Personalized lifestyle interventions for the prevention and treatment of type 2 diabetes

Hoogh, I.M. de

2

BENEFICIAL EFFECT OF PERSONALIZED LIFESTYLE ADVICE COMPARED TO GENERIC ADVICE ON WELLBEING AMONG DUTCH SENIORS – AN EXPLORATIVE STUDY

Esmée L. Doets*, Iris M. de Hoogh*, Nancy Holthuysen, Suzan Wopereis, Muriel C.D. Verain, Jos van den Puttelaar, Koen Hogenelst, André Boorsma, Emily P. Bouwman, Marielle Timmer, Wilrike J. Pasman, Marjan van Erk, Machiel J. Reinders

* These authors contributed equally

Physiology & Behavior, 2019

ABSTRACT

The aim of this explorative study is to evaluate whether personalized compared to generic lifestyle advice improves wellbeing in a senior population. We conducted a nine-week single-blind randomized controlled trial including 59 participants (age 67.7 ± 4.8 years) from Wageningen and its surrounding areas in the Netherlands. Three times during the intervention period, participants received either personalized advice (PA), or generic advice (GA) to improve lifestyle behavior. Personalization was based on metabolic health measurements and dietary intake resulting in an advice that highlighted food groups and physical activity types for which behavior change was most urgent. Before and after the intervention period self-perceived health was evaluated as parameter of wellbeing using a self-perceived health score (single-item) and two questionnaires (Vita-16 and Short Form-12). Additionally, anthropometry, and physical functioning (short physical performance battery, SPPB) were assessed.

Overall scores for self-perceived health did not change over time in any group. Resilience and motivation (Vita-16) slightly improved only in the PA group, whilst mental health (SF-12) and energy (Vita-16) showed slight improvement only in the GA group. SPPB scores improved over time in both the PA and GA group. PA participants also showed a reduction in body fat percentage and hip circumference, whereas these parameters increased in the GA group. Our findings suggest that although no clear effects on wellbeing were found, still, at least on the short term, personalized advice may evoke health benefits in a population of seniors as compared to generic advice.

1. INTRODUCTION

Physical activity and a healthy diet are lifestyle behaviors that significantly contribute to the prevention of chronic diseases and obesity [1-4]. In the Netherlands, more than 55% of the population has been classified as being insufficiently active [5] and over 35% reported sedentary behavior of 7–16 hours per day [6]. In the senior population in Europe the percentage of people being insufficiently active and reporting high sedentary behavior (13.3%) is even higher as compared to the adult population (8.5 – 9.6 %). In terms of dietary behavior, the Dutch National Food Consumption Survey showed that from 2007-2010 only 12-14% of the Dutch senior population met the recommended intake for vegetables and 17-26% met the recommended intake for fruit [7]. This survey also showed that more than 90% of the senior population exceeded the upper limit for saturated fat intake. These findings indicate a need for improvement in lifestyle behaviors among seniors that benefit public health.

Improving lifestyle requires a change in behavior. Previous studies show that personalized feedback and advice are more effective for improving dietary patterns and increasing physical activity than providing general information [8-14]. Personalization entails that feedback and advice are tailored to one individual, based on his or her characteristics. A potential reason that personalization is effective, is that people are more likely to pay attention to information that is relevant for them, and thus the impact of that information increases. Furthermore, in general people underestimate the likelihood that negative live events happen to them [15]. This optimistic bias could potentially be influenced by personalized information based on parameters that give an objective health risk indication like body weight, body fat percentage, food intake, but also genetic profiles.

In the current study, a holistic approach of personalization of lifestyle advice is adopted that encompasses tailoring the content of the advice (which information should be included in the message?), but also tailoring the form of the advice (how should the message be communicated?) and providing behavioral change support (how can the individual be aided in implementing the advice?). The content of the advice will be personalized based on previous investigations from the Food4Me research consortium including an array of lifestyle, phenotypic and genetic data which is fed back to the individual in prescription for action (16, 17). It was previously demonstrated that dietary advice tailored to an individual's health status is more effective for improving health parameters as compared to a generic advice [18-21].

The form in which advice is communicated has a pivotal role in changing behavior. Relevant insights from social psychology and marketing research are therefore needed to compose personal feedback for consumers that is effective in helping them to choose and maintain an optimal lifestyle. For example, actual behavior change can be aided by setting clear and achievable goals, for instance by forming "if-then plans" or "implementation intentions"

[22]. Social Cognitive Theory [23]) gives insight into how individuals regulate their behavior to achieve goals that can be maintained over time. An important aspect of this theory is self-efficacy, which is defined as the extent to which one believes in her or his own ability to reach a certain goal[24]. Since personalized lifestyle advice is a tool to help individuals regulate or change their lifestyle behaviors, the degree to which a person feels capable to implement a lifestyle advice determines the extent to which an individual will ultimately initiate and maintain behavior change [24]. In addition, some participants like to choose from many options to adapt their behaviors, whereas others are satisfied with only a few choice options. People with a lower tendency to maximize their choice are better off with less options [25]. As a result, the preferred number of healthy alternative options offered in a personalized advice may be something that varies per person and should in that sense be personalized too. Previous research established these individual differences in choice maximization (Maximization scale) [25, 26]. Considering these personal preferences and formulating realistic goals that fit within the current lifestyle can help individuals to realize behavior change.

As indicated, a potentially interesting target group for personalized advice for improving dietary behavior and physical activity are elderly people. It is estimated that 30% of seniors older than 60 years and >50% of seniors older than 80 years suffer from progressive loss of muscle mass and function [27-29]. At the same time, there is a high prevalence of overweight and obesity among seniors in the Netherlands, i.e., 60% [30]. Both obesity and age-related decline in muscle mass, strength and functional abilities can be counteracted with a healthy diet and regular physical exercise [28].

To our knowledge, combining data on individual behavior, health status and genetics to generate personalized lifestyle advice has only been used in a limited number of studies [31, 32]. Even less so for studies taking a holistic approach towards personalized nutrition by also including socio-psychological factors and/or behavior change techniques in personalized advice systems [14, 17]. In addition, personalized lifestyle advice for optimizing muscle health in seniors has not been studied before. It is thus unknown whether a senior population is open to personalized lifestyle advice and towards applying such advice in daily life.

In summary, the current study is explorative in nature and its primary focus is to evaluate whether personalized as compared to generic lifestyle advice improves wellbeing of participants in terms of self-perceived health (primary outcome) and objective biological health measures (secondary outcome). Lifestyle advice will be tailored based on dietary intake, genotype, phenotype, and measures of muscle health as well as socio-psychological factors via decision trees that are developed for this study. Additionally, participants will be given support in implementing the personalized advice through the formulation of implementation intentions. As an additional outcome, this explorative study will provide insight in the acceptance of personalized lifestyle advice by a senior population.

2. MATERIALS AND METHODS

2.1. Study participants

Study participants were recruited from the SenTo panel, a consumer panel of Wageningen University and Research, consisting of more than 800 seniors, as described elsewhere [33]. SenTo members aged 60 years and over received an invitation for study participation. Those willing to participate completed a screening questionnaire. Seniors were eligible to participate in the study when they: 1) were ≥ 60 years of age; 2) reported sedentary behavior for at least 10 hours a day; 3) were in good health and 4) had a self-reported BMI of 20-30 kg/m^2. Seniors were excluded from participation when they: 1) used medication known for its effects on blood glucose, cholesterol or insulin; 2) had a history of medical or surgical events including physical limitations, cardiovascular events or cerebrovascular accident, 3) were rehabilitating; 4) had a pacemaker, 5) suffered from diabetes type I or type II; 6) were on a specific diet (slimming or prescribed diet); 7) had physical, mental or practical limitations in using computerized systems; 8) had an alcohol consumption > 28 units/week for males and > 21 units/week for females or 9) experienced unintended weight loss or weight gain of > 2 kg in the three months prior to the screening. Written informed consent was obtained from all participants. The study was approved by the Medical Ethics Committee of Wageningen University (METC-WU 15/12; NL53218.081.15, date of approval 28-08-2015) and was registered in the Dutch Trial Register (NTR5490). This study was conducted in accordance with the Declaration of Helsinki.

2.2. Study design

The explorative study was designed as a parallel randomized controlled trial with an intervention period of nine weeks. A period of nine weeks seems to be sufficient to evaluate the initiation of behavior change [34] as well as of physical health changes (35-39). Participating seniors were not informed about the purpose of the study (single-blind). Participants were randomly allocated to either the intervention group or the control group balanced for gender, muscle health (i.e., hand grip strength) and socio-psychological factors (i.e., individual differences in choice maximization). Both at baseline and at the end of the intervention period well-being was assessed even as biological health parameters. After the intervention period, satisfaction with the received advice was evaluated using a combination of multiple-choice and open-ended questions. Subjects were informed about the actual purpose of the study, immediately after the last test session.

Besides wellbeing and the biological health parameters reported on here, also PhenFlex challenge tests (standardized liquid mixed meal) were conducted to assess phenotypic flexibility as a measure of health. These results were not used as input for the personalization of dietary advice and will be presented elsewhere.

2.3. Control treatment: Generic advice

At the start of the intervention period, participants received feedback on their health status based on extensive baseline measurements. Subsequently, the control group (n=29) received Generic Advice (GA) for improving their muscle health, using a leaflet with the national food-based dietary guidelines as published by the Netherlands Nutrition Centre [40]. This leaflet contained guidelines on the consumption of five categories of basic food products: 1-fruit and vegetables; 2-potatoes, bread, rice, and pasta; 3-dairy, meat, fish, and meat replacement products; 4-low-fat margarines, margarines, and oils; 5-water, as well as generic guidelines for an active lifestyle, meaning at least 30 minutes of physical activity per day.

2.4. Intervention treatment: Personalized advice

At the start of the intervention period, participants received feedback on their health status based on extensive baseline measurements. Subsequently, the intervention group (n=30) received the same leaflet with food-based dietary guidelines as the GA group. In addition, they received personalized advice (PA) through an online portal. The PA promoted muscle health among seniors and was in line with national and international recommendations provided by the Health Council of the Netherlands, the Netherlands Nutrition Centre and International expert groups. The personalized advice was based on the food based dietary guidelines as stated in the generic advice, and resulted in a set of nine personalized advice, of which seven focused on diet (intake of protein, energy, saturated fat, omega-3 fatty acids, salt, vitamin D and liquid not including alcohol) and two focused on physical activity (aerobic and resistance exercise). The content of the nine PA for each participant was determined with nine different underlying decision trees incorporating biological personalization factors outlined in **Table 1**. The cut-off values for each personalization factor as reported in **Table 1** determined which advice was given. Every PA included a green, orange, or red emoji (of a smiling face) that indicated whether the need for behavior change on that aspect was low, moderate, or high. Participants were instructed to formulate implementation intentions [22] in which they described how they planned to apply at least two of the received advices, preferably those advices indicated by an orange or red emoji, using a digital questionnaire with choice menus for time, situation and action. For example, participants had to indicate at which time of the day (e.g., in the evening) and in which situation (e.g., when I watch television) they were planning to replace an unhealthy product that they reported in their 3-day food diary (e.g., crisps) by a healthier product (e.g., whole meal cracker). Based on their personal preference for either many or a few choice options (choice maximization) participants were presented with either 3 or 10 healthy alternatives for the unhealthy product. Healthy alternatives were based on the Dutch Food Database [41].

Table 1: *Biological factors and cut-off values used to personalize lifestyle advice.*

Generic advice	Personalization factor	Classification	Personalization based on SNP	Classification
Protein intake	protein intake[a] BMI, glucose, cholesterol, triglycerides, blood-pressure	recommended (≥1.2 g/kg BW), low (0.52-1.2 g/kg BW), very low (≤0.52 g/kg BW) metabolic healthy; metabolic unhealthy[b]		
Energy intake	BMI waist circumference physical activity energy intake[a]	underweight (<18 kg/m^2), normal (18-30 kg/m^2), overweight/obese (>30 kg/m^2) normal (M<94 cm, F <80 cm), high (M ≥ 94 cm, F ≥ 80 cm) recommended (≥30 min), low (<30 min); recommended (low physical activity: M <2300 kcal, F <1900 kcal; normal physical activity: M <2600 kcal, F <2100 kcal), high (low physical activity: M ≥2300 kcal, F ≥1900 kcal; normal physical activity: M ≥2600 kcal, F ≥2100 kcal)	SNP rs9939609 - gene FTO	risk (AA / TA), non-risk (TT)
Saturated fat intake	fat intake[a]	recommended (≤10% of total energy intake), high (>10% of total energy intake)	SNP rs7903146 – gene TCF7L2	risk (TT/CT), non-risk (CC)
Fish intake	omega-3 fatty acid intake[a]	recommended (≥0.6% of total energy intake), low (<0.6% of total energy intake)	SNP rs174546 - gene FADS1	risk (CC), non-risk (TT/TC)
Liquid intake	age liquid intake[a]	<70 y, ≥70 y recommended (age <70 y: ≥1.5 L, age ≥70 y: ≥1.7 L); low (age <70 y: <1.5 L, age ≥70 y: <1.7 L)		

Generic advice	Personalization factor	Classification	Personalization based on SNP	Classification
Salt intake	blood pressure salt intake[a]	recommended (SBP <130 mmHg AND DBP <85 mmHg), high (SBP ≥130 mmHg OR DBP ≥85 mmHg) recommended (≤6 g/day), high (>6 g/day)		
Vitamin D intake	vitamin D intake[a]	recommended (≥10 mcg/day) vs low (<10 mcg/day)	SNP rs731236 - gene VDR taq1	risk (CC), non-risk (CT/TT)
Endurance training	SPPB score	low (0-4), medium (5-8), high (9-12)	SNP rs4341 - rs4343 - gene ACE. SNP rs143383 - gene GDF5	risk (LL), non-risk (DD). risk (CT/TT), non-risk (CC)
Resistance training	hand grip strength	low vs normal[c]	SNP rs4341 - rs4343 - gene ACE. SNP rs143383 - gene GDF5	risk (LL), non-risk (DD). risk (CT/TT), non-risk (CC)

SNP, single nucleotide polymorphism; BW, body weight; M, Males; F, females; SBP, systolic blood pressure; DBP, diastolic blood pressure; [a] Intake values are estimated from food diaries; [b] Metabolic unhealthy is defined as increased waist circumference (M ≥ 94 cm; F ≥ 80 cm) or BMI >30 kg/m^2 combined with either increased fasting triglycerides (≥150 mg/dL) or decreased HDL-cholesterol (M ≤ 1,03 mmol/L, F ≤1,28 mmol/L) or increased blood pressure (systolic ≥130 mmHg OR diastolic ≥85 mmHg) or increased fasting glucose (≥5.6 mmol/L). [c] Cut-off values for hand grip strength are age and gender specific based on meta-analysis by Bohannon et al. [42]

Twice during the intervention period, the intervention group received an updated version of the PA considering potential changes in dietary behavior (weeks 4 and 7).

2.5. Biological measurements for health feedback

Biological measurements were performed at baseline (T=0) to quantify individual health status to be used in feedback for subjects in both groups (PA + GA) and as input for the decision trees to determine the content of the PA. Participants came to the research facility after an overnight fast. Upon arrival, first some saliva was collected using a buccal swab, to determine the genetic profile (the following SNPs were included: FADS1 rs174546, TCF7L2 rs7903146, FTO rs9939609, VDR-taq1 rs731236, ACE rs4341, ACE rs4343, GDF5 rs143383). Subsequently, finger-stick blood samples were collected from each participant to assess fasting glucose (Medisana MediTouch 2 glucose meter), triglycerides and cholesterol (Mission 3-in-1 cholesterol meter). Blood pressure was measured three times (Medisana MTX). The average blood pressure of the last two measurements was considered for data analysis. All these measurements were performed under supervision of a study nurse. To further characterize muscle health, participants performed the Short Physical Performance Battery (SPPB), which includes a set of physical tests (gait speed, chair stand and balance tests) [43]. SPPB scores can range from 0 (worst performance) to 12 (best performance). Both the total score and the scores on the individual tests were recorded. In addition, handgrip strength was measured using an isometric hand dynamometer (JAMAR, Sammons Preston). The best of three attempts for the left and the right hand yielded the final score for hand grip strength. Body fat percentage was measured with a Tanita weighing scale with bioelectrical impedance measured from leg to leg [44]. Anthropometric data including height, body weight, waist-, hip-, arm- and thigh-circumference were collected by a trained research assistant using standard operation procedures at baseline and at the end of the study period (T=0 and T=1). At baseline and every three weeks throughout the intervention period participants recorded their food intake via a digital food diary on two weekdays and one weekend day (MijnEetmeter, Netherlands Nutrition Centre). From this diary we obtained estimates for intake of calories, protein, vitamin D, saturated fat, omega-3 fatty acids, salt, and liquid. A physical activity tracker was provided to the participants for monitoring their daily physical activity. However, due to a lot of technical problems with the device, it was removed from the study after the first advice.

2.6. Self-perceived health

Both at baseline and at the end of the intervention period, self-perceived health was evaluated with a single-item question (self-perceived health score) and further specified with the Dutch translation of the Short-Form 12 (SF12) [45] and the Vita-16, a short questionnaire addressing the core dimensions of vitality: energy (Cronbach's α = .84), motivation (Cronbach's α = .92) and resilience (Cronbach's α = .92) [45]. *2.7 Socio-psychological factors*

At baseline, all participants completed a questionnaire that included the shortened Maximization Scale (8 items, 7-points Likert-scale, Cronbach's α = .83) based on Nenkov et al. [26]. Based on the median score of the Maximization scale we split the intervention group in those with preference for many choice options when formulating implementation intentions (i.e., 10) and those with preference for few options (i.e. 3).

Self-efficacy towards eating proteins (6 items, 7-points Likert scale, Cronbach's α = .97) and self-efficacy towards exercise (6 items, 7-points Likert scale, Cronbach's α = .94) were evaluated at T=0 and T=1 with a questionnaire based on Strecher et al. [47]. For these multi-item scales, combined scores were calculated by averaging the individual items. The translated and backwards translated versions of the questionnaire have been used and tested in previous studies, except for some specific items. These items are adjusted to measure factors specifically for this study. Pre-tests have been conducted to determine whether the adjusted items are interpreted as they were intended.

2.7. Quantitative and qualitative evaluation

To evaluate compliance with the advice, two weeks after each PA, participants in the PA group were asked to report to what extent they applied their formulated implementation intentions on a 7-points Likert scale. At the end of the intervention period, all participants received a questionnaire to report on compliance with the food based dietary guidelines (7-points Likert scale) and perceived healthiness of the diet (10-points structured line scale). Acceptance of the PA including tools and measurements was evaluated with open and multiple-choice questions.

2.8. Statistical analysis

All analyses were performed with SPSS, version 25.0. Due to the explorative nature of the study and the small size of the sample, we refrained from using statistical difference tests. Instead, we decided to report the mean estimates together with the confidence intervals (CIs). Doing so allows us to obtain an indication of the precision of the sample means and their differences while avoiding the flaws accompanied with using statistical difference tests [48]). Baseline characteristics of participants in the PA and GA group were compared and changes over time (T1 vs T0) were examined.

3. RESULTS

3.1. Baseline characteristics

Table 2 shows baseline characteristics of participants. A total of 59 participants (22 males, 37 females) with a mean age of 67.7 ± 4.8 years were included in the study. Confidence intervals of the mean differences in characteristic between the intervention (PA) and control group (GA) include 0, indicating that the two groups were similar at baseline. Mean BMI (based on height and body weight measured at the research facility) was 26.1 kg/m^2, thus slightly above the recommended upper level of 24.9 kg/m^2. Self-reported BMI was used to select participants (20-30 kg/m^2), but at baseline BMI turned out to be higher than 30 for 9 participants. Mean reported sedentary behavior was 12.5 hours a day. In general, mean nutrient intakes at baseline were in line with dietary reference values except for saturated fat, salt and vitamin D. Intake of saturated fat and salt exceeded the recommended maximum intake of respectively 20 and 6 grams per day as stated on the website of the Netherlands Nutrition Centre (http://www.voedingscentrum.nl). Mean vitamin D intake was below the recommended daily intake of 10 mcg; however, supplement intake was not recorded. For the socio-psychological measures, scores on the 7-point composite scales were above the midpoint of the scale, except for the maximization scale (**Table 2**). This implies that participants reported relatively high self-efficacy regarding protein intake (mean = 6.05) and exercising (mean = 5.61). Mean score on the maximization scale was below the midpoint of the scale (mean = 3.08), indicating that participants are generally satisfied with a limited number of choice options.

Table 2: *Baseline characteristics of study population* [a]

	Total study population (N= 59)[b]	Generic advice (GA) (N = 29)[b]	Personalized advice (PA) (N = 30)[b]	Mean difference, 95% CI
Age	67.7 (4.8)	67.4 (4.25)	68.0 (5.38)	-0.6 [-3.1, 2.0]
Age (range)	60 – 79 years	61-75 years	60-79 years	-
Gender:				
Male (%)	37.3%	37.9%	36.7%	-
Female (%)	62.7%	62.1%	63.3%	
BMI[c]	26.1 (3.2)	26.0 (3.4)	26.1 (3.0)	0.0 [-0.3, 0.2]
BMI (range)[c]	20.1-32.8	20.1-32.8	21.4-31.4	-
Calorie intake (kcal/day)	1825 (510)	1790 (472)	1852 (545)	-61.7 [-344.1, 220.8]
Protein intake (g/day)	80.1 (21.2)	82.9 (23.2)	77.9 (19.6)	5.0 [-6.7, 16.7]
Saturated fat intake (g/day)	26.1 (11.8)	27.1 (11.5)	25.3 (12.1)	1.8 [-4.7, 8.3]
Omega-3 fatty acid intake (mg/day)	1.4 (1.0)	1.4 (0.9)	1.5 (1.1)	-0.1 [-0.6, 0.4]
Salt intake (g/day)	6.1 (2.2)	5.9 (1.9)	6.2 (2.4)	-0.4 [-1.5, 0.8]
Vitamin D intake from foods (mcg/day)	2.4 (1.5)	2.5 (1.4)	2.3 (1.7)	0.1 [-0.7, 1.0]
Liquid intake (L/day)	2.0 (.7)	2.0 (.7)	2.0 (.8)	0.0 [-0.4, 0.4]
Maximization Scale[d]	3.1 (1.2)	3.2 (1.3)	3.0 (1.0)	0.2 [-0.5, 0.8]
Self-efficacy regarding exercising[d]	5.6 (1.1)	5.5 (1.1)	5.7 (1.1)	-0.3 [-0.8, 0.3]
Self-efficacy regarding eating proteins[d]	6.1 (.9)	6.0 (1.0)	6.1 (1.0)	-0.1 [-0.6, 0.4]

a Data are reported as mean (SD) unless indicated differently; CI = confidence interval; b N varies between variables due to missing data; c BMI based on clinical measurements; d Answering scales range from 1 to 7

3.2. Personalized advice

Figure 1 shows how many participants in the PA group received a green, orange, or red emoji for the first (week 1) and last advice (week 7), i.e., how many participants demonstrated respectively a low, moderate, or high need for behavior change for that specific item. Need for behavior change with respect to physical activity in terms of endurance and resistance training was low to moderate for most participants in the PA group. This also applies to liquid intake and to a lesser extent to salt and protein intake. At baseline, need for behavior change with respect to general guidelines about calorie intake, saturated fat intake, omega-3 fatty acid intake and vitamin D intake was high for about half of the study participants, indicating a scope for improvement. Such improvement was observed for omega-3 fatty acids; the PA compliance with the final advice on omega-3 fatty acids was good for almost all participants. Adherence to general guidelines about intake of saturated fat and liquids also improved during the intervention period. Despite the focus on muscle health in this study and a high number of formed implementation intentions for protein intake at baseline (n=14), protein intake worsened during the study, with more participants receiving an orange emoji and less participants receiving a green emoji. Next to protein intake, participants in the intervention group often formulated implementation intentions for improving vitamin D intake (n=19), calorie intake (n=13), and saturated fat intake (n=10).

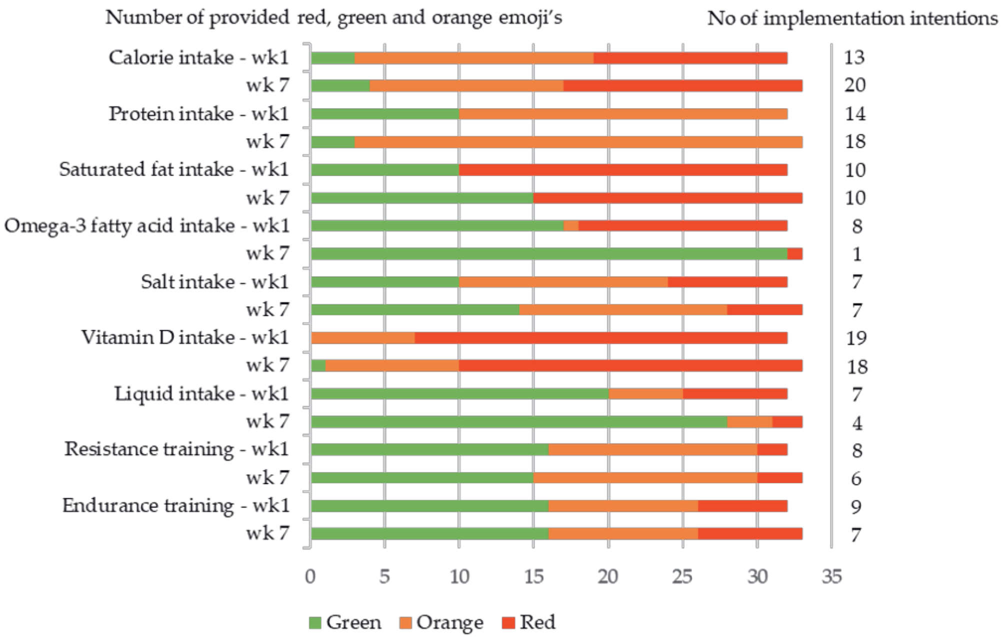

***Figure 1**: Need for behavior change in the PA group: number of participants receiving green, orange, and red emoji per advice at first (wk1) and last (wk7) personalized advice moment.*

3.3. Self-perceived health and self-efficacy

Table 3 shows mean scores and corresponding CIs on self-perceived health measures (self-perceived health score, SF12 and Vita-16) at baseline (T0) and at the end of the study period (T1). Also, the difference scores and their CIs between T0 and T1 are displayed in the table. These results show that most of the times scores did not improve over time as mean differences are around zero and CIs include zero. However, the mental health dimension of the Short-Form 12 and the energy sub-scale of Vita-16 increased for the GA group. In the PA group scores for motivation and resilience (sub-scales of Vita-16) slightly improved over time. Self-efficacy regarding protein intake tends to decrease over the course of the intervention period for both the PA and GA group. This is in line with the decline of protein intake during the study. Self-efficacy regarding exercise shows no changes. The final column of Table 3 shows the mean differences and their CIs between the PA and GA group. The small mean differences and CIs including zero indicate no differences between the two groups, as is also indicated by the generally large overlap between the CIs of the GA and PA group.

3.4. Biological measurements

Table 4 shows changes in biological measurements during the intervention period. The mean scores and corresponding CIs in both the PA and GA group indicate that SPPB scores improved over time. Furthermore, the PA group showed a greater reduction in waist circumference. Note that regarding fat percentage and hip circumference we observe an opposite effect when comparing the GA to the PA group: fat percentage and hip circumference increases for the GA group, while these parameters decrease for the PA group. The final column of Table 4 shows the mean differences and their CIs between the PA and GA group. The small mean differences and CIs including zero indicate no differences between the two groups, as is also indicated by the generally large overlap between the CIs of the GA and PA group.

3.5. Quantitative and qualitative evaluation by participants

We observed no differences between the GA and PA group in perceived compliance with Dutch food based dietary guidelines (7-points-scale, GA: mean=5.26 ± 1.37; PA: mean=5.18 ± 1.01) and perceived healthiness of actual diet (10-points scale, GA: mean=7.26 ± 1.76; PA: mean=7.68 ± 1.09) at the end of the study. The PA group indicated they increased their awareness, knowledge, and insight in individual health behaviors. Mean self-reported compliance with the formulated implementation intentions was 4.86 (7-points scale, SD=1.46). Some participants (n=8) experienced difficulties with the digital food diary, especially the user friendliness of the application had a low score (2.4 on a 7-points scale). In general, all participants evaluated the study as very positive and all, but one indicated they would participate again.

Table 3: *Changes in self-reported health measures over time within and between groups*

	Generic advice (N = 29)	Personalized advice (N = 30)	Mean difference
Self-perceived health (1-5) T0	3.5 [3.2, 3.7]	3.5 [3.3, 3.8]	0.0 [-0.4, 0.3]
T1	3.5 [3.2, 3.8]	3.4 [3.1, 3.7]	0.1 [-0.3, 0.5]
Difference T1-T0	0.0 [-0.1, 0.2]	-0.1 [-0.4, 0.2]	0.2 [-0.2, 0.5]
SF12_Physical health (0-100) T0	51.0 [48.0, 54.1]	49.7 [47.1, 52.4]	1.5 [-2.4, 5.4]
T1	50.9 [48.5, 53.2]	49.6 [47.0, 52.2]	1.3 [-2.2, 4.7]
Difference T1-T0	-0.2 [-3.3, 2.9]	-0.2 [-2.4, 2.1]	0.0 [-3.7, 3.7]
SF12_Mental health (0-100) T0	52.2 [48.8, 55.6]	54.9 [52.0, 57.8]	-2.5 [-6.8, 1.8]
T1	54.4 [51.4, 57.4]	54.2 [52.1, 56.4]	0.2 [-3.4, 3.7]
Difference T1-T0	2.2 [0.0, 4.4]	-0.7 [-3.1, 1.7]	2.9 [-0.2, 6.1]
Vita16_Energy (1-7) T0	5.2 [4.6, 5.7]	5.5 [5.1, 5.8]	-0.2 [-0.9, 0.4]
T1	5.6 [5.2, 6.0]	5.5 [5.1, 5.9]	0.1 [-0.4, 0.7]
Difference T1-T0	0.4 [0.0, 0.9]	0.0 [-0.3, 0.3]	0.4 [-0.1, 1.0]
Vita16_Motivation (1-7) T0	5.4 [4.8, 5.9]	5.3 [4.9, 5.7]	0.0 [-0.6, 0.7]
T1	5.6 [5.3, 5.9]	5.7 [5.3, 6.0]	0.0 [-0.5, 0.4]
Difference T1-T0	0.3 [-0.2, 0.8]	0.3 [0.0, 0.7]	-0.1 [-0.6, 0.5]
Vita16_Resilience (1-7) T0	5.3 [4.8, 5.8]	5.2 [4.7, 5.6]	0.2 [-0.5, 0.8]
T1	5.6 [5.3, 5.9]	5.6 [5.3, 5.9]	0.0 [-0.4, 0.5]
Difference T1-T0	0.3 [-0.2, 0.8]	0.4 [0.1, 0.8]	-0.1 [-0.7, 0.5]
Vita16_Overall vitality (1-7) T0	5.3 [4.8, 5.8]	5.3 [5.0, 5.7]	0.0 [-0.6, 0.6]
T1	5.6 [5.3, 5.9]	5.6 [5.3, 5.9]	0.1 [-0.4, 0.5]
Difference T1-T0	0.4 [-0.1, 0.8]	0.2 [0.0, 0.5]	0.1 [-0.4, 0.6]
Self-efficacy_exercise (1-7) T0	5.4 [4.8, 5.9]	5.6 [5.2, 6.1]	-0.2 [-0.8, 0.3]
T1	5.2 [4.6, 5.9]	5.4 [4.9, 5.8]	-0.1 [-0.8, 0.5]
Difference T1-T0	-0.2 [-0.8, 0.4]	-0.3 [-0.8, 0.2]	0.1 [-0.7, 0.9]
Self-efficacy_protein intake (1-7) T0	5.8 [5.4, 6.3]	6.2 [5.8, 6.6]	-0.1 [-0.6, 0.4]
T1	5.2 [4.7, 5.7]	5.6 [5.3, 6.0]	-0.3 [-0.9, 0.3]
Difference T1-T0	-0.6 [-1.2, 0.0]	-0.5 [-1.0, -0.1]	-0.1 [-0.8, 0.6]

Note: 95% CIs are reported in brackets.

Table 4: *Changes in biological measures over time within and between groups*

	Generic advice (N = 29)	**Personalized advice (N = 30)**	**Mean difference**
SPPB (1-12) T0	10.3 [9.7, 10.8]	10.3 [9.7, 10.9]	-0.1 [-0.8, 0.7]
T1	10.7 [10.3, 11.1]	11.1 [10.7, 11.4]	-0.3 [-0.8, 0.2]
Difference T1-T0	0.5 [0.1, 0.9]	0.8 [0.3, 1.2]	-0.3 [-0.8, 0.3]
Fat (%) T0	31.5 [28.2, 34.8]	32.8 [30.0, 35.5]	-0.5 [-4.7, 3.6]
T1	32.1 [29.1, 35.0]	31.7 [28.4, 34.9]	0.6 [-3.6, 4.8]
Difference T1-T0	0.6 [-0.5, 1.7]	-1.1 [-2.3, 0.1]	1.7 [0.2, 3.3]
Waist (cm) T0	93.6 [88.8, 98.3]	93.4 [89.5, 97.2]	1.0 [-4.7, 6.7]
T1	93.2 [88.6, 97.7]	91.5 [87.5, 95.5]	2.3 [-3.3, 8.0]
Difference T1-T0	-0.4 [-1.6, 0.8]	-1.9 [-2.9, -0.8]	1.4 [-0.1, 2.8]
Hip (cm) T0	100.1 [97.2, 103.1]	101.0 [98.3, 103.7]	-0.4 [-4.2, 3.4]
T1	101.0 [98.2, 103.7]	99.9 [97.1, 102.6]	1.6 [-2.1, 5.2]
Difference T1-T0	0.8 [-0.3, 1.9]	-1.1 [-2.8, 0.6]	2.0 [0.0, 3.9]
BMI (kg/m^2)T0	25.8 [24.5, 27.0]	26.3 [25.2, 27.3]	-0.1 [-1.7, 1.6]
T1	25.8 [24.6, 27.1]	26.1 [25.0, 27.2]	0.1 [-1.5, 1.8]
Difference T1-T0	0.1 [-0.2, 0.3]	-0.1 [-0.3, 0.1]	0.2 [-0.1, 0.5]
Grip Strength Dominant Hand (kg) T0	32.6 [28.9, 36.3]	32.8 [29.4, 36.1]	0.6 [-4.2, 5.4]
T1	32.2 [28.4, 36.0]	32.8 [29.6, 36.0]	-0.4 [-5.2, 4.3]
Difference T1-T0	0.4 [-1.2, 2.0]	0.0 [-1.1, 1.1]	0.6 [-1.3, 2.5]

Note: 95% CIs are reported in brackets.

4. DISCUSSION

In this explorative study, we evaluated the potential of personalized lifestyle advice for improving wellbeing in a population of independently living, sedentary seniors. In this study, wellbeing was operationalized by self-perceived health as well as biological measures, including body composition, blood markers and physical function tests. Results showed that seniors receiving lifestyle advice over a period of nine weeks, either personalized or generic, improved physical function. In addition, there are subtle indications for potential beneficial health effects among those receiving PA. Our findings provide a cautious indication that on the short-term personalized advice may evoke additional health benefits in seniors as compared to generic lifestyle advices. Note that these findings are only applicable to our specific study population and cannot be translated to the general population.

4.1. General feedback for both GA and PA group

First, since all participants received feedback on their health status, monitored dietary intake and were equipped with an activity tracker, participants in both the GA group and the PA group were more aware of their individual (muscle) health and lifestyle behavior. Previous studies show that increased awareness of personal health status and behavior may induce behavior change, in terms of adhering to a healthier diet (when monitoring dietary intake) or increasing physical activity (when using an activity tracker) [49-53]. The motivation level of our study population was not evaluated, but probably relatively high as seniors were recruited from an elderly network that is regularly involved in studies on sensory evaluation and eating behavior. In addition, in general participants in lifestyle interventions seem to have a higher motivation for behavior change as compared to non-participants research [54]. Motivation to carry out a goal-directed behavior is a highly important success factor for behavior change interventions and therefore should be measured at baseline to allow better interpretation of the results [55]. Next to being motivated, however, the ability to translate this motivation into action is also key for successful behavior change. This is also referred to as self-regulation [56, 57]. Previous research demonstrated that self-regulation is important for initiating health-enhancing behaviors (e.g., consuming fruit and vegetables) and the inhibition of health risk behaviors (e.g., consuming products rich in saturated fat). However, as both types of behavior have different executive function determinants, being successful in initiating health enhancing behaviors does not automatically mean that an individual is successful in inhibiting risk behaviors too [58]. Further research on how to personalize dietary advice based on self-regulation determinants is recommended as self-regulation is highly relevant for compliance on the longer term.

4.2. Dietary advice for PA group and dietary behavior change

Among participants of the PA group, the behavior change needed was mainly the intake of calories, saturated fat, omega-3 fatty acids and vitamin D (red emoji) and the intake of protein (orange emoji) (Figure 2). This is in line with results from the Dutch food consumption survey among vital older adults showing that intake of saturated fat and salt exceeds recommended dietary intakes whereas the intake of whole meal products, fruit and fish is generally below the recommendation [59]. PA provided in our study was effective in improving adherence to dietary guidelines regarding saturated fat, omega-3 fatty acids, liquid, and salt. For improving intake of calories and vitamin D, the provided dietary advice seemed less effective, whereas for protein intake the PA even worsened adherence over time. This data was not available for the GA group and could therefore not be compared in terms of dietary behavior change over time. The effectiveness of the advice on the different dietary aspects may be related to the practical applicability of the advice as also demonstrated before by Sahyoun and colleagues [55]. For saturated fat, omega-3 fatty acids, liquid and salt, advice were related to the consumption of specific food groups (e.g., snacks, fish, drinks, processed foods) and probably relatively easy to implement in daily practice when motivated to change behavior [607]. Implementation may be facilitated as consumers are able to recognize foods high in saturated fat and/or salt content and moreover, they are generally aware that foods high in salt or saturated fat content are not included in the food-based dietary guidelines [60]. Furthermore, front-of-pack labelling enhances attention to and facilitates the use of nutrition information on both dietary aspects [61-63]. In addition, many food manufacturers perform product reformulations to reduce saturated fat and/or salt content and thereby increased the availability of more healthy product variants. This also facilitates consumers in making healthy food choices.

Despite our observation that many participants formulated implementation intentions to optimize their calorie or protein intake, compliance with the PA advice did not improve throughout the study period. Advice on both dietary aspects might have been less straightforward, i.e., not related to specific food groups and therefore more difficult to implement into daily life than other dietary aspects, e.g., salt intake. Moreover, in our study consumers formulated one implementation intention per advice, meaning that they selected one type of food to be replaced by another. We chose this strategy as it has been suggested before that consumers can only handle a few behavior changes/implementation intentions at a time [64, 65]. To effectuate a meaningful change in protein or energy intake, replacing one food by a healthier alternative is likely to be insufficient. This means that to notice a change in protein or energy intake, either the study should have been implemented for a longer period or participants had to replace more products from their usual diet by alternative products in line with the PA based on available product information e.g., on food labels, besides the implementation intention formulated. This requires a high level of motivation to change behavior and understanding of nutrition information as also shown before [61, 66]. The complexity of the (personalized) advice on protein intake is also reflected in a decreased level of self-efficacy regarding protein intake in both the PA and the GA group at the end of the study as compared to baseline. Self-efficacy is a concept that is difficult to influence. In the literature there are inconsistent findings on the effect of an intervention on self-efficacy (e.g., 67, 68). This can be explained by the fact that the effect of a self-efficacy intervention depends on the technique used [69] and on the individual [70]. The loss in self-efficacy could also be due to participants experiencing this research as a reminder of their (unhealthy) diet, which might lead to a lack of confidence in someone's ability to succeed in following dieting advice and ultimately resulting in lower self-efficacy [68]. In their meta-analysis, Prestwich et al. [69] revealed that indeed emotional stress could undermine a positive effect on self-efficacy. Interventions that incorporate techniques that help to manage this stress were more successful in raising dietary self-efficacy than interventions that do not. We recommend future research in the context of personalized nutrition advice to also include some kind of stress management technique as part of the intervention.

Obtaining sufficient vitamin D from foods is difficult, especially for older adults, therefore the advice is to take daily supplements. However, the digital food diary we used in this study did not record supplement use and therefore it is impossible to say something about compliance for this nutrient.

4.3. Health effects of personalized advice

Participants receiving PA had a stronger beneficial decline in body fat percentage, waist circumference and hip circumference than those receiving GA, although confidence intervals show a lot of overlap, which implies that these statements can only be done with the necessary restraints. The fact that no changes were observed for BMI could be due to the relatively small changes in fat%, hip and waist circumference: a 1-point decrease in BMI would require a weight loss of approximately 3 kg. The bioimpedance leg-to-leg method has been recommended as a practical tool that is accurate for clinical monitoring of fat% changes over time during weight management in older adults [44]. Xie et al. previously showed in postmenopausal women, a CV within days of 1.1% and a CV between days of 2.1% [71]. The changes in fat% observed in our study are 0.6/31.5=1.9% for the GA group versus 1.1/32.8 = 3.4% for the PA group. When we consider the CVs, we cannot be sure whether our results are due to measurement error or actual changes in fat%, although the beneficial effects seen in the PA group are in line with reduced waist and hip circumferences in this group.

There is a limited number of studies that previously investigated effects of lifestyle counselling on body composition and physical function outcomes in older adults [72, 73]. Harrigan et al. observed significant larger declines in hip circumference, waist circumference and fat percentage among participants receiving personal advice during a period of 6 months as compared to participants receiving usual care [72]. Santanasto et al. evaluated physical function scores among older adults receiving either a physical activity intervention or a general health education intervention on a weekly basis. In both study groups physical performance improved after 6 months, however the effects were stronger in the intervention group [73]. This is in line with our results as both PA and GA resulted in improved SPPB scores at the end of the study period. It has been suggested that among overweight or obese older adults, modest weight loss improves physical function, most likely through a decline in fat mass [74, 75].

Finally, while self-perceived vitality, specifically motivation and resilience (Vita-16), shows an indication for improvement over time for the PA group, self-perceived health did not improve. It could be that the study duration was too short after all to detect changes in self-perceived overall health, while changes in specific areas of vitality are potentially easier to detect over a shorter time frame. Motivation as measured with the Vita-16 reflects ´an individual’s motivation to set goals in life and try to achieve these goals’ [46]. as people in the PA group were actively involved in setting lifestyle goals and behavior change, this may have led to the increase in motivation. Resilience reflects an individual’s ability to cope with the daily problems and challenges of life. The PA did provide participants concrete support and tips in improving their lifestyle, but it is difficult to say what exactly caused the increase in resilience scores.

Remarkably, mental health scores as part of the SF-12 slightly increased within the GA group, while (both the generic and personalized) advice was not aimed at improving mental health. Improvements in mental health because of lifestyle change are not plausible after only nine weeks and the observed increase does not seem to be clinically relevant, as is also indicated by the absolute scores on mental health, which are not different between the two groups.

4.4. LIMITATIONS

Some limitations of this study must be considered. Firstly, multiple levels of personalization (genotype, phenotype, dietary intake, personality, preferences) are used. Therefore, it is not possible to conclude what aspect of the personalized advice was most effective. Previous studies demonstrated beneficial effects of personalized nutrition advice [19, 31], but it remains unclear whether personalization of advice based on genotype or phenotype has additional value compared to personalization based on dietary intake alone [20, 76]. Although personalization of advice based on phenotype or genotype may not have an added value with respect to compliance, there can still be an added value with respect to improving specific health outcomes in an individual. It would be interesting to compare a study group receiving PA with a group which receives help in implementing the general guidelines for healthy nutrition and physical activity. Then it will become evident whether further personalization on phenotype, genotype or eating habits has added benefit.

Secondly, and because of the explorative nature of the study, the sample size was not based on the statistical power needed for interaction effects. This could be an explanation for the relatively small (interaction) effects. Furthermore, the study population already relatively active, despite the high level of sedentary behavior, and had a generally healthy food pattern at baseline. In future studies, current activity patterns and dietary intake could be used as inclusion/exclusion criteria to ensure that there is more room for improvement.

Thirdly, participants in the study were instructed to use the device MijnEetmeter (Netherlands Nutrition Centre) for monitoring dietary intake. Besides tracking dietary intake, this device can also provide feedback on intake of calories, macronutrients, and some micronutrients. This implies that also the GA group received some feedback through MijnEetmeter, which may have interfered with our results. However, the feedback given by MijnEetmeter was based on dietary intake only, and focused on generic guidelines for calories, macronutrient intake (fat, saturated fat, protein, carbs, fiber) and salt. Next to the MijnEetmeter feedback, the PA group was provided a web portal that showed to which extent a participant reached the guidelines for different dietary categories with orange, red and green icons. This allowed this group to select those advice categories where there is most room for improvement for them personally. The GA group did not have such an opportunity.

Fourthly, the frequency of personalized feedback and advice in our study was fixed, however it can be assumed that the optimal frequency of personalized advice and reminders to the advice varies between individuals. To further optimize personalization of lifestyle advice, the relation between frequency of exposure and compliance should be further studied. Furthermore, we used personal health data as well as personal preferences to make the generic (population-based) recommendations more personal. Up to now, evidence-based knowledge on subgroups/strata of people is too limited to be used for personalized advice, however this will change in the coming years.

Finally, the duration of the study was relatively short. Based on previous studies, a period of nine weeks seemed sufficient to evaluate the initiation of behavior change [34] as well as of small physical health changes [35-39], however whether this behavior change persists and whether health effects are maintained should be further evaluated on the longer term. Despite these limitations we were able to show that personalized advice results in additional health effects compared to generic advice, therefore demonstrating that personalized advice has a strong potential for improving the wellbeing of older adults.

5. CONCLUSION

In the present explorative study, we showed that personalized advice may evoke health benefits in a population of seniors as compared to generic advice.

Acknowledgments: The authors are grateful to all seniors that participated in the study. We also thank Stefanie Kremer and Jan Top for their valuable scientific contribution to the design of the research. This work was supported by the Ministry of Economic Affairs TO2 flex program. The funder had no role in the design, analysis or writing of this article.

Declarations of Interest: None.

REFERENCES

1. World Health Organization. Diet, Nutrition and the Prevention of Chronic Diseases. Joint WHO/FAO Expert Consultation. WHO Technical Report Series no. 916. Geneva: WHO, 2003.
2. McKenzie, F., Biessy, C., Ferrari, P. et al. Healthy lifestyle and risk of cancer in the European Prospective Investigation into Cancer and Nutrition Cohort Study. Medicine 2016, 95, 1-10
3. Thorp, A. A., Owen, N., Neuhaus, M. et al. Sedentary behaviors and subsequent health outcomes in adults a systematic review of longitudinal studies, 1996–2011. Am J Prev Med 2011, 41, 207-215.
4. Proper, K.I., Singh, A.S., van Mechelen, W. et al. Sedentary behaviors and health outcomes among adults: a systematic review of prospective studies. Am J Prev Med 2011, 40, 174-182
5. Sjöström, M., Oja, P., Hagströmer, M. et al. Health-enhancing physical activity across European Union countries: the Eurobarometer study. J Publ Health, 2006, 14, 1–10
6. Bennie, J.A., Chau, J.Y., van der Ploeg, H.P. et al. The prevalence and correlates of sitting in European adults-a comparison of 32 Eurobarometer-participating countries. Int J Behav Nutr Phys Act, 2013, 10, 107-120
7. Van Rossum, C.T.M., Fransen, H.P., Verkaik-Kloosterman, J. et al. Dutch National Food Consumption Survey 2007-2010: Diet of children and adults aged 7 to 69 years. RIVM rapport 350050006, Bilthoven, The Netherlands, 2011
8. Brug, J., Campbell, M., van Assema, P. The application and impact of computer-generated personalized nutrition education: a review of the literature. Patient Educ Couns, 1999, 36, 145-156.
9. Fjeldsoe, B.S., Marshall, A.L., Miller, Y.D. Behavior change interventions delivered by mobile telephone short-message service. Am J Prev Med 2009, 36, 165-173.
10. Krebs, P., Prochaska, J.O., Rossi, J.S. A meta-analysis of computer-tailored interventions for health behavior change. Prev Med 2010, 51, 214-221.
11. Kris-Etherton, P.M., Taylor, D.S., Smiciklas-Wright, H. et al. High-soluble-fiber foods in conjunction with a telephone-based, personalized behavior change support service result in favorable changes in lipids and lifestyles after 7 weeks. J Am Diet Assoc 2002, 102, 503-510.
12. Marcus, B. H., Napolitano, M. A., King, A. C. et al. Telephone versus print delivery of an individualized motivationally tailored physical activity intervention: Project STRIDE. Health Psych 2007, 26, 401-
13. Bull, F. C., Kreuter, M. W., Scharff, D. P. Effects of tailored, personalized and general health messages on physical activity. Patient Educ Couns, 1999, 36, 181-192.
14. Parekh, S., Vandelanotte, C., King, D. et al. Improving diet, physical activity and other lifestyle behaviours using computer-tailored advice in general practice: a randomised controlled trial. Int J Behav Nutr Phys Act 2012, 9, 108-
15. Sharot, T. The optimism bias. Curr Biol 2011, 21, R941-R945.
16. Stewart-Knox, B.J., Markovina, J., Rankin, A., Bunting, B., Kusnezof, A., Fischer, A., Poínhos, R., Vaz de Almeida, M.D., Panzone, L., Gibney, M., & Frewer, L. Making personalised nutrition the easy choice: policies to break down the barriers and reap the benefits. Food Policy 2016, 63, 134-144.
17. van Ommen B et al. Systems biology of personalized nutrition. Nutr Rev. 2017, 1;75(8):579-599.
18. Adriaanse, M. A., de Ridder, D. T., de Wit, J. B. Finding the critical cue: implementation intentions to change one's diet work best when tailored to personally relevant reasons for unhealthy eating. Pers Soc Psychol Bull 2009, 35, 60-71.

19. Zeevi, D., Korem, T., Zmora, N. et al. Personalized nutrition by prediction of glycemic responses. Cell 2015, 163, 1079-1094.
20. Celis-Morales, C., Livingstone, K. M., Marsaux, C. F., Macready, A. L., Fallaize, R., O'Donovan, C. B., ... & San-Cristobal, R. Effect of personalized nutrition on health-related behaviour change: evidence from the Food4me European randomized controlled trial. International journal of epidemiology 2016, 46(2), 578-588.
21. de Toro-Martín, J., Arsenault, B., Després, J. P., & Vohl, M. C. Precision nutrition: A review of personalized nutritional approaches for the prevention and management of metabolic syndrome. Nutrients 2017, 9(8), 913.
22. Gollwitzer, P. M. Implementation intentions. Strong effects of simple plans. Am Psychol 1999, 54, 493-503
23. Bandura, A. (1997). Self-Efficacy: The Exercise of Control. London: Worth Publishers.
24. Bandura, A. Self-efficacy: toward a unifying theory of behavioral change. Psychol Rev 1977, 84, 191.
25. Schwartz, B., Ward, A., Monterosso, J. et al. Maximizing versus satisficing: Happiness is a matter of choice. J Pers Soc Psychol 2002, 83, 1178-1197.
26. Nenkov, G.Y., Morrin, M., Ward, A., et al. A short form of the Maximization Scale: Factor structure, reliability and validity studies. Judgm Dec Mak 3, 2008, 371-388.
27. Cruz-Jentoft, A.J., Baeyens, J.P., Bauer, J.M. et al. Sarcopenia: European consensus on definition and diagnosis Report of the European Working Group on Sarcopenia in Older People. Age Ageing 2010, 39, 412-423.
28. Deutz, N.E., Bauer, J.M., Barazzoni, R. et al. Protein intake and exercise for optimal muscle function with aging: recommendations from the ESPEN Expert Group. Clin Nutr 2014, 33, 929-936.
29. Baumgartner, R.N., Koehler, K.M., Gallagher, D. et al. Epidemiology of sarcopenia among the elderly in New Mexico. Am J Epidemiol 1998, 147, 755-763
30. Van den Brink, C.L., Blokstra, A. Hoeveel mensen hebben overgewicht? In: Volksgezondheid Toekomst Verkenning, Nationaal Kompas Volksgezondheid. Bilthoven: RIVM, <http://www.nationaalkompas.nl> Nationaal Kompas Volksgezondheid\Determinanten\Persoons-gebonden\Overgewicht, 23 juni 2014.
31. Abrahams, M., Frewer, L.J., Bryant, E. et al. Factors determining the integration of nutritional genomics into clinical practice by registered dietitians. Trends Food Sci Technol 2016, 59, 139-147.
32. Celis-Morales, C., Livingstone, K.M., Marsaux, C.F. Design and baseline characteristics of the Food4Me study: a web-based randomised controlled trial of personalised nutrition in seven European countries. Genes Nutr 2015, 10, 450.
33. Kremer, S., Holthuysen, N., Boesveldt, S. The influence of olfactory impairment in vital, independently living older persons on their eating behaviour and food liking. Food Qual Pref 2014, 38, 30-39.
34. Lally, P., van Jaarsveld, C.H.M., Potts, H.W.W., & Wardle, J. How are habits formed: Modelling habit formation in the real world. European Journal of Social Psychology 2010, 40(6), 998-1009.
35. Fazelzadeh, P., Hangelbroek, R. W., Joris, P. J., Schalkwijk, C. G., Esser, D., Afman, L., ... & Van Duynhoven, J. Weight loss moderately affects the mixed meal challenge response of the plasma metabolome and transcriptome of peripheral blood mononuclear cells in abdominally obese subjects. Metabolomics 2018, 14(4), 46.

36. Esser, D., Mars, M., Oosterink, E., Stalmach, A., Müller, M., & Afman, L. A. Dark chocolate consumption improves leukocyte adhesion factors and vascular function in overweight men. The FASEB Journal 2014, 28(3), 1464-1473.
37. Vink, R. G., Roumans, N. J., Čajlaković, M., Cleutjens, J. P. M., Boekschoten, M. V., Fazelzadeh, P., ... & Goossens, G. H. Diet-induced weight loss decreases adipose tissue oxygen tension with parallel changes in adipose tissue phenotype and insulin sensitivity in overweight humans. International journal of obesity 2017, 41(5), 722.
38. Pasman, W. J., Van Erk, M. J., Klöpping, W. A. A., Pellis, L., Wopereis, S., Bijlsma, S., ... & Kardinaal, A. F. M. Nutrigenomics approach elucidates health-promoting effects of high vegetable intake in lean and obese men. Genes & nutrition 2013, 8(5), 507.
39. Kardinaal, A. F., van Erk, M. J., Dutman, A. E., Stroeve, J. H., van de Steeg, E., Bijlsma, S., ... & Wopereis, S. Quantifying phenotypic flexibility as the response to a high-fat challenge test in different states of metabolic health. The FASEB Journal 2015, 29(11), 4600-4613.
40. Netherlands Nutrition Center. Richtlijnen voedselkeuze. Den Haag, the Netherlands, 2011.
41. NEVO-online version 2016/5.0, http://nevo-online.rivm.nl/. RIVM, Bilthoven
42. Bohannon RW, Peolsson A, Massy-Westropp N et al. Reference values for adult grip strength measured with a Jamar dynamometer: a descriptive meta-analysis. Physiotherapy 2006, 92, 11-15
43. Guralnik, J.M., Ferrucci, L., Pieper, C.F. et al. Lower extremity function and subsequent disability: consistency across studies, predictive models, and value of gait speed alone compared with the short physical performance battery. J Gerontol A Biol Sci Med Sci 2000, 55, M221-M231.
44. Ritchie, J. D., Miller, C. K., & Smiciklas-Wright, H. Tanita foot-to-foot bioelectrical impedance analysis system validated in older adults. Journal of the American Dietetic Association, 2005, 105(10), 1617-1619.
45. Mols, F., Pelle, A.J., Kupper, N. Normative data of the SF-12 health survey with validation using postmyocardial infarction patients in the Dutch population. Qual Life Res 2009, 18, 403-14.
46. Strijk, J.E., Wendel-Vos, G.C.W., Picavet, H.S.J. et al. Wat is vitaliteit en hoe is het te meten? Tijdschr gezondheidswetenschappen 2015, 93, 32-40.
47. Strecher, V.J., DeVellis, B.M., Becker, M.H. et al. The role of self-efficacy in achieving health behavior change. Health Educ Q 1986, 13, 73-92.
48. Cumming, G.The new statistics: Why and how. Pyschological Science 2014, 25(1), 7-29.
49. Bravata, D.M., Smith-Spangler, C., Sundaram, V. et al. Using pedometers to increase physical activity and improve health: a systematic review. JAMA 2007, 298, 2296-2304.
50. Gilmore, L. A., Duhé, A. F., Frost, E. A., & Redman, L. M. The technology boom a new era in obesity management. J Diabetes Sci Technol, 2014, 8, 596-608
51. Naimark, J.S., Madar, Z., Shahar, D.R. The Impact of a Web-Based App (eBalance) in Promoting Healthy Lifestyles: Randomized Controlled Trial. J Med Internet Res 2015, 17, e56
52. Turner-McGrievy, G.M., Beets, M.W., Moore, J.B. et al. Comparison of traditional versus mobile app self-monitoring of physical activity and dietary intake among overweight adults participating in an mHealth weight loss program. J Am Med Inform Assoc 2013, 20, 513-518.
53. Zuckerman, O., Gal-Oz, A. Deconstructing gamification: evaluating the effectiveness of continuous measurement, virtual rewards, and social comparison for promoting physical activity. Pers Ubiquitous Comput 2014, 18, 1705-1719
54. Britton, A., McKee, M., Black, N., McPherson, K., Sanderson, C., & Bain, C. Threats to Applicability of Randomised Trials: Exclusions and Selective Participation. Journal of Health Services Research & Policy 1999, 4(2), 112–121.

55. Sahyoun, N.R., Pratt, C.A., Anderson, A.M.Y. Evaluation of nutrition education interventions for older adults: a proposed framework. J Am Diet Assoc 2004, 104, 58-69.
56. Hagger, M. S. Self-regulation. An important construct in health psychology research and practice. Health Psychology Review 2010, 4, 57–65. doi:10.1080/ 17437199.2010.503594.
57. Hofmann, W., Schmeichel, B. J., & Baddeley, A. D. Executive functions and self-regulation. Trends in Cognitive Sciences 2012, 16, 174–180. doi:10.1016/ j.tics.2012.01.006
58. Allom, V., & Mullan, B. Individual differences in executive function predict distinct eating behaviours. Appetite 2014, 80, 123-130.
59. Ocké, M.C., Buurma-Rethans, E.J.M., de Boer, E.J. et al. Diet of community-dwelling older adults. Dutch National Food Consumption Survey-Older adults 2010-2012. RIVM report 050413001/2013. Bilthoven, the Netherlands: National Institute for public health and environment (RIVM)
60. Mahtani, K.R. Simple advice to reduce salt intake. Br J Gen Pract 2009, 59, 786-787.
61. Grunert, K.G., Wills, J.M., Fernández-Celemín, L. Nutrition knowledge, and use and understanding of nutrition information on food labels among consumers in the UK. Appetite 2010, 55, 177-189.
62. Becker, M.W., Bello, N.M., Sundar, R.P. et al. Front of pack labels enhance attention to nutrition information in novel and commercial brands. Food policy 2015, 56, 76-86.
63. Roberto, C.A., Khandpur, N. Improving the design of nutrition labels to promote healthier food choices and reasonable portion sizes. Int J Obes 2014, 38, S25-S33.
64. de Vet, E., Oenema, A., Brug, J. More or better: Do the number and specificity of implementation intentions matter in increasing physical activity? Psychol Sport Exerc, 2011, 12(4), 471-477.
65. Verhoeven, A.A., Adriaanse, M.A., de Vet, E. et al. Identifying the 'if' for 'if-then'plans: Combining implementation intentions with cue-monitoring targeting unhealthy snacking behaviour. Psychology Health 2014, 29, 1476-1492.
66. Soederberg Miller, L.M., Cassady, D.L. The effects of nutrition knowledge on food label use. A review of the literature. Appetite, 2015, 92, 207-216.
67. Luszczynska, A., Horodyska, K., Zarychta, K., Liszewska, N., Knoll, N., & Scholz, U. Planning and self-efficacy interventions encouraging replacing energy-dense foods intake with fruit and vegetable: A longitudinal experimental study. Psychology & health 2016, 31(1), 40-64. https://doi.org/10.1080/08870446.2015.1070156.
68. Pedersen, S., Grønhøj, A., & Thøgersen, J. Texting your way to healthier eating? Effects of participating in a feedback intervention using text messaging on adolescents' fruit and vegetable intake. Health education research 2016, 31(2), 171-184. https://doi.org/10.1093/her/cyv104.
69. Prestwich, A., Kellar, I., Parker, R., MacRae, S., Learmonth, M., Sykes, B., ... & Castle, H. How can self-efficacy be increased? Meta-analysis of dietary interventions. Health Psychology Review 2014, 8(3), 270-285. https://doi.org/10.1080/17437199.2013.813729.
70. Keller, J., Motter, S., Motter, M., & Schwarzer, R. Augmenting fruit and vegetable consumption by an online intervention: Psychological mechanisms. Appetite 2018, 120, 348-355. https://doi.org/10.1016/j.appet.2017.09.019.
71. Xie, X., Kolthoff, N., Bärenholt, O., & Nielsen, S. P. Validation of a leg-to-leg bioimpedance analysis system in assessing body composition in postmenopausal women. International journal of obesity 1999, 23(10), 1079.
72. Harrigan, M., Cartmel, B., Loftfield, E. et al. Randomized trial comparing telephone versus in-person weight loss counseling on body composition and circulating biomarkers in women treated

for breast cancer: the Lifestyle, Exercise, and Nutrition (LEAN) study. J Clin Oncol 2015, 34, 669-676.

73. Santanasto, A.J., Glynn, N.W., Lovato, L.C. et al. Effect of Physical Activity versus Health Education on Physical Function, Grip Strength and Mobility. J Am Geriatr Soc 2017, 65, 1427-1433
74. Santanasto, A.J., Glynn, N.W., Newman, M.A. et al. Impact of weight loss on physical function with changes in strength, muscle mass, and muscle fat infiltration in overweight to moderately obese older adults: a randomized clinical trial. J obes, Published online: 10 October 2010 doi: 10.1155/2011/516576.
75. Beavers, K.M., Miller, M.E., Rejeski, W.J. et al. Fat mass loss predicts gain in physical function with intentional weight loss in older adults. J Gerontol A Biol Sci Med Sci, 2012, 68, 80-86.
76. Hollands, G.J., French, D.P., Griffin, S.J. et al. The impact of communicating genetic risks of disease on risk-reducing health behaviour: systematic review with meta-analysis. BMJ 2016, 352, i1102