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The Role of Self-Regulation in the Effect of Self-Tracking of Physical Activity and Weight on BMI

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Abstract

Self-tracking of health may have positive effects on lifestyle behavior and weight loss; however, not much is known about the role of psychological processes in this effect. The purpose of this study was to assess to what extent a change in self-regulation capabilities can explain weight loss after 4 and 12 months of self-tracking physical activity and weight. An explorative cohort study was conducted with measurements at baseline (T0), 4 months (T1), and 12 months (T2). Healthy adult volunteers ($N = 80$) were included and provided with a digital weight scale and an activity tracker. Personal characteristics as well as the intention to change weight and physical activity were measured at T0. Self-regulation capabilities (goal orientation, self-direction, decision making, and impulse control) were measured with the Self-Regulation Questionnaire at T0, T1, and T2, together with body weight. At T0, all four dimensions of self-regulation were negatively related to BMI ($p < .01$). At T1, weight significantly declined compared to T0 (− 2.0 kg/− 0.64 kg/m^2, $p < .001$). At T2, this weight loss was maintained (− 1.8 kg/− 0.57 kg/m^2, $p < .01$). At T1, intention to lose weight, self-weighing frequency, and an increase in goal orientation explained weight loss. At T2, an increase in decision making explained weight loss. Incremental self-regulation capabilities may explain weight loss after engaging in self-tracking of physical activity and weight. Future research should focus on exploring effective ways to further enhance self-regulation when using self-tracking technology and to assess the impact of different types of self-regulation stimuli on weight loss.

Keywords Self-regulation · Self-weighing · Self-tracking · Physical activity · Weight loss

Introduction

Overweight and physical inactivity are known risk factors for a number of chronic diseases such as diabetes, cardiovascular disease, and cancer (Lee et al. 2012). Self-tracking of health-related variables (i.e., the act of measuring one's own health by using different tools and/or technology) has been suggested as a possible way to create awareness about individual health and to stimulate optimization of different health behaviors and health outcomes (Almalki et al. 2015; Kozak et al. 2017; Whitehead and Seaton 2016). Self-tracking of physical activity and weight are two ways of self-quantification that have been previously studied. Several studies determined an increase of physical activity as a result of self-tracking of physical activity in different populations both with and without additional intervention components (de Vries et al. 2016; Qiu et al. 2014). In addition, frequent self-weighing has been found to be an effective stimulation to lose weight (LaRose et al. 2016; Pacanowski and Levitsky 2015; Rosenbaum et al. 2017; Zheng et al. 2015). However, although self-tracking of physical activity and weight are considered as promising intervention strategies, they may not help every person to acquire a more active lifestyle or to lose weight. A complete picture about which individual does or does not achieve lifestyle changes and weight loss as a result of using self-tracking

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technology and the psychological factors that may play a role in weight outcomes by using it is currently lacking (Pacanowski and Levitsky 2015). Therefore, there is a need for research aimed at identifying the psychological working mechanism of this technology.

There are several theoretical models that may be used to understand self-tracking of health (behavior) in relation with health behavior change including the social cognitive theory, temporal self-regulation theory, feedback intervention theory, and control theory (Bandura 2004, 1998; Hall and Fong 2007; Kluger and DeNisi 1996; Mann et al. 2013; Suls and Wallston 2003). All of these theories emphasize goal-setting, self-monitoring, and feedback as important principles for health behavior change. Therefore, these principles are conceptualized as behavior change techniques (BCTs) (Michie et al. 2011, 2013): the basic components of interventions that are effective in changing behavior and the active ingredients of interventions. These BCTs are being increasingly incorporated within consumer self-tracking technology (Lyons et al. 2014; Sullivan and Lachman 2017). We propose that these BCTs within consumer self-tracking devices can impact a person's self-regulation capabilities and subsequently explain weight loss. Figure 1 illustrates this proposed working mechanism of increased self-regulation on weight loss induced by self-tracking technology, based on the principles of control theory.

Self-regulation of behavior is a broad construct, defined as an individual's ability to establish, monitor, and implement goals in order to successfully regulate own behavior (Brown et al. 1999; Hall and Fong 2007; Mann et al. 2013). This encompasses both behavioral, cognitive, and emotional processes (Mann et al. 2013). Self-regulation ability has been emphasized as a crucial factor in order to achieve health promotion (Bandura 2004, 1998; Kramer and Kowatsch 2017; Mann et al. 2013). According to Gavora et al., self-regulation can be divided into four different dimensions; goal orientation (the degree to which an individual attempts to fulfill personal goals, e.g., by plan making), self-direction (the degree to which one can formulate learning goals and learns from previous experiences), decision making (the ability to make decisions and find multiple ways to achieve goals), and impulse control (the ability for an individual to manage short-term interferences with goals). These dimensions are considered as being different but not fully autonomous processes for self-regulation (Gavora et al. 2015; Jakesova et al. 2016). Self-regulation components are being stimulated by self-tracking devices through the following BCTs that are incorporated in self-tracking technology: goal setting of behavior, goal setting of outcome, review behavior goals, discrepancy between current behavior and own goals, review of outcome goals, feedback on behavior, self-monitoring of behavior, self-monitoring on outcome of behavior, prompts/cues, and social rewards (Michie et al. 2014). These BCTs have earlier been found to increase self-regulative health behavior (Lyons et al. 2014; Mercer et al. 2016; Samdal et al. 2017; Teixeira et al. 2015).

In summary, the body of knowledge regarding the effects of self-quantification of health is increasing. However, the mechanism behind the effect is still unclear. In this explorative study, participants have been provided with two devices for self-quantification of physical activity and weight. The primary aim of this study was to assess to what extent change in self-regulation capabilities can explain weight loss after 4 and 12 months of self-tracking physical activity and weight. We hypothesized that increases in goal orientation and self-direction would be especially related to weight loss, as increases in these domains comprise an increase in ability to set goals and to learn from previous behavior. In addition, since previous research found that people with overweight or obesity have a greater likelihood to overestimate their physical activity compared to people with a healthy weight (Tully et al. 2014) and, therefore, may benefit more from using self-tracking devices, we hypothesize that the relation between an increase in self-regulation and weight loss is different for people with overweight (BMI ≥ 25) compared to people with a healthy weight (BMI < 25).

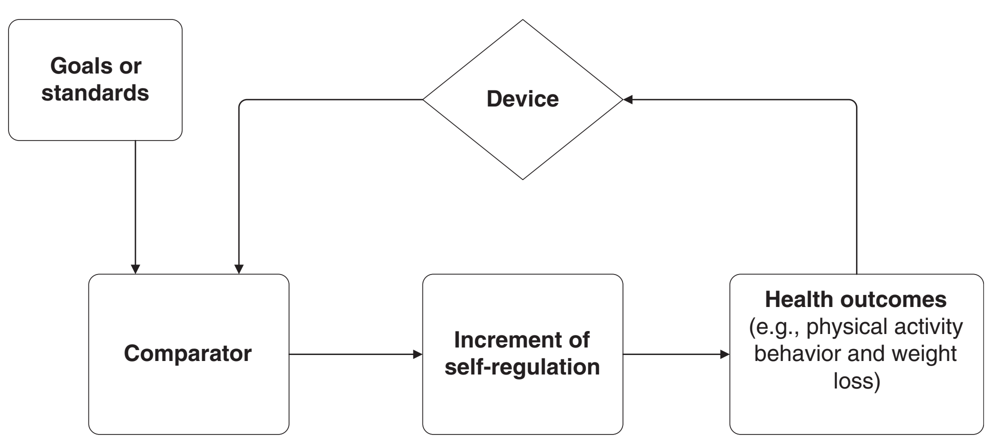

Fig. 1 Proposed working mechanism of self-tracking of health based on the Control Theory. The health goal serves as a reference value, while the self-tracking device functions as the error detector. The self-tracking individual is the comparator. Both the possible increment of self-regulation and health outcomes functions as output

Methods

Sample

A 12-month explorative study was conducted within the Lifelines cohort study in the Netherlands (Scholtens et al. 2014). Lifelines is a multi-disciplinary prospective population-based cohort study examining in a unique three-generation design the health and health-related behaviors of 167,729 persons living in the north of the Netherlands. Eligible participants were provided with an activity tracker and a digital weight scale. Inclusion criteria of the participants were ≥ 25 years and access to a smartphone with internet (IOS or Android). Participants were excluded if they were already in the possession of an activity monitor or smart weight scale or were not able to engage in self-tracking of physical activity or weight due to physical, social, cognitive, and/or mental problems. This also meant that people with underweight (BMI < 18.5) and people with severe obesity (BMI > 35) in combination with health problems or people with morbid obesity (BMI > 40) were excluded. In total, 101 participants were invited to participate in the study, of which 95 participants were pre-included and received the devices (Fig. 2). Informed consent was obtained from all of the participants. Ethical approval was granted within the Lifelines program by the University Medical Center Groningen (METc 2007/152) based on the declaration of Helsinki of Ethical Principles for Medical Research Involving Human Subjects.

Procedures

Participants came to the research office of Lifelines to pick up their devices and an explanatory guide on how to install and to use them. The Withings Pulse *(Withings Inc., Issy-les-Moulineaux, France)* measured physical activity (steps per day, distance walked, height climbed, and calories burned) and sleep. The Withings WS-30 *(Withings Inc., Issy-les-Moulineaux, France)* measured weight and body mass index (BMI). Participants were instructed to wear the Pulse daily at the same, self-selected wearing position and to weigh themselves at the same moment of the day to increase reliability of the weight measurements. No specific instructions were given concerning how often the participants should weigh themselves (in order to study the natural use). Participants were informed that they could use the devices to monitor their own physical activity behavior and weight and to check whether these comply to existing health guidelines, i.e., of being sufficiently active (7500–10.000 steps/d) and having a healthy weight (BMI < 25). For this, participants created a personal account at Withings and connected both devices with the Withings Health Mate application. This app showed graphically the individual's personal health data over time

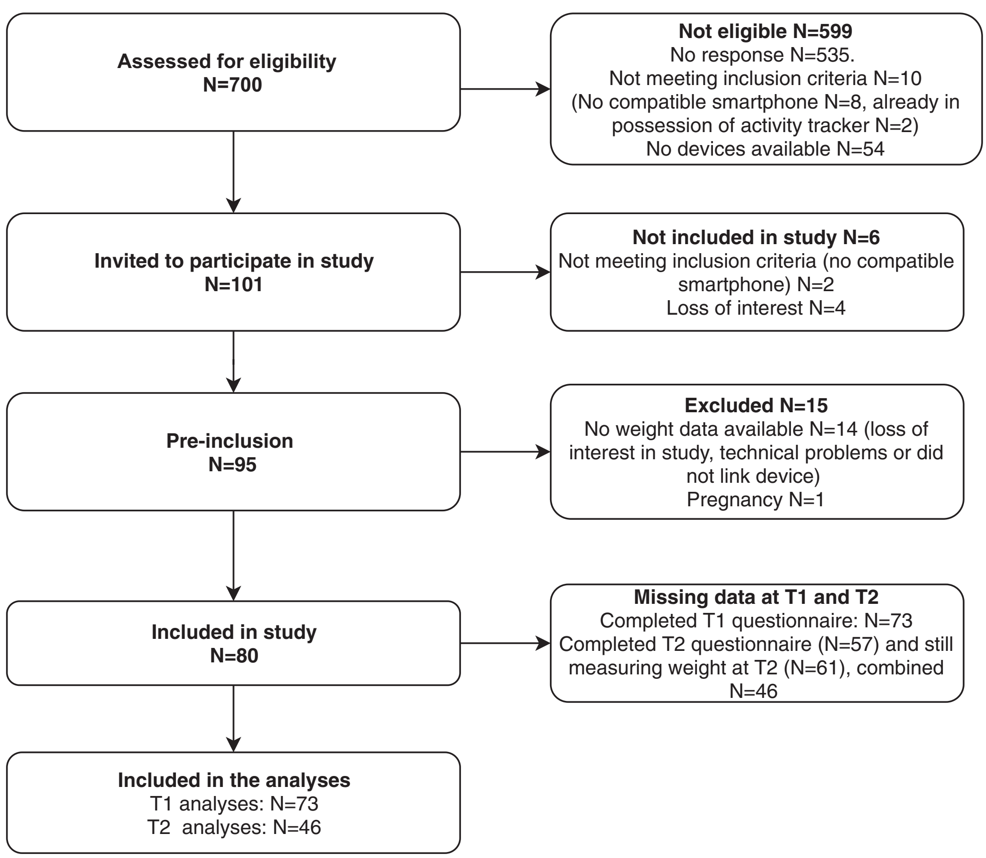

Fig. 2 Flow of participants through the study

and provided automatically generated personalized feedback messages concerning progression toward the self-selected goals of the participants. During the setup, the app automatically prompted users to select these individually relevant goals. If the participants lost or broke their activity tracker or when technical problems occurred, the Pulse was replaced during the first 6 months of the study. Thereafter, no replacement was possible due to a restricted availability of the activity tracker. The scale automatically recognizes which individual is using the scale; therefore, only data of the study participant was sent to the personal account of this user. All of the data (weight and weighing frequency) were retrieved from Withings by Lifelines and anonymously made available for data analyses.

Measures

Participants completed a digital questionnaire at the beginning of the study (T0), after 4 months (T1) and after 12 months (T2).

Weight and weighing frequency were retrieved from the Withings WS-30 weight scale, using the weight self-measurements that the participants conducted. Weight change between T0–T1, T1–T2, and T0–T2 was calculated from these weight measurements at these time points. Weighing frequency was calculated from baseline to T1 and from baseline to T2. Subsequently, during those periods, the number of measurements were categorized in a low frequency (self-weighing less than once per week), a moderate frequency (self-weighing once or several times per week), and a high frequency (self-weighing minimally 6 days per week, i.e., daily self-weighing) (Rosenbaum et al. 2017).

Personal characteristics (age, gender, education) were assessed in a digital questionnaire at baseline. The height of the participants was objectively measured and retrieved from the biobank of the Lifelines cohort study. BMI was assessed using this height measure and the weight during the first measurement of the current study (T0), at T1 and at T2.

Intention to change physical activity and intention to change weight was measured using two 1-item questionnaires. Participants were asked “do you intend to change your physical activity pattern?” and “do you intend to change your weight?”. The participant could indicate (1) the intention to increase activity/lose weight, (2) no intention to change, or (3) the intention to decrease activity/gain weight.

The four dimensions of self-regulation were measured with the self-regulation questionnaire (Brown et al. 1999). This questionnaire was slightly modified to increase specificity for self-regulation of health behavior (physical activity, nutrition, and body weight). Example items for the four subscales are as follows: “I have personal health standards, and try to live up to them” (goal orientation), “I usually only have to make a mistake one time in order to learn from it” (self-direction), “normally, I am able to find several ways when I want to change something in my health behavior” (decision making), and “I get easily distracted from my plans” (impulse control, example of a reverse item). For the goal orientation and decision making example items, “health” was added to the original item. Item scores could range from 1 (strongly disagree) to 5 (strongly agree). A higher average score indicates a higher self-regulation on the specific scale. The average of the scores on the different subscales: goal orientation (items 27, 30, 31, 48, 58), self-direction (items 8, 21, 28, 33, 50, 54, 57) decision making (items 32, 35, 38, 39, 46, 52, 53), and impulse control (items 1, 5, 6, 10, 19, 20, 26, 62) were calculated according to the grouping of Gavora et al. (Gavora et al. 2015). All of the items can be found in the Appendix. Cronbach’s alpha was calculated with these items belonging to one subscale. These included 0.69, 0.74, 0.66, and 0.83, respectively. For goal orientation, item 31 “I am set in my ways” was deleted from the scale because this item resulted in a lower alpha (internal consistency of the scale).

Analyses

All of the variables were evaluated by using descriptive statistics, and change scores of BMI and the four dimensions of self-regulation were calculated by subtracting the T0 score from the T1 and T2 scores and by subtracting the T1 score from the T2 score.

Then, the relationship between each of the four dimensions of self-regulation capacity (goal orientation, self-direction, decision making, and impulse control) and BMI at baseline was assessed by using Pearson correlation analysis. BMI change between T0 and T1, T1 and T2, and between T0 and T2 were assessed by paired samples t tests. Thereafter, for the time periods when a significant BMI change was found, it was assessed whether this change was related to an increase of the four separate dimensions of self-regulation by using univariate linear regression analysis. Hereby, it was also examined whether there were any significant interaction effects for the relationship between the increments of each of the four dimensions of self-regulation and weight loss, by baseline weight class (BMI ≥ 25 vs. < 25).

Thereafter, predictors for BMI changes between T0 and T1 and between T0 and T2 were analyzed by assessing personal characteristics (i.e., age, gender, education, BMI), intention to change weight, intention to change physical activity, self-weighing frequency, and changes in self-regulation capabilities in a multivariate linear regression analysis. Significant predictors were analyzed by using the “backward” method. Also, mediation analyses were conducted using the PROCESS application of Hayes (Hayes 2012) in order to assess whether the expected relation of self-weighing frequency with BMI change was mediated by an increase of any of the four dimensions of self-regulation.

In order to deal with missing data, results were analyzed with both complete data and with analyses in which missing data were replaced by baseline values [last observation carried forward (LOCF)]. In addition, attrition analyses were conducted comparing complete cases at T2 with cases with incomplete data at T2, with respect to personal variables (age, gender, BMI), self-weighing frequency, and self-regulation at baseline. All of the analyses were conducted by using SPSS, version 22, 2010, IBM-SPSS Inc.

Results

At baseline, 80 eligible participants filled out the questionnaire and installed both devices. At T1 (4 months), 73 participants had completed the questionnaire, and at T2 (12 months), 57 participants had done so. At T1, 78 participants had weight data available, and at T2, 61 participants were still measuring their weight (i.e., had at least one weight measurement at T1/T2 or within a range of 2 months from T1/T2). This resulted in a study group of $N = 80$ at baseline, $N = 73$ at T1, and $N = 46$ at T2 in the combined analyses of self-regulation and weight. Figure 2 describes the flow of participants through the study. The mean age (SD) at baseline was 48.4 (6.7) years; mean body weight was 78.5 (14.9) kg; and mean BMI 25.9 (3.6) kg/m^2 (BMI range 18.8–34.9 kg/m^2, 47% BMI 18–24.9, 40% BMI 25–29.9, 14% BMI ≥ 30). At baseline, 56% of the study population intended to increase their physical activity, whereas 44% intended to stay the same. In addition, 56% intended to lose weight, 29.8% intended to stay the same, and 14.2% intended to gain weight. To increase physical activity and to lose weight, 38.8% intended both.

Association Between BMI and Self-Regulation Capabilities at Baseline

At baseline, significant negative Pearson correlations were found between BMI and the different dimensions of the self-regulation questionnaire (r between −0.32 and − 0.43, $p < .01$). Table 1 presents the correlation coefficients of the four dimensions of self-regulation. The correlation coefficients between the four self-regulation scales were between 0.50 (self-control and decision making) and 0.75 (impulse control and self-direction) at baseline ($p < .001$).

Table 1 Correlations between BMI and self-regulation at T0 ($N = 80$)

	BMI at T0
Self-regulation at T0	− 0.32**
Goal orientation	− 0.43**
Self-direction	− 0.41**
Decision making	− 0.39**
Impulse control	

**$p < 0.01$

BMI Changes at the Different Time Points

Paired samples t tests revealed a significant decline in weight and BMI at T1 and T2. Mean BMI (SD) decreased from 25.9 (3.6) at T0 to 25.2 (3.6) at T1 (Mean difference − 0.64 (0.92) kg/m^2; CI − 0.43; − 0.85; $p < .001$). At T2, mean BMI was 25.3 (3.5) (mean difference − 0.57 (1.2) kg/m^2; CI −0.26; −0.88; $p < .01$). Mean weight (SD) decreased from 78.5 kg (14.9) at T0 to 76.4 kg (14.6) at T1 and 77.1 kg (14.2) at T2 (mean difference − 2.0 (2.8) kg at T1, and − 1.8 (3.7) kg at T2). No significant BMI change (mean difference 0.017 (0.98) kg/m^2, $p = .892$) and weight change (mean difference 0.02 (2.9) kg, $p = .951$) occurred between T1 and T2.

Univariate Relations Between Change in Self-Regulation and BMI Change

Mean changes in self-regulation varied between 0.02 (decision making) and 0.16 points (impulse control) from T0 to T1 and were significant for goal orientation and impulse control ($p < .05$). Between T0 and T2, mean changes varied between − 0.02 (decision making) and 0.15 points (goal orientation) and was only significant for goal orientation ($p < .05$). Table 2 shows the univariate relations between the changes in the four different self-regulation scales and the BMI change between baseline and T1 and baseline and T2. An increase in goal orientation was significantly related to a decrease in BMI at T1. An increase in decision making was significantly related to a decrease in BMI at T2. A significant interaction effect was found for BMI class (i.e., BMI < 25 vs. ≥ 25) on the relation between the increment of self-direction capability and weight loss: for participants with a BMI ≥ 25, an increase in self-direction was significantly related to weight loss (β = − 0.93, $p < .01$) whereas no significant relationship was found for individuals with a BMI < 25 ($p = .456$, Table 2).

The LOCF-analyses for BMI change between T0–T1 revealed additional interaction effects for BMI class: goal orientation BMI < 25 (β = − 0.14, $p = .656$), BMI ≥ 25(β = − 0.75, $p = .017$); self-direction BMI < 25 (β = − 0.21, $p = 0.556$), BMI ≥ 25 (β = − 0.93, $p < 0.001$); and decision making BMI < 25 (β = 0.25, $p = .560$), BMI ≥ 25(β = − 0.94, $p = 0.021$). For impulse control no interaction effect was found (β = − 0.24, $p = 0.262$).

At T2, only for decision making an interaction effect was found: BMI < 25 (β = − 1.03, $p = .037$), and BMI ≥ 25 (β = − 2.27, $p < 0.01$). The associated betas for the other self-regulation scales were similar to the original analysis: goal orientation (β = − 0.63, $p = 0.042$), self-direction (β = − 0.22, $p = 0.497$), and impulse control (β = − 0.23 $p = 0.399$).

Table 2 Univariate regression coefficients of change scores in the different self-regulation dimensions on BMI change at T1 and T2

	BMI change between T0 and T1 (*N* = 73)		
Change score of specific dimension:	β	SE	*p* value
Goal orientation	− 0.45	0.22	0.049
Self-direction			
BMI < 25	0.25	0.36	0.494
BMI > 25	− 0.93	0.32	0.006
Decision making	−0.55	0.30	.071
Impulse control	−0.22	0.22	.321
	BMI change between T0-T2 (N = 46)		
Change score of specific dimension:	β	SE	p value
Goal-orientation	−0.63	0.33	.067
Self-direction	−0.36	0.37	.338
Decision making	−2.61	0.46	<.001
Impulse control	−0.23	0.27	.399

Multivariate Explaining Factors for BMI Change at T1 and T2

Table 3 depicts the significant predictors for the short- and long-term change in BMI from the multivariate linear regression analysis. Self-weighing frequency, intention to lose weight, and an increase in goal orientation remained significant in the final model for BMI change at T1 (F(4.68) = 4.5, R^2 = .21, $p < .01$). At T2, the only variable that explained the variance in BMI change was the increase in decision making between T0 and T2 (F(1.44) = 32.9, R^2 = .43, $p < .001$). The LOCF analyses at T1 revealed a similar pattern: difference goal orientation (β = − 0.51), weekly weighing frequency (β = − 0.51), daily weighing frequency (β = − 0.83), and wanting to lose weight (β = − 0.40) remained significant in the final model ((F(4.75) = 4.3, R^2 = 0.19, $p < .01$). At T2, next to change in decision making (β = − 1.36), also a daily weighing frequency (β = − 1.04) remained significant in the final model of the LOCF analysis (F(2.77) = 14.9, R^2 = .28, $p < .001$).

Table 3 Significant multivariate explaining factors for BMI change at T1 and at T2

	β	SE	p value
BMI change at T1 (N = 73)			
Intercept	*.37*	*.31*	*.233*
Change goal orientation	−.53	.22	.017
Weighing frequency			
Daily	−1.02	.33	.003
Weekly	−.76	.28	.008
Less than weekly (ref)			
Intention weight loss at T0			
Want to lose weight	−.48	.22	.034
Want to stay the same (ref)			
BMI change at T2 (N = 46)			
Intercept	*−.57*	*.13*	*<.001*
Change decision making	−2.61	.46	<.001

Mediation Analyses

To assess whether the relation of self-weighing frequency with BMI change was mediated by an increase of any of the four dimensions of self-regulation, mediation analyses were performed. For this, the continuous variable "number of self-weighing measurements" was Log transformed due to a non-normal distribution of this variable, both between T0 and T1 and between T0 and T2. The analyses revealed no mediation effects: both self-weighing frequency (direct path) and increase of self-regulation were independently related to weight loss at T1 and T2, but self-weighing frequency was not related to increment of self-regulation. Only for decision making at T2, a significant mediation effect was found: the indirect effect of self-weighing frequency on BMI change through an increase in decision making was − 0.50 (CI − 1.19; −0.07) (F(1.44) = 5.03, R^2 = 0.1, p = 0.03). However, this effect did not remain in the LOCF analyses: − 0.14 (CI − 0.43; 0.003, (F(1.78) = 2.8 R^2 = 0.04, p = .098).

Differences at Baseline Between Completers and Non-completers at T2

Univariate ANOVA analyses revealed significant differences at baseline between completers (*N* = 46) and non-completers (*N* = 34) at T2: completers were significantly older (mean difference 4.4 years, F(1.78) = 2.49, $p < .01$) and had higher self-regulation scores at T0 (goal orientation 0.25 points, F(1.78) = 4.24, p = 0.043, self-direction 0.33 points F(1.78) = 7.39, $p < 0.01$, impulse control 0.34 points F(1.78) = 6.37, p = 0.014), except for decision-making (0.14 points F(1.78) = 3.02, p = .086). No differences existed for gender, baseline BMI (mean difference −

1.29 kg/m^2, F = 2.499, p = 0.118) or BMI change between T0-T1 (mean difference 0.05 kg/m^2, F(1.76) = 0.069, p = 0.793).

Discussion

This study aimed to describe the relation between BMI and (change in) self-regulation after 4 and 12 months of self-tracking physical activity and weight. The dimensions of self-regulation were all negatively related to BMI at baseline; thus, people with a higher self-regulation for health behavior had a lower BMI from the start. After 4 months of self-tracking, participants showed a moderate decrease in body weight and BMI. The reduced weight was maintained up to 12 months, but no additional weight loss occurred between 4 and 12 months. We determined that increases in different processes of self-regulation, i.e., goal orientation and self-direction in a subgroup of people with overweight, were related to weight loss after 4 months whereas an increase in decision making was related to weight loss after 12 months. This result fits in our theoretical model (Fig. 1) which proposes that an increase of self-regulation explains weight loss. We also found that a higher self-weighing frequency was related to weight loss. However, the mediation analyses revealed that the relation between self-weighing frequency and weight loss was not mediated by an increase of self-regulation. Thus, self-weighing frequency and increment of self-regulation are two independent factors influencing weight loss. Our findings may imply that self-regulation processes are playing a different role at short term and long term. Goal orientation and decision making both reflect self-regulatory goal striving processes (Mann et al. 2013). Goal orientation comprises the planning and actual implementation of health goals. Decision making reflects the ability to make decisions and to find multiple ways to achieve goals. This is important for dealing with setbacks in the process of doing so. Thus, our results suggest that an increase in planning and implementation of health goals contribute to short-term weight loss (4 months). An increase in the ability to find multiple ways to achieve goals may be more important for a successful long-term weight loss (12 months).

Our results are in line with and extend the results of other studies concerning weight loss and self-regulation. Kliemann et al. found that an increase in overall self-regulation for weight loss (without distinction in sub capabilities) mediated the effect of a brief weight loss intervention on weight loss after 3 months. In line with our short-term results about goal orientation, they also found that the participants who logged their weight and behavior more often and made more plans for behavior change showed a greater weight loss (Kliemann et al. 2017). McKee et al. found in their qualitative research that people who successfully maintained weight loss differed in self-regulation capabilities compared to people who were not successful. People who maintained weight loss were better able to set realistic goals, construct a plan or certain routine for their diet, and monitor their progress (McKee et al. 2013). These skills also correspond to our goal orientation subscale and to the use of the self-tracking devices. Another dimension of self-regulation, i.e., change in self-direction, did not explain weight loss in our multivariate analysis. However, we found that an increase in self-direction, i.e., learning about own mistakes, was significantly related to weight loss for people with overweight whereas this relationship was not found in people with a healthy weight. This may be an important finding since learning about one's own behavior and how to improve it is a crucial process for accomplishing successful behavior change (Kluger and DeNisi 1996; Mann et al. 2013). To our knowledge, no studies thus far have reported about specific self-direction or decision making capabilities in relation with self-tracking and (long-term) weight loss.

Our finding that most weight loss occurred within the first months after beginning with self-tracking physical activity and weight is in line with previous studies (Appel et al. 2011; Zheng et al. 2016). Another study on effects of self-weighing with comparable time intervals found a comparable short-term weight loss but a larger weight loss after 12 months (3.5 kg, CI − 4.30 to − 2.71) (Anderson et al. 2014). This is probably explained by the more extensive intervention program used in this study, whereas our study was not set up as a weight loss intervention program. In addition, our finding that more frequent self-weighing is related to a greater weight loss is similar to the findings of other studies about this topic (LaRose et al. 2016; Pacanowski and Levitsky 2015; Rosenbaum et al. 2017; Zheng et al. 2015). An explanation for the impact of frequency of self-weighing may be that an individual who daily or weekly self-weighs receives feedback on a regular basis and is, therefore, able to detect relationships with one's recent behavior and weight. Also, an individual can readily observe lapses and react on them immediately. This explanation is in line with the feedback intervention theory (Kluger & DeNisi) and two recent review articles that clearly demonstrate that feedback enhances health behavior change (Hermsen et al. 2017; Schembre et al. 2018).

The results of this study imply that to achieve weight loss using self-tracking devices, attempts should be made to stimulate people to weigh themselves weekly or daily. In addition, strategies should be provided to optimize self-regulation capabilities. For instance, different behavior change techniques can be deployed to achieve an increase in goal orientation and decision making capabilities, such as goal setting of behavior, goal setting of outcomes, and action planning (e.g., providing a format whereby the user can construct a plan of how to accomplish a certain goal using different methods). To enhance the "self-direction" capability of self-regulation, feedback from a device or health practitioner should emphasize learning, for instance, how much increment in physical activity or what changes in diet are needed to achieve weight loss. Whether different dimensions of self-regulation are differently related to weight loss at short term and long term need to be confirmed in future studies. Future research should further be aimed at exploring effective ways to further enhance self-regulation when using self-tracking technology and to assess the impact of different types of self-regulation stimuli on weight loss. Such research would enhance the understanding of the relationship of self-regulation and weight loss. Furthermore, since our results showed that completers at T2 already had a significantly higher self-regulation at the start compared to non-completers, future studies should consider providing extra support for continuing with self-tracking and completing study measurements to participants showing lower baseline self-regulation scores.

Our study has a number of strengths and limitations. This is one of the first studies that elaborated on the role of self-regulation on BMI change when using self-tracking technology. Limitations of the study are that our study sample had a fairly low-average BMI at baseline and that we experienced missing data at T2. This might have affected our analyses based on complete cases; however, our LOCF analyses showed quite similar results, thereby supporting our analyses based on complete cases. In addition, this study might have gained with collecting and analyzing the data from the activity trackers. This was not done because the focus of this study was on self-regulation and weight loss. Furthermore, our participants were recruited from within a preexisting cohort study which may have introduced a certain selection bias.

In conclusion, self-regulation capabilities play an important role in weight and weight loss when using health self-quantification technology. Self-tracking of physical activity and weight results in a modest weight loss after 4 months which is maintained after 12 months. Incremental self-regulation capabilities may explain this weight loss, together with self-weighing frequency and intention to lose weight. Future studies should confirm and elaborate on these findings.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

References

Almalki, M., Gray, K., & Martin-Sanchez, F. (2015). Refining the concepts of self-quantification needed for health self-management: A thematic literature review. *Computer, 79*, 1–5.

Anderson, A. S., Craigie, A. M., Caswell, S., Treweek, S., Stead, M., Macleod, M., et al. (2014). The impact of a bodyweight and physical activity intervention (BeWEL) initiated through a national colorectal cancer screening programme: Randomised controlled trial. *BMJ, 348*, g1823.

Appel, L. J., Clark, J. M., Yeh, H.-C., Wang, N.-Y., Coughlin, J. W., Daumit, G., … Geller, S. (2011). Comparative effectiveness of weight-loss interventions in clinical practice. *New England Journal of Medicine, 365*(21), 1959–1968.

Bandura, A. (1998). Health promotion from the perspective of social cognitive theory. *Psychology and Health, 13*(4), 623–649.

Bandura, A. (2004). Health promotion by social cognitive means. *Health Education & Behavior, 31*(2), 143–164. https://doi.org/10.1177/1090198104263660.

Brown, J. M., Miller, W. R., & Lawendowski, L. A. (1999). The self-regulation questionnaire. Retrieved from https://casaa.unm.edu/inst/SelfRegulation%20Questionnaire%20(SRQ).pdf. Accessed 06 Oct 2015.

de Vries, H. J., Kooiman, T. J. M., van Ittersum, M. W., van Brussel, M., & de Groot, M. (2016). Do activity monitors increase physical activity in adults with overweight or obesity? A systematic review and meta-analysis. *Obesity, 24*(10), 2078–2091. https://doi.org/10.1002/oby.21619.

Gavora, P., Jakešová, J., & Kalenda, J. (2015). The Czech validation of the self-regulation questionnaire. *Procedia-Social and Behavioral Sciences, 171*, 222–230.

Hall, P. A., & Fong, G. T. (2007). Temporal self-regulation theory: A model for individual health behavior. *Health Psychology Review, 1*(1), 6–52. https://doi.org/10.1080/17437190701492437.

Hayes, A. F. (2012). PROCESS: A versatile computational tool for observed variable mediation, moderation, and conditional process modeling [White paper]. Retrieved from http://www.afhayes.com/public/process2012.pdf. Accessed 11 Dec 2018.

Hermsen, S., Moons, J., Kerkhof, P., Wiekens, C., & Groot, M. D. (2017). Determinants for sustained use of an activity tracker: Observational study. *JMIR mHealth and uHealth, 5*(10), e164.

Jakesova, J., Gavora, P., & Kalenda, J. (2016). Self-regulation of behaviour: Students versus other adults. *International Journal of Educational Psychology, 5*(1), 56.

Kliemann, N., Vickerstaff, V., Croker, H., Johnson, F., Nazareth, I., & Beeken, R. J. (2017). The role of self-regulatory skills and automaticity on the effectiveness of a brief weight loss habit-based intervention: Secondary analysis of the 10 top tips randomised trial. *International Journal of Behavioral Nutrition and Physical Activity, 14*(1). https://doi.org/10.1186/s12966-017-0578-8.

Kluger, A. N., & DeNisi, A. (1996). The effects of feedback interventions on performance: A historical review, a meta-analysis, and a preliminary feedback intervention theory. *Psychological Bulletin, 119*(2), 254–284. https://doi.org/10.1037/0033-2909.119.2.254.

Kozak, A. T., Buscemi, J., Hawkins, M. A. W., Wang, M. L., Breland, J. Y., Ross, K. M., & Kommu, A. (2017). Technology-based interventions for weight management: Current randomized controlled trial evidence and future directions. *Journal of Behavioral Medicine, 40*(1), 99–111.

Kramer, J.-N., & Kowatsch, T. (2017). Using feedback to promote physical activity: The role of the feedback sign. *Journal of Medical Internet Research, 19*(6).

LaRose, J. G., Lanoye, A., Tate, D. F., & Wing, R. R. (2016). Frequency of self-weighing and weight loss outcomes within a brief lifestyle intervention targeting emerging adults. *Obesity Science & Practice, 2*(1), 88–92.

Lee, I. M., Shiroma, E. J., Lobelo, F., Puska, P., Blair, S. N., Katzmarzyk, P. T., et al. (2012). Effect of physical inactivity on major non-communicable diseases worldwide: An analysis of burden of disease and life expectancy. *The Lancet, 380*(9838), 219–229. https://doi.org/10.1016/S0140-6736(12)61031-9.

Lyons, E. J., Lewis, Z. H., Mayrsohn, B. G., & Rowland, J. L. (2014). Behavior change techniques implemented in electronic lifestyle

activity monitors: A systematic content analysis. *Journal of Medical Internet Research, 16*(8), e192. https://doi.org/10.2196/jmir.3469.
Mann, T., de Ridder, D., & Fujita, K. (2013). Self-regulation of health behavior: Social psychological approaches to goal setting and goal striving. *Health Psychology, 32*(5), 487–498. https://doi.org/10.1037/a0028533.
McKee, H., Ntoumanis, N., & Smith, B. (2013). Weight maintenance: Self-regulatory factors underpinning success and failure. *Psychology and Health, 28*(10), 1207–1223. https://doi.org/10.1080/08870446.2013.799162.
Mercer, K., Li, M., Giangregorio, L., Burns, C., & Grindrod, K. (2016). Behavior change techniques present in wearable activity trackers: A critical analysis. *JMIR mHealth and uHealth, 4*(2), e40. https://doi.org/10.2196/mhealth.4461.
Michie, S., Ashford, S., Sniehotta, F. F., Dombrowski, S. U., Bishop, A., & French, D. P. (2011). A refined taxonomy of behaviour change techniques to help people change their physical activity and healthy eating behaviours: The CALO-RE taxonomy. *Psychology & Health, 26*(11), 1479–1498. https://doi.org/10.1080/08870446.2010.540664.
Michie, S., Richardson, M., Johnston, M., Abraham, C., Francis, J., Hardeman, W., Eccles, M. P., Cane, J., & Wood, C. E. (2013). The behavior change technique taxonomy (v1) of 93 hierarchically clustered techniques: Building an international consensus for the reporting of behavior change interventions. *Annals of Behavioral Medicine, 46*(1), 81–95.
Michie, S., Atkins, L., & West, R. (2014). The behaviour change wheel: A guide to designing interventions. The Behavior Change Wheel: Book Launch Event.
Pacanowski, C. R., & Levitsky, D. A. (2015). Frequent self-weighing and visual feedback for weight loss in overweight adults. *Journal of Obesity, 2015*.
Qiu, S., Cai, X., Chen, X., Yang, B., & Sun, Z. (2014). Step counter use in type 2 diabetes: A meta-analysis of randomized controlled trials. *BMC Medicine, 12*(1), 36. https://doi.org/10.1186/1741-7015-12-36.
Rosenbaum, D. L., Espel, H. M., Butryn, M. L., Zhang, F., & Lowe, M. R. (2017). Daily self-weighing and weight gain prevention: A longitudinal study of college-aged women. *Journal of Behavioral Medicine*, 1–8.
Samdal, G. B., Eide, G. E., Barth, T., Williams, G., & Meland, E. (2017). Effective behaviour change techniques for physical activity and healthy eating in overweight and obese adults; systematic review and meta-regression analyses. *International Journal of Behavioral Nutrition and Physical Activity, 14*(1), 42.
Schembre, S. M., Liao, Y., Robertson, M. C., Dunton, G. F., Kerr, J., Haffey, M. E., Burnett, T., Basen-Engquist, K., & Hicklen, R. S. (2018). Just-in-time feedback in diet and physical activity interventions: Systematic review and practical design framework. *Journal of Medical Internet Research, 20*(3), e106.
Scholtens, S., Smidt, N., Swertz, M. A., Bakker, S. J. L., Dotinga, A., Vonk, J. M., et al. (2014). Cohort profile: LifeLines, a three-generation cohort study and biobank. *International Journal of Epidemiology, 44*(4), 1172–1180.
Sullivan, A. N., & Lachman, M. E. (2017). Behavior change with fitness technology in sedentary adults: A review of the evidence for increasing physical activity. *Frontiers in Public Health, 4*. https://doi.org/10.3389/fpubh.2016.00289.
Suls, J., & Wallston, K. A. (2003). Social psychological foundations of health and illness. Blackwell series in health psychology and behavioral medicine. https://doi.org/10.1002/9780470753552.
Teixeira, P. J., Carraa, E. V., Marques, M. M., Rutter, H., Oppert, J.-M., De Bourdeaudhuij, I., et al. (2015). Successful behavior change in obesity interventions in adults: A systematic review of self-regulation mediators. *BMC Medicine, 13*(1), 1.
Tully, M. A., Panter, J., & Ogilvie, D. (2014). Individual characteristics associated with mismatches between self-reported and accelerometer-measured physical activity. *PLoS One, 9*(6), e99636. https://doi.org/10.1371/journal.pone.0099636.
Whitehead, L., & Seaton, P. (2016). The effectiveness of self-management mobile phone and tablet apps in long-term condition management: A systematic review. *Journal of Medical Internet Research, 18*(5).
Zheng, Y., Klem, M. L., Sereika, S. M., Danford, C. A., Ewing, L. J., & Burke, L. E. (2015). Self-weighing in weight management: A systematic literature review. *Obesity, 23*(2), 256–265.
Zheng, Y., Sereika, S. M., Ewing, L. J., Danford, C. A., Terry, M. A., & Burke, L. E. (2016). Association between self-weighing and percent weight change: Mediation effects of adherence to energy intake and expenditure goals. *Journal of the Academy of Nutrition and Dietetics, 116*(4), 660–666.