0.092	0.043	0.137	SE-BCT_14	0.038	0.122	0.097*	2.473
SE-BCT_15	0.077	0.473	−0.003	0.080	SE-BCT_15	0.034	0.111	**0.103*****	3.789
SE-BCT_16	−0.004	0.080	0.014	0.084	SE-BCT_16	−0.011	0.075	0.059	0.266
SE-BCT_17	−0.065	0.280	**0.192*****	4790.237	SE-BCT_17	**−0.102****	3.509	**0.452*****	2.27e+32
SE-BCT_18	0.009	0.082	0.085	0.683	SE-BCT_18	−0.006	0.072	**0.135*****	68.486
SE-BCT_19	0.004	0.080	−0.041	0.131	SE-BCT_19	0.021	0.083	0.033	0.107
SE-BCT_20	0.031	0.105	−0.050	0.167	SE-BCT_20	0.052	0.201	0.013	0.076
SE-BCT_21	−0.058	0.218	0.023	0.094	SE-BCT_21	**0.104****	4.280	0.080	0.800
SE-BCT_22	−0.085	0.695	0.102*	1.817	SE-BCT_22	−0.023	0.086	**0.276*****	2.12e+11
SE-BCT_23	−0.041	0.133	**0.167*****	324.869	SE-BCT_23	−0.055	0.222	**0.367*****	8.87e+20
SE-BCT_24	−0.037	0.120	0.106*	2.334	SE-BCT_24	−0.019	0.082	**0.216*****	3.14e+6
SE-BCT_25	−0.033	0.109	**0.124*****	7.970	SE-BCT_25	0.069	0.422	**0.206*****	613907.9
SE-BCT_26	**−0.124****	7.831	**0.190*****	3930.419	SE-BCT_26	**−0.107****	5.173	**0.297*****	1.87e+13

K´s Tau: Kendall´s Tau

* weak evidence, **moderate evidence, *** strong evidence for relationship

while there are few small associations between SE-BCTs and goal difficulty.

Is the use of SE-BCTs related to indicators of successful PA and NUT behavior? To investigate the relationship between SE-BCTs and progress in self-set goals, physical activity and healthy eating, respectively, we again calculated non-parametric Bayesian correlation coefficients. As shown in Table 4, for the PA domain strong evidence for positive relationships between SE-BCTs and PA-MET were found. The highest correlations were observed for the overall SE-BCT use and for the SE-BCTs 6, 12, 13, 17, and 26 (correlations greater than 0.20). The correlations between SE-BCTs and goal progress (SE-BCT 6, 17) were lower, but SE-BCT 26 (*time management*) stands out here as well. For the NUT domain, also strong evidence for positive relationships between SE-BCTs and healthy eating was observed. The highest correlations were found for the overall SE-BCT use and for the SE-BCTs 2, 5 13, 17, 23, 24, 26 (correlations greater than 0.20). In contrast to the PA domain, strong evidence for positive relationships between SE-BCTs and goal progress were more frequent. To name but a few examples, SE-BCTs 5, 17, and 26 correlated greater than 0.30 with progress in self-set goals. A comparison between the correlational patterns for PA and NUT shows that they are partly different, but partly similar. For example, SE-BCTs 17 (*repeating behavior*) and 26 (*time management*) stand out with high correlations with indicators of goal success in both behavioral domains. A summary of the strongest correlations ($r > .20$) between SE-BCTs and physical activity (PA-MET) and healthy eating are displayed in Fig. 2.

In addition to the relationships of single BCTs with PA and NUT behavior, we examine whether some SE-BCTs combinations are better predictors of successful behavior than others. Therefore, we tested the effects of all 26 SE-BCTs (controlled for each other in a Bayesian multiple regression) on physical activity, healthy eating, and goal progress. The best fitting SE-BCT models to predict (a) PA-MET, (b) PA goal progress, (c) healthy eating style, and (d) NUT goal

Table 4 Bayesian correlations (Kendall´s Tau) between SE-BCTs and indicators of healthy behavior change for PA and NUT. Strong evidence for relationships are highlighted in bold

PA	Progress_PA		PA_MET		NUT	Progress_NUT		Eating Style	
	K´s Tau	BF_{10}	K´s Tau	BF_{10}		K´s Tau	BF_{10}	K´s Tau	BF_{10}
SE-BCT_PA	0.051	0.175	**0.208*****	218978.7	SE-BCT_NUT	**0.134*****	63.631	**0.211*****	1.498e+6
SE-BCT_1	0.035	0.116	**0.126*****	18.192	SE-BCT_1	**0.157*****	820.649	**0.192*****	74522.44
SE-BCT_2	0.024	0.095	0.109**	4.361	SE-BCT_2	**0.217*****	3.493e+6	**0.249*****	1.050e+9
SE-BCT_3	−0.054	0.191	0.085	0.871	SE-BCT_3	**−0.216*****	1.192e+6	0.063	0.322
SE-BCT_4	0.056	0.207	**0.142*****	80.639	SE-BCT_4	**0.183*****	21652.93	**0.135*****	67.924
SE-BCT_5	0.070	0.348	**0.189*****	15581.49	SE-BCT_5	**0.301*****	5.38e+13	**0.201*****	287355.2
SE-BCT_6	**0.163*****	217.178	**0.201*****	79546.81	SE-BCT_6	**.231*****	3.841e+7	**0.167*****	25.83.7
SE-BCT_7	0.051	0.172	0.106**	3.552	SE-BCT_7	**0.115*****	10.438	**0.178*****	10989.91
SE-BCT_8	0.015	0.086	**0.119*****	10.173	SE-BCT_8	**0.171*****	4513.530	**0.170*****	4123.496
SE-BCT_9	−0.067	0.304	**0.120*****	10.656	SE-BCT_9	−0.029	0.098	**0.133*****	54.045
SE-BCT_10	0.105*	2.195	**0.198*****	56532.11	SE-BCT_10	**0.12*****	15.780	**0.191*****	17999.35
SE-BCT_11	−0.019	0.088	**0.128*****	20.964	SE-BCT_11	0.096*	2.283	0.085*	1.074
SE-BCT_12	0.035	0.115	**0.207*****	204812.1	SE-BCT_12	0.035	0.111	0.084*	1.052
SE-BCT_13	0.058	0.215	**0.209*****	239763.4	SE-BCT_13	**0.191*****	72580.26	**.209*****	958752.8
SE-BCT_14	0.035	0.116	**0.125*****	18.474	SE-BCT_14	0.078	0.691	0.055	0.222
SE-BCT_15	−0.091	0.931	0.101*	2.454	SE-BCT_15	0.044	0.145	0.090*	1.522
SE-BCT_16	0.005	0.080	**0.125*****	15.852	SE-BCT_16	0.037	0.120	0.089*	1.442
SE-BCT_17	**0.161*****	176.781	**0.209*****	262919.2	SE-BCT_17	**.345*****	3.41e+18	**0.235*****	8.179e+7
SE-BCT_18	−0.016	0.089	**0.116****	7.534	SE-BCT_18	**0.131*****	51.036	0.181	16133.59
SE-BCT_19	−0.037	0.119	0.092*	1.418	SE-BCT_19	−0.009	0.079	0.121	17.751
SE-BCT_20	−0.048	0.159	0.065	0.324	SE-BCT_20	−0.074	0.560	0.074	0.574
SE-BCT_21	0.038	0.124	**0.141*****	72.061	SE-BCT_21	0.070	0.448	**0.165*****	2043.757
SE-BCT_22	0.065	0.282	**0.157*****	382.991	SE-BCT_22	**0.208*****	889098.6	**0.170*****	3753.806
SE-BCT_23	0.039	0.127	0.097*	1.935	SE-BCT_23	**0.296*****	1.67e+13	**0.232*****	4.821e+7
SE-BCT_24	0.047	0.155	**0.159*****	472.278	SE-BCT_24	**0.220*****	6.323e+6	**0.218*****	4.230e+6
SE-BCT_25	0.116**	4.337	**0.135****	41.453	SE-BCT_25	0.101**	3.330	0.114**	9.571
SE-BCT_26	**.204*****	19120.3	**0.218*****	1.04e+6	SE-BCT_ 26	**0.300*****	3.65e+13	**.221****	7.06e+16

K´s Tau: Kendall´s Tau

* weak evidence **moderate evidence *** strong evidence for relationship

progress were identified (for details see Additional File 5). The strongest evidence to predict PA-MET was found for SE-BCT26 (time management) (BF = 1169.192) and for SE-BCT10 (detailed plans) (BF = 494.590), and the combination of both (BF = 6513.340). Also in predicting goal progress, SE-BCT26 (time management) turned to out to be the strongest single predictor (BF = 305.995), with a large increase in strength of evidence when being combined with SE-BCT 6 (self-encouragement) and SE-BCT 15 (environmental cues as reminders) (BF = 25266.015).

In the NUT domain, no single SE-BCT was among the top prediction models to predict healthy eating style or progress in NUT goal (Additional File 5, part c, d). Instead, combinations of multiple SE-BCTs are shown to be more predictive for healthy eating (e.g., SE-BCTs 2, 13, 14, 21, 24, 26) (BF = 2.668e + 12) and for NUT goal progress (i.e., SE-BCT3, 17, 20, 21, 23, 26) (BF = 1.584e + 20).

Discussion

The intention of this study was to measure self-enacted BCTs, examine their frequency of occurrence, psychometric structure, and relationships with theoretically plausible antecedents and consequences. A fundamental question is whether individuals can comprehend the formulation of SE-BCTs, which were derived from theoretical considerations and interventions grounded in the BCT taxonomy (Abraham & Michie, 2008). Additionally, it is crucial to assess whether individuals perceive SE-BCTs as valid descriptions of their behavior. The observation of typical questionnaire response patterns, including agreement to the SE-BCT statement with intra- and interindividual variability and variability across behavioral domains, lends empirical support to these assumptions. This allows for a deeper insight into the data.

Characterizing SE-BCTs across behavioral domains

From the descriptive data, we learned that some SE-BCTs are used more intensively than others across the behavioral domains of physical activity (PA) and healthy nutrition (NUT). As Fig. 2 illustrates, the *time management* strategy (SE-BCT 26; "I plan my time so that my PA/NUT behavior fits into everyday life") scored very high in both the NUT and PA domain, whereas other strategies like *considering other's approval* (SE-BCT 3; "I consider whether or not other people like my changed PA/NUT behavior") are used far less. Intriguingly, SE-BCT 26 was also the strategy with high correlations with goal attainment in both the PA and the NUT domain (PA-MET, healthy eating) (see Fig. 2). Thus, people indeed seem to proactively choose BCTs that are actually conducive to their specific behavior change goals and self-enact them. This also holds for *practicing and repeating behavior* (SE-BCT17), and for *encouraging oneself* (SE-BCT 6) in the PA domain and for *weighing costs and benefits* and *identifying obstacles* (SE-BCT 2,5) in the NUT domain, respectively. Whether the reason for choosing the SE-BCTs is that people find these SE-BCTs most intuitive or feasible, or whether these SE-BCTs have prevailed in an empirical test in real life (experience of efficiency in the past and therefore retention of the strategy), is the subject of future research.

In addition to the similarities between SE-BCT use in the two behavioral domains, there was also evidence for differences. Participants seek information about the relationship between behavior and consequences (SE-BCT 1) and about how to perform the behavior correctly (SE-BCT 8) more often when they want to achieve a NUT goal than a PA goal. It is left to future research to find out whether people need more information for NUT (e.g., how many calories are in which food?), whether they assume that information is more important for achieving a dietary goal than for achieving an PA goal (e.g., because nutrition behavior appears to be more complex than PA), or whether information for NUT is simply more easily available (e.g., internet, social media) or easier to understand. Compared to the PA domain, participants also report to practice and repeat behaviors that bring them closer to their goal (SE-BCT 17) more strongly in the NUT domain, and to identify and avoid situations that could jeopardize their goal attainment (SE-BCT 23). In PA, on the other hand, it seems more common to set graded tasks (SE-BCT 7: „I start with easy tasks and increase the difficulty until I reach my PA/NUT goal."), which fits the principle of graduation (in intensity or frequency) of a physical workout with the goal of regulating body weight or increasing performance. In summary, the answer to the first question is that we have learned from the exploration of the 26-items SE-BCT questionnaire that people self-enact BCTs included in Abraham and Michie´s (2008) taxonomy, but to a greater or lesser extent and that they use effective BCTs more intensively.

Gender and age and differences in SE-BCT use

Analyses of gender differences showed that men and women differed in only two out of 26 SE-BCTs. First, men agreed more strongly with the item to specify their PA desires in terms of specific goals (SE-BCT 4). As planning is one of the most effective strategies for increasing physical activity (Peng et al., 2022), the more extensive use of this strategy may partly explain why men - despite being generally less involved in health behaviors and having an overall less healthy lifestyle than women (Hunter, & Rosairo, 2010) – are more physically active than women (Azevedo et al., 2007). The greater use of planning processes by men in our sample may also be due to the fact that planning appears to be more successful as a strategy for improving physical activity for men than for women. Secondly, we found evidence of higher scores in SE-BCT 3 in the domain NUT, which means that men pay more attention than women to whether or not other people like their changed dietary behavior.

Regarding age, we found weak evidence for a negative relationship with SE-BCT 14 in both behavioral domains: with increasing age, participants use the SE-BCT "rewarding myself for PA or healthy nutrition" less frequently. Additionally, in the NUT domain, older people consider less than younger people whether or not others like their behavior (BCT 3) and are less likely to agree to self-monitor their behavior (SE-BCT 12). Interestingly, the latter two BCTs (self-monitoring, normative information) are among those that French et al. (2014) identified as self-regulatory techniques which, while generally having a high impact, were found to be ineffective for PA in older individuals. In a meta-analysis testing the effectiveness of BCTs for NUT behavior (Lara et al., 2014), self-monitoring, normative information, and rewards did not stand out as particularly effective for older individuals (for them, feedback, goal-setting, and barrier identification were more effective). Perhaps the less frequent use of SE-BCT 3, 12, and 14 represents a functional adaptation to their decreasing effectiveness with age. Studies, including interviews with various age groups, are needed to ask for reasons behind the (non)use of SE-BCTs to explain these differences.

Relationships between SE-BCTs in psychometric networks

The Bayesian psychometric network analyses show that some SE-BCTs are closely linked to each other in both the PA and NUT network, but there are differences between

these networks as well. Some of the theory-driven clusters of BCTs proposed by Michie et al. (2015) also emerged in the SE-BCTs network: SE-BCTs that involve the "social environment" (*consider other people´s approval*, *social comparison*, *social support*, *being a role model)*, SE-BCTs that concern "knowledge" (*search for information*, *weighing pros and cons of behavior according to health outcomes*, *looking for information*, *looking for experts)*, and SE-BCTs dealing with "environmental context" (*using cues to remind on behavior*, *reminding myself to perform behavior)* are placed closely together and display strong links in the PA and NUT network alike. Also, cross- SE-BCT clusters are related by strong edges, such as *matching behavior with goal* and *planning time* with *using self-instructions* and *self-motivating statements*, and *identifying and removing obstacles* with *identifying fall backs and avoiding them.* The clusters "skill" (*graded tasks* and *practicing and repeating behavior*) and "behavioral regulation" (*identifying and removing obstacles* and *documenting behavior*) were only found in the PA, but not in the NUT network. In some cases, SE-BCTs are directly related in one network (e.g. PA: *set graded tasks* and *practicing and repeating behavior; NUT: identifying obstacles and removing them* and *encouraging myself to exert effort*), but only indirectly in the other. Two possible reasons for why not all clusters proposed by Michie et al. (2015) for BCTs were found so clearly in our networks could be that SE-BCTs are indeed related to each other differently than BCTs, and that Michie et al. (2015) did not use a data-driven psychometric network approach but rather a theory-driven expert consensus approach. However, for our goal to describe the relationship of SE-BCTs in a psychometric network and to better understand their relationship to each other, a psychometric network analysis was better suited as a first step in a research process.

Potential antecedents and consequences of SE-BCTs

Support for the hypothesis of a positive relationship with SE-BCTs was mainly found for goal *importance*. The overall correlation pattern is similar across both behavioral domains: The more important the PA or NUT goal is, the more strongly do participants agree with several SE-BCTs (1, 2, 4–8, 10, 17, 23, 25, 26). It is, however striking that these correlations are consistently lower in the PA domain (small effect sizes according to Cohen, 1988) than in the NUT domain (e.g., five correlations on moderate effect size level). To name but a few examples, the more important the NUT goal, the more participants practice and repeat goal relevant behaviors (SE-BCT 17, r=.452), aim to identify obstacles that interfere with NUT behavior and look for solutions to overcome them (SE-BCT5, r=.415), identify situations in which they could fall back into an unhealthy eating behavior and try to avoid them (SE-BCT23, r=.367), weigh the benefits and costs of NUT in terms of health outcomes (SE-BCT2, r=.365), and encourage themselves to exert effort (SE-BCT6, r=.365). In sum, if NUT goals are important, people are likely to engage in various SE-BCTs. In contrast, SE-BCTs involving the "social environment" (SE-BCTs 3, 19, 20, 21) are all not correlated with NUT goal importance. *Goal difficulty* was only related to SE-BCT 26 and this unexpectedly in a negative direction in both behavioral domains: The more difficult the PA or NUT goal was rated, the less time planning was directed toward fitting the corresponding goal-directed behavior into daily life. At second glance, this could be interpreted as a partly functional strategy, because the probability of goal attainment decreases with increasing difficulty (Atkinson, 1957). In summary, our hypothesis was partially confirmed: 12 PA-SE-BCTs and 18 NUT-SE-BCTs were positively related to the importance of the PA or NUT goals, with stronger correlations for NUT than for PA.

Correlational analyses revealed evidence for positive relationships between 20 PA-SE-BCTs and the PA-MET score. The more participants use SE-BCTs to achieve their PA goal, the higher their level of self-reported physical activity. In addition, support for a positive relationship was found for most of the 26 NUT- SE-BCTs and healthy eating style score and progress in the reported NUT goal. Although these are only small-to-moderate correlations, the association is substantial considering that the SE-BCTs relate to a specific goal, whereas the PA and healthy eating questionnaires refer to a much broader, overarching behavioral domain (i.e., general PA and healthy eating behavior). Also in line with the hypotheses, SE-BCTs in the NUT domain were positively related to progress toward the NUT goal, whereas SE-BCTs in the PA domain were unexpectedly unrelated to progress in the PA goal. One reason for this might be that the question about goal progress allows room for interpretation by the participants, for example, regarding the reference points or timeframes to which goal progress can be related. This ambiguity in our assessment might explain why SE-BCTs in the physical activity (PA) and nutrition (NUT) domains are differently related to goal progress. Taken all analyses together, however, the results are consistent with our assumption that SE-BCTs are associated with indicators of successful health behavior. Our exploration whether some individual SE-BCTs or combinations of SE-BCTs were better able than others to predict PA-MET, healthy eating, and progress in health goals revealed a relatively clear answer in the PA-domain. The single best predictor of PA-MET and goal progress was the SE-BCT *planning time so that PA fits into one´s everyday life* (SE-BCT26). This is in line with findings in intervention studies showing the high effectiveness of planning for health goals (Peng et al., 2022). We

further showed that *specifying where*, *when*, *how*, *and with whom to be physically active* (SE-BCT 10) considerably improves the prediction of PA-MET. This perfectly fits with previous research analyzing spontaneous (rather than experimentally-induced) action planning and confirmed their strong effects for PA [Bieleke & Keller, 2021, Carraro, & Gaudreau, 2013, Rise et al., 2003). PA goal progress could best be predicted by adding *self-encouragement* (SE-BCT6) and *external cues in the environment* (SE-BCT15) to *planning processes* (SE-BCT26).

For NUT, the answer to the question of which SE-BCTs have the greatest predictive power seems far more complex than for PA. No single SE-BCT was among the top predictors of healthy eating style or progress in NUT goals. Instead, the combination of multiple SE-BCTs provided the best prediction of healthy eating style as well as progress toward dietary goals. This item combination includes *planning time* (SE-BCT 26) but also five other SE-BCTs. Summing up, "planning time so that the relevant behavior fits into one´s everyday life" is in the natural repertoire of individuals´ behavior change techniques (with means > 5.0) and it is used successfully used in PA as well as in NUT. NUT goal progress and healthy eating, however seem to be more complicated to predict (by a broader variety of SE-BCTs) than engagement in PA.

Future directions of SE-BCT research

Our study uses the concept of proactive self-enacted behavior change techniques (SE-BCTs) that based on the Compendium of self-enactable BCTs (Knittel et al., 2020) along with a measurement tool and initial data supporting the validity of the inventory. Future research with expanded methodological and substantive approaches can complement these findings and advance SE-BCTs research in many ways. For example, while the cross-sectional data offer valuable insights into structural aspects of SE-BCTs, adopting a longitudinal perspective would allow to explore the effects of SE-BCTs on behavior change and potentially underlying temporal dynamics or interactions. For example, "I search for information" might be the right technique to select an appropriate physical activity and to learn how to perform a movement correctly. However, for implementation into everyday life, the use of behavioral prompts might be more useful, and for behavior maintenance, seeking social support. Experiences with exercising or nutrition (healthy eating is enjoyable) and physical changes (changes in body weight and fat-muscle ratios) as well as success and failure in applying SE-BCTs can interact with the application of subsequent SE-BCTs. Furthermore, individual characteristics (e.g., body weight and physical constitution, self-control, size of social networks) might benefit or hinder SE-BCT use and effectiveness and therewith goal attainment. In brief, important insights can be expected from a study design that can capture temporal and interactive dynamics and considers individual differences.

We generated items based on the 26-BCT taxonomy by Abraham and Michie (2008) to develop a questionnaire with a manageable number of items that pertained to relevant and specific behaviors. An alternative approach might involve the 93-BCT taxonomy developed by Michie et al. (2013), or might find other selection criteria for SE-BCTS derived from the 123 self-enactable behavior change technique compendium (Knittle et al., 2020).

Compared to traditional methods of recruiting participants, using online crowdsourcing platforms such as MTurk has both advantages (e.g., larger subject pool, more diverse sample) and disadvantages (e.g., ethical concerns about low payment, need to ensure data quality; Tompkins, & Swift, 2019). Our broad approach of asking many individuals very generally about their physical activity or nutrition goals led to a wide variety of responses regarding goals. Specifying the sample to individuals who are already actively trying to change their behavior (e.g., new registrations at a gym or visits to websites for dietary changes) and/or standardizing the goals themselves (e.g., adherence to clearly defined WHO recommendations for physical activity and nutrition) could advance SE-BCT research in the next step. In summary, future research should use alternative methods to generate large samples with sufficient statistical power to investigate the robustness of our findings across methodological approaches, participants, and types of goals.

A final and crucial example of advancing SE-BCT research is the consideration of individual differences and inequalities when analyzing SE-BCTs and designing studies and interventions. By capturing and analyzing age and gender, we have addressed two important individual differences that can give rise to inequalities (e.g., in physical activity), and yet a multitude of diversity dimensions remains to be examined. For instance, future research might capitalize on the PROGRESS PLUS framework (e.g., place; race; occupation; gender and gender; religion; education; socioeconomic status; social capital; disability) to identify and classify inequality-relevant data (Karran et al. (2023). These approaches and further optimizations, in our opinion, are worthwhile as SE-BCT research has significant potential to counteract physical inactivity and unhealthy nutrition.

The potential of SE-BCTs

The notional ideal to combat the pandemic of physical inactivity and unhealthy diet would be to empower people to apply self-regulation which is *customized* and *autonomous*. SE-BCTs have the potential to contribute to this ideal:

Previous research has shown that *customized* (synonyms: personalized, tailored) interventions, i.e., those that adapt as closely as possible to the individual characteristics of people, their behaviors, or social environments, are more effective than more general "one-size-fits-all" approaches (Noar et al., 2007, Tong et al., 2021). People are unique in the complex constellation of their health behaviors, their social and material environments (e.g., availability of social support from family or friends, financial means), and their experiences with previous behavior change strategies (e.g., success or failure in past dieting endeavors). People are the experts on their personalities - a fact that future health behavior research is called upon to consider (O'Connor, 2020). People themselves are best qualified to select the behavior change technique that is most appropriate (= best customized) for them (for a critical view see below). In terms of *customization*, SE-BCTs seem to be ideal.

Choice of behavior fosters *autonomous motivation* (see Self-Determination Theory, Deci & Ryan, 1985). Autonomous motivation means that people regulate themselves by self-endorsed reasons and behaviors that fit what they enjoy (intrinsic motivation), matches their core values (integrated motivation), or from that they expect a benefit that is personally relevant (identified regulation). In contrast to *controlled motivation* in which people feel internally pressured (introjected motivation), or are pressured from outside (external regulation), more autonomous forms of regulation change health behavior more effectively and sustainably (e.g., Ntoumanis et al., 2021). In Sheeran et al. (2021) meta-analysis, for example, autonomous motivation was found to lead to a medium change in health behaviors. SE-BCTs are by definition pro-actively chosen by people themselves and therefore have a high potential to trigger autonomous motivation and thereby healthy behavior.

Another advantage of SE-BCTs concerns the size of the problem: Effective behavior change interventions as reported in the introduction do often not seem easy to be *scaled up* so that population-wide benefits could be achieved (Reis et al., 2016; Milat et al., 2013), because they are often costly and directed to a relatively small number of people. Consequently, they fail to effectively address the global pandemic of physical inactivity (Lane et al., 2021), and unhealthy diet. In contrast, SE-BCTs have the great advantage that they *are already scaled up* because people use them on their own, there are no costs from externally triggered interventions, and they are accepted by people. In summary, SE-BCTs are excellent starting points for *customization*, *autonomy* and *scaling-up*.

However, self-regulation using SE-BCTs can only be beneficial if people have relevant knowledge about themselves: SE-BCTs have to be chosen according to one´s preferences, adapted according to one's current stage of behavior change, changes in one's health goals, different life circumstances, and changes in one's needs. The question of whether people possess such self-knowledge is questionable and is critically discussed (Ghorbani et al., 2014; Vazire & Carlson, 2010). The Compendium of self-enactable BCTs (Knittle et al., 2020) already moves in this direction by assisting people in providing additional explanations on how to use the compendium. The explanations begin with the recommendation to identify a behavior that the individual wants to change, proceed to selecting a technique, adapting it to specific behavior and personal preferences, testing it, and, if necessary, choosing alternative self-enactable BCTs until an effective technique is found. These, however, are complex and dynamic processes that require sophisticated metacognitive knowledge and regulation (Flavell, 1979). We believe that expanding and teaching people these metacognitive skills could greatly enhance the success of SE-BTCs. To conclude, SE-BCTs appear to be measurable through questionnaires, with initial analyses showing theory-consistent relationships among them and with PA and NUT behaviors. We consider further exploration to be valuable, as a better understanding of SE-BCTs could help address the high prevalence of physical inactivity and unhealthy eating.

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Data availability OSF– Anonymized View-Only-Link: https://osf.io/g6c8r/?view_only=957a269b9d3242c4af72f483e299aaa6.

Declarations

Ethics approval The study was conducted in accordance with the Declaration of Helsinki. The Ethics Committee (institutional review board, IRB) of the author´s university considered an IRB assessment unnecessary in accordance with its guidelines (RefNo: IRB23KN07-006w/) and therefore, waived the need of ethics approval.

Consent to participate Informed consent was obtained from all individual participants included in the study.

Competing interests The authors declare no competing interests within the last 3 years of conducting the research and preparing the work for submission. Any interests outside this timeframe that could reasonably influence the submitted work are disclosed to ensure transparency and enable readers to form their own judgments.

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