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ORIGINAL ARTICLE

Body weight dynamics following intentional weight loss and physical performance: the Look AHEAD Movement and Memory Study

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Summary

Objective

The aim of this study was to explore the impact of body weight change following intentional weight loss on measures of physical performance in adults with diabetes.

Design and methods

Four hundred fifty individuals with type 2 diabetes (age, 59.0 ± 6.9 years; body mass index, 35.5 ± 5.9 kg/m^2) who participated in the Look AHEAD Movement and Memory Study and lost weight 1 year after being randomized to an intensive lifestyle intervention were assessed. Body weight was measured annually, and participants were categorized as continued losers/maintainers, regainers, or cyclers based on a ±5% annual change in weight. Objective measures of physical performance were measured at the year 8/9 visit.

Results

Forty-four percent, 38% and 18% of participants were classified as regainers, cyclers, and continued losers/maintainers, respectively. In women, weight cycling and regain were associated with worse follow-up expanded physical performance battery score (1.46 ± 0.07 and 1.48 ± 0.07 vs. 1.63 ± 0.07, both $p \leq 0.02$) and slower 20-m walking speed (1.10 ± 0.04 and 1.08 ± 0.04 vs. 1.17 ± 0.04 m/s, both $p < 0.05$) compared with continued or maintained weight loss. Male cyclers presented with weaker grip strength compared with regainers or continued losers/maintainers (30.12 ± 2.21 vs. 34.46 ± 2.04 and 37.39 ± 2.26 kg; both $p < 0.01$).

Conclusions

Weight cycling and regain following intentional weight loss in older adults with diabetes were associated with worse physical function in women and grip strength in men.

Keywords: Physical performance, type 2 diabetes mellitus, weight cycling, weight loss.

Introduction

The prevalence of disability increases with age and is accelerated in the presence of diabetes (1,2). Physical disability contributes to loss of independence, premature mortality and increased healthcare spending (3,4) and is consistently predicted by poor performance on several objective measures of physical function and strength (5–7). As older adults make up an increasingly larger proportion of the diabetic population (8), identification and treatment of risk factors for diabetes-related disability are emerging as a significant public health research priority.

Obesity is closely associated with diabetes and is a well-characterized, modifiable predictor of functional

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decline in older adults (9–13). Treatments for obesity, such as diet and exercise interventions, that result in significant weight loss frequently yield immediate improvement in risk factors for diabetes progression (14) and physical performance (15–17). However, for most individuals, stable, long-term, weight loss maintenance is unlikely (18–20), and data assessing the impact of weight fluctuation following intentional weight loss on physical performance in older adults, particularly those at increased risk for disability, are limited.

Some insight into this question is provided from three prospective epidemiologic studies, with data suggesting weight loss and weight cycling are associated with increased risk of mobility disability in middle-aged and older adults (21–23). However, these studies did not assess objective measures of physical function and strength, and only one (23) controlled for self-reported intentionality of weight change. To the best of our knowledge, the long-term impact of body weight change following an intentional, structured weight loss programme on objective measures of physical performance in older adults with diabetes has yet to be assessed. Results are necessary to comprehensively evaluate the long-term benefits and risks of intentional weight loss in this population.

The purpose of this study is to explore the associations of weight change following intentional weight loss (i.e. weight pattern classification of weight loss maintainers, continued losers, regainers or cyclers based on a ±5% annual change in weight) on objective measures of physical function and strength, including expanded physical performance battery (PPB) score, 20- and 400-m walk tests, and grip and knee strength, measured in the Action for Health in Diabetes (Look AHEAD) Movement and Memory (M&M) ancillary study. We hypothesize that individuals who experience weight cycling or weight regain following intentional weight loss will perform worse on measures of physical function and strength compared with individuals who continue to lose weight or maintain their weight loss.

Methods and procedures

Look AHEAD study design

The design and methods of the Look AHEAD trial have been published previously (24). In brief, Look AHEAD recruited individuals with type 2 diabetes who were 45–76 years of age and had a body mass index (BMI) $>25\,kg/m^2$ ($>27\,kg/m^2$ in participants on insulin), glycosylated haemoglobin (HbA1c) $<11\%$, systolic blood pressure <160 mmHg, diastolic blood pressure <100 mmHg and triglycerides <600 mg/dL. Participants were randomized to a usual care condition (i.e. diabetes support and education) or to an intensive lifestyle intervention (ILI), with a goal in the ILI arm of inducing a loss of 7% or more of initial weight and increasing physical activity to 175 min or more per week (25).

The Look AHEAD M&M ancillary study enrolled Look AHEAD participants at four clinical centres to assess physical and cognitive function at either their year 8 or 9 Look AHEAD clinical examination. Only Look AHEAD participants who were currently active (i.e. had not been lost to follow-up or refused further Look AHEAD activity) at the Baton Rouge, Denver, Memphis and Pittsburgh clinics and who provided separate informed consent were eligible to enrol. The Look AHEAD M&M protocol and consent forms were approved by local institutional review boards prior to use. Primary outcome papers, including recruitment and retention details, were published with modest treatment effects observed for physical, but not cognitive, function endpoints (26,27).

Study population

Because this analysis examines the effect of changing weight dynamics following intentional weight loss on physical performance, only individuals in the ILI arm were included. A total of 2570 Look AHEAD participants were randomized to the ILI arm, of which 499 participated in the Look AHEAD M&M ancillary study and had a clinic visit during the year 8/9 exam. Ninety-one percent of this subgroup lost at least 0.1% of their baseline weight at the year 1 visit and had at least two additional annual weights ($n = 455$). Participants lacking pertinent covariates [$n = 5$; 3 missing diabetes duration and 2 missing Short Form-36 Health Survey {SF-36}] were further excluded, yielding a final analysis sample of 450 participants (197 men and 253 women).

Weight pattern classifications

Certified clinic staff, masked to intervention assignment, collected annual measures of weight, using a Tanita BWB 800 digital scale (Tanita Corp., Arlington Heights, IL), throughout the Look AHEAD trial. Longitudinal measures of body weight were used to classify individuals into three weight pattern categories, (i) continued losers or maintainers, (ii) regainers and (iii) cyclers, utilizing definitions previously employed in the Cardiovascular Health Study (22). Briefly, a 5% weight change from year to year was used to define weight patterns, as a change $\geq 5\%$ is considered clinically significant (28), and the participant year 1 (i.e. post-intensive weight loss or post Phase I (25)) weight served as the referent point. Weight at follow-up visits during years 2–8 were first compared with both the referent point and weight from previous year to

categorize each follow-up visit into one of the three weight pattern categories. Then, weight pattern category at each follow-up visit was compared with other follow-up visit categories to yield an overall weight pattern category across the 8-year follow-up period.

Participants were classified as 'maintainers' if their weight changed by $<5\%$ from the prior year and from the year 1 weight. Participants were classified as 'regainers' if they gained $\geq 5\%$ from the prior year and the year 1 weight and 'continued losers' if they lost $\geq 5\%$ from the prior year and the year 1 weight. Once a participant was categorized as a regainer or continued loser, they remained in that group unless weight changed sufficiently in the opposite direction to qualify them as a 'cycler'. For example, if a participant lost $\geq 5\%$ weight in comparison with year 1, yet gained in comparison with the previous year, they would be categorized as a cycler for that follow-up year and would remain a cycler for the overall weight pattern category. Similarly, having a combination of 'loser' and 'gainer' across yearly categories would result in an overall cycler categorization. Due to the relatively small number of participants classified as either continued losers ($n = 49$) or maintainers ($n = 35$), these categories were combined for subsequent analyses.

Physical function and strength assessments

The Look AHEAD M&M study assessed objective measures of physical function and strength using certified staff who were masked to intervention assignment during a clinic exam at the eighth or ninth year of Look AHEAD follow-up (27). The expanded physical performance battery (expanded PPB; (5,29)) consists of standing balance tasks, time to complete five repeated chair stands and a 4-m walk to assess usual gait speed. Performance on these tasks is converted to a continuous score, ranging from 0 to 3, with higher scores indicative of better performance ($n = 445$). Usual walking speed over 20 m and walking endurance over 400 m were also measured (30) ($n = 430$ and 413 for the 20- and 400-m walk tests, respectively). Grip strength (kg) was measured twice in each hand using an isometric Hydraulic Hand Dynamometer (Jamar, Bolingbrook, IL). The maximum force from two trials for the stronger hand was used in the analyses ($n = 425$). Maximum knee extensor muscle strength (lb; one repetition maximum) was assessed on a Nautilus One™ Leg Extension machine ($n = 328$). The right leg was tested unless there was a contraindication (e.g. prior knee surgery). If participants experienced knee pain during the test and there were no contraindications to test the other leg, the other leg was tested.

Potential risk factors for physical limitations

All baseline physical performance risk factor measurements were obtained by certified staff. Self-reported characteristics (i.e. age, gender, race, education and smoking status) and medical history were captured using standardized questionnaires. Participants brought current prescription medications to update medication records. Subscales of the SF-36 were used as measures of self-reported bodily pain and physical functioning status, with higher scores indicative of better functioning or well-being (31). Depressive symptoms were assessed using the Beck Depression Inventory (BDI). Total scores on the BDI range from 0 to 63, with higher scores indicating more symptoms of depression (32).

Height was measured in duplicate using a stadiometer, and BMI was calculated as weight in kilograms divided by height in square meters. Blood specimens were collected after at least a 12-h fast and were analysed by the Central Biochemistry Laboratory (Northwest Lipid Research Laboratories, University of Washington, Seattle, WA) using standardized laboratory procedures for measuring HbA1c. A maximal graded exercise test was administered at baseline, with results recorded as metabolic equivalents (METS). Lastly, total length of hospital stays prior to the ancillary visit was assessed based on participant medical records.

Statistical analysis

Due to a significant association between gender and weight pattern classification, all results are presented stratified by gender and were initially analysed using descriptive statistics. Comparisons between groups were carried out using chi-square tests for proportions and *t*-tests or ANOVA procedures for continuous variables. The Wilcoxon rank sum test was used for BDI due to non-normality. Analysis of covariance models was used to compare all outcome measures. Three sets of models were fitted for each outcome measure: a minimal model including age, gender, race, education and clinic site as covariates (model 1), a further adjusted model that also included baseline insulin use, hypertension, cardiovascular disease (CVD) history, smoking status, BMI, HbA1c, self-reported diabetes duration, baseline fitness (METS), SF-36 physical functioning and pain subscales, and BDI score (<11 or ≥ 11); interim hospitalizations (model 2); and a third model that also adjusted for year 1 weight change from baseline (model 3). Additional sensitivity analyses were performed, including (i) stratification of analyses by achievement of the study weight loss goal ($\geq 7\%$) at year 1 and (ii) separation of the weight cyclers into single or multiple cycler categories resulting in a

four-category weight pattern variable. All analyses were performed in SAS 9.3 (Cary, NC), and a two-sided α level of 0.05 was considered significant.

Results

Participant characteristics

Average age of the study sample ($n = 450$) was 59.0 ± 6.9 years, 56% were women and 20% were African–American. Baseline BMI was 35.5 ± 5.9 kg/m^2, and average percent weight loss at the year 1 visit was 10.2 ± 6.5%, with men reporting greater losses than women (−11.1 ± 6.1% vs. −9.5 ± 6.7%; $p = 0.01$). Compared with other ILI participants at the Look AHEAD M&M clinics ($n = 221$), participants included in our analyses were more likely to have a college or graduate education ($p < 0.01$), not have had a hospital stay during follow-up ($p < 0.01$) and have lower baseline HbA1c (0.23%; $p = 0.01$).

Characteristics of men and women at baseline, by weight pattern category, are shown in Table 1. Overall, the majority of participants were categorized as regainers (44%), followed by weight cyclers (38%) and then continued losers/maintainers (18%), with women more likely to be classified as weight cyclers and men more likely to be classified as regainers ($p < 0.01$). No difference in weight pattern category was seen by age, education, diabetes duration and control, chronic disease (diabetes-related variables, hypertension or CVD), depression, smoking status, fitness or self-reported pain at baseline for either gender, although marginally significant group differences in baseline hypertension and depression, and total length of hospital stays prior to the ancillary visit were seen in men. Both men and women classified as regainers or weight cyclers were more likely to be White than continued loser/maintainers (who were more likely to be African–American/Black). Men classified as weight cyclers were also more likely to have a higher weight/BMI and worse self-reported physical functioning at baseline than continued losers/maintainers or regainers.

Change in weight by weight pattern category

Year 1 percent weight change differed among weight pattern categories for both genders. Interestingly, both men and women who achieved the 7% weight loss goal at year 1 had 2.91 (1.68–5.06) and 7.82 (4.38–13.96) times the odds of being classified as a cycler or regainer than a continued loser/maintainer, respectively, compared with participants who did not meet the 7% weight loss goal at year 1. By the year 8 visit, on average, regainers gained (mean ± SD) 9.6 ± 6.7 kg (10.3 ± 6.9 and 8.7 ± 6.3 kg for men and women, respectively), weight cyclers gained 1.4 ± 10.4 kg (1.2 ± 9.5 and 1.5 ± 10.9 kg for men and women, respectively) and continued losers/maintainers lost 4.9 ± 7.5 kg (−2.7 ± 3.9 and −6.3 ± 8.9 kg for men and women, respectively) from the year 1 visit weight (Figure 1).

Associations between physical performance and weight pattern category

Performance on physical function and strength tests at the year 8/9 visit, by weight pattern category and gender, is presented in Table 2. Overall, mean gait speed was faster than 1.0 m/s for both the 20- and 400-m walk. Expanded PPB score was 1.68 ± 0.40, and men had greater grip and knee strength than women. In unadjusted analyses, weight pattern category was found to be predictive of expanded PPB score, gait speed and grip strength in men. Weight cyclers consistently performed worse on select measures of physical performance and strength (compared with regainers for PPB and gait speed, and both losers/maintainers and regainers for grip strength; Table 2). Conversely, in unadjusted analyses, weight pattern category did not appear to be predictive of follow-up physical performance or strength in women.

Table 3 presents adjusted ANOVA results of physical performance measures by weight cycling category for men and women, respectively. Interestingly, in minimally adjusted models (model 1), weight cycling was associated with a lower score on the expanded PPB, slower walking speed and weaker grip strength in men. After further covariate adjustment (model 2), however, only grip strength in men was associated with weight pattern category ($p < 0.01$). Specifically, weight cyclers had lower grip strength at the year 8/9 visit when compared with weight regainers or continued losers/maintainers (30.12 ± 2.21 vs. 34.46 ± 2.04 and 37.39 ± 2.26 kg, respectively). Additional adjustment for year 1 percent weight change did not significantly alter effect size estimates; however, a trend was observed for weaker knee extensor strength in the continued losers/maintainer category compared with regainer or cycler categories (model 3; $p = 0.08$). When absolute knee extensor strength was divided by weight (to yield relative knee strength), this association was further attenuated.

A nearly opposite pattern was observed in women, with associations produced in models 1 and 2 suggestive of no effect of weight pattern classification on follow-up physical performance. However, after further adjustment for year 1 weight change from baseline (model 3), weight regain and cycling were associated with lower PPB score ($p = 0.02$) and slower 20-m gait speed ($p = 0.03$) compared with a pattern of weight maintenance or continued weight

Table 1 Descriptive baseline characteristics by gender and weight cycling category

	Male					Female				
	Overall	Weight pattern category*					Weight pattern category*			
	N or Mean ± SD	Losers/maintainers *N* (%) or Mean ± SD	Regainers *N* (%) or Mean ± SD	Cyclers *N* (%) or Mean ± SD	*p***	Overall *N* or Mean ± SD	Losers/maintainers *N* (%) or Mean ± SD	Regainers *N* (%) or Mean ± SD	Cyclers *N* (%) or Mean ± SD	*p***
Total	197	32	108	57		253	48	90	115	
Age (years)	60.12 ± 6.64	60.72 ± 6.92	59.78 ± 6.69	60.44 ± 6.49	0.71	58.09 ± 6.96	58.50 ± 7.04	58.01 ± 6.82	57.98 ± 7.08	0.90
<60	97	17 (53.13)	53 (49.07)	27 (47.37)	0.87	150	26 (54.17)	55 (61.11)	69 (60.00)	0.72
≥60	100	15 (46.88)	55 (50.93)	30 (52.63)		103	22 (45.83)	35 (38.89)	46 (40.00)	
Race					<0.01					0.08
African–American/Black	21	8 (25.00)	9 (8.33)	4 (7.02)		71	21 (43.75)	20 (22.22)	30 (26.09)	
White	164	21 (65.63)	97 (89.81)	46 (80.70)		163	23 (47.92)	64 (71.11)	76 (66.09)	
Other/mixed	12	3 (9.38)	2 (1.85)	7 (12.28)		19	4 (8.33)	6 (6.67)	9 (7.83)	
Education					0.46					0.52
High school or less	15	2 (6.25)	10 (9.26)	3 (5.26)		54	12 (25.00)	15 (16.67)	27 (23.48)	
Post high school	67	8 (25.00)	41 (37.96)	18 (31.58)		104	22 (45.83)	38 (42.22)	44 (38.26)	
College/graduate	115	22 (68.75)	57 (52.78)	36 (63.16)		95	14 (29.17)	37 (41.11)	44 (38.26)	
Body mass index (kg/m^2)	34.55 ± 5.26	33.93 ± 6.20	33.63 ± 4.64	36.65 ± 5.30	<0.01	36.19 ± 6.20	37.36 ± 6.33	35.39 ± 5.89	36.32 ± 6.35	0.20
Weight (kg)	108.6 ± 18.66	106.1 ± 21.97	106.2 ± 16.43	114.4 ± 19.68	0.02	96.39 ± 17.41	99.49 ± 17.14	94.11 ± 16.04	96.88 ± 18.44	0.21
Year 1 percent weight change***	-11.1 ± 6.14	-6.92 ± 4.68	-13.6 ± 5.98	-8.57 ± 4.77	<0.01	-9.52 ± 6.69	-5.58 ± 3.48	-10.9 ± 6.13	-10.1 ± 7.50	<0.01
HbA1c (%)	7.15 ± 1.16	7.08 ± 0.81	7.08 ± 1.17	7.32 ± 1.31	0.42	7.17 ± 1.07	7.25 ± 1.10	7.08 ± 1.07	7.21 ± 1.05	0.60
Any insulin use (% yes)	30	5 (15.63)	16 (14.81)	9 (15.79)	0.98	43	13 (27.08)	15 (16.67)	15 (13.04)	0.09
Diabetes duration (years)	6.92 ± 6.24	6.75 ± 3.60	6.66 ± 6.59	7.51 ± 6.77	0.70	5.64 ± 6.04	5.08 ± 5.45	5.92 ± 7.18	5.65 ± 5.28	0.74
Hypertension (% yes)	165	24 (75.00)	88 (81.48)	53 (92.98)	0.06	210	43 (89.58)	71 (78.89)	96 (83.48)	0.28
Cardiovascular disease history (% yes)	42	9 (28.13)	21 (19.44)	12 (21.05)	0.57	28	8 (16.67)	6 (6.67)	14 (12.17)	0.18
Beck Depression Inventory****	4.07 ± 3.88	4.22 ± 3.87	3.49 ± 3.27	5.07 ± 4.71	0.14	5.89 ± 4.86	7.13 ± 6.27	5.96 ± 4.45	5.33 ± 4.43	0.27
<11	182	28 (87.50)	104 (96.30)	50 (87.72)	0.07	219	38 (79.17)	80 (88.89)	101 (87.83)	0.24
≥11	15	7 (12.28)	4 (3.70)	4 (12.50)		34	10 (20.83)	10 (11.11)	14 (12.17)	
Smoking status					0.65					0.88
Never	67	13 (40.63)	39 (36.11)	15 (26.32)		153	26 (54.17)	57 (63.33)	70 (60.87)	
Former	122	18 (56.25)	65 (60.19)	39 (68.42)		88	19 (39.58)	29 (32.22)	40 (34.78)	
Current	8	1 (3.13)	4 (3.70)	3 (5.26)		12	3 (6.25)	4 (4.44)	5 (4.35)	
Fitness (METs)	8.27 ± 2.03	8.39 ± 2.14	8.48 ± 1.84	7.81 ± 2.25	0.12	6.76 ± 1.65	6.45 ± 1.42	6.84 ± 1.69	6.81 ± 1.71	0.36
Short Form-36 Health Survey										
Bodily pain	51.28 ± 8.87	52.73 ± 8.65	51.57 ± 8.59	49.92 ± 9.47	0.32	49.70 ± 8.54	48.15 ± 9.38	50.17 ± 7.74	49.97 ± 8.77	0.38
Physical functioning	49.44 ± 7.22	50.32 ± 6.06	50.49 ± 6.80	46.95 ± 8.06	<0.01	47.33 ± 8.26	45.85 ± 8.05	48.05 ± 7.98	47.39 ± 8.56	0.33
Total length of hospital stays prior to ancillary visit (days)					0.07					0.71
0	81	12 (37.50)	50 (46.30)	19 (33.33)		100	19 (39.58)	40 (44.44)	41 (35.65)	

1–7	75	14 (43.75)	42 (38.89)	19 (33.33)	88	18 (37.50)	27 (30.00)	43 (37.39)	
>7	41	6 (18.75)	16 (14.81)	19 (33.33)	65	11 (22.92)	23 (25.56)	31 (26.96)	

*Weight pattern categories defined based on ±5% change in annual weight.
**Chi-square for categorical variables and ANOVA *F*-test for continuous.
***Compared with baseline.
****p*-value is from Wilcoxon rank sum test.
HbA1c = glycosylated haemoglobin; METS = metabolic equivalents; SD, standard deviation.

loss. Interestingly, for both genders, the association between slower gait speed and lower grip strength estimates did not differ by bouts of weight cycling (all pairwise comparisons between one weight cycle and multiple cycles, $p > 0.10$).

Lastly, because year 1 percent weight change appeared to be such an influential covariate to model results, analytic models 1 and 2 were stratified by achievement of the study-wide weight loss goal at year 1 (7% of baseline weight). Stratification did not affect results in women; however, the association between weight cycling and low grip strength remained only for men who lost ≥7% of their baseline weight at year 1 ($p = 0.04$). Additionally, in minimally adjusted models (model 1), cycling men who lost ≥7% of baseline weight at year 1 also had significantly lower expanded PPB scores ($p = 0.01$), and slower 20-m ($p = 0.03$) and 400-m ($p = 0.02$) gait speed than loser/maintainer or regainer groups, although these findings were attenuated to non-significance after adjustment for additional covariates (data not shown).

Discussion

This study is the first to assess the effect of weight pattern dynamics following intentional weight loss on objective measures of physical function and strength in a well-functioning sample of older adults with diabetes. Differential classification of weight pattern status following weight loss by gender was observed, with women more likely to be classified as weight cyclers and continued losers/maintainers than men over the 7 years of follow-up. Women categorized as weight cyclers and regainers presented with worse expanded PPB score and slower 20-m gait speed at the year 8/9 clinic visit compared with women categorized as continued losers/maintainers. Similarly, men categorized as weight cyclers presented with weaker follow-up grip strength compared with men in the regainer or continued loser/maintainer categories. Importantly, effect size differences observed between weight pattern categories (i.e. expanded PPB score, 0.16; gait speed, 0.08 m/s; grip strength, 6 kg) are considered clinically meaningful (33,34). Thus, clinicians promoting weight loss in this population should emphasize stable weight loss maintenance for prolonged functional independence.

Results presented here contribute to a growing body of literature assessing the effect of weight change on physical performance in at-risk populations for future disability. Our findings support and extend reports generated from other large, observational studies, linking weight gain (35,36) and variability (22,23) in middle-to-late life

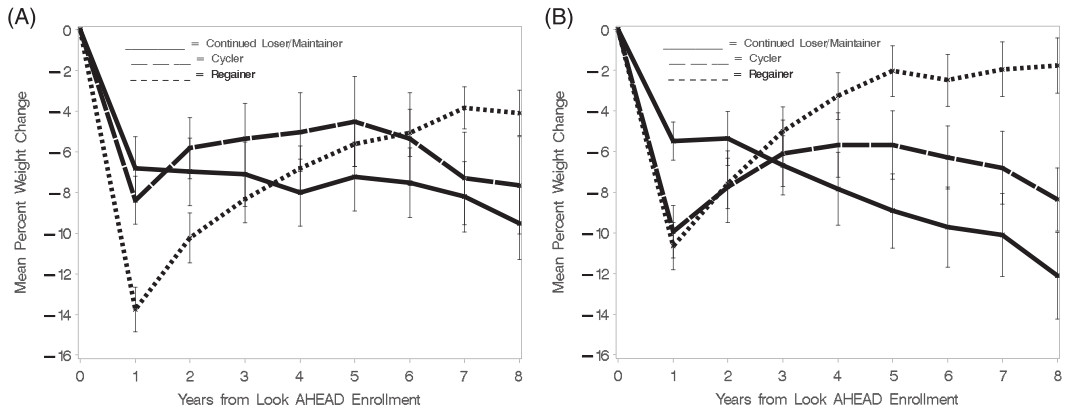

Figure 1 Graphical depiction of weight loss trends for each weight pattern category for men (A) and women (B).

Table 2 Physical performance measures at Look AHEAD Y8/Y9 Memory and Movement ancillary visit by gender and weight cycling category

		Weight pattern category				
Physical performance measures	Overall *N*	Losers/maintainers Mean ± SD	Regainers Mean ± SD	Cyclers Mean ± SD	Mean ± SD	*p**
Expanded PPB score (range 0–3)						
Male	195	1.73 ± 0.40	1.69 ± 0.43	1.81 ± 0.33	1.61 ± 0.46	0.02
Female	250	1.64 ± 0.40	1.67 ± 0.35	1.64 ± 0.43	1.63 ± 0.39	0.94
20-m gait speed (m/s)						
Male	189	1.21 ± 0.20	1.22 ± 0.22	1.25 ± 0.18	1.15 ± 0.23	0.02
Female	241	1.12 ± 0.22	1.14 ± 0.20	1.14 ± 0.25	1.10 ± 0.21	0.63
400-m gait speed (m/s)						
Male	185	1.12 ± 0.19	1.13 ± 0.19	1.15 ± 0.17	1.06 ± 0.21	0.04
Female	228	1.03 ± 0.17	1.02 ± 0.15	1.04 ± 0.19	1.03 ± 0.17	0.93
Grip strength (kg)						
Male	189	39.08 ± 8.72	42.10 ± 8.82	39.82 ± 7.91	35.99 ± 9.34	<0.01
Female	236	24.80 ± 5.96	24.02 ± 5.58	25.61 ± 6.40	24.54 ± 5.78	0.94
Knee extensor strength (lb)						
Male	164	70.40 ± 22.88	63.78 ± 22.42	73.69 ± 21.60	67.07 ± 25.13	0.08
Female	164	32.79 ± 12.54	29.19 ± 10.38	33.63 ± 13.62	33.62 ± 12.36	0.21

*From unadjusted ANOVA *F*-test.
PPB = physical performance battery.

with lower self-reported functional status, particularly in women, by providing confirmatory data using objective measures of physical performance. Long-term results (8–9 years) presented here are also in agreement with an emerging body of shorter-term (12–18 months) randomized controlled trial data, suggesting that lifestyle-based interventions resulting in intentional weight loss of 7–10% are associated with improved physical function and strength in older adults (16,17,37). It is interesting to note that the year 1 weight change was strongly related to weight pattern classification over the next 7 years [with achievement of the 7% weight loss goal at year 1 associated with increased odds of weight regain {women only} and cycling {men and women}] and may also exacerbate associations between body weight dynamics and physical performance.

Gender differences reported here are intriguing and may be explained by weight change associated changes in body composition. Longitudinal studies of body composition in older adults show a tendency towards a loss of lean and a gain of fat mass over time, which may be exaggerated during a cycle of weight regain (38), particularly in older women (39). Total body fat mass is more strongly associated with physical performance in women (compared with men) (40), and a relative increase in fat mass in women classified as regainers or weight cyclers in the current study may explain their worse follow-up expanded PPB score and 20-m gait speed. This line of

Table 3 Adjusted ANOVA results of testing physical performance measures with weight cycling category from gender stratified analyses

	Weight pattern category			
	Losers/maintainers	Regainers	Cyclers	
Physical performance measures	LSMean ± SE	LSMean ± SE	LSMean ± SE	Weight cycling *p*-value
Expanded PPB score (range 0–3)				
Male				
Model 1	1.69 ± 0.07	1.78 ± 0.06	1.59 ± 0.06	<0.01
Model 2	1.73 ± 0.09	1.80 ± 0.08	1.71 ± 0.08	0.26
Model 3	1.74 ± 0.09	1.80 ± 0.08	1.72 ± 0.09	0.44
Female				
Model 1	1.69 ± 0.06	1.62 ± 0.05	1.61 ± 0.04	0.52
Model 2	1.57 ± 0.07	1.45 ± 0.07	1.46 ± −0.07	0.13
Model 3	1.63 ± 0.07	1.46 ± 0.07	1.48 ± 0.07	0.02
20-m gait speed (m/s)				
Male				
Model 1	1.21 ± 0.04	1.26 ± 0.03	1.16 ± 0.04	<0.01
Model 2	1.20 ± 0.05	1.23 ± 0.05	1.19 ± 0.05	0.41
Model 3	1.23 ± 0.05	1.23 ± 0.05	1.21 ± 0.05	0.87
Female				
Model 1	1.16 ± 0.03	1.14 ± 0.03	1.11 ± 0.03	0.31
Model 2	1.14 ± 0.04	1.09 ± 0.04	1.07 ± 0.04	0.11
Model 3	1.17 ± 0.04	1.10 ± 0.04	1.08 ± 0.04	0.03
400-m gait speed (m/s)				
Male				
Model 1	1.13 ± 0.04	1.17 ± 0.03	1.08 ± 0.04	<0.01
Model 2	1.11 ± 0.05	1.14 ± 0.04	1.10 ± 0.05	0.37
Model 3	1.13 ± 0.05	1.14 ± 0.04	1.12 ± 0.05	0.80
Female				
Model 1	1.03 ± 0.03	1.03 ± 0.02	1.03 ± 0.02	0.98
Model 2	1.00 ± 0.03	0.97 ± 0.03	0.98 ± 0.03	0.52
Model 3	1.02 ± 0.03	0.97 ± 0.03	0.98 ± 0.03	0.27
Grip strength (kg)				
Male				
Model 1	41.43 ± 1.74	37.86 ± 1.37	34.03 ± 1.46	<0.01
Model 2	38.07 ± 2.19	34.36 ± 2.05	30.75 ± 2.16	<0.01
Model 3	37.39 ± 2.26	34.46 ± 2.04	30.12 ± 2.21	<0.01
Female				
Model 1	22.69 ± 0.93	24.55 ± 0.78	23.34 ± 0.68	0.17
Model 2	22.67 ± 1.25	24.45 ± 1.26	23.27 ± 1.18	0.21
Model 3	22.98 ± 1.30	24.49 ± 1.27	23.36 ± 1.19	0.30
Knee extensor strength (lb)				
Male				
Model 1	63.47 ± 4.79	72.54 ± 3.80	67.99 ± 4.30	0.13
Model 2	65.94 ± 6.00	75.86 ± 5.48	73.51 ± 5.94	0.11
Model 3	64.71 ± 6.18	76.02 ± 5.49	72.22 ± 6.15	0.08
Female				
Model 1	28.23 ± 2.49	34.07 ± 2.11	33.51 ± 1.90	0.08
Model 2	27.53 ± 3.59	33.69 ± 3.42	34.00 ± 3.35	0.05
Model 3	27.99 ± 3.70	33.72 ± 3.43	34.08 ± 3.36	0.08

Model 1 = age, gender, race, education and clinic. Model 2 = Model 1 + baseline insulin use, hypertension, cardiovascular disease history, smoking status, body mass index, glycosylated haemoglobin %, self-reported diabetes duration, baseline fitness, Short Form-36 Health Survey physical functioning and pain subscales, Beck Depression Inventory (<11 or ≥11) and interim hospitalizations. Model 3 = Model 2 + year 1 weight change from baseline.
PPB = physical performance battery.

thinking is only speculative, however, and should be the focus of future work as we do not specifically examine associations between change in body composition and physical performance. The negative association between cycling and grip strength in men is in general agreement with other findings linking weight fluctuation to increased risk of physical disability (22,23); however, it is curious that this association was only observed in one outcome measure (of five). Overall, men are less likely to present with disability than women (41), and perhaps their physical performance is also less likely to be affected by changing weight dynamics.

Strengths of this study include the use of measured weights to assess changing weight dynamics following an intentional weight loss and adjustment for multiple covariates, which may confound our observed relationship between weight pattern classification and physical performance. This study is not without limitations, however. Because physical performance measures were only assessed at the year 8/9 visit, changes over time could not be assessed. A general limitation in this field of research is the lack of an operational definition for weight cycling. Although our choice of 5% weight change was used previously in a similarly designed study (22) and is consistent with clinically meaningful weight change (28), conclusions may differ by weight pattern definitions used. Varying definitions also make true cross-study comparisons difficult; studies testing similar hypotheses varied in weight change thresholds used to construct their weight pattern categories from a relative 5% weight change (21,22), to an absolute weight change of 5–30 lb (23,36), to absolute change over time (35), and no other study assigned weight pattern categories following an intentional weight loss intervention (as was carried out in the present analysis). Lastly, extrapolation of results should be limited to similar populations, particularly with regard to age and disease status.

In sum, data presented here suggest that weight regain and cycling following intentional weight loss in middle-aged and older adults with diabetes contribute to worse physical function in women and grip strength in men. Importantly, for weight cyclers, this was true despite a relatively small increase in absolute weight from the year 1 visit. Given the known immediate benefit of weight loss on physical performance measures, adoption of effective weight loss maintenance strategies may have the potential to maintain and preserve independent living in overweight and obese, middle-aged and older adults with diabetes.

Conflicts of Interest Statements

The authors have no competing interests.

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GAB, JOH, DKH, JMJ, KCJ and SBK designed the research; RHN and KMB analysed data; KMB, GAB, JOH, DKH, JMJ, KCJ, RHN and SBK contributed to the writing of the article; KMB had primary responsibility for final content. All authors read and approved the final manuscript.

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