J Behav Med (2014) 37:37–46
DOI 10.1007/s10865-012-9460-y

Anger, adiposity, and glucose control in nondiabetic adults: findings from MIDUS II

Vera K. Tsenkova · Deborah Carr · Christopher L. Coe · Carol D. Ryff

Received: July 18, 2011 / Accepted: September 26, 2012 / Published online: October 12, 2012

Abstract Anger has been linked to cardiovascular disease, but few studies have examined the relationship between anger and type 2 diabetes. The aim was to investigate associations among different indicators of anger expression, adiposity, and nondiabetic glucose metabolism in a national survey of adults. Participants were 939 adults without diabetes in the Midlife in the US study (MIDUS II). Glucose metabolism was characterized by fasting glucose, insulin, insulin resistance, and glycosylated hemoglobin (HbA_{1c}). Spielberger's Anger Expression inventory was used to measure suppressed anger (anger-in), expressed anger (anger-out), and controlled anger (anger-control). We investigated the relationship between anger and glucose metabolism, and whether anger amplified the adverse relationship between body weight distribution (body mass index = BMI and waist-to-hip ratio = WHR) and glucose metabolism. Multivariate-adjusted analyses revealed an association between anger-out and both insulin and insulin resistance. As predicted, anger-in amplified the relationships between BMI and insulin and insulin resistance, while anger-out amplified the association between WHR and insulin and insulin resistance. Low anger-control was associated with higher glucose. None of the three anger measures was significantly associated with HbA_{1c}. Our findings extend previous research on anger as a potential risk factor for type 2 diabetes by demonstrating that anger expression is associated with clinical indicators of glycemic control, especially among those with pre-existing risk due to obesity and high central adiposity.

Keywords Anger · Diabetes · Obesity · Glucose · Insulin · HOMA-IR · Insulin resistance · HbA1c

Introduction

Prior research has highlighted the importance of anger in the etiology of cardiovascular disease, demonstrating a strong association between anger and coronary calcification, acute myocardial infarction, subclinical atherosclerosis, and overall coronary heart disease risk (al'Absi & Bongard, 2006; Haukkala et al., 2010; Koh et al., 2003; Merjonen et al., 2008; Mittleman et al., 1995; Williams et al., 2000). Anger and hostility also have been associated with metabolic syndrome (Cohen et al., 2010; Gremigni, 2006; Nelson et al., 2004; Niaura et al., 2000; Raikkonen et al., 2002). Despite the shared etiological risk factors for cardiovascular disease and type 2 diabetes, few studies have evaluated the role of anger in glycemic control. One prospective study documented a modest increase in risk for type 2 diabetes among people who had higher scores on an

V. K. Tsenkova (✉)
Center for Women's and Health Disparities Research, University of Wisconsin-Madison, 310N. Midvale Blvd, Madison, WI 53706, USA
e-mail: tsenkova@wisc.edu

D. Carr
Department of Sociology and Institute for Health, Health Care Policy and Aging Research, Rutgers University, New Brunswick, NJ, USA

C. L. Coe
Department of Psychology, University of Wisconsin-Madison, Madison, WI, USA

C. D. Ryff
Institute on Aging and Department of Psychology, University of Wisconsin-Madison, Madison, WI, USA

anger temperament scale (Golden et al., 2006). Different dimensions of anger have been associated with fasting glucose and insulin in nondiabetic adults, particularly among those with potential vulnerabilities, such as being physically unfit, a caregiver, or unmarried (Raikkonen et al., 1999; Shen et al., 2008; Siegman et al., 2002; Suarez, 2006; Vitaliano et al., 1996). Prior research has indicated that the relationship between psychosocial factors such as stress and glucoregulation may partially be mediated by a risk factor for type 2 diabetes—adiposity (Heraclides et al., 2012; Surwit et al., 2010). However, we know of no previous work examining whether anger amplifies the relationship between the most prominent risk factors for type 2 diabetes—body mass index (BMI) and waist-to-hip ratio (WHR), and glucose regulation.

Our overarching aim was to document the relationships among anger expression, adiposity, and glucoregulation in nondiabetic individuals from a national sample of adults. Anger expression was operationalized with the Spielberger's State Trait Anger Expression questionnaire (Spielberger, 1996), a theoretically-informed measure for characterizing anger expression that has been previously linked to hypertension, acute myocardial infarction, and cardiovascular disease (Haukkala et al., 2010; Igna et al., 2009; Izawa et al., 2011). Spielberger's Anger Expression Scales were developed in the early 1980s with the goal of identifying and measuring the typical ways people express anger (Spielberger, 1983, 1996, Spielberger and Reheiser, 2004) and is the most widely used and accepted anger scale (Mayne & Ambrose, 1999). Two primary modes of anger expression are identified: anger-out (expressing angry feelings in aggressive behavior directed toward other people or objects) and anger-in (suppressing angry feelings and holding them in). A further dimension of interest is anger-control, which addresses individual differences in efforts to manage the expression of angry feelings, such as attempts to calm down (Spielberger and Reheiser, 2004).

Our goals were to first describe the relationships among anger, adiposity, and fasting glucose, insulin, insulin resistance, and glycosylated hemoglobin (HbA_{1c}). Second, we investigated whether anger modifies the relationship between body fat distribution and glucose control (glucose, insulin, insulin resistance, HbA_{1c}). We expected that the highest levels of glucose, insulin, insulin resistance, and HbA_{1c} would be evident among those with the highest BMI and WHR levels in combination with high anger-in and anger-out, or low anger-control. That is, high levels of anger would moderate the link between adiposity and glucoregulation. Importantly, our study focused on a nondiabetic sample, allowing us to explore the interplay of risk factors associated with glucoregulation during the nonpathological stage prior to disease, and thus has implications for prevention of later morbidity.

Research design and methods

Study population and design

These analyses used data from the Midlife in the US II (MIDUS II) study, a longitudinal follow-up of the original MIDUS I study (N = 7,108) conducted in 1995/1996 to investigate the role of behavioral, psychological, and social factors in physical and mental health. All eligible participants were non-institutionalized, English-speaking adults in the coterminous United States, initially 25–74 years of age. Approximately 9–10 years after the baseline assessment, respondents were re-contacted (longitudinal retention rate was 75 %, adjusted for mortality). MIDUS II obtained comprehensive biomarker assessments on a subsample of participants who had completed a phone interview and self-administered questionnaires. Forty-three percent of the MIDUS II participants also participated in the biological data collection. This rate is somewhat lower than other epidemiological studies involving a visit to a health clinic (e.g., 57 % response rate in the Cardiovascular Health Study) (Fried et al., 1998). However, the MIDUS biological protocol was more intensive than other studies, requiring travel and an overnight stay at the clinic. This subsample was not significantly different from the main MIDUS sample on age, sex, race, marital status, or income variables, although participants were significantly more likely to have a college degree and significantly less likely to have completed only high school or some college compared with the main sample (Love et al., 2010).

The current analyses used data from the biological subsample of MIDUS II and included 1,255 participants ages 34–84 ($M = 54.52$, $SD = 11.71$), more than half of whom (57 %) were female and 28% had a high school education or less. We excluded 224 participants from the analyses with likely diabetes, including those with HbA_{1c} above 6.5 %, fasting glucose above 126 mg/dl, or taking anti-diabetic medications (e.g., Metformin). Further cases excluded from analyses were some with partially missing data, including HbA_{1c} levels (n = 20), glucose (n = 19), insulin (n = 19), race (n = 39), anger-in (n = 1), anger-out (n = 2), anger-control (n = 1), BMI (n = 1), WHR (n = 1) education (n = 1), and income (n = 26). No participants were missing data on age, gender, smoking status, and weekly exercise. People who were missing glucose metabolism data did not differ from the rest of the biological subsample on any of the anger or obesity measures. People who were missing income data did not differ from those who provided income data on any of the major variables. We also excluded 39 persons who reported a race other than black or white due to small sample size. Supplementary analyses comparing them to our analytical sample showed that they not differ from the analytical

Table 1 Means (and SDs) or proportions for all measures (N = 939)

	Mean (SD)	Range	%
Dependent variables			
Fasting glucose (mg/dl)	95.1 (9.2)	67–125	
Fasting insulin (uIU/ml)	11.9 (9.9)	1–97	
HOMA-IR	2.9 (2.6)	.2–27.1	
HbA_{1c} (%)	5.8 (.4)	3.6–6.5	
Independent variables			
BMI (continuous variable)	28.9 (6)	15–60.4	
Normal weight (<24.99)			26.9
Overweight (25–29.99)			37.1
Obese (>30)			36.0
Waist to hip ratio (WHR)	.89 (.10)	.62–1.14	
Anger-in	14.8 (4.1)	8–31	
Anger-out	13 (3.5)	8–29	
Anger-control	10 (2.2)	4–14	
Control variables			
Race (1 = white)			85
Gender (1 = male)			43
Age (years)	56.7 (11.5)	34–84	
Total household income	74,404 (59,470)	0–300,000	
Education (years)	14 (2.5)	8–21	
Exercise 3 + times a week (1 = years)			79
Current smoker			13

sample on any of the glucose metabolism measures, BMI, WHR, anger-in, and anger-out, but had significantly lower anger-control ($p < .05$).

After dropping 316 cases, a final analytic sample of 939 nondiabetic participants was attained with complete data. Tables 1 and 2 include descriptive information and correlations for all variables in our analyses.

Measures

Fasting glucose, insulin, and HbA_{1c} samples were obtained during an overnight stay in a General Clinical Research Center (GCRC). The HbA_{1c} assay was a colorimetric total-hemoglobin determination combined with an immunoturbidometric HbA_{1c} assay, carried out using a Cobas Integra Systems instrument (Roche Diagnostics) (Wolf et al., 1984). Fasting insulin was measured with an ADVIA Centaur Insulin assay, performed on a Siemens Advia Centaur analyzer. Fasting glucose was measured via an enzymatic assay photometrically on an automated analyzer (Roche Modular Analytics P). HOMA-IR was calculated using an established formula: the product of fasting glucose and fasting insulin, divided by a constant (405) (Matthews et al., 1985). Obesity, indexed by body mass index (BMI), was calculated using measurements obtained by MIDUS staff and was derived by dividing a respondent's weight (in kilograms) by their height (in meters squared). Central adiposity was indexed by waist-hip ratio (WHR), calculated by dividing an individual's waist in inches (measured around the abdomen just above the hip bone) by their hip (maximum hip extension measurement). BMI and WHR were used as continuous variables in all analytical models.

Anger expression was measured using Spielberger's Anger Expression Inventory (Spielberger, 1996). Three conceptually and statistically distinct subscales were used: (1) Anger-in indexed the degree to which individuals suppress angry feelings; (2) Anger-out measured angry feelings that are expressed in aggressive verbal or physical behavior directed toward other people or objects, and (3) Anger-control reflected efforts to manage anger expression. Anger-in included eight statements such as "I keep things inside," "I am irritated more than others are aware," and "I harbor grudges." Anger-out was comprised of eight statements such as "I slam doors," "I say nasty things," "I make sarcastic remarks," and "I argue with others." Anger-control included four statements such as "I control my temper" and "I calm down faster." For each item, the participants rated themselves on a 4-point scale from 1 (almost never) to 4 (almost always). For each scale, the mean score of the items was calculated, with an allowance of up to one missing item per respondent. Mean scores were multiplied by the number of items in the scale to retain the range of the original scale from 8 to 32 for anger-in, and anger-out scores, and from 4 to 16 for anger-control. Anger-in, anger-out, and anger-control all had good internal consistency (Cronbach's $\alpha = 0.82$, 0.77, and 0.69, respectively). The anger expression subscales were treated as continuous variables.

Statistical methods

Fasting glucose, insulin, and HOMA-IR were log-transformed to achieve normal distributions. Hierarchical multiple regression was used and all predictor variables were mean-centered and outliers were top-coded. All models were multivariate-adjusted for relevant covariates: age (continuous), race (black or white), gender (male or female), engaging in exercise for 20 min three times a week (yes or no), current smoking status (yes or no), household income (continuous), and years of education (continuous). Each of these variables has been shown elsewhere to correlate with anger and diabetes risk. All interaction terms were computed as the product of the main effect variables centered at their mean. Each interaction model contained two interactions: the product of one measure of anger with BMI and the product of the same measure of anger with WHR (i.e., anger-in × BMI and anger-in × WHR).

Table 2 Zero-order correlations among all variables (N = 939)

	Age	Smoking	Gender	Race	Exercise	WHR	BMI	Income
Age	1.00							
Smoking	−.16**	1.00						
Gender	0.00	0.04	1.00					
Race	.18**	−.23**	0.06	1.00				
Exercise	−0.03	−0.02	0.04	.12**	1.00			
WHR	.13**	0.06	.66**	0.01	−0.06	1.00		
BMI	−.07*	−0.01	0.02	−.14**	−.16**	.29**	1.00	
Income	−.15**	−.12**	.10**	.23**	.08*	−0.04	−0.06	1.00
Education	−0.02	−.22**	.08*	.23**	0.06	−0.05	−.10**	.35**
Anger-in	−.27**	.14**	.07*	−0.06	−0.06	0.03	0.06	0.01
Anger-out	−.24**	0.06	−0.03	−.10**	−0.02	−0.03	.1**	0.06
Anger-control	.14**	−.09**	.07*	.17**	0.03	0.06	−0.06	.08*
Glucose	0.02	0.04	.19**	−0.05	−0.03	.32**	.26**	−0.02
Insulin	−0.06	0.02	.08*	−.07*	−.13**	.37**	.54**	−0.03
HOMAIR	−0.06	0.02	.10**	−.07*	−.13**	.39**	.54**	−0.03
HbA1c	.26**	0.03	−.10**	−.08*	−.10**	.09**	.15**	−.10**

	Education	Anger-in	Anger-out	Anger-control	Glucose	Insulin	HOMAIR	HbA1c
Age								
Smoking								
Gender								
Race								
Exercise								
WHR								
BMI								
Income								
Education	1.00							
Anger-in	0.00	1.00						
Anger-out	0.01	.25**	1.00					
Anger-control	.10**	−.15**	−.31**	1.00				
Glucose	−.08*	−0.02	0.00	−.09**	1.00			
Insulin	−.11**	.09**	.11**	−0.05	.44**	1.00		
HOMAIR	−.11**	.08*	.10**	−0.06	.54**	.99**	1.00	
HbA1c	−.09**	−.12**	−0.05	−0.04	.19**	.12**	.14**	1.00

** $p < .01$; * $p < 0.05$

Statistically significant interaction terms were interpreted by graphing predicted scores for respondents in theoretically meaningful groups.

To check for possible subgroup differences, statistical interactions of the three anger measures (anger-in, anger-out, and anger-control) with race and gender on glucose metabolism (glucose, insulin, HOMA-IR, and HbA_{1c}) were assessed. Because no statistically significant interactions of anger on glucose metabolism by race and gender were detected, the entire sample was analyzed as one group.

The MIDUS project population has two types of biological dependencies embedded within the dataset. Among the main sample respondents, some participants have siblings who also participated in the study, and the original survey also included some monozygotic and dizygotic twins. The nondiabetic subsample of the biomarker cohort used for the current analyses included 112 related individuals (siblings, twins). Two steps were taken to determine the potential influence of these dependencies. First, including the dichotomous variable "twin status," coded yes or no, as a covariate in all analyses did not change any of the observed relationships. Second, a resampling strategy was employed: one member from each sibling pair in the MIDUS data was randomly selected and then analyses were re-estimated after deleting all dependencies among related respondents. These findings were

then compared with the results from the full sample. We found no evidence for bias: the patterns of all main effects and interactions remained the same and coefficient sizes varied only slightly.

Results

Descriptive statistics and correlations are presented in Tables 1 and 2. Summaries of the multivariate analyses regressing the measures of glucose metabolism on anger and adiposity are provided in Tables 3, 4, and 5. All models are multivariate-adjusted for age, race, gender, engaging in exercise for 20 min 3 times a week, current smoking status, BMI, WHR, household income, and years of education.

In the analyses of main effects, anger-in was not independently associated with any of the four indicators of glucose metabolism. However, anger-in interacted with BMI to predict insulin ($R^2 = 0.36$, $B = 0.07$, $p < .05$) and HOMA-IR ($R^2 = 0.36$, $B = 0.06$, $p < .05$). In both models, R^2 change after adding the interaction showed a trend toward significance ($R^2 = .002$, $p = .05$ and $R^2 = .002$, $p = .07$, respectively). For both interactions, the highest levels of insulin or HOMA-IR were evident among people who had both higher BMI and higher anger-in (see Table 3 and Fig. 1). Simple slopes analyses confirmed that anger-in amplified the relationship between BMI and insulin (at 1 *sd* above mean of anger-in, $\beta = .49$, $t = 10.43$, $p < .001$; at 1 *sd* below the mean for anger-in, $\beta = .35$, $t = 7.35$, $p < .001$) and insulin resistance (at 1 *sd* above mean of anger-in, $\beta = .48$, $t = 10.8$, $p < .001$; at 1 *sd* below the mean for anger-in, $\beta = .35$, $t = 7.72$, $p < .001$). Anger-in was not significantly associated with glucose or HbA_{1c} as a main effect or moderator of BMI and WHR.

As predicted, anger-out was independently associated with insulin and HOMA-IR and also interacted with WHR to predict insulin ($R^2 = 0.36$, $B = 0.06$, $p < .05$) and HOMA-IR ($R^2 = 0.37$, $B = 0.07$, $p < .05$) (see Table 4 and Fig. 1). In both models, there was a significant R^2 change after the interaction was added ($R^2 = .004$, $p = .04$ and $R^2 = .004$, $p = .02$, respectively). Simple slopes analyses confirmed that anger-out amplified the relationship between WHR and insulin (at 1 *sd* above the mean for anger-out, $\beta = .41$, $t = 8.42$, $p < .001$; at 1 *sd* below the mean for anger-out, $\beta = .28$, $t = 5.3$, $p < .001$) and insulin resistance (at 1 *sd* above mean of anger-out, $\beta = .42$, $t = 9.3$, $p < .001$; at 1 *sd* below the mean for anger-out, $\beta = .29$, $t = 5.8$, $p < .001$). Anger-out was not linked to glucose or HbA_{1c} levels as a main effect or moderator of BMI and WHR.

Consistent with our hypothesis, anger-control was independently associated with glucose ($R^2 = 0.14$, $B = -0.09$, $p < .01$) and marginally interacted with WHR to predict insulin ($R^2 = 0.36$, $B = 0.05$, $p = .06$) and HOMA-IR ($R^2 = 0.36$, $B = 0.05$, $p = .09$) (see Table 5). Anger-control was not associated with HbA_{1c} as a main effect or moderator of BMI and WHR.

Table 3 Regression results for anger-in, adiposity, and nondiabetic glucoregulation

	Glucose[a]		Insulin		HOMAIR		HbA1c[a]	
	β	*p*	*β*	*p*	*β*	*p*	*β*	*p*
Predictors								
Age	0.00	0.98	**−0.07**	**0.02**	**−0.06**	**0.03**	**0.26**	**0.00**
Race	−0.02	0.53	0.01	0.65	0.01	0.74	**−0.09**	**0.01**
Gender	0.03	0.55	**−0.16**	**0.00**	**−0.15**	**0.00**	**−0.18**	**0.00**
Regular exercise	0.02	0.53	−0.03	0.27	−0.03	0.35	−0.05	0.14
Current smoker	0.02	0.63	−0.01	0.66	−0.01	0.74	0.06	0.08
Income	0.01	0.70	0.02	0.42	0.02	0.42	0.01	0.75
Education	−0.05	0.13	−0.05	0.09	−0.05	0.07	−0.03	0.44
BMI	**0.18**	**0.00**	**0.42**	**0.00**	**0.42**	**0.00**	**0.11**	**0.00**
WHR	**0.25**	**0.00**	**0.36**	**0.00**	**0.37**	**0.00**	**0.14**	**0.00**
Anger-in	−0.04	0.17	0.04	0.15	0.03	0.25	−0.06	0.06
BMI × anger-in	0.01	0.88	**0.07**	**0.02**	**0.06**	**0.02**	0.00	0.98
WHR × anger-in	0.02	0.64	0.00	0.90	0.00	0.96	−0.03	0.36
Adjusted R^2	0.13		0.36		0.36		0.13	

Standardized regression coefficients are shown. Bolded effects are significant at $p < .05$

[a] In trimmed models without the two interactions effects, significance levels and coefficients varied very slightly and no significant changes (e.g., previous significant association changed to nonsignificant) were observed

Table 4 Regression results for anger-out, adiposity, and nondiabetic glucoregulation

	Glucose[a]		Insulin		HOMAIR		HbA1c[a]	
	β	p	β	p	β	p	β	p
Predictors								
Age	0.01	0.78	**−0.07**	**0.02**	**−0.06**	**0.03**	**0.27**	**0.00**
Race	−0.02	0.52	0.02	0.49	0.02	0.58	**−0.09**	**0.01**
Gender	0.03	0.53	**−0.15**	**0.00**	**−0.14**	**0.00**	**−0.19**	**0.00**
Regular exercise	0.02	0.44	−0.03	0.24	−0.03	0.32	−0.04	0.17
Current smoker	0.01	0.83	−0.02	0.51	−0.02	0.56	0.05	0.11
Income	0.02	0.62	0.03	0.39	0.03	0.38	0.01	0.75
Education	−0.05	0.12	−0.05	0.06	−0.06	0.05	−0.03	0.46
BMI	**0.20**	**0.00**	**0.44**	**0.00**	**0.44**	**0.00**	**0.10**	**0.00**
WHR	**0.24**	**0.00**	**0.34**	**0.00**	**0.35**	**0.00**	**0.14**	**0.00**
Anger-out	−0.01	0.80	**0.06**	**0.02**	**0.06**	0.04	−0.03	0.44
BMI × anger-out	−0.04	0.18	−0.04	0.14	−0.04	0.11	0.04	0.28
WHR × anger-out	0.05	0.09	**0.06**	**0.02**	**0.07**	0.02	−0.02	0.57
Adjusted R^2	0.13		0.36		0.37		0.12	

Standardized regression coefficients are shown. Bolded effects are significant at $p < .05$

[a] In trimmed models without the two interactions effects, significance levels and coefficients varied very slightly and no significant changes (e.g., previous significant association changed to nonsignificant) were observed

Table 5 Regression results for anger-control, adiposity, and nondiabetic glucoregulation

	Glucose[a]		Insulin[a]		HOMAIR[b]		HbA1c[a]	
	β	p	β	p	β	p	β	p
Predictors								
Age	0.02	0.52	**−0.08**	**0.01**	**−0.07**	**0.01**	**0.28**	**0.00**
Race	−0.01	0.74	0.02	0.57	0.01	0.63	**−0.08**	**0.01**
Gender	0.03	0.53	**−0.16**	**0.00**	**−0.15**	**0.00**	**−0.19**	**0.00**
Regular exercise	0.02	0.44	−0.03	0.20	−0.03	0.28	−0.04	0.17
Current smoker	0.01	0.79	−0.01	0.65	−0.01	0.70	0.05	0.13
Income	0.02	0.58	0.03	0.34	0.03	0.33	0.01	0.71
Education	−0.05	0.17	−0.06	0.05	**−0.06**	**0.04**	−0.03	0.43
BMI	**0.18**	**0.00**	**0.42**	**0.00**	**0.42**	**0.00**	**0.12**	**0.00**
WHR	**0.26**	**0.00**	**0.36**	**0.00**	**0.37**	**0.00**	**0.13**	**0.00**
Anger-control	**−0.09**	**0.00**	−0.02	0.43	−0.03	0.23	−0.05	0.15
BMI × anger-control	−0.01	0.77	0.00	0.95	0.00	0.91	0.06	0.08
WHR × anger-control	−0.02	0.56	0.05	0.06	0.05	0.09	0.01	0.82
Adjusted R^2	0.14		0.36		0.36		0.13	

Note Standardized regression coefficients are shown. Bolded effects are significant at $p < .05$

[a] In trimmed models without the two interactions effects, significance levels and coefficients varied very slightly and no significant changes (e.g., previous significant association changed to nonsignificant) were observed

[b] In trimmed models without the two interactions effects, education was no longer a significant predictor ($\beta = -.05$, $p = .06$). No other significant changes (e.g., previous significant association changed to nonsignificant) were observed

Discussion

The preclinical progression to type 2 diabetes is only partly explained by demographic, health, and psychological risk factors. Even obesity and central adiposity, the most frequently documented and most well understood risk factors for type 2 diabetes, do not result in an inevitable progression to diabetes. While more than 80 % of people with type 2 diabetes are obese, most obese people never develop diabetes (Attie, 2004). Recent research has suggested that

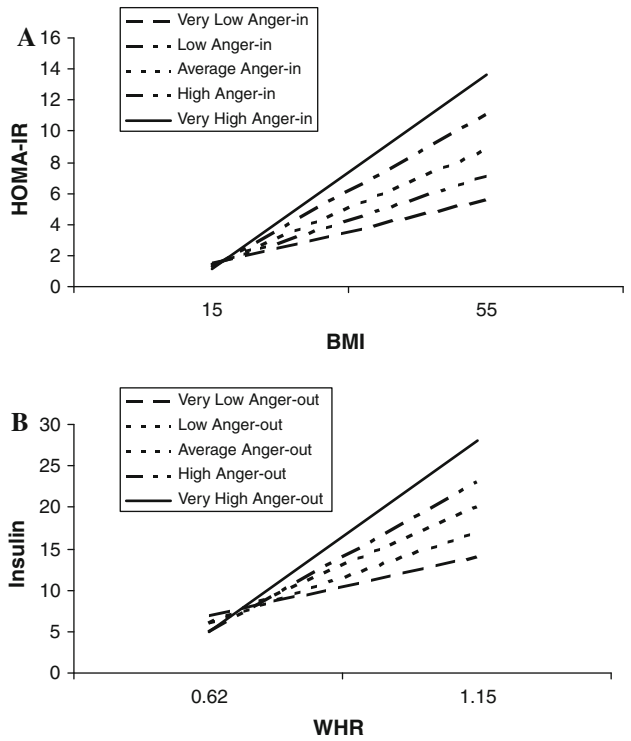

Fig. 1 **a** Anger-in amplifies the relationship between BMI and HOMA-IR ($p < .05$). **b** Anger-out augments the relationship between WHR and insulin ($p < .05$). Note that *High Anger* is plotted at 1 standard deviation (SD) above the mean for Anger and *Low Anger* is plotted at 1 SD below the mean. *Very High Anger* is plotted at 2 SD above the mean for *Anger* and *Very Low Anger* is plotted at 2 SD below the mean for Anger

psychosocial factors are associated with glucose metabolism and are also likely to be particularly relevant for those individuals who are vulnerable to type 2 diabetes due to other risk factors such as being physically unfit (Siegman et al., 2002). The results from the current analyses supported our core hypotheses: anger expression was independently, and in combination with BMI and WHR, linked to clinical indicators of glucose metabolism among nondiabetic adults. Adjustments for demographics, socioeconomic status, and health status and behaviors were included, thereby sharpening the focus on the distinctive contribution of anger expression to glycemic control.

The key findings were that anger-in and anger-out amplified the relationship between BMI, WHR, and glucose metabolism, with the highest insulin and HOMA-IR levels observed among people with both high adiposity and high anger. However, the relationship between anger-control and glucose metabolism did not depend on body fat distribution: low anger-control was associated with higher fasting glucose regardless of BMI and WHR. While anger has been associated with adiposity (Gleiberman et al., 2008; Midei et al., 2010), our study is the first to document a synergistic relationship of anger and adiposity on glucoregulation in nondiabetic individuals, showing that anger-in and anger-out amplify the adverse relationships between adiposity and glucoregulation.

We confirmed prior reports based on smaller samples that implicated some indicators of anger as being associated with specific measures of nondiabetic glycemic control (Raikkonen et al., 1999; Siegman et al., 2002; Suarez, 2006; Vitaliano et al., 1996). However, we extended these analyses by demonstrating that the interplay of high anger-in and anger-out and adiposity is associated with poorer glycemic control. Our results underscore the importance of psychosocial factors in glycemic control. For example, it is known that stress-induced catecholamine release amplifies the relationship between adiposity and fasting glucose (Surwit et al., 2010), and that stress hampers glucose control in obese animals (Surwit et al., 1984). This relationship between anger and several indices of glucose regulation also is consistent with our prior work showing that people who felt discriminated against due to being overweight evidenced a stronger association between their WHR and HbA_{1c} (Tsenkova et al., 2010). Additionally, a recent Whitehall II study showed that work stress is associated with higher risk for type 2 diabetes among obese women, which was not seen in men or nonobese women (Heraclides et al., 2012). Many studies have linked anger to hypertension and cardiovascular disease, but ours is the first to clearly implicate an equivalent role of anger-in, anger-out, and anger control in glucose metabolism in nondiabetic people (Everson et al., 1998; Haukkala et al., 2010; Merjonen et al., 2008; Mittleman et al., 1995; Suls & Bunde, 2005).

The relationship between anger and glucoregulation needs further inquiry. Psychosocial factors may influence diabetic glycemic control directly through known physiological pathways (i.e., activation of hypothalamic–pituitary–adrenal axis) and indirectly through self-care (Peyrot et al., 1999; Surwit et al., 2002a). The exclusion of diabetic participants allowed us to describe the psychophysiological association without the additional confounds of clinical treatments and adherence to self-care regimens and diet control (Yi et al., 2008). Anger expression may act in part via chronic or recurrent activation of neuroendocrine pathways, leading to the excessive release of catecholamines and glucocorticoids, or through the initiation of proinflammatory responses (Gouin et al., 2008; Kiecolt-Glaser et al., 1993, 2005). The slope of diurnal release of cortisol is shallower among obese people (Kumari et al., 2010). Given that anger increases cortisol levels, it is possible that anger-related cortisol elevations are associated with glycemic dysregulation among obese people. Among nondiabetic people, uncontrolled anger may also result in less healthy behavior, although we did statistically adjust for exercise habits and current smoking status.

Future research is needed to test these possible pathways, including in the context of experimental paradigms designed to induce anger.

Although this study provides support for a combined effect of anger expression and adiposity on nondiabetic glucose control, there were several limitations. The main constraint pertains to the cross-sectional design, which did not permit the determination of causal ordering. However, our use of a nondiabetic sample and previous prospective research linking anger to glucoregulation makes it less likely that the poor glycemic control was the precipitating event that caused problems with anger management (Golden et al., 2006; Shen et al., 2008). With the ongoing longitudinal follow-up, this biological subsample of MIDUS will allow for predictive investigations of factors that precipitate the conversion to clinical diabetes. Another important limitation is that many of the African-American participants were drawn from a city-specific oversample (i.e., Milwaukee). Milwaukee was chosen as the intensive research site in order to purposively include adequate numbers of African-Americans from both lower and middle/upper income neighborhoods. Thus, they are not nationally representative. It should be noted, however, that the findings were not driven by racial factors, nor were there differences in the pattern of associations between white and black participants, as evidenced by lack of significant interaction terms. It is not clear if the results generalize to other ethnicities.

Beyond assessments of anger, hostility has also been reliably associated with cardiovascular disease and glucose metabolism (Georgiades et al., 2009; Haukkala et al., 2010; Kawakami et al., 1995; Shen et al., 2008; Suarez, 2006; Surwit et al., 2009; Surwit et al., 2002b; Vitaliano et al., 1996), but due to the lack of specific hostility measures, we could not ascertain the extent to which anger and hostility had an overlapping influences on glucose metabolism. Finally, the relatively large number of interaction terms that we assessed may have increased the chance for Type I error, although our comprehensive assessment of both several types of anger and multiple components of glucoregulation, makes it less likely that the linkage between the primary factors of anger and adiposity and core outcome variable of glucoregulation was spurious.

The results extend our prior findings on psychosocial factors such as neuroticism and perceived discrimination as moderators of the relationship between adiposity and glucoregulation (Tsenkova et al., 2010, 2012). Given the relationship between anger-out and neuroticism (Costa et al., 1989), it is important to note that the MIDUS assessment of neuroticism did not include underlying facets, one of which is angry hostility (McCrae & Costa, 2003). In fact, none of the adjectives used to operationalize neuroticism included anger content. Further, two aspects of anger used in this study, anger-in and anger control, are absent in facet-based assessment of neuroticism. Thus that different components of anger were found in the present study to moderate the relationship between adiposity and glucoregulation constitutes further evidence that psychological factors play an important role in understanding how body weight distribution is linked with glucose metabolism.

Our study provides evidence that adiposity and psychosocial factors have a synergistic relationship with glucoregulation prior to the emergence of type 2 diabetes. Specifically, the analyses suggest that anger expression should be included among the established risk factors for type 2 diabetes, and that its relationship to glucose metabolism, particularly among at-risk people, deserves further attention as a major vulnerability factor. Anger-in, anger-out, and anger control generally correspond to anger management styles of suppression, expression, and control (Mayne & Ambrose, 1999). These distinctions are useful for designing tailored interventions that focus on cognitive and behavioral management strategies to improve life style and inter-personal ways of interacting and communicating that affect glucoregulation. Future research that employs longitudinal or experimental designs is needed to delineate the physiological and behavioral pathways underlying these relationships, as well as to identify the subgroups, such as physically unfit and older people, who will be most harmed by latent anger or compromised by inadequate control over its expression.

Acknowledgments This research was supported by a grant from the National Institute on Aging (P01-AG020166; Carol D. Ryff, Principal Investigator) to conduct a longitudinal follow-up of the MIDUS (Midlife in the US) investigation. The original study was supported by the John D. and Catherine T. MacArthur Foundation Research Network on Successful Midlife Development. We thank the staff of the Clinical Research Center at the University of Wisconsin-Madison, at the University of California—Los Angeles, and at Georgetown University for their support in conducting this study. Data collection was supported by the following Grants M01- RR023942 (Georgetown), M01-RR00865 (UCLA) from the General Clinical Research Centers Program, and 1UL1RR025011 (UW) from the Clinical and Translational Science Award (CTSA) program of the National Center for Research Resources, National Institutes of Health. The first author of this study was supported by the National Institute on Aging (K01AG041179) and by the Eunice Kennedy Shriver National Institute of Child Health And Human Development (T32HD049302). The content is solely the responsibility of the authors and does not necessarily represent the official views of the Eunice Kennedy Shriver National Institute of Child Health and Human Development or the National Institutes of Health.

References

al'Absi, M., & Bongard, S. (2006). Neuroendocrine and behavioral mechanisms mediating the relationship between anger expression and cardiovascular risk: Assessment considerations and improvements. *Journal of Behavioral Medicine, 29*, 573–591.

Attie, A. D. (2004). Genetic and genomic studies of type 2 diabetes in mice. *International Congress Series, 1262*, 220–223.

Cohen, B. E., Panguluri, P., Na, B., & Whooley, M. A. (2010). Psychological risk factors and the metabolic syndrome in patients with coronary heart disease: Findings from the Heart and Soul Study. *Psychiatry Research, 175*, 133–137.

Costa, P. T., McCrae, R. R., & Dembroski, T. M. (1989). Agreeableness vs. antagonism: Explication of a potential risk factor for CHD. In A. Siegman & T. M. Dembroski (Eds.), *In search of coronary-prone behavior: Beyond type A* (pp. 41–63). Hillsdale, NJ: Erlbaum.

Everson, S. A., Goldberg, D. E., Kaplan, G. A., Julkunen, J., & Salonen, J. T. (1998). Anger expression and incident hypertension. *Psychosomatic Medicine, 60*, 730–735.

Fried, L. P., Kronmal, R. A., Newman, A. B., Bild, D. E., Mittelmark, M. B., Polak, J. F., et al. (1998). Risk factors for 5-year mortality in older adults: The Cardiovascular Health Study. *JAMA, 279*, 585–592.

Georgiades, A., Lane, J. D., Boyle, S. H., Brummett, B. H., Barefoot, J. C., Kuhn, C. M., et al. (2009). Hostility and fasting glucose in African American women. *Psychosomatic Medicine, 71*, 642–645.

Gleiberman, L., Greenwood, T. A., Luke, A., Delgado, M. C., & Weder, A. B. (2008). Anger types: Heritability and relation to blood pressure, body mass index, and left ventricular mass. *Journal of Clinical Hypertension (Greenwich), 10*, 700–706.

Golden, S. H., Williams, J. E., Ford, D. E., Yeh, H. C., Sanford, C. P., Nieto, F. J., et al. (2006). Anger temperament is modestly associated with the risk of type 2 diabetes mellitus: The Atheroslcerosis risk in communities study. *Psychoneuroendocrinology, 31*, 325–332.

Gouin, J. P., Kiecolt-Glaser, J. K., Malarkey, W. B., & Glaser, R. (2008). The influence of anger expression on wound healing. *Brain, Behavior, and Immunity, 22*, 699–708.

Gremigni, P. (2006). Cynical hostility and the metabolic syndrome: A case-control study. *Monaldi Archives for Chest Disease, 66*, 224–229.

Haukkala, A., Konttinen, H., Laatikainen, T., Kawachi, I., & Uutela, A. (2010). Hostility, anger control, and anger expression as predictors of cardiovascular disease. *Psychosomatic Medicine, 72*, 556–562.

Heraclides, A. M., Chandola, T., Witte, D. R., & Brunner, E. J. (2012). Work stress, obesity and the risk of type 2 diabetes: Gender-specific bidirectional effect in the Whitehall II Study. *Obesity (Silver Spring), 20*(2), 428–433.

Igna, C. V., Julkunen, J., & Vanhanen, H. (2009). Anger expression styles and blood pressure: Evidence for different pathways. *Journal of Hypertension, 27*, 1972–1979.

Izawa, S., Eto, Y., Yamada, K. C., Nakano, M., Yamada, H., Nagayama, M., et al. (2011). Cynical hostility, anger expression style, and acute myocardial infarction in middle-aged Japanese men. *Behavioral Medicine, 37*, 81–86.

Kawakami, N., Araki, S., Ohtsu, H., Hayashi, T., Masumoto, T., & Yokoyama, K. (1995). Effects of mood states, smoking and urinary catecholamine excretion on hemoglobin A1c in male Japanese workers. *Industrial Health, 33*, 153–162.

Kiecolt-Glaser, J. K., Loving, T. J., Stowell, J. R., Malarkey, W. B., Lemeshow, S., Dickinson, S. L., et al. (2005). Hostile marital interactions, proinflammatory cytokine production, and wound healing. *Archives of General Psychiatry, 62*, 1377–1384.

Kiecolt-Glaser, J. K., Malarkey, W. B., Chee, M., Newton, T., Cacioppo, J. T., Mao, H. Y., et al. (1993). Negative behavior during marital conflict is associated with immunological down-regulation. *Psychosomatic Medicine, 55*, 395–409.

Koh, K. B., Choe, K. O., & An, S. K. (2003). Anger and coronary calcification in individuals with and without risk factors of coronary artery disease. *Yonsei Medical Journal, 44*, 793–799.

Kumari, M., Chandola, T., Brunner, E., & Kivimaki, M. (2010). A nonlinear relationship of generalized and central obesity with diurnal cortisol secretion in the Whitehall II study. *Journal of Clinical Endocrinology and Metabolism, 95*, 4415–4423.

Love, G. D., Seeman, T. E., Weinstein, M., & Ryff, C. D. (2010). Bioindicators in the MIDUS national study: Protocol, measures, sample, and comparative context. *Journal of Aging and Health, 22*(8), 1059–1080.

Matthews, D. R., Hosker, J. P., Rudenski, A. S., Naylor, B. A., Treacher, D. F., & Turner, R. C. (1985). Homeostasis model assessment: Insulin resistance and beta-cell function from fasting plasma glucose and insulin concentrations in man. *Diabetologia, 28*, 412–419.

Mayne, T. J., & Ambrose, T. K. (1999). Research review on anger in psychotherapy. *Journal of Clinical Psychology, 55*, 353–363.

McCrae, R. R., & Costa, P. T. (2003). *Personality in adulthood: A five-factor theory perspective*. New York: Guilford Press.

Merjonen, P., Pulkki-Raback, L., Puttonen, S., Keskivaara, P., Juonala, M., Telama, R., et al. (2008). Anger is associated with subclinical atherosclerosis in low SES but not in higher SES men and women. The cardiovascular risk in young Finns study. *Journal of Behavioral Medicine, 31*, 35–44.

Midei, A. J., Matthews, K. A., & Bromberger, J. T. (2010). Childhood abuse is associated with adiposity in midlife women: possible pathways through trait anger and reproductive hormones. *Psychosomatic Medicine, 72*, 215–223.

Mittleman, M. A., Maclure, M., Sherwood, J. B., Mulry, R. P., Tofler, G. H., Jacobs, S. C., et al. (1995). Triggering of acute myocardial infarction onset by episodes of anger. Determinants of myocardial infarction onset study investigators. *Circulation, 92*, 1720–1725.

Nelson, T. L., Palmer, R. F., & Pedersen, N. L. (2004). The metabolic syndrome mediates the relationship between cynical hostility and cardiovascular disease. *Experimental Aging Research, 30*, 163–177.

Niaura, R., Banks, S. M., Ward, K. D., Stoney, C. M., Spiro, A., 3rd, Aldwin, C. M., et al. (2000). Hostility and the metabolic syndrome in older males: The normative aging study. *Psychosomatic Medicine, 62*, 7–16.

Peyrot, M., McMurry, J. F., Jr., & Kruger, D. F. (1999). A biopsychosocial model of glycemic control in diabetes: Stress, coping and regimen adherence. *Journal of Health and Social Behavior, 40*, 141–158.

Raikkonen, K., Matthews, K. A., & Kuller, L. H. (2002). The relationship between psychological risk attributes and the metabolic syndrome in healthy women: Antecedent or consequence? *Metabolism, 51*, 1573–1577.

Raikkonen, K., Matthews, K. A., Kuller, L. H., Reiber, C., & Bunker, C. H. (1999). Anger, hostility, and visceral adipose tissue in healthy postmenopausal women. *Metabolism, 48*, 1146–1151.

Shen, B. J., Countryman, A. J., Spiro, A., I. I. I., & Niaura, R. (2008). The prospective contribution of hostility characteristics to high fasting glucose levels: The moderating role of marital status. *Diabetes Care, 31*, 1293–1298.

Siegman, A. W., Malkin, A. R., Boyle, S., Vaitkus, M., Barko, W., & Franco, E. (2002). Anger, and plasma lipid, lipoprotein, and glucose levels in healthy women: the mediating role of physical fitness. *Journal of Behavioral Medicine, 25*, 1–16.

Spielberger, C. D. (1983). *Manual for the state–trait anxiety inventory (Form Y) ("Self-evaluation questionnaire")*. Palo Alto, CA: Consulting Psychologists Press.

Spielberger, C. D. (1996). *State-trait anger expression inventory: Professional manual*. FL: Odessa.

Spielberger, C., & Reheiser, E. (2004). Measuring anxiety, anger, depression, and curiosity as emotional states and personality traits with the STAI, STAXI, and STPI. In M. Hersen (Ed.),

Comprehensive handbook of psychological assessment: Personality assessment. Hoboken: Wiley.

Suarez, E. C. (2006). Sex differences in the relation of depressive symptoms, hostility, and anger expression to indices of glucose metabolism in nondiabetic adults. *Health Psychology, 25*, 484–492.

Suls, J., & Bunde, J. (2005). Anger, anxiety, and depression as risk factors for cardiovascular disease: The problems and implications of overlapping affective dispositions. *Psychological Bulletin, 131*, 260–300.

Surwit, R. S., Feinglos, M. N., Livingston, E. G., Kuhn, C. M., & McCubbin, J. A. (1984). Behavioral manipulation of the diabetic phenotype in ob/ob mice. *Diabetes, 33*, 616–618.

Surwit, R. S., Lane, J. D., Millington, D. S., Zhang, H., Feinglos, M. N., Minda, S., et al. (2009). Hostility and minimal model of glucose kinetics in African American women. *Psychosomatic Medicine, 71*, 646–651.

Surwit, R. S., van Tilburg, M. A., Zucker, N., McCaskill, C. C., Parekh, P., Feinglos, M. N., et al. (2002a). Stress management improves long-term glycemic control in type 2 diabetes. *Diabetes Care, 25*, 30–34.

Surwit, R. S., Williams, R. B., Lane, J. D., Feinglos, M. N., Kuhn, C. M., & Georgiades, A. (2010). Plasma epinephrine predicts fasting glucose in centrally obese African-American women. *Obesity (Silver Spring), 18*, 1683–1687.

Surwit, R. S., Williams, R. B., Siegler, I. C., Lane, J. D., Helms, M., Applegate, K. L., et al. (2002b). Hostility, race, and glucose metabolism in nondiabetic individuals. *Diabetes Care, 25*, 835–839.

Tsenkova, V., Carr, D., Coe, C., & Ryff, C. D. (2012). Synergistic effect of neuroticism and BMI on glucose metabolism in nondiabetic adults. *Psychotherapy and Psychosomatics, 81*(5) 327–328.

Tsenkova, V. K., Carr, D., Schoeller, D. A., & Ryff, C. D. (2010). Perceived weight discrimination amplifies the link between central adiposity and nondiabetic glycemic control (HbA1c). *Annals of Behavioral Medicine, 41*, 243–251.

Vitaliano, P. P., Scanlan, J. M., Krenz, C., & Fujimoto, W. (1996). Insulin and glucose: Relationships with hassles, anger, and hostility in nondiabetic older adults. *Psychosomatic Medicine, 58*, 489–499.

Williams, J. E., Paton, C. C., Siegler, I. C., Eigenbrodt, M. L., Nieto, F. J., & Tyroler, H. A. (2000). Anger proneness predicts coronary heart disease risk: Prospective analysis from the atherosclerosis risk in communities (ARIC) study. *Circulation, 101*, 2034–2039.

Wolf, H. U., Lang, W., & Zander, R. (1984). Alkaline haematin D-575, a new tool for the determination of haemoglobin as an alternative to the cyanhaemiglobin method. II. Standardisation of the method using pure chlorohaemin. *Clinica Chimica Acta, 136*, 95–104.

Yi, J. P., Yi, J. C., Vitaliano, P. P., & Weinger, K. (2008). How does anger coping style affect glycemic control in diabetes patients? *International Journal of Behavioral Medicine, 15*, 167–172.