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Age- and Sex-Specific Analyses of Diet Quality and 4-Year Weight Change in Nonobese Adults Show Stronger Associations in Young Adulthood

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ABSTRACT

Background: Although the general importance of diet quality in the prevention of unintentional weight gain is known, it is unknown whether its influence is age or sex dependent.

Objective: The aim of this study was to investigate whether the strength of the association between diet quality and 4-y weight change was modified by age and sex.

Methods: From the Dutch population-based Lifelines Cohort, 85,618 nonobese adult participants (age 18–93 y), recruited between 2006 and 2013, were included in the study. At baseline, diet was assessed with a 110-item food-frequency questionnaire. The Lifelines Diet Score, based on international evidence for diet-disease relations at the food group level, was calculated to assess diet quality. For analyses, the score was divided in quintiles (Qs). Body weight was objectively measured at baseline and after a median follow-up of 44 mo (25th−75th percentile: 35–51 mo). In between, body weight was self-reported twice. Linear mixed models were used to investigate the association between diet quality and weight change by sex and in 6 age categories (18–29, 30–39, 40–49, 50–59, 60–69, and ≥70 y).

Results: Mean 4-y weight change decreased over age categories. Confounder-adjusted linear mixed models showed that the association between diet quality and weight change was modified by sex (*P*-interaction = 0.001). In women, the association was also modified by age (*P*-interaction = 0.001). Poor diet quality was most strongly associated with weight gain in the youngest men [Q1 compared with Q5: +0.33 kg/y (95% CI: 0.10, 0.56)] and women [+0.22 kg/y (95% CI: 0.07, 0.37)]. In contrast, in women aged ≥70 y, poor diet quality was associated with greater weight loss [−0.44 kg/y (95% CI: −0.84, −0.05)].

Conclusions: Poor diet quality was related to higher weight gain, especially in young adults. Oppositely, among women aged ≥70 y, poor diet quality was related to higher weight loss. Therefore, a healthful diet is a promising target for undesirable weight changes in both directions. *J Nutr* 2020;150:560–567.

Keywords: diet quality, nutrition, weight change, weight gain, overweight, obesity, age, sex, life course, nonobese adults

Introduction

Gradual but persisting increases in body weight of the worldwide population may jeopardize the achievement of the global obesity target to curb the rise of obesity by 2025 (1). Weight gain is typically an age-related phenomenon, and the importance of lifestyle in its prevention is well known. However, it is unknown whether it is of equal importance over the life course, and for both sexes.

Diet is a major lifestyle factor relevant for overweight prevention. At the food product level, meta-analyses convincingly showed that sugar-sweetened beverages contributed to weight gain. In adults, 1 serving per day increase in sugar-sweetened beverages resulted in an additional 0.22 kg increase of body weight per year (2). In contrast, foods like fruit, vegetables, yogurt, nuts, and whole grain products were inversely associated with weight gain in 3 large prospective cohort studies (3). With regard to overall diet quality, prospective cohort studies reported that better adherence to the Mediterranean Diet was associated with lower 2-y weight change (4), and lower 3-y obesity incidence in overweight adults (5). In addition, a meta-analysis of randomized controlled trials (RCTs) showed that Mediterranean Diet adherence positively contributed to intentional weight loss. However, this effect was only statistically

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significant when the Mediterranean diet was associated with a restriction in energy intake or increase in physical activity, or when trials had a follow-up longer than 6 mo (6). However, whether the above results apply to all age categories, and to both men and women, is unknown, which is also due to the fact that the majority of described evidence comes from studies including young or middle-aged adults.

Weight change can differ between age categories and men and women. A longitudinal study in middle-aged Americans (51–61 y at baseline) showed that the pace at which BMI (kg/m^2) increased over time was higher among younger men and women (7). Similar findings were reported for younger (18–24 y) compared to older (25–30 y) men in the CARDIA (Coronary Artery Risk Development in Young Adults) study (8), as well as for 20–29 y compared to 40–49-y-old men in the longitudinal Tromsø study (9). Both studies did not find such age differences in women. Although previous studies report a prospective gain in weight, weight gain may not be persistent over the full adult life course. For example, in the American National Health and Nutrition Examination Survey, between 1999 and 2016 body weight was consistently higher in men and women aged 40–59 y than those aged 20–39 y, while after age 60 y, body weight was consistently lower than during age 40–59 y (10). Regarding sex, a higher general pace of weight gain in men than in women was described in several studies (9, 11, 12), while worldwide obesity prevalence is greater in women (1).

As mentioned above, weight change could be dependent on diet quality. Furthermore, our previous study investigating diet quality in the Lifelines Cohort illustrated that diet quality was higher in women and in older age groups (13). Other studies investigating measures of diet quality reported similar findings (14, 15). However, in addition to differences in diet quality, differences in the magnitude or direction of the association between diet quality and weight change may also be involved in age- and sex-specific weight changes. In the large, contemporary Lifelines Cohort Study (16), we integrated age and sex in the investigation of diet quality and 4-y weight change, to answer the question of whether their association would be uniform or age and sex specific.

Methods

Cohort design and study population

The Lifelines Cohort Study is a multidisciplinary prospective population-based cohort study examining in a unique 3-generation design, the health and health-related behaviors of 167,729 persons living in the North of the Netherlands. It employs a broad range of investigative procedures in assessing the biomedical, sociodemographic, behavioral, physical, and psychological factors which contribute to health and disease of the general population, with a special focus on multimorbidity and complex genetics. The overall design and rationale of the study have been described in detail elsewhere (16, 17). Participants were included in the study between 2006 and 2013, and written informed consent was obtained from all participants. The Lifelines study is conducted according to the principles of the Declaration of Helsinki and approved by the Medical Ethics Committee of the University Medical Center Groningen, The Netherlands.

At the time of this report, 4 assessment rounds had taken place [T1 = baseline, median + IQR of time in months to follow-up rounds: T2 = 13 (12–14), T3 = 24 (23–27), T4 = 44 (35–51)]. Participants reporting unwanted weight loss at baseline (defined as 6 kg/6 mo or 3 kg/1 mo in the questionnaire) or excessive weight loss between T1 and T4 (>50% of body weight) were excluded from the study. Furthermore, participants reporting pregnancy or chronic diseases which may influence diet or weight (cardiovascular diseases, cancer, diabetes, thyroid disease, and inflammatory bowel diseases) at baseline or during follow-up were excluded. Participants for whom data on diet, baseline body weight, or covariates were missing or unreliable were excluded as well. Finally, because this study focuses on the prevention of obesity, and because the process of weight change in obese individuals may involve more genetic, psychiatric, and environmental factors than the process in nonobese individuals, participants who were already obese at baseline (BMI >30 kg/m^2) were excluded as well. Out of 152,662 adult Lifelines participants, 85,616 met the inclusion criteria and were included in the study (**Supplemental Figure 1**). Obesity was the most common reason for exclusion (n = 24,068).

Data collection

Anthropometrics.

At baseline (T1) and T4, height and body weight without shoes and heavy clothing were measured at 12 Lifelines research sites using the SECA 222 stadiometer and the SECA 761 scale, and rounded to the nearest 0.5 cm and 0.1 kg. Measured weight at T1 and T4 was available for 85,618 and 56,390 participants, respectively. At T2 and T3, body weight was self-reported through questionnaires by 71,719 (T2) and 53,390 (T3) participants.

Demographics and lifestyle.

Self-administered questionnaires were used to collect baseline data regarding demographics (ethnicity and education) and lifestyle (alcohol, smoking, and physical activity). The validated Short Questionnaire to Assess Health-Enhancing Physical Activity (SQUASH) was used to assess physical activity (18). Leisure Time and Commuting Moderate to Vigorous Physical Activity (LC-MVPA), including sports, at moderate [4.0–6.4 metabolic equivalent (MET)] to vigorous (≥6.5 MET) intensity was calculated in minutes per week (18). Alcohol consumption was estimated based on Lifelines' food-frequency questionnaire (FFQ) (19). If ethnicity was unknown, participants were assumed to be of Dutch nationality, since Dutch is the dominant ethnicity of the cohort (99.0%). Missing data in MVPA were imputed with the Hot Deck imputation macro for SPSS (20), which replaced a missing value with the value of a participant who is similar in smoking status, education level, and energy intake.

Dietary assessment.

At baseline, dietary intake was assessed using a 110-item semiquantitative FFQ assessing food intake over the previous month (19). Energy intake was estimated from the FFQ data by using the 2011 Dutch Food Composition Database (21). FFQ data were considered unreliable when the ratio between reported energy intake and basal metabolic rate, calculated with the Schofield equation (22), was below 0.50 or above 2.75, or when energy intake was below 800 kcal/d (males) or 500 kcal/d (females) (23).

The Lifelines Diet Score (LLDS) was calculated as a measure of relative diet quality. The development of this food-based diet score has been described in detail elsewhere (13). In short, the LLDS is based on the scientific evidence summarized in the 29 systematic reviews of international peer-reviewed literature regarding associations of diet with chronic diseases, which the Dutch Health Council performed in the process of the development of the 2015 Dutch Dietary Guidelines. The LLDS ranks the relative intake of 9 food groups with proven

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Abbreviations used: FFQ, food-frequency questionnaire; LC-MVPA, Leisure Time and Commuting Moderate to Vigorous Physical Activity; LLDS, Lifelines Diet Score; MET, metabolic equivalent; Q, quintile; RCT, randomized controlled trial.

positive health effects and 3 food groups with proven negative health effects (24). For each of the food groups, quintiles of consumption in g/1000 kcal are determined and awarded 0 to 4 points (**Supplemental Tables 1** and **2**). For the positive food groups, that is, vegetables, fruit, whole-grain products, legumes and nuts, fish, oils and soft margarines, unsweetened dairy, coffee, and tea, higher scores are awarded to higher quintiles of consumption. For the negative food groups, that is red and processed meat, butter and hard margarines, and sugar-sweetened beverages, higher scores are awarded to lower quintiles of consumption. The sum of these LLDS components varied from 0 to 48. The LLDS scores were then categorized into quintiles, with Q1 including 20% of participants with the lowest diet quality and Q5 including 20% of participants with the highest diet quality (LLDS range Q1: 0–18, Q2: 19–22, Q3: 23–25, Q4: 26–29, Q5: 30–48). The quintiles for each product group were predefined in the total Lifelines Cohort (13).

Data analysis

Self-reported weights are sensitive to underreporting, so self-reported weights at T2 and T3 needed to be adjusted (25). At T4, self-reported body weight was available in addition to objectively measured body weight. For 6 age categories separately (18–29, 30–39, 40–49, 50–59, 60–69, and ≥70 y), the mean difference between self-reported and measured weight at T4 was calculated and used to adjust self-reported weights at T2 and T3. For descriptive purposes, weight change between T1 and T4 was standardized to a 4-y period to account for differences in follow-up time.

Subject-specific linear mixed models were fitted to investigate the age- and sex-specific associations of diet quality with the change in body weight over time since baseline. Models included random intercepts and slopes, allowing each participant to have an individual starting point and trajectory of change in body weight. The covariance matrix was unstructured. All results were presented in crude form, as well as with multivariable adjustment. The latter were adjusted for potential confounders at baseline, including education level (low, moderate, high), smoking status (current, former, never), physical activity (LC-MVPA in min/wk), energy intake (kcal/d), alcohol intake (g/d), and BMI at baseline (kg/m^2). The models also included interactions of confounders with time to adjust not only intercepts but also the slopes of weight change.

First, we investigated whether sex modified the association of diet quality and body weight change, by including the 3-way interaction of sex, LLDS in quintiles, and time in years (as well as 2-way interactions and variables separately) in a model with body weight as the dependent variable. In case of a significant 3-way interaction in crude and multivariable adjusted models, the following analyses were performed stratified by sex.

In the first model of interest, age in 6 categories, LLDS in quintiles, and their interactions with time in years were included in the model as fixed factors, to investigate the differences in weight change among age groups and quintiles of the LLDS.

In the second model of interest, the 3-way interaction of LLDS, age category, and time was added to the model, to investigate whether age modified the association of diet quality with body weight change in men or women. Analyses were then also stratified by age category to illustrate the age-specific associations of diet quality and weight change.

In a sensitivity analysis in 51,816 participants we investigated whether the association between diet quality and weight change was explained by changes in muscle mass, by including change in 24-h urinary creatinine excretion as a proxy for muscle mass (26).

In all models, the most weight stable age category was used as the reference (age 50–59 y). For the LLDS, Q5 representing the highest diet quality was set as the reference. Data analysis was performed in IBM SPSS 23 (SPSS). *P* values <0.05 were considered to represent significant results.

Results

Study population

Baseline characteristics of the study population (55.7% female, age 18–93 y) showed differences between men and women, and between age categories (**Table 1**). Education level was lower in older age groups, especially in women. Mean body weight was 84.5 ± 10.1 kg for men and 69.7 ± 9.1 kg for women. Mean LLDS in the oldest compared with the youngest age group was 5.6 points (approximately 1 SD) higher in men and 6 points higher in women. For all age categories, mean LLDS was approximately 2 to 3 points higher in women than in men. No relevant differences in baseline characteristics were observed between participants with complete compared with those with incomplete follow-up (**Supplemental Table 3**).

Observed change in measured body weight

For illustration, **Figure 1** shows baseline body weight in the 6 age categories, combined with the change in measured body weight between T1 and T4. Body weight values showed a curve over the life course and peaked in age category 40–49 y. From the youngest to oldest age group, mean 4-y change in measured body weight ranged from 1.76 kg to −1.12 kg in men and from 1.19 kg to −0.68 kg in women (**Table 2**). Both absolute and relative to mean baseline body weight, weight gain in young adults (18–29 y) and weight loss in older adults (≥70 y) was more extreme in men. However, over the life course, weight gain was more persistent in women, illustrated by a comparable weight gain in all age categories until age 50 y. With regard to diet quality, mean weight changes in the lowest quintile of the LLDS were 1.29 kg and 0.75 kg greater than those in the highest quintile of the LLDS, in men and women, respectively (Table 2).

Sex-specific associations of age and diet quality with weight change

Sex significantly modified the association of diet quality and body weight change (*P*-crude = 0.005, *P*-adjusted = 0.001), and further analyses were therefore stratified by sex. In both men and women, age and diet quality were independently associated with weight change in the crude and adjusted model ($P < 0.001$ for fixed effects) (**Table 3**). Multivariable adjusted estimates for age categories illustrated that weight gain was approximately 0.15 kg/y higher in women in the 3 youngest age groups (18–29, 30–39, and 40–49 y) than in the reference category, age 50–59 y. For men, multivariable adjusted yearly weight change in comparison to the reference group, 50–59 y, was 0.32 kg (95% CI: 0.27, 0.37) higher in 18–29-y-olds, which was approximately 3 times higher than estimates for men aged 30–39 y [0.09 kg/y (95% CI: 0.05, 0.13)] and 40–49 y [0.11 kg/y (95% CI: 0.07, 0.15)]. Regarding diet quality, the multivariable adjusted model estimated that yearly weight change, regardless of age category, in Q1 compared to reference Q5, was 0.15 kg (95% CI: 0.10, 0.20) higher in men, and 0.12 kg (95% CI: 0.07, 0.16) higher in women.

Age-specific associations of diet quality and weight change

The association between diet quality and weight change was significantly modified by age category in women ($P = 0.001$ for both crude and adjusted analyses), but not in men ($P = 0.111$ and $P = 0.139$ for crude and adjusted analyses, respectively). **Figure 2** illustrates the estimated association of diet quality and annual weight change in analyses stratified by age category (**Supplemental Tables 4** and **5**). In both men and women, the association of poor diet quality (LLDS Q1) with weight gain was strongest in the youngest age group [Q1 compared with Q5 = 0.33 kg/y (95% CI: 0.10, 0.56) in men and 0.22 kg/y (95% CI: 0.07, 0.37) in women]. In addition, in older women (age ≥70 y), poor diet quality was associated

TABLE 1 Baseline characteristics of 85,616 adult Lifelines participants included in this study, stratified by age category and sex[1]

		Age category, y (n)											
		Males						Females					
	Total (85,616)	18–29 (5862)	30–39 (8320)	40–49 (12,908)	50–59 (6435)	60–69 (3572)	≥70 (833)	18–29 (7357)	30–39 (9352)	40–49 (17,153)	50–59 (8656)	60–69 (4331)	≥70 (837)
Demographics													
Age, y	43.4 ± 12.5	24.8 ± 3.4	34.7 ± 2.9	44.7 ± 2.9	53.6 ± 3.0	63.7 ± 2.6	73.7 ± 3.7	23.5 ± 3.5	35.2 ± 2.8	44.7 ± 2.9	53.6 ± 3.0	63.6 ± 2.7	73.5 ± 3.4
White, East/West European ethnicity	99.0	98.9	98.9	99.1	98.9	99.2	99.4	99.0	98.4	98.8	99.3	99.5	99.3
Education level													
Low	26.0	15.0	17.7	26.7	31.7	41.2	45.3	12.7	14.1	23.3	37.0	59.2	69.5
Moderate	41.0	53.2	41.5	39.5	34.3	25.6	23.3	53.4	43.8	46.2	36.5	20.2	14.9
High	33.0	31.8	40.8	33.8	34.0	33.2	31.5	33.9	42.1	30.5	26.5	20.5	15.5
Anthropometry													
Weight at baseline, kg	76.3 ± 12.1	80.4 ± 10.5	85.0 ± 10.3	86.5 ± 9.8	85.3 ± 9.5	83.0 ± 9.0	80.8 ± 8.0	67.3 ± 9.3	69.9 ± 9.4	70.5 ± 9.0	70.0 ± 8.7	69.5 ± 8.3	68.4 ± 8.3
BMI, kg/m^2	24.6 ± 2.7	23.7 ± 2.7	25.0 ± 2.5	25.6 ± 2.4	25.7 ± 2.3	25.8 ± 2.2	25.7 ± 2.2	23.0 ± 2.8	23.9 ± 2.8	24.3 ± 2.7	24.6 ± 2.7	25.1 ± 2.6	25.4 ± 2.7
Lifestyle													
LLDS	23.9 ± 6.1	19.7 ± 5.4	21.7 ± 5.4	22.5 ± 5.4	24.0 ± 5.5	25.1 ± 5.6	25.3 ± 5.4	21.9 ± 6.0	24.0 ± 5.7	25.0 ± 5.8	27.2 ± 5.8	28.2 ± 5.6	27.9 ± 5.6
Energy intake, kcal/d	2102 ± 625	2542 ± 714	2500 ± 645	2462 ± 649	2329 ± 605	2152 ± 541	2085 ± 496	1812 ± 474	1904 ± 483	1887 ± 475	1812 ± 448	1740 ± 419	1701 ± 386
Alcohol													
User, %	85.6	94.1	92.3	91.6	92.8	91.5	87.3	86.1	76.7	78.7	83.3	80.1	71.2
Consumption among consumers, g/d	6.4 (2.6–12.4)	9.8 (4.7–17.1)	7.1 (3.4–15.1)	7.1 (3.2–15.8)	9.5 (4.1–17.1)	9.8 (4.4–17.4)	8.2 (1.8–6.9)	3.7 (1.8–6.9)	3.2 (1.5–6.9)	4.9 (1.7–9.3)	6.4 (2.5–12.1)	6.6 (2.6–12.2)	6.1 (1.8–10.9)
Smoking status, %													
Current	21.1	31.5	26.9	22.5	18.7	13.7	8.5	25.9	21.3	19.7	18.4	9.9	3.6
Former	30.6	9.6	23.8	27.7	42.4	56.2	69.4	9.1	24.4	30.2	47.6	49.3	40.3
Never	48.3	58.9	49.3	49.8	38.8	30.1	22.1	65.0	54.3	50.1	34.0	40.8	56.2
LC-MPVA, min/wk	205 (75–385)	270 (100–460)	180 (60–360)	180 (60–360)	210 (60–405)	240 (60–405)	300 (120–570)	230 (100–400)	180 (72–330)	180 (71–360)	210 (90–390)	270 (120–480)	240 (120–480)

[1]Values are presented as percentage, mean ± SD for normally distributed data, or median (25th–75th percentile) for skewed data. LC-MPVA, Leisure time and Commuting Moderate and Vigorous Physical Activity; LLDS, Lifelines Diet Score.

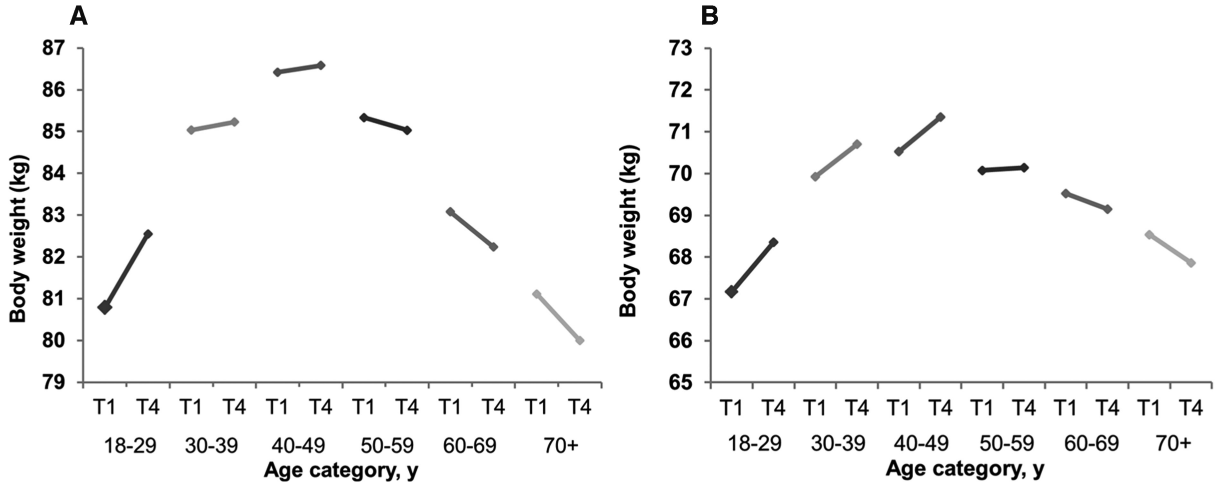

FIGURE 1 Illustration of mean body weight and 4-y weight change in men (A) and women (B) over the life course. Body weight in kilograms, at baseline (T1) and 4th assessment (T4). Unadjusted data from 24,926 male and 31,475 female participants who had both T1 and T4 measurements. Interval between T1 and T4 standardized to 4 y. Median + IQR of time in months to follow-up round T4 = 44 (35–51).

with higher weight loss [Q1 compared with Q5 = −0.44 kg/y (95% CI: −0.84, −0.05)]. The sensitivity analysis including change in 24-h creatinine excretion attenuated the estimates, but showed a similar pattern (**Supplemental Tables 6** and **7** and **Supplemental Figure 2**). The number of participants and body weight observations per quintile of the LLDS across strata of sex and age can be found in **Supplemental Tables 8** and **9**.

Discussion

This large prospective study in nonobese adults of the contemporary Dutch Lifelines cohort showed that the association of diet quality with weight change differed over the life course and between men and women. The association between poor diet quality and weight gain was strongest in young adults (age 18–29 y). In elderly women (≥70 y), on the other hand, the association of diet quality and weight change was reversed, meaning that lower diet quality was associated with greater weight loss. This illustrates the relevance of a healthful diet in the prevention of undesirable weight changes over the life course.

The relation of diet as a determinant of weight gain goes beyond diet quantity, illustrated by various observational cohort studies reporting inverse associations of measures of diet quality with overweight- and obesity-related outcomes, also after adjustment for energy intake (27). The overall, adjusted estimates for the association of diet quality with weight change found in our study (0.15 and 0.12 kg/y in men and women, for Q1 compared with Q5) were comparable to those of other prospective studies with body weight as the outcome measure. For example, in the Framingham Offspring study (mean age 51.7 y), the difference in weight change between the lowest compared with the highest score of the 5-point Diet Quality Index was approximately 0.14 and 0.17 kg/y in men and women, respectively (28). In men of an Australian population-based cohort (aged 25–75 y), yearly change in BMI in the

TABLE 2 Observed 4-y weight change among age categories and levels of diet quality, in both men and women[1]

	Weight change			
	Males[2]		Females[2]	
	Absolute, kg	Relative to body weight	Absolute, kg	Relative to body weight
Age category, y				
18–29	1.76 ± 6.15	2.19	1.19 ± 6.17	1.77
30–39	0.19 ± 4.99	0.23	0.78 ± 5.61	1.11
40–49	0.17 ± 4.78	0.19	0.83 ± 5.12	1.17
50–59	− 0.30 ± 4.35	− 0.36	0.07 ± 4.73	0.10
60–69	− 0.84 ± 4.12	− 1.02	− 0.37 ± 4.06	− 0.54
Age ≥70	− 1.12 ± 3.76	− 1.38	− 0.68 ± 3.49	− 0.99
Diet quality (LLDS quintile)				
Q1 (1–18)	0.79 ± 5.36	0.95	1.02 ± 5.63	1.47
Q2 (19–22)	0.25 ± 4.94	0.29	0.77 ± 5.29	1.10
Q3 (23–25)	0.12 ± 4.88	0.14	0.66 ± 5.13	0.94
Q4 (26–29)	− 0.31 ± 4.56	− 0.37	0.37 ± 5.00	0.53
Q5 (30–46)	− 0.50 ± 4.41	− 0.60	0.27 ± 5.04	0.39

[1]Values presented as mean ± SD for absolute, and percentage for relative weight change. Weight change between T1 and T4, interval standardized to 4 y. Median + IQR of time in months to follow-up round T4 = 44 (35–51). LLDS, Lifelines Diet Score; Q, quintile.
[2]Table based on 24,926 male and 31,475 female participants with measured body weight at T1 and T4.

TABLE 3 Associations of age accounting for differences in diet quality, and associations of diet quality accounting for differences in age, with yearly weight change[1]

	Males ($n = 37{,}930$)		Females ($n = 47{,}686$)	
	Crude	Adjusted[2]	Crude	Adjusted[2]
Age category, y				
18–29	0.459 (0.411, 0.508)	0.320 (0.270, 0.371)	0.194 (0.148, 0.240)	0.145 (0.097, 0.194)
30–39	0.116 (0.073, 0.159)	0.088 (0.045, 0.132)	0.142 (0.101, 0.183)	0.138 (0.095, 0.180)
40–49	0.102 (0.064, 0.141)	0.108 (0.069, 0.147)	0.156 (0.121, 0.191)	0.154 (0.118, 0.190)
50–59	Reference	Reference	Reference	Reference
60–69	−0.120 (−0.171, −0.068)	−0.121 (−0.172,−0.069)	−0.099 (−0.148, −0.051)	−0.097 (−0.147, −0.048)
≥70	−0.179 (−0.274, −0.084)	−0.187 (−0.282, −0.092)	−0.186 (−0.285, −0.088)	−0.193 (−0.293, −0.094)
LLDS quintile (range)				
Q1 (1–18)	0.175 (0.127, 0.224)	0.154 (0.104, 0.204)	0.120 (0.076, 0.164)	0.118 (0.071, 0.164)
Q2 (19–22)	0.101 (0.054, 0.148)	0.106 (0.058, 0.154)	0.070 (0.032, 0.109)	0.074 (0.034, 0.114)
Q3 (23–25)	0.084 (0.035, 0.133)	0.092 (0.043, 0.142)	0.050 (0.011, 0.088)	0.060 (0.020, 0.099)
Q4 (26–29)	0.016 (−0.034, 0.065)	0.023 (−0.026, 0.072)	0.005 (−0.031, 0.041)	0.013 (−0.024, 0.049)
Q5 (30–46)	Reference	Reference	Reference	Reference

[1]Values are presented as estimates (β) and 95% CIs for weight change per year in kilograms from crude and adjusted linear mixed models. LLDS, Lifelines Diet Score; Q, quintile.
[2]Adjusted for baseline education level, smoking status, energy intake, alcohol intake, BMI, LC-MVPA, and their interactions with time, so that both intercept and slope were adjusted for confounders.

lowest compared with the highest quartile of diet quality was 0.06 kg/m^2 higher, which equals 0.17 kg for an individual with a height of 1.70 m and a BMI of 25. No association was found for women (29).

Our results illustrate that these general associations, and even the absence of an association in women, may not be true for all age categories. By illustrating the age-specificity of the association of diet quality and changes in weight, we showed that these general associations may represent a combination of strong inverse associations in young and weaker or reversed associations in older participants. It must be noted, however, that the evidence described here comes from prospective cohort studies, which do not provide information on causality. A meta-analysis of RCTs on the effect of the Mediterranean Diet on weight loss did not find a significant effect on weight loss when the diet was not combined with a restriction in energy intake (6). However, many RCTs only have short-term follow-up, so to be able to further investigate the causal effect of diet quality beyond diet quantity on change in body weight over the life-course, long-term RCTs are needed.

In both men and women, age-specific associations between diet quality and weight change showed a gradual decrease in strength over the age categories. The strongest inverse association was found in the youngest age group, where men with a poor diet quality (Q1) gained on average 1.3 kg more over 4 y than men adhering to a high-quality diet. For women, this was almost 1 kg. The age trend was most pronounced in women, where age was a significant modifier of the association of diet quality with weight change. Specifically, in the youngest age category, baseline body weight was still relatively low. This emphasizes the potential benefit of a healthful diet in early adulthood, when overweight may still be preventable.

In contrast with the general finding that poor diet quality was related to higher weight gain, elderly women (age ≥70 y) adhering to a poor quality diet lost approximately 1.8 kg more weight in 4 y than women with a high quality diet. The question

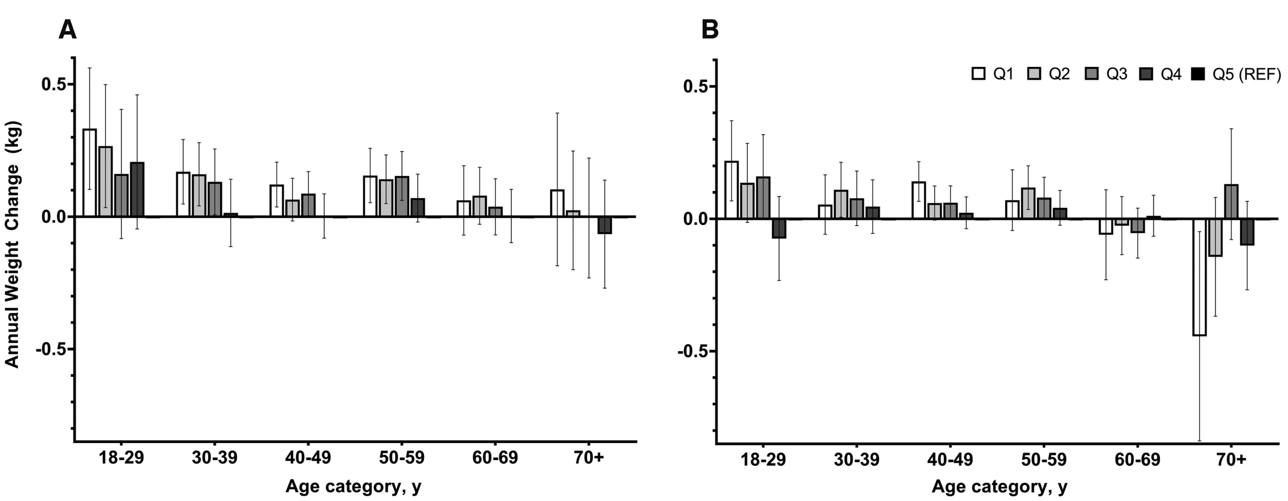

FIGURE 2 Diet quality in association with estimated annual weight change by age category, in 37,930 men (A) and 47,686 women (B). Reference quintile 5 (right) of the LLDS represents highest diet quality. Estimates derived from age-stratified linear mixed models adjusted for baseline education level, smoking status, energy intake, alcohol intake, BMI (kg/m^2), and LC-MPVA and their interactions with time, so that both intercept and slope were adjusted for confounders. LLDS range per quintile: Q1: 1–18, Q2: 19–22, Q3: 23–25, Q4: 26–29, Q5: 30–46. LC-MPVA, Leisure time and Commuting Moderate and Vigorous Physical Activity; LLDS, Lifelines Diet Score.

was raised whether this was a favorable loss of fat mass, or whether this weight loss was accompanied by a potentially unfavorable loss of muscle mass. In a sensitivity analysis, we estimated that 0.5 kg of this weight change was explained by loss of muscle mass. However, it must be noted that change in 24-h creatinine excretion was used as a proxy for change in muscle mass, which may not have captured change in muscle mass accurately. In elderly individuals, loss of body mass and muscle mass is associated with higher mortality risk (30–32). That we could not replicate these findings in men may be related to results of a prior study, in which malnutrition was a risk factor for sarcopenia in elderly women, but not in men (33). Together, our results showed that by limiting weight gain in young adults and limiting weight loss in elderly women, a high-quality diet may contribute to the prevention of undesirable weight changes in both directions.

Strengths of our study include the large contemporary cohort, which enabled stratification by age and sex while maintaining sufficient power. In addition, the novel food-based LLDS to express diet quality is in line with current scientific evidence on diet–disease relationships. Although information regarding many potential confounding factors was available, residual confounding remains possible. For example, we were not able to adjust for menopausal status in women, which could have introduced bias, primarily in analyses in women aged 40–60 y. Furthermore, although linear mixed models allow the inclusion of participants with incomplete follow-up, it is possible that survival bias exists. Death is often preceded by a loss of weight, and the absence of these data points could have contributed to an underestimation of the magnitude of weight loss in the oldest age categories. We hypothesize that this would be primarily the case in males, due to a higher number of deaths in the male Lifelines population (in July 2019, 761 males and 530 females of the cohort had passed away). Another limitation is that dietary information was only available at baseline. However, based on Smith et al. (34), who compared the association of baseline diet and change in diet with weight gain, the most likely expectation is that the lack of information on dietary change underestimated the association between diet quality and weight change in this study. Lastly, since we excluded obese participants because of the focus on prevention of obesity rather than treatment, the exclusion of this subgroup of the population may have introduced bias in our estimates of weight change, since it would be expected that heavier individuals would contribute to a decrease in mean weight change due to regression to the mean. Our results should therefore be interpreted with caution and are only applicable to generally healthy, nonobese individuals.

In summary, this large study in nonobese adult participants of the Lifelines cohort showed greater weight gain among younger age groups and among groups with lower diet quality. More importantly, the association between poor diet quality and weight gain was strongest in young adults (aged 18–29 y), both in men and women. Combined with the fact that prevalence of overweight is still relatively low in young Dutch adults, we conclude that young adulthood may be a window of opportunity for weight gain prevention through diet quality improvement. On the other hand, adhering to a healthy diet was related to lower weight loss in elderly women (aged ≥70 y). Thus, the same dietary guidelines for the prevention of chronic diseases may contribute both to prevention of weight gain in young men and women, and weight loss in elderly women. In future research, study populations should be extended toward childhood to further focus on optimal windows of opportunity for weight gain prevention.

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References

1. Di Cesare M, Bentham J, Stevens GA, Zhou B, Danaei G, Lu Y, Bixby H, Cowan MJ, Riley LM, Hajifathalian K, et al. Trends in adult body-mass index in 200 countries from 1975 to 2014: a pooled analysis of 1698 population-based measurement studies with 19.2 million participants. Lancet 2016;387:1377–96.
2. Malik VS, Pan A, Willett WC, Hu FB. Sugar-sweetened beverages and weight gain in children and adults: a systematic review and meta-analysis. Am J Clin Nutr 2013;98:1084–102.
3. Mozaffarian D, Hao T, Rimm EB, Willett WC, Hu FB. Changes in diet and lifestyle and long-term weight gain in women and men. N Engl J Med 2011;364:2392–404.
4. Sánchez-Villegas A, Bes-Rastrollo M, Martínez-González MA, Serra-Majem L. Adherence to a Mediterranean dietary pattern and weight gain in a follow-up study: the SUN cohort. Int J Obes 2006;30:350–8.
5. Mendez MA, Popkin BM, Jakszyn P, Berenguer A, Tormo MJ, Sanchéz MJ, Quirós JR, Pera G, Navarro C, Martinez C, et al. Adherence to a Mediterranean diet is associated with reduced 3-year incidence of obesity. J Nutr 2006;136:2934–8.
6. Esposito K, Kastorini C-M, Panagiotakos DB, Giugliano D. Mediterranean diet and weight loss: meta-analysis of randomized controlled trials. Metab Syndr Relat Disord 2011;9:1–12.
7. Botoseneanu A, Liang J. Social stratification of body weight trajectory in middle-age and older Americans: results from a 14-year longitudinal study. J Aging Health 2011;23:454–80.
8. Burke G, Bild DE, Hilner JE, Folsom AR, Wagenknecht LE, Sidney S. Differences in weight gain in relation to race, gender, age, and education in young adults: the CARDIA study. Ethn Health 1996; 327–35.
9. Jacobsen BK, Njolstad I, Thune I, Wilsgaard T, Lochen ML, Schirmer H. Increase in weight in all birth cohorts in a general population: the Tromso study, 1974–1994. Arch Intern Med 2001;161: 466–72.
10. Fryar CD, Kruszon-Moran D, Gu Q, Ogden CL. Mean body weight, height, waist circumference, and body mass index among adults: United States, 1999–2000 through 2015–2016. Natl Health Stat Report 2018;122 :1–16.
11. Chiriboga DE, Ma Y, Li W, Olendzki BC, Pagoto SL, Merriam PA, Matthews CE, Hebert JR, Ockene IS. Gender differences in predictors of body weight and body weight change in healthy adults. Obesity 2008;16:137–45.
12. Schulz M, Nöthlings U, Hoffmann K, Bergmann MM, Boeing H. Identification of a food pattern characterized by high-fiber and low-fat food choices associated with low prospective weight change in the EPIC-Potsdam Cohort 1. J Nutr 2005;135:1183–9.
13. Vinke PC, Corpeleijn E, Dekker LH, Jacobs DR, Jr., Navis G, Kromhout D. Development of the Lifelines Diet Score (LLDS) and its application in 129,369 Lifelines participants. Eur J Clin Nutr 2018;72: 1111–9.

14. Wang DD, Leung CW, Li Y, Ding EL, Chiuve SE, Hu FB, Willett WC. Trends in dietary quality among adults in the United States, 1999 through 2010. JAMA Intern Med 2014;174:1587–95.
15. Guenther PM, Kirkpatrick SI, Reedy J, Krebs-Smith SM, Buckman DW, Dodd KW, Casavale KO, Carroll RJ. The Healthy Eating Index-2010 is a valid and reliable measure of diet quality according to the 2010 Dietary Guidelines for Americans. J Nutr 2014;144: 399–407.
16. Scholtens S, Smidt N, Swertz MA, Bakker SJL, Dotinga A, Vonk JM, Van Dijk F, Van Zon SKR, Wijmenga C, Wolffenbuttel BHR, et al. Cohort Profile: LifeLines, a three-generation cohort study and biobank. Int J Epidemiol 2015;44:1172–80.
17. Stolk RP, Rosmalen JGM, Postma DS, De Boer RA, Navis G, Slaets JPJ, Ormel J, Wolffenbuttel BHR. Universal risk factors for multifactorial diseases: LifeLines: a three-generation population-based study. Eur J Epidemiol 2008;23:67–74.
18. Wendel-Vos GCW, Schuit AJ, Saris WHM, Kromhout D. Reproducibility and relative validity of the short questionnaire to assess health-enhancing physical activity. J Clin Epidemiol 2003;56: 1163–9.
19. Siebelink E, Geelen A, de Vries JHM. Self-reported energy intake by FFQ compared with actual energy intake to maintain body weight in 516 adults. Br J Nutr 2011;106:274–81.
20. Myers TA. Goodbye, listwise deletion: presenting hot deck imputation as an easy and effective tool for handling missing data. Commun Methods Meas 2011;5:297–310.
21. NEVO-tabel (2011). Dutch Food Composition Table 2011—version 3 [Internet]. 2011 [cited 2018 Nov 19]. Available from: http://www.rivm.nl/Documenten_en_publicaties/Algemeen_Actueel/Nieuwsberichten/2011/Nieuwe_NEVO_tabel_2011_beschikbaar.
22. Schofield WN. Predicting basal metabolic rate, new standards and review of previous work. Hum Nutr Clin Nutr 1985;39(Suppl 1):5–41.
23. Willett W. Issues in analysis and presentation of dietary data. Nutr Epidemiol. 2012. p. 306.
24. Kromhout D, Spaaij CJK, de Goede J, Weggemans RM. The 2015 Dutch food-based dietary guidelines. Eur J Clin Nutr. 2016;70: 869–78.
25. Visscher TLS, Viet AL, Kroesbergen HT, Seidell JC. Underreporting of BMI in adults and its effect on obesity prevalence estimations in the period 1998 to 2001. Obesity 2006;14:2054–63.
26. Alexandrov N V, Eelderink C, Singh-Povel CM, Navis GJ, Bakker SJL, Corpeleijn E. Dietary protein sources and muscle mass over the life course: the Lifelines cohort study. Nutrients 2018;10:1–17.
27. Asghari G, Mirmiran P, Yuzbashian E, Azizi F. A systematic review of diet quality indices in relation to obesity. Br J Nutr 2017;117:1055–65.
28. Quatromoni PA, Pencina M, Cobain MR, Jacques PF, D'Agostino RB. Dietary quality predicts adult weight gain: findings from the Framingham Offspring Study. Obesity 2006;14:1383–91.
29. Arabshahi S, van der Pols JC, Williams GM, Marks GC, Lahmann PH. Diet quality and change in anthropometric measures: 15-year longitudinal study in Australian adults. Br J Nutr 2012;107:1376–85.
30. Nguyen ND, Center JR, Eisman JA, Nguyen TV. Bone loss, weight loss, and weight fluctuation predict mortality risk in elderly men and women. J Bone Miner Res 2007;22:1147–54.
31. Harrington M, Gibson S, Cottrell RC. A review and meta-analysis of the effect of weight loss on all-cause mortality risk. Nutr Res Rev 2009; 22:93.
32. Marzetti E, Calvani R, Tosato M, Cesari M, Di Bari M, Cherubini A, Collamati A, D'Angelo E, Pahor M, Bernabei R, et al. Sarcopenia: an overview. Aging Clin Exp Res 2017;29:11–7.
33. Tay L, Ding YY, Leung BP, Ismail NH, Yeo A, Yew S, Tay KS, Tan CH, Chong MS. Sex-specific differences in risk factors for sarcopenia amongst community-dwelling older adults. Age (Omaha) 2015;37: 1–12.
34. Smith JD, Hou T, Hu FB, Rimm EB, Spiegelman D, Willett WC, Mozaffarian D. A comparison of different methods for evaluating diet, physical activity, and long-term weight gain in 3 prospective cohort studies. J Nutr 2015;145:2527–34.