

4-2012

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Publication Info

Published in *Prevention Science*, Volume 13, Issue 2, 2012, pages 183-195.

Héroux, M., Janssen, I., Lee, D-C., Sui, X., Hébert, J.R., Blair, S.N. (2012). Clustering of unhealthy behaviors in the aerobics center longitudinal study. *Prevention Science*, 13(2), 183-195. DOI: 10.1007/s11121-011-0255-0

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Clustering of Unhealthy Behaviors in the Aerobics Center Longitudinal Study

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Published online: 18 October 2011

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Abstract

Background Clustering of unhealthy behaviors has been reported in previous studies; however the link with all-cause mortality and differences between those with and without chronic disease requires further investigation.

Objectives To observe the clustering effects of unhealthy diet, fitness, smoking, and excessive alcohol consumption in adults with and without chronic disease and to assess all-cause mortality risk according to the clustering of unhealthy behaviors.

Methods Participants were 13,621 adults (aged 20–84) from the Aerobics Center Longitudinal Study. Four health behaviors were observed (diet, fitness, smoking, and drinking). Baseline characteristics of the study population and bivariate relations between pairs of the health behaviors were evaluated separately for those with and without chronic disease using cross-tabulation and a chi-square test. The odds of partaking in unhealthy behaviors were also calculated. Latent class analysis (LCA) was used to assess clustering. Cox regression was used to assess the relationship between the behaviors and mortality.

Results The four health behaviors were related to each other. LCA results suggested that two classes existed. Participants in class 1 had a higher probability of partaking in each of the four unhealthy behaviors than participants in class 2. No differences in health behavior clustering were found between participants with and without chronic disease. Mortality risk increased relative to the number of unhealthy behaviors participants engaged in.

Conclusion Unhealthy behaviors cluster together irrespective of chronic disease status. Such findings suggest that multi-behavioral intervention strategies can be similar in those with and without chronic disease.

Keywords Health behaviors · Clustering · Chronic disease · All-cause mortality

Introduction

There is much uncertainty and debate about the proportion of mortality in the United States and other developed countries attributable to tobacco smoking, poor diet, physical inactivity, and excessive alcohol consumption; however, there is agreement that these four unhealthy behaviors account for the vast majority of preventable causes of death (Adler and Rehkopf 2008; Lopez et al. 2006; Mathers and Loncar 2006; World Health Organization 2009). There also is evidence that these four unhealthy behaviors often occur simultaneously within an individual (Chioloro et al. 2006; Fine et al. 2004; Kvaavik et al. 2010; Laaksonen et al. 2001; Poortinga 2007; Schuit et al. 2002). For example, a recent study reported that over 70% of adults with one of these four unhealthy behaviors engaged in at least one of the remaining three (Poortinga 2007). Despite this evidence, the majority of public health and

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clinical interventions focus only on changing a single unhealthy behavior. A more efficient approach may be to focus on interventions that target the several unhealthy behaviors simultaneously. Indeed, based on previous research examining the clustering of several health behaviors, the National Cancer Institute-funded Behavior Change Consortium was predicated on focusing on two or more health-related behaviors (Hebert et al. 2008). Identifying which unhealthy behaviors typically occur simultaneously within the same individual can help inform these types of interventions.

Several studies have examined which unhealthy behaviors are most likely to occur simultaneously or cluster within individuals (Berrigan et al. 2003; Blakely et al. 2004; Chiolero et al. 2006; Donovan et al. 1993; Fine et al. 2004; Ingledew et al. 1995; Laaksonen et al. 2001; Laaksonen et al. 2002; Laska et al. 2009; Metzger et al. 2008; Pate et al. 1996; Poortinga 2007; Schuit et al. 2002). These studies have used a variety of statistical techniques to assess clustering, and this makes it difficult to compare their findings. Although the results are somewhat varied, the strongest associations between unhealthy behaviors appear to be between smoking and the three remaining behaviors (inactivity, diet, alcohol) (Laaksonen et al. 2002; Poortinga 2007). Also, there is evidence suggesting that although the prevalence of unhealthy behaviors varies with gender, race, and age the clustering of these behaviors is similar irrespective of these demographic characteristics (Berrigan et al. 2003; Laaksonen et al. 2001; Poortinga 2007). For example in a study done by Berrigan et al. (2003), non-Hispanic white, non-Hispanic black, and Mexican American participants displayed similar patterns of clustering among unhealthy behaviors (Berrigan et al. 2003). Health behaviors may improve after diagnosis of a chronic disease (Patterson et al. 2003; Pinto et al. 2000; Wallstrom et al. 2005); however, studies have yet to examine the influence of chronic disease status within the context of unhealthy behavior clustering.

To date, most of the studies that have examined the clustering of unhealthy behaviors have used crude and imprecise methods of measuring these health behaviors, particularly diet (Byun et al. 2010; Mitchell et al. 2010) and physical activity (Blair et al. 1985). For the most part, only one or two dietary variables have been obtained through simple questionnaires (e.g., in the Behavior Change Consortium frequency of fruit and vegetable intake) were used as a marker of dietary intake (Hebert et al. 2008; Yaroch et al. 2008). Similarly, self-reported measures from questionnaires were used to assess physical activity (Blakely et al. 2004; Chiolero et al. 2006; Poortinga 2007; Schuit et al. 2002). Examining dietary patterns obtained through comprehensive diet records and using objective measures of physical activity may yield more accurate measures of these behaviors for cluster analysis (Aadahl et al. 2007; Day et al. 2001; Tokudome et al. 2005).

This study aimed to address some of the gaps and limitations in the previous literature examining the clustering of unhealthy behaviors. Our objectives were to: (1) observe the clustering effects of unhealthy diet, physical inactivity, smoking, and excessive alcohol consumption within adults; (2) use a comprehensive dietary assessment and cardiorespiratory fitness exam to assess how a poor diet and physical inactivity relate to each other and other unhealthy behaviors; (3) determine whether the clustering of unhealthy behaviors differs in those with and without chronic disease; and (4) assess all-cause mortality risk according to the individual unhealthy behaviors and a clustering of unhealthy behaviors.

Methods

Participants

The study sample consisted of a subset of 13,621 participants from the Aerobics Center Longitudinal Study (ACLS) who had 3-day diet record data available between 1987 and 1999. The ACLS is a prospective, observational study of men and women who participated in a preventive medical examination at the Cooper Clinic in Dallas, TX, USA. ACLS participants are predominantly (>95%) non-Hispanic white, well-educated (>75% college graduates), and employed in professional or executive occupations (Blair et al. 1989a; Wei et al. 1999). Individuals in the analyses reported here were similar to the overall ACLS cohort.

The standardized data collection procedures employed in the ACLS are described in detail in previous reports (Blair et al. 1989b; Lee et al. 1999). Briefly, data collection for all of the variables included in this study, with the exception of the all-cause mortality outcome, occurred at baseline. These data included a medical history questionnaire, a thorough physical examination, fasting blood chemistry analyses, symptom-limited maximal exercise test for the measurement of fitness, and a dietary assessment. The medical history questionnaire was self-administered and included information regarding demographics, family history and personal health habits. Physical examination procedures were conducted in a standardized manner by trained personnel following a manual of procedures. All participants gave written informed consent. The study was reviewed and approved annually by the Institutional Review Board at the Cooper Institute (Blair et al. 1989b, 1996; Finley et al. 2006).

Health Behaviors

While we recognize that the four health behaviors examined fall along a continuum, for the purpose of this present study

they were all classified as dichotomous variables (healthy vs. unhealthy behavior) in order to simplify the presentation of the results, and to assist in translating the findings into meaningful public health messages (Rothman 2002).

Unhealthy Diet

The dietary assessment consisted of a 3-day diet record that required respondents to keep detailed records of everything they ate over 2 pre-assigned weekdays and 1 weekend day. Participants were provided with written instructions on how to accurately describe foods and estimate portion sizes. Participants kept an ongoing, real-time written record of foods consumed during and between meals, including assessing portion sizes using common household measures. Registered dietitians at the Cooper Clinic coded and analyzed the diet records using the Cooper Clinic Nutrition and Exercise Evaluation system (Finley et al. 2006). This provided detailed dietary information on the overall diet such as the number of foods consumed from specific food groups, total caloric content, the volume of micronutrients (vitamins and minerals) and the volume and caloric content of macronutrients (fat, protein, carbohydrate and alcohol).

In a previous study we developed an Unhealthy Eating Index in the ACLS cohort based on the 3-day diet records (Héroux et al. 2010). The Unhealthy Eating Index was generated using reduced rank regression, and is characterized by a dietary pattern containing foods that predict clinical risk factors for chronic disease (HDL-cholesterol, total cholesterol, blood pressure, triglycerides, white blood cell count, uric acid, body mass index, and fasting glucose). Participants with high scores on the Unhealthy Eating Index were those who had diets high in added fats, non-whole grains, processed meat, red meat, white potato products, and low in non-citrus fruits. For this report, the Unhealthy Eating Index was used as a composite measure of the dietary behavior of the participants. Based on previous analyses examining the relationship between the Unhealthy Eating Index and mortality risk (Héroux et al. 2010), Unhealthy Eating Index scores were first divided into quintiles and were then grouped into two categories: “unhealthy diet” (quintile 5) and “healthy diet” (quintiles 1–4). Groups were divided in this fashion as there was little difference in risk between the 1st and 4th quintiles but a significant difference in risk between the 4th and 5th quintiles (Héroux et al. 2010).

Physically Inactive and Unfit

Physical activity was measured through a self-report questionnaire, which assessed physical activity patterns over the previous 3 months. If the participant reported partaking in an activity, (s)he was asked to provide additional information about the frequency and distance or time spent in the activity.

This information was used to divide participants into three mutually exclusive categories: (i) “physically inactive” (no activity); (ii) moderately active (sporting or leisure-time physical activity other than walking or jogging; or walk or jog up to 16 km/week); and (iii) highly active (walk or jog >16 km/week) (Kampert et al. 1996). For the purposes of this study, those in the moderately and highly active groups were combined into a single “physically active” group.

Cardiorespiratory fitness (hereafter referred to as ‘fitness’) was used as an additional marker of physical activity in this study. In fact, because of the measurement errors (e.g., recall and social desirability bias) associated with self-reported physical activity measures (Adams et al. 2005; Sallis and Saelens 2000), the primary analyses were based on measures of fitness rather than physical activity. Although fitness has a genetic component (Bouchard et al. 1997), to a large extent, it is a reflection of an individual’s physical activity habits over recent months and weeks (Aadahl et al. 2007; Finley et al. 2006). Fitness was assessed by a symptom-limited maximal exercise treadmill test using a modified Balke protocol (Balke and Ware 1959). Participants began walking on the treadmill with no elevation at 5.3 km/h. At the end of the first minute the elevation was increased to 2%. Thereafter, the elevation was increased 1% per minute until the 25th minute. For the few participants who were able to continue for >25 min, elevation remained constant and speed was increased each minute by 0.32 km/h. Participants continued the test to the limits of volitional fatigue. Time to completion on the treadmill was used to estimate $\dot{V}O_{2\max}$ in metabolic equivalents (METs) (one MET = $3.5 \text{ ml O}_2 \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) from the Balke protocol using the following formula: $\dot{V}O_{2\max} = [1.44 \times (\text{minutes on treadmill}) + 14.99] / 3.5$ (Katzmarzyk et al. 2005; Pollock et al. 1976). Participants were classified as ‘unfit’ or ‘fit’ based on the lowest 20% and upper 80%, respectively, of the age- and sex-specific distribution of METs in the overall ACLS population. These cut-points are from previous reports on the relation between fitness and all-cause mortality in the ACLS, which indicate that there is little difference in risk across the 2nd through 5th fitness quintiles, but a big difference in risk between the 1st and 2nd fitness quintiles (Blair et al. 1996). Thus, in addition to those who were in the top 20% (quintile 5), participants who scored in the middle 60% (quintiles 2 to 4) were classified as fit. Because there is no widely accepted categorization of fitness, and because we wanted to maintain consistency in our methods with other ACLS studies, we continue to use this approach.

Smoking

The medical history questionnaire asked participants if they currently smoked cigarettes. If they responded yes to this question they were categorized as current smokers. All others were categorized as non-smokers.

Heavy Drinking

Alcohol intake was captured in the medical history questionnaire. Participants were asked how many drinks per week they consumed of beer, wine, and/or hard liquor. One unit of alcohol was defined as 12 oz (3.41 dl) of beer, 5 oz (1.42 dl) of wine, or 1.5 oz (0.43 dl) of liquor. Participants were divided into two categories based on the sex-specific weekly upper limits as recommended by the National Institute on Alcohol Abuse and Alcoholism (National Institute on Alcohol Abuse and Alcoholism 1995). “Heavy drinkers” were those women who consumed ≥ 8 drinks and those men who consumed ≥ 15 drinks within the past week. All other participants were considered “non/light drinkers”. Of the heavy drinkers in the present study, males drank an average of 23 drinks per week and females drank an average of 15 drinks per week. There were no differences in the descriptive characteristics or mortality risk estimates in the non-drinkers and light drinkers in the current study (data not shown).

Chronic Disease Status

Participants were divided into two groups: (1) those with no history of chronic diseases, and (2) those who reported having one or more of the following conditions: diabetes, cardiovascular disease (stroke or myocardial infarction), hypertension, and cancer. These chronic diseases were chosen because it is well established that diagnosis of one or more of these diseases can result in changes in lifestyle behaviors including the four health behaviors examined in this study (Neutel and Campbell 2008; World Health Organization 2005). Disease status was obtained at baseline through a standardized questionnaire that inquired specifically about past and current diabetes, stroke, myocardial infarction, hypertension, and cancer.

Mortality Follow-Up

After their baseline exam, participants were followed until they died, or until December 31, 2003, whichever came first. Possible decedents were identified from the National Death Index and verified with official death certificates from their home states. The National Death Index has a sensitivity of 96% and specificity of 100% in cohort studies (Centers for Disease Control and Prevention 2003).

Statistical Analyses

All analyses were performed using SAS version 9.1 (Release 9.1 Cary, NC: SAS Institute Inc.). Baseline characteristics of

the study population and bivariate relations between pairs of the health behaviors were evaluated separately for those with and without chronic disease using cross-tabulation and a chi-square test. The odds of partaking in unhealthy behaviors were also calculated.

Traditional cluster and factor analyses were designed for continuous variables. Because the four unhealthy behaviors considered here are dichotomous variables, latent class analysis (LCA) was used to assess clustering as LCA is suitable for dichotomous variables (Lanza et al. 2007; Vermunt and Magidson 2002, 2005). LCA is a statistical method for finding subtypes of related cases (latent classes) from multivariate categorical data. LCA is used in a manner analogous to cluster and factor analysis (Vermunt and Magidson 2002, 2005). That is, given a sample of participants measured on several variables, one can determine if there are a small number of groups into which the participants fall (Laska et al. 2009; Vermunt and Magidson 2002, 2005). The PROC LCA command procedure was used to estimate model parameters (Lanza et al. 2007). A simple two-class model consisting of only the four health behaviors was first assessed. In order to select the appropriate number of classes and maximize model fit, the two-class model was compared with successively fit models which specified an increasing number of latent classes (up to three classes as the 4-class model would not converge). In selecting the final model (e.g., 2- or 3-class model) the BIC and AIC criteria were examined across models as well as model interpretability (Lanza et al. 2007). Based on these criteria, a 2-class model was selected. Once this model was selected, the grouping option was used within the LCA analysis to determine whether or not the probability of class membership differed in those with no history of chronic disease and those with current/former chronic disease. By comparing the G^2 difference of the basic model and the grouped model to a chi-square distribution with the degrees of freedom equal to the difference in degrees of freedom between the models, the analysis indicated that measurement invariance should not be rejected ($p > 0.05$) and therefore that class membership was not significantly different for the two groups. A 2-class LCA model was then run including the covariates option to control for age and gender. Age and gender were not stratified in the model as exploratory analyses suggested that class membership was similar in all age groups and in men and women (data not shown). The Outpram option was also used to output the probability of class membership for each participant. Participants were then divided into class 1 or 2 based on their highest probability score (Goodman 2007).

Cox proportional hazard regression analyses were used to predict the hazard ratio (HR) of mortality over the follow-up period according to engagement in unhealthy

behaviors. Age, gender, year of examination, and health status were included as covariates in the regression models. Based on the proportion of the cohort engaged in each unhealthy behavior, and the HR of mortality associated with each unhealthy behavior, the population attributable risk percentage was calculated for each health behavior using the following formula: PAR% (Cole and MacMahon 1971; Walter 1978)=[P_e (HR-1)]/[P_e (HR-1)+1]*100 where P_e is the prevalence of the health behavior within the population, and HR is the relative risk of all-cause mortality for that unhealthy behavior (using model 2). The population attributable risk is a calculation of the percentage of all-cause mortality (that would occur in a population with similar attributes to the cohort) attributable to each of the unhealthy behaviors.

Results

Participant Characteristics

Baseline characteristics of participants are presented in Table 1. Of the total sample, 4,630 (34%) had at least one of the chronic diseases. The majority (65.6%) of participants were between the ages of 40–59 years and 52.6% were overweight or obese. Approximately 8.9% of the cohort were unfit, 10.9% were smokers, and 3.1% were heavy drinkers. Over half (66.8%) of the cohort engaged in none of the four unhealthy behaviors. The prevalence and distribution of the four unhealthy behaviors was not different in those with and without chronic disease (Table 1).

Relationship Between Health Behaviors

Table 2 shows the relationship between the health behaviors according to chronic disease status. The patterns of relationships between health behaviors were similar for the groups with and without chronic disease. Independent of chronic disease status, all four health behaviors were significantly (*p*<0.05) related to each other, with the exception of fitness vs. alcohol, and within those with chronic disease, diet vs. alcohol. Within the participants with no history of chronic disease, those with an unhealthy diet were 2.45 (95% confidence interval: 2.10–2.98) times more likely to be unfit, 2.02 (1.74–2.35) times more likely to be a smoker, and 1.61 (1.21–2.15) times more likely to be a heavy drinker by comparison to those with a healthy diet. The strongest relationships were observed between the smoking and alcohol intake behaviors; smokers were 2.69 (2.00–3.62) times more likely to be heavy drinkers in comparison to non-smokers. Gender differences (*p*<0.05) were present for all behaviors, with the exception of

Table 1 Aerobics Center Longitudinal Study participant baseline characteristics

	No history of chronic disease N=8,991	Current or former chronic disease N=4,630
Age		
20–39 y	24.6%	12.9%
40–59 y	65.6%	67.3%
≥60 y	9.8%	19.8%
Females	28.1%	17.1%
Body Mass Index (kg/m ²)		
Normal weight (<25)	54.2%	34.2%
Overweight (25–30)	37.3%	44.2%
Obese (≥30)	8.5%	21.6%
Diet		
Healthy diet	81.3%	77.4%
Unhealthy diet	18.7%	22.6%
Fitness		
Fit	93.7%	85.8%
Unfit	6.3%	14.2%
Physical Activity		
Physically active	75.3%	71.8%
Inactive	24.7%	28.2%
Smoking Status		
Non-smokers	89.1%	89.2%
Smokers	10.9%	10.8%
Alcohol Intake		
Non/light drinkers	97.0%	96.8%
Heavy drinkers	3.0%	3.2%
# Unhealthy Behaviors		
0	69.2%	62.2%
1	24.1%	27.0%
2	5.7%	9.0%
3	1.0%	1.7%
4	0.1%	0.1%

cardiorespiratory fitness in men and women without chronic disease. For this reason, all further analyses were controlled for gender.

Results from the LCA analysis, which was controlled for age and gender, suggested that two classes were present (Table 3). Because class membership did not differ between those with and without chronic disease, the two groups were merged and results are presented for the whole cohort. The latent class probabilities suggested that 38% of the cohort were in class 1 and 62% were in class 2 (log likelihood of model=-16338). Class 1 membership was characterized by a higher probability of partaking in each of the four unhealthy behaviors, particularly for unhealthy diets (51.2% vs. 1.2%). The number of unhealthy behaviors each participant engaged in was calculated according to

Table 2 Relationship between health behaviors

	Prevalence or Odds Ratio (95% CI) ^a for Engagement in Unhealthy Behavior			
	Unhealthy Diet	Unfit	Smokers	Heavy Drinkers
Participants with no history of chronic disease				
Diet				
Healthy diet,%	–	5.2%	8.9%	2.3%
Unhealthy diet,%		11.3%	19.4%	4.5%
Odds ratio (95% CI)		2.45 (2.10–2.98)	2.02 (1.74–2.35)	1.61 (1.21–2.15)
Fitness				
Fit,%	17.7%	–	10.1%	2.6%
Unfit,%	33.4%		22.4%	3.3%
Odds ratio (95% CI)	2.47 (2.03–3.00)		2.53 (2.05–3.13)	1.22 (0.76–1.97)
Smoking				
Non-smokers,%	16.9%	5.5%	–	2.2%
Smokers,%	33.2%	13.0%		6.54
Odds ratio (95% CI)	1.99 (1.71–2.32)	2.53 (2.04–3.13)		2.69 (2.00–3.62)
Alcohol Intake				
Non/Light drinkers,%	18.3%	6.3%	10.5%	–
Heavy drinkers,%	31.4%	7.8%	26.4%	
Odds ratio (95% CI)	1.62 (1.22–2.17)	1.23 (0.76–1.98)	2.72 (2.02–3.66)	
Participants with chronic disease				
Diet				
Healthy diet,%	–	10.8%	8.9%	2.3%
Unhealthy diet,%		25.8%	17.3%	4.3%
Odds ratio (95% CI)		2.50 (2.07–3.00)	1.66 (1.36–2.05)	1.26 (0.86–1.84)
Fitness				
Fit,%	19.5%	–	9.6%	2.7%
Unfit,%	41.2%		17.8%	3.0%
Odds ratio (95% CI)	2.50 (2.07–3.00)		1.79 (1.42–2.25)	0.90 (0.55–1.46)
Smoking				
Non-smokers,%	20.9%	13.0%	–	2.3%
Smokers,%	36.2%	23.4%		6.8%
Odds ratio (95% CI)	1.65 (1.34–2.03)	1.78 (1.41–2.24)		2.45 (1.63–3.69)
Alcohol Intake				
Non/light drinkers,%	22.2%	14.1%	10.3%	–
Heavy drinkers,%	34.9%	15.5%	26.4%	
Odds ratio (95% CI)	1.32 (0.90–1.94)	0.91 (0.55–1.48)	2.46 (1.63–3.71)	

All relationships were significant ($p \leq 0.05$) with the exception of alcohol intake vs. fitness in those with and without chronic disease and diet vs. alcohol intake in those with chronic disease

^aOdds ratio (95% confidence interval) for engagement in the corresponding unhealthy behavior. The healthy behavior was used as the referent category. Odds ratios were controlled for age and gender.

class membership (Table 3). A much higher percentage of participants in class 1 engaged in two or more unhealthy behaviors by comparison to participants in class 2 (27.1% vs. 0.2%).

Relationship Between Health Behaviors and Mortality

During the follow-up period, 445 deaths occurred over the 597,009 person-years of observation. Table 4 shows the risks for all-cause mortality according to engagement in the unhealthy behaviors. The risk estimates for model 1 were controlled for age, gender, year of examination, and history of chronic diseases. The risk estimates for model 2 were

controlled for each of the remaining three health behaviors in addition to the aforementioned covariates. After controlling for the other health behaviors, unfit individuals had a 2.16 (95% confidence interval: 1.64–2.85) times higher risk of mortality than fit individuals and smokers had a 1.35 (1.01–1.81) times higher risk of mortality than non-smokers. The risk estimates for mortality were not significantly different between those with a healthy diet and those with an unhealthy diet ($p=0.32$) and between non/light drinkers and heavy drinkers ($p=0.52$). The population attributable risk calculations, which were a function of the prevalence of the unhealthy behaviors and their independent associations with mortality, suggested

Table 3 Results of the latent class analysis used to identify classes of participants based on health behaviors, after controlling for age and gender

Unhealthy Behavior	Class 1 (N=3,950)	Class 2 (N=9,671)
Diet		
Healthy diet	48.8%	98.8%
Unhealthy diet	51.2%	1.2%
Fitness		
Fit	84.6%	94.9%
Unfit	15.4%	5.1%
Smoking		
Non-smokers	79.4%	95.0%
Smokers	20.6%	5.0%
Alcohol Intake		
Non/light drinkers	93.8%	98.9%
Heavy drinkers	6.2%	1.2%
# Unhealthy Behaviors ^a		
0	5.9%	91.7%
1	66.7%	8.1%
2	23.0%	0.2%
3	4.1%	0.0%
4	0.2%	0.0%

Values represent the probability of class membership

^a Including an unhealthy diet, low fitness, smoking, and heavy drinking

that 9.4% of the deaths in the cohort resulted from having low fitness, 2.9% of the deaths resulted from an unhealthy diet, 3.7% from smoking, and 0.6% from heavy drinking. Collectively, these four unhealthy behaviors accounted for 16.6% of the deaths in the cohort.

The number of unhealthy behaviors in which individuals partook and health behavior clustering were significant predictors of all-cause mortality (Table 4). Compared to those who partook in no unhealthy behaviors, mortality risk was increased by 1.46 (1.20–1.83) times in those who partook in one unhealthy behavior, by 2.37 (1.69–3.34) times in those who partook in 2 unhealthy behaviors, and by 1.98 (0.81–4.82) times in those who partook in 3 or 4 unhealthy behaviors. There was a small sample size ($N=171$) in the group with three or four unhealthy behaviors, which may explain the lack of statistical significance ($p=0.14$) for all-cause mortality risk in that group. Finally, by comparison to participants in class 2, participants in class 1 had a hazard ratio of mortality of 1.55 (1.22–1.97).

Findings for Physical Inactivity

All of the analyses shown in Tables 2 to 4 were repeated using self-reported physical activity in place of fitness. The results for physical activity, which are provided

in Tables 1 to 3 in the online-only Appendix, were very similar to those reported for fitness in Tables 2 to 4. The major difference in the results presented for physical activity in the online-only appendix versus those presented for fitness were for the hazard ratio for mortality and population attributable risk calculations, which were attenuated for the self-reported physical activity measure by comparison to the objective measure of fitness. Specifically, the hazard ratio for all-cause mortality was 1.20 (0.97–1.50) in the physically inactive participants relative to the physically active participants (Appendix Table 7), and the corresponding population attributable risk calculation for physical inactivity was 4.9% (Appendix Table 7). By comparison, the hazard ratio and population attributable risk estimates for low fitness were 2.16 (1.64–2.85) and 9.4%, respectively (Table 4).

Discussion

The present study sought to examine the clustering of four unhealthy lifestyle behaviors (unhealthy diet, inactivity/fitness, smoking, and heavy drinking). All four behaviors were related to each other with the exception of fitness and alcohol. The strongest relationship was observed between smoking and alcohol consumption. Interestingly, no differences in health behavior clustering were found between participants with and without chronic disease. As expected, mortality risk increased relative to the number of unhealthy behaviors participants engaged in.

It is difficult to make direct comparisons between the behavioral relationships found in this and other studies as various measurement and analytical approaches have been used. For example, previous studies have included different population groups, used different statistical techniques (e.g., correlation, factor analysis, cluster analysis), and used different tools to measure the health behaviors. What is noteworthy is that, irrespective of these differences, the majority of these studies have concluded that health behaviors conform to a multidimensional model of health behavior patterns (Berrigan et al. 2003; Williams and Wechsler 1972). In fact, several studies have found that the clustering of behaviors is fairly constant across various age and ethnic groups as well as in males and females (Berrigan et al. 2003; Laaksonen et al. 2001; Poortinga 2007). Similar to what was found here, the lack of association between fitness and alcohol has been reported in other studies (Ingledeew et al. 1995; Laaksonen et al. 2002; Schuit et al. 2002) as has the strong relationship between drinking and smoking (Laaksonen et al. 2002; Poortinga 2007).

The current study was unique in that it assessed whether or not differences in health behavior clustering patterns

Table 4 All-cause mortality risk according to engagement in different unhealthy behaviors

	Unhealthy Behaviors	HR (95% CI) Model 1	HR (95% CI) Model 2	Population Attributable Risk (PAR)
	Diet			
	Healthy diet	1.0	1.0	2.9%
	Unhealthy diet	1.29 (1.00–1.68)	1.15 (0.89–1.50)	
	Fitness			
	Fit	1.0	1.0	9.4%
	Unfit	2.28 (1.74–3.00)	2.16 (1.64–2.85)	
	Smoking			
	Non-smokers	1.0	1.0	3.7%
	Smokers	1.50 (1.12–2.01)	1.35 (1.01–1.81)	
	Alcohol Intake			
	Non/light drinkers	1.00	1.0	0.6%
	Heavy drinkers	1.24 (0.68–2.26)	1.22 (0.67–2.23)	
	# Unhealthy Behaviors			
	0	1.0	–	–
	1	1.46 (1.20–1.83)	–	–
	2	2.37 (1.69–3.34)	–	–
	3 to 4	1.98 (0.81–4.82)	–	–
	Class 1	1.55 (1.22–1.97)	–	–
	Class 2	1.0	–	–

HR (95% CI)=hazard ratio (95% confidence interval)

Model 1: controlled for age, gender, year of examination, history of chronic disease.

Model 2: controlled for age, gender, year of examination, history of chronic disease, and the remaining 3 health behaviors

$PAR\% = [P_e (HR-1)] / [P_e (HR-1) + 1] * 100$ where P_e is the prevalence of the health behavior within the population, and HR is the relative risk of all-cause mortality for that unhealthy behavior (using model 2)

existed between those with and without chronic disease. Although previous studies report that the lifestyle behaviors often improve after a chronic disease diagnosis (Patterson et al. 2003; Pinto et al. 2000; Wallstrom et al. 2005), with the exception of fitness, the proportion of those with the unhealthy behavior was similar in the groups with and without chronic disease. Furthermore, the clustering of unhealthy behaviors did not vary according to chronic disease status.

Previous studies examining the relation between the number of unhealthy behaviors and all-cause mortality have consistently reported increasing risks with increasing number of unhealthy behaviors (Byun et al. 2010; Mitchell et al. 2010; Tsubono et al. 2004). For example, in a study done by Tsubono et al. (2004), the relative risks of all-cause mortality when comparing men who partook in 1, 2, 3, or 4 versus 0 unhealthy behaviors were 1.20 (95% confidence interval: 0.83–1.74), 1.66 (1.17–2.35), 1.94 (1.36–2.78), and 3.96 (2.26–6.95), respectively (Tsubono et al. 2004). Similarly, in the present study mortality risk was increased by ~50% in the presence of a single unhealthy behavior and by ~100% in the presence of 2 or more unhealthy behaviors.

Similar to other studies examining the impact of lifestyle factors on mortality (Laaksonen et al. 2001; Laaksonen et al. 2002; Schuit et al. 2002), the pattern of findings in our paper suggest that all-cause mortality risk increases with the number of unhealthy behaviors that a person partakes in. Furthermore, in this cohort 16.6% of deaths were attributed to partaking in the 4 unhealthy behaviors. A study by Chiuvé et al. (2006) reported that by leading a healthy

lifestyle characterized by not smoking, exercising regularly, eating a healthy diet, consuming moderate alcohol, and maintaining a healthy weight, participants had the potential of avoiding 62% of cardiovascular events (Chiuvé et al. 2006). When compared to the present study, the higher attributable risk reported most likely results from the differences in health behaviors assessed, the different outcomes assessed (i.e., cardiovascular events vs. all-cause mortality), and the higher prevalence of the unhealthy behaviors within the study population (i.e., 71% low exercise, 60% poor diet).

The findings of this study are important for several reasons. Firstly, the results support the notion that interventions may be more efficient if they focus on multiple unhealthy behaviors rather than a single behavior. For example, 73.6% of the heavy drinkers in the ACLS were also smokers, suggesting that there is a strong tendency for heavy drinkers to smoke. Thus, interventions aimed at decreasing heavy drinking may benefit from a component aimed at decreasing smoking. Secondly, our results suggest that those with and without chronic disease could benefit from the same interventions. Combining interventions for those with and without chronic disease would be economical, while also bridging the stigmatization gap that often occurs in those with chronic disease (Joachim and Acorn 2000). Thirdly, these findings can be used to influence general prevention policies by demonstrating the need to address multiple health behaviors in political efforts aimed at the general population. Finally, the results add further support to existing literature stressing the importance of living a healthy lifestyle.

As with any study, this one has several strengths and weaknesses that need to be mentioned. The major strengths include the use of 3-day dietary records, laboratory-determined fitness, and the large number of participants who were followed over several years. In terms of limitations, it must be noted that this study used self-reported dietary data which are prone to a variety of measurement errors. One such bias that has become well established is a response set reflecting a tendency to present a diet that adheres more closely to social norms and public health recommendations (Hebert et al. 1995, 1997, 2008). Furthermore, the ACLS participants who completed 3-day diet records did so voluntarily with the knowledge that they would be reviewing their diet records with a dietician. Therefore, additional selection and reporting biases may have been introduced. Additionally, 3 days of dietary intake may not be an accurate representation of habitual intake. Despite the limitations of the methods used to assess dietary intake, 3-day diet records have been shown to be a more accurate representation of actual food intake than food frequency questionnaires (Day et al. 2001; Tokudome et al. 2005), which have been routinely used in similar studies (Laaksonen et al. 2002; Poortinga 2007; Schuit et al. 2002). It also must be noted that both alcohol consumption and smoking status were self-reported. Although alcohol consumption may appear to be difficult to recall accurately, there is good evidence that intake of alcoholic beverages among non-problem drinkers is reported accurately (Hebert et al. 1997b). In addition, because only four health behaviors were included in the LCA analyses, it is unlikely that more than two classes would emerge. Furthermore, the common practice of dichotomizing health behavior variables, and concomitant issues concerning cut-points, may have implications for the findings (MacCallum et al. 2002). It must also be noted that classifying individuals into one discrete class based on probability of being in a class likely resulted in some non-differential misclassification. This measurement error likely biased the relationships between class memberships

and all-cause mortality towards the null. The generalizability of the results is restricted given that the ACLS cohort is predominantly white and from middle and upper socio-economic strata. Nevertheless, the homogenous nature of the sample helps to ensure internal control over factors such as ethnicity and socioeconomic status. Furthermore, studies have shown that although the prevalence of partaking in negative behaviors differs with socioeconomic status, ethnicity, and age, the clustering of behaviors is similar in different demographic groups (Berrigan et al. 2003; Laaksonen et al. 2001; Poortinga 2007). Finally, some potentially important demographic variables, such as marital status, were not collected in the ACLS cohort and were therefore not controlled for in the regression models. This may have resulted in some residual confounding.

In conclusion, negative health behaviors cluster together, irrespective of chronic disease status. The risk of all-cause mortality increases with the number of unhealthy behaviors one partakes in. These findings can be used as support for multi-behavioral intervention strategies where several risk behaviors are addressed simultaneously.

Acknowledgements Supported by National Institutes of Health grants AG06945, HL62508, and R21DK088195, and an unrestricted research grant from the Coca-Cola Company. M. Héroux was supported by a doctoral award from the Canadian Institutes of Health Research. I. Janssen was supported by investigator awards from the Canadian Institutes of Health Research, the Ontario Ministry of Research and Innovation, and the Canada Research Chairs program. J. Hébert was supported by an Established Investigator Award in Cancer Prevention and Control from the Cancer Training Branch of the National Cancer Institute (K05 CA136975). The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health. We thank the Cooper Clinic physicians and technicians for collecting the baseline data, and staff at the Cooper Institute for data entry and data management.

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Appendix

Table 5 Relationship between health behaviors

	Prevalence (%) or Odds Ratio (95% CI) for Engagement in Unhealthy Behavior			
	Unhealthy Diet	Physically Inactive	Smokers	Heavy Drinkers
Participants with no history of chronic disease				
Diet				
Healthy diet,%	–	21.8%	8.9%	2.3%
Unhealthy diet,%		37.4%	19.4%	4.5%
Odds ratio (95% CI)		2.12 (1.88–2.39)	2.02 (1.74–2.35)	1.61 (1.21–2.15)
Physical Activity				
Physically active	15.5%	–	8.8%	2.4%
Inactive	28.2%		17.2%	3.5%
Odds ratio (95% CI)	2.14 (1.90–2.41)		2.09 (1.81–2.40)	1.36 (1.04–1.80)
Smoking				
Non-smokers,%	16.9%	23.0%	–	2.2%
Smokers,%	33.2%	39.0%		6.5%
Odds ratio (95% CI)	1.99 (1.71–2.32)	2.08 (1.81–2.39)		2.69 (2.00–3.62)
Alcohol Intake				
Non/Light drinkers,%	18.3%	24.5%	10.5%	–
Heavy drinkers,%	31.4%	31.8%	26.4%	
Odds ratio (95% CI)	1.62 (1.22–2.17)	1.34 (1.02–1.77)	2.72 (2.02–3.66)	
Participants with chronic disease				
Diet				
Healthy diet,%		23.9%	8.9%	2.3%
Unhealthy diet,%	–	43.0%	17.3%	4.3%
Odds ratio (95% CI)		2.23 (1.91–2.60)	1.66 (1.36–2.05)	1.26 (0.86–1.84)
Physical Activity				
Physically active,%	17.9%	–	8.7%	2.7%
Inactive,%	34.4%		16.0%	3.0%
Odds ratio (95% CI)	2.25 (1.93–2.62)		1.85 (1.52–2.24)	0.96 (0.65–1.41)
Smoking				
Non-smokers,%	20.9%	26.5%	–	2.3%
Smokers,%	36.2%	41.8%		6.8%
Odds ratio (95% CI)	1.65 (1.34–2.03)	1.84 (1.51–2.23)		2.45 (1.63–3.69)
Alcohol Intake				
Non/light drinkers,%	22.2%	28.1%	10.3%	–
Heavy drinkers,%	34.9%	30.2%	26.4%	
Odds Ratio (95% CI)	1.32 (0.90–1.94)	0.92 (0.62–1.35)	2.46 (1.63–3.71)	

All relationships significant ($p \leq 0.05$) with the exception of alcohol intake vs. physical activity and diet vs. alcohol intake in those with chronic disease

* Odds ratio (95% confidence interval) for engagement in the corresponding unhealthy behavior. The healthy behavior was used as the referent category. Odds ratios were controlled for age and gender.

Table 6 Results of the latent class analysis used to identify classes of participants based on health behaviors, after controlling for age and gender

Health Behaviors	Class 1 (N=3,850)	Class 2 (N=9,771)
Diet		
Healthy diet	47.3%	98.4%
Unhealthy diet	52.7%	1.6%
Physical Activity		
Active	61.4%	81.2%
Inactive	38.6%	18.8%
Smoking		
Non-smokers	78.7%	95.0%
Smokers	21.3%	5.0%
Alcohol Intake		
Non/light drinkers	93.7%	98.8%
Heavy drinkers	6.3%	1.2%
# Unhealthy Behaviors		
0	1.6%	77.9%
1	53.7%	21.2%
2	36.3%	0.9%
3	8.0%	0.0%
4	0.2%	0.0%

Values represent the probability of class membership⁴

Table 7 All-cause mortality risk according to engagement in different unhealthy behaviors

Health Behaviors	HR (95% CI) Model 1	HR (95% CI) Model 2	Population Attributable Risk (PAR)
Diet			
Healthy diet	1.0	1.0	4.0%
Unhealthy diet	1.29 (1.00–1.68)	1.21 (0.93–1.58)	
Physical Activity			
Physically active	1.0	1.0	4.9%
Inactive	1.27 (1.02–1.57)	1.20 (0.97–1.50)	
Smoking			
Non-smokers	1.0	1.0	4.4%
Smokers	1.50 (1.12–2.01)	1.42 (1.06–1.90)	
Alcohol Intake			
Non/light drinkers	1.0	1.0	0.4%
Heavy drinkers	1.24 (0.68–2.36)	1.16 (0.64–2.12)	
# Unhealthy Behaviors			
0	1.00	–	–
1	1.13 (0.91–1.41)	–	–
2	1.67 (1.22–2.28)	–	–
3 to 4	2.07 (1.15–3.73)	–	–

Table 7 (continued)

Health Behaviors	HR (95% CI) Model 1	HR (95% CI) Model 2	Population Attributable Risk (PAR)
Class 1	1.52 (1.19–1.93)	–	–
Class 2	1.0	–	–

HR (95% CI)=hazard ratio (95% confidence interval)

Model 1: controlled for age, gender, year of examination, history of chronic disease.

Model 2: controlled for age, gender, year of examination, history of chronic disease, and the remaining 3 health behaviors

PAR%=[P_e (HR-1)]/[P_e (HR-1)+1]*100 where P_e is the prevalence of the health behavior within the population, and HR is the relative risk of all-cause mortality for that unhealthy behavior (using model 2)

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