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Life Events, Physical Activity, and Weight Loss Maintenance: Decomposing Mediating and Moderating Effects of Health Behavior

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Abstract

Background—This analysis helps clarify the individual and joint effects of moderate to vigorous physical activity (MVPA) in concert with significant life events (eg, divorce, marriage, job change or loss, pregnancy, etc) on weight following a behavioral weight loss intervention.

Methods—Data from the Tracking Study weight loss trial were utilized to perform a 4-way decomposition of moderation and mediation of life events (1 vs 0) and MVPA (low <2500 kcal vs high ≥2500 kcal) on 24-month weight.

Results—The total effect of life events and MVPA on weight was estimated to be 1.63 kg (95% confidence interval = 0.30 to 2.96; $P = .02$). The controlled direct effect of life events on 24-month weight suggested that experiencing at least one life event controlling for MVPA was associated with an increase of 2.31 kg (95% confidence interval = 0.29 to 4.33) at 24 months. Other interaction and mediation estimates were not statistically significant.

Conclusions—This analysis offers new potential for examining health behaviors that may act as both mediators and effect modifiers of health. Although more work is needed to understand the interaction of life events and MVPA on weight loss maintenance, findings help rule out mediation. Life events and MVPA should be considered for their unique effects on weight loss maintenance in the future.

Keywords

methods; obesity; interventions

During the maintenance phase following weight loss programs, when intervention support for weight loss behaviors taper off, individuals are at higher risk for weight gain. Predicting and promoting successful maintenance is challenging and few randomized controlled trials have been conducted to examine behavioral factors associated with maintenance.¹ Cohort studies have identified regular moderate to vigorous physical activity (MVPA) as a strong correlate of successful weight loss maintenance.^{2,3} Although the caloric expenditure associated with physical activity is likely the major mechanism through which higher levels of physical activity mitigate weight regain, the role of life stressors in this process has not been examined. Importantly, MVPA has been shown to improve mood and ability to cope with life stressors including daily hassles, divorce, legal issues, job loss or change, and death of close friends or family members.⁴⁻⁶ Although research has focused on specific life events that have triggered individuals to lose weight,⁷ the role of life stressors in the weight loss maintenance phase, including whether and/or how physical activity may affect the relationship between life events and weight regain has received limited attention.

Obtaining a better understanding of the relationships among physical activity, stressful life events, and weight regain is important given that physical activity may function as a moderator and a mediator of weight regain. For example, MVPA participation may moderate the relationship between stressful life events and associated weight gain. That is, the effect of life events on weight regain may differ depending on how physically active is an individual, with higher levels of MVPA a protective factor. Conversely, MVPA may mediate the relationship between life events and weight regain, such that the occurrence of stressful life events is associated with reductions in MVPA, which in turn contribute to weight regain. Current research has focused on specific life events that have prompted individuals to lose weight and take on behavior change that has been sustained.⁷ However, examination of the impacts of major life events that may interrupt or negatively impact behavior change progress after weight loss programs, or factors such as physical activity that may modify these impacts, have not received the same attention. This pathway is worthy of exploration given that individuals who have recently adopted or increased MVPA are at higher risk for disengagement and relapse due to stressful life events.⁸ This risk for behavioral relapse due to the occurrence of life events has the following intervention as a common consideration in behavioral maintenance theory as well.⁹ However, little empirical evidence exists about the effects of major life events on physical activity in the context of weight loss interventions.

It is important to understand whether physical activity is a moderator and/or a mediator of the relationship between life events and weight loss maintenance following participation in a behavioral weight loss intervention. The aim of this work was to examine the impact of physical activity, in the context of life events, on weight following an active weight loss intervention. Although adherence to high MVPA has been associated with better weight loss maintenance,² this analysis attempted to clarify the individual and joint effects of significant life events and MVPA on weight out to 24 months. We hypothesized the total effect of

greater reporting of life events on weight within a lifestyle weight loss intervention would be influenced by individuals' physical activity levels during the maintenance phase. Using this decomposition method, we further expected a portion of the effect of reported life events on weight following a behavioral weight loss intervention would be moderated by physical activity level during the maintenance period, such that individuals who participated in higher levels of physical activity would weigh less at 24 months despite life events that were experienced. Finally, a portion of the effect of reported life events on weight following a behavioral weight loss intervention would be mediated by physical activity during the maintenance period, such that the occurrence of significant life events would lead to increased weight through low participation in MVPA.

Methods

Study Design and Population

To assess differences in life events and the association with MVPA and 24-month weight following a year-long weight loss intervention, data from a randomized controlled weight loss trial were utilized. The Tracking Study was a 3-arm randomized trial comparing the efficacy of self-weighing prescriptions during a behavioral weight loss intervention on weight and psychological outcomes over 24 months.¹⁰

Men and women residing throughout the Minneapolis-St Paul, MN metropolitan area were enrolled between July 2012 and August 2013. Eligibility criteria required that participants had a body mass index between 25 and 40 kg/m², access to home wireless internet, no recent weight loss greater than 10 pounds or history of bariatric surgery, and no history of significant physical or mental health concerns, including a binge eating disorder. Women could not be pregnant or breastfeeding or have plans to become pregnant for the 24 months of the study.¹⁰ A total of 339 individuals gave consent and were enrolled in the Tracking Study. Both the Tracking Study and this secondary data analysis were approved by the University of Minnesota Internal Review Board.

Individuals were recruited, randomized, and began the intervention in 3 waves staggered 6 months apart beginning in July 2012. Participation in the final wave concluded in September 2015. Detailed information regarding the Tracking Study has been published elsewhere.¹⁰ A standard behavioral weight loss intervention was conducted for the first 12 months of the study.^{10,11} Activities included, dietician-lead in-person group meetings with education and discussion weekly for 6 months, biweekly for 2 months, and monthly for 4 months, followed by a 12-month measurement-only maintenance period. Participants completed questionnaires and anthropometric measures at baseline, 6-, 12-, 18-, and 24-month time points.

Life Events

Individuals reported life events at 24 months, occurring in the prior 12-month maintenance period. An adaptation of the Life Experiences Survey¹² assessed different types of life events, including marriage, pregnancy, death of spouse or close family members, divorce, job loss or change, and change of residence, retrospectively, over the 12 months prior to

administration. The measure was shortened to avoid undue participant burden during lengthy survey procedures for this study while still capturing key life events; all events assessed are listed in Table 1. Although participant responses tend to fluctuate over time, the measure has shown satisfactory reliability ($r = .63-.64$) over 6-week test-retest evaluation.¹² Individuals were categorized and compared using a classification of no life events (0 life experiences reported) and some life events (1 life experiences reported). This definition is consistent with previous work that has examined the impact of one major life event on weight.¹³ To adjust for previous behaviors and experiences during the weight loss intervention the total number of life events reported during the active weight loss phase (measured at 12 mo) was included as a covariate.

Physical Activity

Participants self-reported MVPA via the Paffenbarger Activity Questionnaire (PAQ) at baseline, 6, 12, 18, and 24 months.¹⁴ This questionnaire assessed respondent's MVPA in the previous week in both closed and open-form questions. Activity responses were categorized into light, moderate, and vigorous physical activity, using self-reported duration and researcher-coded intensity to estimate calories spent participating in the various physical activity intensities during the previous week. In addition, the amount of walking and stair climbing were specifically assessed in 2 separate questions.^{14,15} Responses to these questions were incorporated into a total caloric expenditure calculation. Estimated energy expenditure was validated against VO_2 maximal output and had acceptable validity ($r = .60$).¹⁵ A binary variable indicating high MVPA at 24 months was defined as low (<2500 kcal) and high (≥ 2500 kcal). This cut point was defined by previous work into MVPA recommendations required for successful maintenance following weight loss.¹⁶⁻¹⁸ Baseline MVPA was included as a covariate to account for physical activity level prior to intervention.

Weight

The primary outcome of interest was weight (in kilograms) measured at 24 months. Trained staff measured weight at all assessment visits. Baseline and 12-month (the end of active intervention) weights were included in the models to account for prior weight change during active intervention.

Covariates

Covariates included self-reported demographic characteristics collected at baseline: gender, race/ethnicity, educational attainment, marital status, and age. Due to the demographic background of the sample, race/ethnicity was collapsed to a binary covariate (white/other) as well as education level (college degree or more/less than a college degree), marital status (married/other), and gender (male/female). Age was treated as a continuous variable as well as weight and PAQ measured physical activity.

Finally, diet measured at 12 months was used as a covariate in all models to account for weight status associations with caloric intake. Dietary measures were collected using a self-reported Dietary History Questionnaire-II¹⁹ at baseline, 6-, 12-, 18-, and 24-month time points. This online questionnaire asks participants whether they consumed a list of 134 foods

and beverages over the past year, followed by average frequency and portion consumed in the past month to estimate caloric average intake. It has been validated using 24-hour dietary recalls ($r = .62-.66$).²⁰ The 12-month time point was most important as a covariate to correspond with dietary behaviors at the end of the active intervention, prior to the maintenance phase.

Analysis

Recently proposed statistical methods allow for the assessment of mediation and moderation simultaneously.²¹ This decomposition of mediating and moderating effects, proposed by VanderWeele,²¹ has thus far been used to examine the effects of genetic and physiologic exposures on health outcomes. However, this method also has the potential to offer a unique and innovative way to explore the effects of health behaviors that may act as both mediators and moderators of health outcomes.

A 4-way decomposition model to assess mediation and moderation, developed by VanderWeele²¹ was used to examine the proposed hypotheses. This decomposition method resulted in separate 4 components that make up the total effect of life events and high MVPA on weight. Figure 1A–1D illustrates these 4 components and the relationships they represent. The first component, the controlled direct effect (CDE), estimated the portion of the effect of life events on weight controlling for MVPA. This component is the independent effect of life events alone on weight. The second component, the reference interaction (INTref), estimated the effect of life events and high MVPA on weight due only to moderation. The third component, the mediated interaction (INTmed), estimated the portion of the effect of life events and high MVPA on weight that was both mediated and moderated. The fourth and final component, the mediated main effect or pure indirect effect (PIE), accounted for the portion of the effect of life events on weight that is due only to mediation through reported MVPA.²¹

Regression models, conditional on covariates were specified using PROC NLMIXED (version 9.4; SAS, Cary, NC). Code provided by VanderWeele²¹ was used to estimate the CDE, the PIE, and the INTmed and the INTref. Our main hypothesis of interest was the total effect of life events on 24-month weight, computed by combining all 4 components. This method utilized the binary exposure variable (1 life events vs 0 life events), the binary mediator (<2500 kcal vs ≥2500 kcal), and the continuous weight variable. All covariates were standardized to the mean and SD prior to regression modeling.

To test the first subhypothesis the percent of the effect due to interaction was computed. Using this method, only additive interactions were assessed. The percent of the total effect that is due to interaction between high MVPA and life events was found by summing the INTref and the INTmed over the TE.²¹

To test the second subhypothesis, the percent of the total effect that is due to mediation was computed. The percent of the total effect of life events on 24-month weight that is mediated through MVPA was found by summing of the PIE and the INTmed over the TE.²¹

Results

Summary statistics for participants reporting each category of life events (1 life events vs 0 life events) reported at 24 months as well as the baseline sample are provided in Table 2. Of the 339 individuals who were enrolled in the original study, 230 participants contributed complete data for this analysis. Pairwise comparisons examined differences between the baseline characteristics of participants with complete data at 24 months to the sample that was excluded from this analysis for incomplete data. Those who were included in this analysis were older (48.2 [9.5] y vs 43.1 [10.8] y; $P < .01$), weighed less at baseline (93.9 [15.6] kg vs 98.7 [13.5] kg; $P < .01$), and had a higher proportion of married (0.72 [0.45] vs 0.60 [0.49]; $P = .03$) participants than the excluded sample. No statistical differences in education level, race, gender, baseline physical activity, or condition were detected.

At 24 months, 52 participants reported having experienced no life events and 178 reported at least one life event in the past 12 months. Those who reported experiencing at least one life event during the maintenance phase had previously reported experiencing on average 2.9 (2.1) life events during the active weight loss phase, whereas those who reported no life events during the maintenance phase had reported experiencing on average 1.9 (1.6) life events during the weight loss intervention. Of those participants who reported experiencing no life events during the maintenance phase, most were white (96%) and married (77%). These percentages were smaller in the group that reported experiencing life events (87% white and 70% married). Finally, those reporting no life events reported substantially more MVPA at 12- and 24-month time points compared with those reporting 1 life events: 2604.9 (2433.7) kcal versus 2017.1 (1635.8) kcal at 12 months, 2459.1 (2260.6) kcal versus 1881.7 (1720.0) kcal at 18 months, and 2618.0 (2158.4) kcal versus 1972.2 (1624.0) kcal at 24 months (see Table 2).

Prior to decomposition, multivariable linear regression models that assessed physical activity and life events independently showed that both life events ($\beta = 1.42$ kg, SE = 0.68, $P = .04$) and MVPA level ($\beta = 1.32$ kg, SE = 0.63, $P = .04$) were independently associated with weight (Table 3). Models with both life events and MVPA treated continuously examined the association with weight out to 24 months and found that an increase in 1 minute of MVPA was statistically significantly associated with a 0.001 kg (SE = 0.0001; $P = .01$) decrease in 24-month weight, whereas life events were not statistically significantly associated. Interactions between life events and MVPA at both time points were not statistically significant in the linear models. Therefore, the interaction terms were excluded from subsequent models.

Results of the full decomposition analysis are found in Table 4. Using 24-month MVPA, the total effect of life events and MVPA on weight was 1.63 kg (95% confidence interval [CI] = 0.30 to 2.96; $P = .02$). The CDE of life events on weight was $\beta = 2.31$ kg (95% CI = 0.29 to 4.33). All other interaction and mediation decomposition estimates (ie, INTref, INTmed, PIE) were not statistically significant (Table 4).

The estimated proportion of the total effect attributed to the interaction (−66%; 95% CI = −199% to 57%) appeared to be larger than the proportion of the total effect attributed to

mediation (9%; 95% CI = -7% to 26%, respectively). However, these estimates were very small and not statistically significant (Table 4).

Discussion and Limitations

This exploration is innovative in the use of a novel statistical method to elucidate the relationship between life events, MVPA, and weight maintenance. The decomposition approach used here offers more information about the relationship between life events, MVPA, and weight than the traditional multivariable regression model reported in Table 3. Results of the decomposition support our main hypothesis that the total effect of life events and high MVPA at 24 months (during the maintenance period) was statistically significantly associated with weight. This is consistent with previous work examining the separate effects of life events²² and MVPA^{2,3} on weight maintenance. Results of the decomposition model highlight the importance of accounting for MVPA when considering the effect of life events on weight loss maintenance.

The subhypotheses assessing moderation and mediation were not supported as the 4 decomposed results were not statistically significant. Though not statistically significant, both interaction estimates (INTref and INTmed) point to a negative interaction or moderation, which is suggestive that those achieving a higher level of MVPA weigh less despite life events experienced. In addition, the CDE, the effect of life events in isolation on weight, controlling for any mediation or moderation by MVPA, was statistically significant and greater than the total effect. This suggests that mediation of the effect of life events on weight gain through MVPA is unlikely. This is somewhat inconsistent with previous work suggesting that major life events often lead to low physical activity.²³ However, to our knowledge, this is the first study that has explored the mediation effects of several different potential life events and MVPA on weight in a weight loss sample, suggesting that although MVPA is integral for weight loss maintenance,³ more work is needed to understand the role of life events on this relationship.

Overall, findings suggest that more understanding of how major life events may enable or disrupt behavior changes in weight loss interventions is needed. Although the 24-month follow-up allows exploration of behavior change over a relatively long period of time following an active weight loss intervention, future work should examine whether these relationships change depending on the nature of the life events. For example, although a positive life event such as a work promotion may result in positive feelings and a negative life event of facing unemployment may result in negative feelings, research has suggested that working longer hours are associated with weight gain.²⁴ Therefore, the effects of positive and negative life events on health behaviors, psychosocial factors, and weight should be further explored. Moreover, other factors that might mitigate the effects of life events on weight including social support, education level, and socioeconomic status should be examined. Successful weight loss maintenance is the outcome of a relatively complex set of maintained behaviors beyond MVPA that require further examination to be fully understood.²⁵ Similarly, life events impact many behaviors and factors that may influence weight. Therefore, this study may only offer narrow insights into the relationship between life events and 24-month weight. However, noting the relatively small number of participants

who experienced no life events, intervention components to help mitigate the effects of life events will be important for successful maintenance going forward.

There are several limitations that should be noted. First, the identification of the 4 component effects requires several assumptions regarding confounding. After covariate adjustment, this method assumes no other unmeasured confounding of the effects of life events on either 24-month weight or MVPA, as well as no unmeasured confounding of the effects of MVPA on 24-month weight. Finally, it is assumed that all recanting witness variables are included as covariates. That is, all confounders between MVPA and 24-month weight who are affected by life events have been measured and accounted for in the models. Each of these assumptions are described in more detail by VanderWeele²¹ and Vansteelandt²⁶ and Pearl.²⁷

Although multiple covariates were included in this analysis, the above assumptions are very strong and unmeasured confounding within this complex relationship of life events, MVPA, and weight likely remain. In addition, measuring only weight and height may ignore body composition changes that did not result in weight loss but may affect health, such as by increases in muscle mass and decreased fat mass. However, due to the focus of the curriculum on lowering caloric intake through dietary changes,¹⁰ we expect that individuals who had gained weight through muscle mass increase coupled with fat loss to be few and far between.

The potential for measurement error in the self-reporting of life events and MVPA is another limitation. It is plausible, that participants may incorrectly remember the time window of these life events. Furthermore, life events were reported concurrently with MVPA, which has the potential to introduce recall bias and impact the temporality assumptions of the statistical models as well. Examining life events in shorter intervals, and prior to measuring MVPA and weight in future work may help to address this issue.

Self-reporting MVPA may introduce additional measurement error. Previous work has suggested differential MVPA reporting dependent on weight status suggesting that individuals with higher weight may over report MVPA.²⁸ At baseline and 12 months, approximately half of the individuals in this sample were randomized to wear accelerometers for 7 days to assess the validity of this questionnaire. At 12 months, accelerometry measured MVPA was sufficiently correlated with the PAQ measure ($r = .56$; $P < .01$). However, future work using objective MVPA measurements will be important to improve this work. Furthermore, the PAQ only assessed MVPA, thus no conclusions can be made regarding the role of light intensity physical activity.

This analysis method required complete data for effect estimation and missing data from participants narrowed the available sample size considerably. To address this issue, imputation models were considered to increase precision. However, these resulted in similar, nonsignificant findings. Thus, only the complete data models were reported in this analysis. In addition, the total effect of life events and MVPA on weight maintenance, though statistically significant, was small. However, the large number of covariate parameters limited the statistical power to detect any small decomposed effects. In the case of the

moderated effects, in particular, the decomposed effects were less than 1 kg each, limiting the detectable signal that may have been overpowered by the number of covariates and the limited sample. Future analyses utilizing a larger, more diverse sample may improve statistical power and should be explored.

Finally, this sample had a large proportion of white, married, and college-educated adults who may have social and economic resources that offer protection from the detrimental effects of life events on weight during weight loss maintenance. When examining those who experienced no life events, the number of nonwhite and nonmarried individuals was even smaller. However, being married, having children, and increased job responsibilities entail their own sets of stressors. Therefore, assessing these relationships in a variety of situations is warranted. Specifically, future work should consider examining this relationship of life events, MVPA, and weight loss maintenance in ethnically and socioeconomically diverse populations who may be likely to experience major life events²⁹ more often.

Conclusions

This paper explored the effects of behavior changes on health outcomes within the context of one's personal environment. Findings suggest that the effects of life events and MVPA on weight loss maintenance should be considered separately when considering weight loss maintenance and designing interventions to prevent weight regain. More work is needed in larger, more diverse samples, with interventions that specifically target weight loss maintenance to fully understand these effects. Further work that explores relationships between life events, MVPA as well as mood and other behaviors affecting weight maintenance remains critical.

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Figure 1 —.

Graphical depictions of single components in decomposition. (A) Controlled direct effect of life events on weight. (B) Reference interactions effect of life events and MVPA on weight. (C) Mediated interaction effect of life events and MVPA on weight. (D) Pure indirect effect of life events on weight mediated through MVPA. MVPA indicates moderate to vigorous physical activity.

Table 1

Life Events Survey List

Event
Marriage
Detention in jail
Death of spouse
Major change to sleeping habits (much more or less sleep)
Death of a close family member:
Mother
Father
Brother
Sister
Grandmother
Grandfather
Other_____
Major change in eating habits (much more or much less food intake)
Foreclosure on mortgage or loan
Death of a close friend
Outstanding personal achievement
Minor law violations (traffic tickets, disturbing the peace, etc)
Men: wife/girlfriends pregnancy
Women: pregnancy
Changed work situation (different work responsibility, major change in working conditions, working hours, etc)
New job
Serious illness or injury of close family member:
Mother
Father
Brother
Sister
Grandmother
Grandfather
Other_____
Sexual difficulties
Trouble with employer (in danger of losing job, being suspended, demoted, etc)
Major change in financial status (a lot better off or a lot worse off)
Major change in closeness of family members (increased or decreased closeness)
Gaining a new family member (through birth, adoption, family member moving in, etc)
Change of residence
Marital separation of mate (due to conflict)
Major change in religious activities (increased or decreased attendance)

Weight, Change in PA, Caloric Intake, Previous Life Events, and Demographics for Levels of Life Events During the Maintenance Phase

Table 2

Characteristics	Baseline sample, n = 339	No life events (reported at 24 mo), n = 52	1 life events (reported at 24 mo), n = 178
Baseline weight, mean (SD), kg	95.5 (15.1)	94.6 (14.3)	93.8 (15.9)
12-mo weight	–	84.5 (14.9)	85.9 (14.9)
24-mo weight	–	87.4 (15.3)	89.5 (15.5)
Baseline PA, measured by PAQ, kcal	1309.9 (1250.9)	1268.2 (1147.0)	1305.4 (1191.8)
12-mo PA	–	2604.9 (2433.7)	2017.1 (1635.8)
24-mo PA	–	2618.0 (2158.4)	1972.2 (1624.0)
Life events, number reported during active weight loss (measured at 12 mo), mean (SD)	–	1.9 (1.6)	2.9 (2.1)
Age, mean years (SD)	46.5 (10.2)	48.5 (9.7)	48.0 (9.5)
Women, n (%)	220 (65)	35 (67)	117 (66)
White, n (%)	293 (86)	50 (96)	155 (87)
College graduate, n (%)	216 (64)	31 (60)	121 (68)
Married, n (%)	230 (68)	40 (77)	125 (70)
Weighting assignment			
No weighing, n	116	19	58
Weekly weighing, n	109	15	63
Daily weighing, n	114	18	57

Abbreviations: PA, physical activity; PAQ, Paffenbarger Physical Activity Questionnaire.

Table 3
Linear Regression Model of Life Events and MVPA on 24-Month Weight (in kilograms)

	β (SE)	P
Adjusted effects at 24-mo PA ^a		
Life events (1 vs 0)	1.42 (0.68)	.04
PA (<2500 kcal vs 2500 kcal)	1.32 (0.63)	.04

Abbreviations: PA, physical activity; MVPA, moderate to vigorous physical activity.

^a Adjustment variables include age, gender, race, education level, marital status, baseline and 12-month weight, baseline PA, 12-month calorie intake, life-event frequency during active weight loss, and randomization arm.

Table 4

Decomposition Model of Life Events and MVPA on 24-Month Weight (in kilograms)

	β (95% CI)	<i>P</i>
Adjusted effects of life events with 24-mo ^a PA		
Total effect	1.63 (0.30 to 2.96)	.02
CDE	2.31 (0.29 to 4.33)	.03
INTref	−0.84 (−2.31 to 0.64)	.26
INTmed	−0.24 (−0.72 to 0.25)	.34
PIE	0.39 (−0.17 to 0.95)	.17
Percent mediation	9% (−7% to 26%)	.28
Percent interaction	−66% (−199% to 57%)	.31

Abbreviations: CDE, controlled direct effect; CI, confidence interval; INTmed, mediated interaction; INTref, reference interaction; MVPA, moderate to vigorous physical activity; PIE, pure indirect effect.

^aAdjustment variables include age, gender, race, education level, marital status, baseline and 12-month weight, baseline physical activity, 12-month calorie intake, life-event frequency during active weight loss, and randomization arm.