ORIGINAL ARTICLE

Terrorism, Acute Stress, and Cardiovascular Health

A 3-Year National Study Following the September 11th Attacks

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Context: The terrorist attacks of 9/11 (September 11, 2001) present an unusual opportunity to examine prospectively the physical health impact of extreme stress in a national sample.

Objective: To examine the degree to which acute stress reactions to the 9/11 terrorist attacks predict cardiovascular outcomes in a national probability sample over the subsequent 3 years.

Design, Setting, and Participants: A national probability sample of 2729 adults (78.1% participation rate), 95.0% of whom had completed a health survey before 9/11 (final health sample, 2592), completed a Web-based assessment of acute stress responses approximately 9 to 14 days after the terrorist attacks. Follow-up health surveys reassessed physician-diagnosed cardiovascular ailments 1 (n=1923, 84.3% participation rate), 2 (n=1576, 74.2% participation rate), and 3 (n=1950, 78.9% participation rate) years following the attacks.

Main Outcome Measures: Reports of physician-diagnosed cardiovascular ailments over the 3 years following the attacks.

Results: Acute stress responses to the 9/11 attacks were associated with a 53% increased incidence of cardiovascular ailments over the 3 subsequent years, even after adjusting for pre-9/11 cardiovascular and mental health status, degree of exposure to the attacks, cardiovascular risk factors (ie, smoking, body mass index, and number of endocrine ailments), total number of physical health ailments, somatization, and demographics. Individuals reporting high levels of acute stress immediately following the attacks reported an increased incidence of physician-diagnosed hypertension (rate ratios, 2.15 at 1 year and 1.75 at 2 years) and heart problems (rate ratios, 2.98 at 1 year and 3.12 at 2 years) over 2 years. Among individuals reporting ongoing worry about terrorism post-9/11, high 9/11-related acute stress symptoms predicted increased risk of physician-diagnosed heart problems 2 to 3 years following the attacks (rate ratios, 4.67 at 2 years and 3.22 at 3 years).

Conclusion: Using health data collected before 9/11 as a baseline, acute stress response to the terrorist attacks predicted increased reports of physician-diagnosed cardiovascular ailments over 3 years following the attacks.

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On 9/11 (September 11, 2001), the US public experienced a terrorist event of extraordinary scope and traumatic impact. Studies have documented substantial short-term psychological response to 9/11,[1-4] but its effect on physical health has received limited attention.[5] Extremely stressful events may precipitate biological processes that increase one's risk of developing cardiovascular ailments.[6-11] Indeed, during the weeks following 9/11, rates of cardiovascular events increased significantly in New York City and surrounding areas.[12-14] Comparable findings were reported in Florida,[15] suggesting the possibility that direct exposure may not have been necessary for the development of 9/11 stress-related health problems. These provocative findings imply that, for some individuals, indirect exposure to extreme stress may produce physiologic responses that contribute to cardiovascular ailments.

Extreme stress may also initiate psychological processes (eg, acute stress reactions) that parallel physiologic stress reactions. Acute stress[16-18] and early physiologic arousal (heart rate)[19,20] are known risk factors for subsequent development of posttraumatic stress disorder (PTSD). While recognizing that the acute stress disorder (ASD) diagnosis has come under recent scrutiny,[21] we suggest that acute stress responses may have value beyond their potential for predicting PTSD. To the extent that acute stress reactions represent the psychological parallel to complex psychophysiological responses to extreme stress, they may help identify individuals whose re-

sponses to stress place them at greater risk for developing physical illness. Although extreme stress can affect cardiovascular health through the subsequent development of PTSD,[22] it is unknown whether early assessment of stress-related symptoms might enhance our ability to identify individuals whose responses to extreme events increase the risk for experiencing cardiovascular ailments over time.

While acute stress may trigger immediate potentially lethal cardiovascular responses,[23-25] acute, subacute, and chronic stress can gradually increase cardiovascular risk through neurohormonal arousal.[10] This physiologic reactivity may be easily rekindled by trauma reminders, leaving individuals vulnerable to the detrimental effects of arousal over time.[26] Perseverative cognition (eg, worry) may serve as a cognitive mechanism that fuels or prolongs stress-related activation before and after stress, increasing the risk for subsequent stress-related health problems.[27,28] Indeed, fear or worry about terror has been linked to low-grade inflammatory processes associated with cardiovascular disease.[29]

We sought to examine the relationship between 9/11-related acute stress and cardiovascular health in a nationwide, 3-year, prospective, longitudinal study. We expected acute stress responses to be prospectively associated with reports of cardiovascular ailments over time, especially among those who continued to worry about terrorism.

METHODS

OVERVIEW AND DESIGN

We conducted a longitudinal study of mental and physical health following the 9/11 attacks with a national probability sample of the US population in collaboration with Knowledge Networks, Inc (KN), a Web-based survey research company.[30] Knowledge Networks, Inc recruits, maintains, and conducts surveys with a nationally representative Web-enabled panel using an anonymous Web-based method.

The KN panel was developed using traditional probability methods for creating national survey samples and was recruited using stratified random-digit-dial telephone sampling. The random-digit-dial method provides a known nonzero probability of selection for every household having a telephone. The recruitment rate for this study was approximately 53%, and the overall KN panel recruitment response rate, based on American Association for Public Opinion Research standards, averaged 41% when this study began.[31]

To ensure representation of population segments that would not otherwise have Internet access, KN provides panel households with Internet connections and appliances that use televisions (TVs) as monitors (Web TV). Panel members participate in brief Web-based surveys 3 to 4 times monthly in exchange for free Internet access or other compensation if the household is already Web enabled. The KN panel closely tracks the distribution of census counts for the US population on age, sex, race, Hispanic ethnicity, educational level, annual income, geographical region, and employment status.[32] To correct for possible nonresponse bias from panel recruitment and attrition, representative samples are selected for panel surveys using post-stratification weights that weight panel distributions to match benchmarks from the most recent government statistics for sex, age, race, ethnicity, educational level, and geographic region. Samples are drawn with probabilities proportional to panel weights using a systematic sample applied to the eligible panel members. Distributions for panel samples resemble, within sampling error, US population distributions for key demographic variables.

Table 1. Sample Comparisons From NHIS and KN on Important Health Ailments

Condition	KN, %	NHIS, %	% Difference[a]
Heart problems	10.1	10.1	0
Stroke	1.8	2.2	–0.4
Hypertension[b]	16.9	22.6	–5.7
Diabetes mellitus	7.1	6.7	0.4
Ulcer	7.1	7.3	–0.2
Migraine	12.2	14.9	–2.7
Cancer	6.3	6.4	–0.1
Current smoker	24.7	23.3	1.4

Abbreviations: KN, Knowledge Networks, Inc; NHIS, National Health Interview Survey.
[a] The overall absolute difference was 1.36%.
[b] This difference may be attributed to question wording. In the NHIS, the question assesses "hypertension, also known as high blood pressure." However, KN only used the term hypertension in its assessment. This difference in terminology may have contributed to the lower prevalence rate of hypertension reported by the KN sample.

Panel members are notified in password-protected e-mail accounts that an assigned survey is available. Surveys are confidential, self-administered, and accessible any time of day for a designated period; participants can complete a survey only once. Members may leave the panel at any time, and receipt of the Web TV and Internet access is not contingent on completion of any particular survey. Comparison of KN panelists' demographic, attitudinal, and behavioral responses to random-digit-dial samples strongly suggests that they do not respond as "professional" respondents.[33]

Early responses to the terrorist attacks were assessed shortly after 9/11, with follow-up assessments of psychosocial responses to 9/11 conducted at 12, 18, 24, and 36 months post-9/11[30]; health assessments were completed in separate surveys before 9/11 and approximately 1 and 2 years after 9/11. The 36-month (3-year) survey combined health and post-9/11 psychosocial assessments. The institutional review boards of the University of California, Irvine, and the University of Denver approved the design and procedures.

MEASURES

Pre-9/11 Health Survey

Between June 17, 2000, and September 9, 2001, 45 938 adult panelists completed an online health survey, modified from the Centers for Disease Control and Prevention's National Center for Health Statistics annual National Health Interview Survey.[34] Respondents were asked, "Has a medical doctor *ever* diagnosed you as suffering from any of the following ailments?" with prompts for 35 physical and mental health ailments. When estimates from the 2000 National Health Interview Survey were compared with a sample of 25 000 KN health surveys on various outcomes, the average difference was less than 1.5% for current smoking, heart problems, cancer, diabetes mellitus, hypertension, ulcer, migraine, and stroke, supporting the validity of these data[35] (**Table 1**). Items from this survey provided the baseline assessments for our respondents (2592 of the 45 938 panelists).

A physician used the *International Classification of Diseases, Ninth Revision, Clinical Modification*[36] standards to classify the 35 health survey ailments into *International Classification of Diseases, Ninth Revision, Clinical Modification* disease system cat-

egories (eg, circulatory, nervous, and respiratory systems). Physician-diagnosed "heart problems," "hypertension," and "stroke" were coded as "circulatory" (henceforth, cardiovascular) ailments. The total number of cardiovascular ailments (range, 0-3) reported before 9/11 served as the baseline premeasure. Cardiac risk factors, including *International Classification of Diseases, Ninth Revision Clinical Modification* endocrine ailments (high cholesterol level and diabetes mellitus), smoking, and body mass index (BMI), and an index (range, 0-2) representing pre-9/11 physician-diagnosed mental health ailments (none, anxiety disorder or depression, or both) were also recorded.

Demographics

Knowledge Networks, Inc, provided data on age, sex, marital status, ethnicity, educational level, and household income, and imputed missing values for annual income with mean income scores for respondent's census block.

Early Response to the Terrorist Attacks

Between September 20 and October 4, 2001, a random sample of 2729 adults (78.1% of the 3496 sampled) from the KN panel completed a modified Stanford Acute Stress Reaction Questionnaire; more than 75% did so 9 to 14 days after the attacks.[37] Items were revised to a 6.5-grade Kincaid reading level, and respondents reported whether they "experienced" or "did not experience" 9/11 stress-related symptoms. Of these respondents, 2592 (95.0% of 2729) had also completed the pre-9/11 health survey, and this group served as the final health sample for the present report.

Individuals whose symptoms met the *DSM-IV* criteria B, C, D, and E for ASD (≥3 dissociative symptoms, ≥1 reexperiencing or intrusive symptom, ≥1 avoidance symptom, and ≥1 arousal or anxiety symptom) were classified as having "high" acute stress.[38] Because most respondents did not meet *DSM-IV* criterion A (direct exposure) and we did not assess symptom duration, respondents were not assumed to have ASD.

Post-9/11 Health

Surveys comparable to the pre-9/11 health survey were readministered annually over the next 3 years to all available respondents from the original pool of 2592 who had completed the pre-9/11 health and early response surveys. Respondents who left the KN panel were allowed to complete the survey online or by mail. Type of survey completed was unrelated to cardiovascular ailments in all assessments. Online survey completion times ranged from 12 to 15 minutes.

Between October 10 and December 6, 2002, 1923 of 2281 available respondents completed the health survey online (84.3% of those fielded and 74.2% of the 2592 respondents who completed the pre-9/11 health and early response surveys). Between October 10, 2003, and March 31, 2004, 1576 of 2123 available respondents completed the health survey (1491 online and 85 by mail; 74.2% of those fielded and 60.8% of respondents who completed the pre-9/11 health and early response surveys). Around the 3-year 9/11 anniversary (September 12 to November 2, 2004), 1950 of 2471 available respondents completed the health survey (1296 online and 654 by mail; 78.9% of those fielded and 75.2% of respondents who had completed the pre-9/11 health and early response surveys).

The pre-9/11 and 1-, 2-, and 3-year post-9/11 health surveys were missing physician-diagnosed ailments for approximately 8% to 9%, 6% to 7%, less than 1%, and less than 1% of respondents, respectively. Patterns of missing data were evaluated using the methods of Little and Rubin[39] (missing at random). Because these tests were nonsignificant ($P > .10$), missing data were imputed within age groups using the expectation maximization method for pre-9/11 and 1-year post-9/11 health data.

Variables identical to baseline pre-9/11 health indices were created representing total number (range, 0-3) of physician-diagnosed cardiovascular ailments reported 1, 2, and 3 years after the attacks. Cardiac risk factors (endocrine ailments and BMI) were also computed for each year.

Somatization

Subjects' tendency to report physical symptoms was assessed 2 ways. First, because somatization is associated with symptoms from multiple systems,[40,41] total number of physician-diagnosed physical health ailments each year (including pre-9/11) was considered a proxy for somatization. Second, subjects completed the somatization subscale from the 18-item Brief Symptom Inventory,[42] a standardized scale with a valid reliable somatization subscale. Reliability was excellent for all assessments ($\alpha = .81$).

Stressful Life Event Exposure

Lifetime exposure to stressful events was assessed during the year after 9/11 by asking participants whether they had ever experienced each of 37 negative events (eg, natural disaster, child abuse) and the age(s) at which they occurred.[30] Ongoing exposure was reassessed with each survey. This measure was modified from the Diagnostic Interview Schedule trauma section,[43] was expanded to include a wider variety of stressful events using primary care patients' reports of lifetime stress,[44] and has provided rates of specific events comparable to those in other community samples.[45,46] Continuous variables were computed representing the number of pre-9/11 childhood (≤17 years) and adulthood stressors. Stressful events directly related to physical health (eg, had a serious accident or illness) were excluded from analyses to avoid confounding stress and health outcomes. A continuous count of events that occurred following the attacks was also computed.

Exposure to the 9/11 Attacks

Items modified from prior research on disaster exposure[47,48] assessed respondents' 9/11-related exposure (degree of exposure to and loss from the attacks, including hours of daily television coverage watched). Individuals were categorized into 1 of 3 levels of exposure: direct exposure (ie, being in the World Trade Center [WTC] or Pentagon, seeing or hearing the attacks in person, or having a close relationship with someone in the targeted buildings or airplanes [ie, meeting criterion A1 for ASD and PTSD]), live media exposure (ie, watching the attacks on television live as they occurred), and no live exposure (ie, seeing videotaped replay or learning of the attacks only after they occurred). US Postal Service residential zip codes were used to compute azimuth distance from the WTC to measure the degree of impact (similar to earthquakes, with lessening impact as distance from the "epicenter" increases). Residency in New York City or Washington, DC, at the time of the attacks was also recorded.

Worries About Terrorism

Each annual 9/11-related survey included 2 items assessing ongoing worries about terrorism (eg, "I worry that an act of terrorism [bioterrorism, hijacking, etc] will personally affect me or someone in my family in the future"). Items were scored on a 5-point Likert scale (1 indicates never; and 5, all the time) and combined as an index of ongoing worry. Reliability was excellent ($\alpha = .82$ to $.84$ for all).

OVERVIEW OF ANALYSES

A computer program (Stata 7.0; Stata Corp, College Station, Texas) designed to handle weighted analysis of complex longitudinal survey data was used, and it provided necessary adjustments of standard errors. Weighted data were adjusted for differences in probabilities of selection and nonresponse within and between households. Poststratification weights were calculated by deriving weighted sample distributions along combinations of demographics and regional status. Similar distributions were calculated using recent US Census Bureau Current Population Survey and KN panel data. Cell-by-cell adjustments over various univariate and bivariate distributions were calculated to make weighted sample cells match those of the US census and KN panel.[49,50] This process was repeated iteratively to reach convergence between the weighted sample and benchmark distributions from the 2001 Current Population Survey.[51] All statistics calculated from the KN panel are subject to sampling variability and nonsampling error. Quality control and edit procedures ensure that the effects of these errors on final survey estimates are minimal.

Preliminary analyses examined time, demographics, pre-9/11 mental health and cardiac ailments, pre- and post-9/11 cardiac risk factors, 9/11 exposure, pre-9/11 lifetime and post-9/11 stressful event exposure, pre- and post-9/11 somatization, and acute stress responses as predictors of cardiovascular ailments over 3 years after the attacks. Nonsignificant variables ($P > .05$) were removed from analyses, and multivariate models were estimated, adjusting for significant variables. The final, most parsimonious, models were obtained by trimming nonsignificant variables from the multivariate model. Effect sizes are presented as adjusted incident rate ratios and adjusted relative risk ratios.

Longitudinal generalized estimating equations (GEEs) for Poisson distributions provided incidence rates over time. Cases missing demographics, 9/11 exposure, and stressful event data and those who had not completed at least 3 of 4 health assessments were excluded, leaving 1760 cases for the final GEE analyses. Because Poisson techniques may violate assumptions about dispersion of residuals (eg, overdispersion), inflate goodness-of-fit tests, and erroneously reduce standard errors, generalized linear modeling (Stata 7.0) was used to adjust for overdispersion.[52] The generalized linear modeling and GEE findings reported later were comparable.

A multinomial logistic regression procedure (Stata 7.0) then identified predictors of cardiac ailments annually. Because few individuals reported strokes, and most of these individuals also reported having hypertension or heart problems, the categorical outcome for these analyses compared individuals with hypertension only, heart problems only, and 2 or more cardiac conditions (ie, any combination of hypertension, heart problems, and stroke) with individuals reporting no cardiac conditions during the 3-year period. Interactions examined whether the relationship between post-9/11 cardiovascular ailments and acute stress symptoms depended on time, age, sex, lifetime stress, or ongoing worries about terrorism. Interactions were initially tested using the full sample—only ongoing worry was significant. The 2- and 3-year ongoing worry scores were then dichotomized using a median split; multinomial logistic regression analyses were conducted within low- and high-worry groups separately.

RESULTS

SAMPLE

The sample was 52.2% female, 61.3% married, 80.0% white, and 10.6% Hispanic. Of the sample, 24.0% had completed some college and 24.0% had a bachelor's degree. For 3 years following 9/11, our sample consistently compared favorably with US Census Bureau annual statistics on age, sex, ethnicity, marital status, and educational level, suggesting that our sample remained demographically similar to the US population.[51] Most weighted differences are within sampling error, although low- to middle-income households were overrepresented (eTable; available at http://www.archgenpsychiatry.com).

ANALYSIS OF NONPARTICIPANTS

Individuals who completed the early response survey (n=2729) did not differ from nonresponders (n=767) in terms of education or marital status. However, responders were older than nonresponders (mean age, 47 vs 39 years; $t_{3494}=12.12$, $P<.001$), reported a slightly lower annual income ($35 000-$40 000 vs $40 000-$50 000; $t_{2886}=2.61$, $P<.009$), and were more likely to be white than black or Hispanic ($\chi^2_3=51.98$, $P<.001$). Individuals who completed the early response survey and the pre-9/11 health survey (n=2592) did not differ significantly from nonrespondents (n=904) on age, sex, marital status, ethnicity, educational level, or income ($P=.29$).

Attrition analyses conducted for each annual follow-up survey revealed no differences between respondents and nonrespondents on pre-9/11 cardiovascular or mental health, acute stress symptoms, sex, ethnicity, marital status, or income. Respondents at each follow-up were older than nonrespondents (1 year: mean, 50 vs 42 years [$t_{2719}=-11.75$, $P<.001$]; 2 years: mean, 51 vs 42 years [$t_{2717}=-14.51$, $P<.001$]; and 3 years: mean, 50 vs 42 years [$t_{2717}=-13.05$, $P<.001$]) and had completed more years of education than nonrespondents at each year (1 year: $\chi^2_4=13.95$, $P<.01$; 2 years: $\chi^2_4=18.76$, $P<.001$; and 3 years: $\chi^2_4=35.18$, $P<.001$). Individuals included in GEE analyses (n=1760) were not significantly different from excluded individuals in terms of pre-9/11 cardiovascular ($P=.087$) or mental health ($P=.21$) status, acute stress symptoms ($P=.74$), sex ($P=.64$), marital ($P=.74$) or educational ($P=.42$) status, or income ($P=.31$). Complete cases were, however, older than those excluded (mean, 50 vs 42 years; $t_{2717}=-11.45$, $P<.001$) and less likely to be black than white ($\chi^2_3=17.47$, $P<.001$).

9/11-RELATED EXPOSURE AND EARLY RESPONSE

Most respondents watched the attacks live on television (1393 [63.2%]), one-third reported no live or direct exposure to the attacks (731 [33.2%]), and a few reported direct exposure (79 [3.6%]). On 9/11, 39 of the respondents (1.6%) lived in Washington, DC; 97 (4.1%) lived within 40 km of the WTC; 144 (6.0%) lived between 41 and 160 km of the WTC; 504 (21.1%) lived between 161 and 800 km of the WTC; 684 (28.7%) lived between 801 and 1600 km of the WTC; and 958 (40.1%) lived more than 1600 km from the WTC. High levels of acute stress symptoms were reported by 10.7% of respondents (unweighted) (weighted, 12.3% of respondents).

CARDIOVASCULAR AILMENTS POST-9/11

Rates of reported physician-diagnosed cardiovascular ailments increased during the 3-year period from 21.5% pre-9/11 (weighted, 18.7%) to 30.5% at 3 years post-9/11

Table 2. GEE Model Predicting Change in the Number of Cardiac Ailments Reported Over 3 Years Following the 9/11 Terrorist Attacks[a]

Variable[b]	Adjusted Incident Rate Ratio (95% Confidence Interval)[c]	*P* Value
Age, y		
35-49	1.91 (1.22-2.98)	<.005
50-64	3.30 (2.17-5.03)	<.001
65-79	4.59 (2.97-7.08)	<.001
≥80	4.17 (2.58-6.76)	<.001
African American ethnicity	1.44 (1.14-1.83)	.002
Pre-9/11 self-reported number of physician-diagnosed cardiac ailments	2.55 (2.31-2.82)	<.001
Time-varying cardiac risk factors		
No. of endocrine ailments	1.10 (1.01-1.21)	.045
Ex-smokers	1.16 (1.00-1.36)	.05
Other time-varying covariates		
No. of physician-diagnosed physical ailments	1.05 (1.02-1.07)	<.001
BSI somatization subscale score	1.06 (0.89-1.25)	.53
9/11 Response (high vs low acute stress)[d]	1.53 (1.19-1.97)	<.001

Abbreviations: BSI, Brief Symptom Inventory; GEE, generalized estimating equations; 9/11, September 11, 2001.

[a] Wald χ^2_{12}=1183.46, $P<.001$ (n=1760). Adjusted incident rate ratios for variables included in the final model are given; the ratios are adjusted for the other variables in the model. The following blocks of variables were tested for inclusion in the final models: (1) demographics (ie, sex, age, marital status, race, ethnicity, education, and annual income); (2) 3-year longitudinal measures of the number of physician-diagnosed physical and mental health ailments, post-9/11 somatization, and *International Classification of Diseases, Ninth Revision, Clinical Modification* endocrine ailments; (3) pre-911 risk factors for cardiovascular ailments (ie, cardiac ailments, body mass index, and smoking); (4) lifetime exposure to stressful events (ie, childhood, adulthood, and post-9/11 events); (5) 9/11-related exposure; and (6) acute stress response. Variables that did not reach significance in preliminary models ($P>.05$) were not included in the final model.

[b] The reference group for age is adults younger than 35 years; for ethnicity, all other ethnicities (non-Hispanic whites, Asians, and Hispanics); and for ex-smokers, the reference group is nonsmokers, social smokers, and current smokers.

[c] The adjusted incident rate ratios represent the rate of disease occurrence in the exposed group divided by the rate of disease occurrence in the unexposed group (reference group) after adjusting for covariates in the model. The ratios show whether an exposure was "preventative" of (<1), "causative" of (>1), or unrelated to (=1) the rate of disease outcome in the exposed population vs the unexposed population.

[d] The 9/11 responses include dichotomous high vs low levels of acute stress symptoms (ie, meeting criteria B, C, and D of the *DSM-IV* acute stress disorder diagnosis).

Table 3. Relative Risk Ratio for High 9/11-Related Acute Stress Predicting Specific Cardiac Ailments 1, 2, and 3 Years After the 9/11 Attacks[a]

Cardiac Ailment Predicted by Acute Stress Symptoms	Adjusted Relative Risk Ratio (95% Confidence Interval)		
	1 y	2 y	3 y
Hypertension	2.15 (1.20-3.84)[b]	1.75 (0.93-3.29)[c]	1.15 (0.55-2.38)
Heart problems	2.98 (1.19-7.49)[d]	3.12 (1.37-7.12)[b]	1.38 (0.55-3.41)
Comorbid cardiac ailments	2.91 (0.97-8.73)[e]	1.96 (0.62-6.20)	1.82 (0.65-5.11)

Abbreviation: See Table 2.

[a] The 1-year Wald χ^2_{30} = 285.29, $P<.001$ (n=1666); 2-year Wald χ^2_{30} = 308.16, $P<.001$ (n = 1449); and 3-year Wald χ^2_{30} = 235.61, $P<.001$ (n=1615). Adjusted relative risk ratios for acute stress symptoms are given. The ratios are adjusted for significant variables: (1) demographics (ie, sex, age, marital status, race, ethnicity, education, and annual income), (2) pre-9/11 physician-diagnosed cardiac and mental health ailments, (3) cardiac risk factors (ie, *International Classification of Diseases, Ninth Revision, Clinical Modification* endocrine ailments, body mass index, and smoking), (4) lifetime exposure to stressful events (ie, childhood, adulthood, and post-9/11 events), (5) 9/11- related exposure, (6) total number of pre-9/11 physician-diagnosed health ailments, and (7) post-9/11 somatization. Variables that did not reach significance in preliminary models ($P>.05$) were not included in the final multivariate models. The final, most parsimonious, model was obtained by trimming nonsignificant variables from the multivariate model.

[b] $P<.01$.

[c] $P<.10$.

[d] $P<.05$.

[e] $P<.06$.

(weighted, 27.3%). Within-subject analyses indicated an increased incidence of cardiac ailments each year following 9/11 (overall, χ^2_3=126.30, $P<.001$), even after adjusting for pre- and post-9/11 cardiac risk factors (endocrine ailments, BMI, and smoking), somatization, and demographics. Pre-9/11 mental health, 9/11-related exposure, and residential proximity to the attacks (New York City or Washington, DC) were unrelated to cardiac ailments during the 3 years following 9/11, after adjusting for pre-9/11 cardiac ailments. Although pre-9/11 cardiac ailments strongly predicted subsequent cardiovascular ailments, they did not predict acute stress responses (ie, no reverse causation).

Table 2 presents findings from weighted GEE analyses predicting the number of cardiovascular ailments reported over 3 years following 9/11. High 9/11-related acute stress symptoms predicted increased incidence of cardiovascular ailments over 3 years following the attacks, even after adjusting for pre-9/11 cardiovascular ailments and mental health, age, ethnicity, pre- and post-9/11 cardiac risk factors (endocrine ailments, smoking, and BMI), pre- and post-9/11 somatization, and lifetime or ongoing stressful event exposure. Individuals meeting criteria B, C, and D of *DSM-IV* for ASD at the early assessment had a 53% higher incidence of reporting physician-diagnosed cardiovascular ailments over 3 years following 9/11 when compared with respondents with low acute stress symptoms. Individuals older than 35 years ($P<.005$ for all) and those with preexisting cardiovascular ailments ($P<.001$) had the highest adjusted incidence rates for subsequent cardiovascular ailments. Separate GEE analyses conducted for heart problems, stroke, and hypertension individually revealed a comparable pattern for each ailment.

Multinomial logistic regression clarified which cardiac ailments were associated with acute stress symptoms for each annual follow-up survey (**Table 3**). Individuals who reported high acute stress symptoms immediately following 9/11 were nearly twice as likely to report being diagnosed as having hypertension and approximately 3 times more likely to report being diagnosed as having heart problems 1 and 2 years following the attacks. A similar trend appeared for 2 or more cardiac ailments 1 year after the attacks ($P<.06$).

Interactions demonstrated that, over time, acute stress symptoms predicted reports of cardiac ailments 2 and 3 years post-9/11, especially among respondents reporting ongoing worries about terrorism. Although acute stress

Table 4. Relative Risk Ratio for High 9/11-Related Acute Stress Predicting Heart Problems 2 and 3 Years After 9/11 Attacks for Low vs High Levels of Worry About Terrorism[a]

Ongoing Worry About Terrorism	Time After the Attacks, y	
	2	3
Low	0.99 (0.19-5.07) [550: 523/27]	0.37 (0.10-1.36) [946: 873/73]
High	4.67 (1.80-12.16) [894: 779/115][b]	3.22 (1.05-9.85) [701: 606/95][c]

Abbreviation: See Table 2.

[a] Data are given as adjusted relative risk ratio (95% confidence interval) [total number of cases for comparison: no acute stress/yes acute stress] for heart problems as predicted by the interaction between ongoing worry about terrorism and acute stress symptoms immediately following the 9/11 attacks. The 2-year Wald $\chi^2_{18}=192.52$, $P<.001$; and the 3-year Wald $\chi^2_{18}=107.21$, $P<.001$. The ratios are adjusted for the following significant variables: (1) demographics (ie, sex, age, marital status, race, ethnicity, education, and annual income), (2) pre-9/11 physician-diagnosed cardiac and mental health ailments, (3) pre- and post-9/11 cardiac risk factors (ie, *International Classification of Diseases, Ninth Revision, Clinical Modification* endocrine ailments, body mass index, and smoking), (4) lifetime exposure to stressful events (ie, childhood, adulthood, and post-9/11 events), (5) 9/11-related exposure, (6) total number of concurrent physician-diagnosed mental and physical health ailments, and (7) post-9/11 somatization. Variables that did not reach significance in preliminary models ($P>.05$) were not included in the multivariate model. The final, most parsimonious, model was obtained by trimming nonsignificant variables from the multivariate model.

[b] $P<.01$.

[c] $P<.05$.

symptoms had no direct relationship with cardiac ailments 3 years post-9/11, they predicted increased reports of heart problems among individuals who reported ongoing worry about terrorism at both 2 and 3 years following the attacks (**Table 4**).

OTHER AILMENTS POST-9/11

Pre-9/11 physician-diagnosed mental health disorders were significantly associated with the total number of physical health ailments reported over 3 years following the attacks ($P=.005$), although they were not specifically associated with an increased risk for cardiovascular ailments ($P=.11$). Rates of other noncardiovascular ailments (respiratory, gastrointestinal, genitourinary, and musculoskeletal) also increased over time post-9/11. However, after controlling for pre-9/11 levels of each ailment and total number of physical health ailments reported over time, acute stress responses were significantly associated only with cardiovascular ailments ($P=.03$).

COMMENT

The 9/11 terrorist attacks have been indirectly linked to increased rates of cardiovascular problems (arrhythmias) in small studies[12-15] of high-risk patients during the early months following 9/11. In this study, the use of a large, representative, national sample and the longitudinal collection of health ailments before and after the 9/11 attacks provided a unique opportunity to examine the role of acute stress response and health outcomes on a national scale over time. To our knowledge, this is the first study to demonstrate that acute psychological responses to 9/11 predicted increased incidence in reports of physician-diagnosed cardiovascular ailments for 3 years in adults, most of whom did not have known preexisting cardiac disease. Moreover, ongoing worries about terrorism seemed to exacerbate the risk of physician-diagnosed heart problems 2 and 3 years later among individuals with high 9/11-related acute stress.

Other research[6,22] addressing the relationship between extreme stress and physical health has often assumed that direct exposure and subsequent development of PTSD are necessary preconditions linking these experiences with health conditions. A recent study[5] found that adults who survived in collapsed or seriously damaged buildings during the WTC attacks reported new onset of physical health ailments, including respiratory, gastrointestinal, neurologic, and dermatologic problems. Our data further suggest the importance of considering the potential public health impact of indirect exposure to extreme stress because most of our respondents were exposed to the attacks only by watching television. Mass media coverage of these attacks likely expanded their impact geographically,[53] and the unexpected, uncontrollable, and unique nature of the attacks enhanced their impact as well.

To our knowledge, this is also the first study with baseline health status documented before a specific stressor, early assessment of stress responses following the event, and health status reassessed annually for 3 years. Our prospective longitudinal design allowed rigorous testing of the stress–response–health outcome relationship. Timing of the acute stress response assessment was critical because rapid assessment allowed us to evaluate early predictors of long-term health outcomes. This is unlike many studies[54,55] that interview respondents many years after the initial stressor, leaving unknown the impact of time and ongoing life experience on reports of stress-related symptoms and health.

Several theories help explain how acute stress reactions to highly stressful events might contribute to the development of cardiovascular ailments. Because acute stress reactions often accompany underlying stress-related physiologic arousal initially,[19,20] they may mark the onset of physiologic processes that ultimately affect cardiovascular health. The allostatic load theory[56] posits that activation of the sympathetic nervous system and hypothalamic-pituitary-adrenal axis sets off a neurohormonal cascade that supports coping initially but threatens health if it persists after the event has passed. Following 9/11, 2 wars, economic downturn, job loss, and subsequent terrorist attack warnings may have perpetuated the stress response and increased the allostatic load on individuals over time. Persistent physiologic responses associated with chronic stress exposure are likely to be detrimental to cardiovascular health.[22,56] Ongoing exposure to stress increases blood pressure; promotes atherosclerosis, hypercoagulation, and arrhythmias[10]; and increases the risk of myocardial infarction through neurohormonal arousal.[57] Our finding that high acute stress increased risk of cardiovascular events among individuals with ongoing worries about terrorism suggests that chronic reminders of the threat (eg, terrorism alerts, worrying, or both) may have prolonged the physi-

ologic arousal in some people, rendering them vulnerable to cardiovascular ailments. This transition from acute to chronic stress may explain why acute stress did not directly predict ailments 3 years post-9/11—by that time, the impact of 9/11 may have manifested through ongoing stress, as indexed by ongoing worry about subsequent terrorism.

Several physiologic pathways have been implicated in biological theories of PTSD.[6,22,56] To the extent that acute stress reactions represent an early form of posttraumatic stress that parallels neurohormonal stress processes, they may help identify individuals whose immediate psychophysiological responses place them at greater risk for subsequent PTSD and cardiovascular ailments. While prior research has evaluated the utility and validity of using acute stress symptoms to predict PTSD, our research extends this work by suggesting the need to consider how acute reactions influence physical health as well. Moreover, acute stress responses may be an early independent risk factor for cardiovascular disease. We found that although pre-9/11 mental health problems predicted acute stress symptoms,[3] they did not predict increased risk for cardiovascular ailments. The specificity of acute stress symptoms in their ability to predict cardiovascular ailments, but not other types of health ailments, suggests that this may be an important area for further study. It is also plausible that preexisting physical health problems render individuals vulnerable to acute stress following trauma or terrorism, which then predicts subsequent health problems. Although we found no supporting evidence for reverse causation in our data, this remains an important area for future study.

This study has several strengths. Its prospective and longitudinal design allowed identification of predictors of reports of physician-diagnosed cardiovascular ailments over 3 years following 9/11. By studying a national sample of individuals exposed to the same event, we did not limit our investigation to specialized populations. We controlled for ongoing stress that may have contributed to subsequent health problems by including the number of post-9/11 stressors as a covariate in our analyses. Our health measure had been benchmarked against the National Health Interview Survey, which itself has been validated against medical records.[58] Finally, all analyses controlled for cardiac risk factors, such as pre- and post-9/11 endocrine ailments (high cholesterol levels and diabetes mellitus), BMI, and smoking, and the individual's tendency to report physical and somatic symptoms.

Nevertheless, self-report measures of physician diagnoses may be influenced by recall biases and are open to interpretation by respondents. Because acute stress did not directly predict 3-year cardiovascular ailments, it is possible that our respondents interpreted "heart problems" to include benign ailments (eg, palpitations) that differ in nature and duration from serious cardiac conditions. Without medical record corroboration, we cannot assume that all individuals reporting physician-diagnosed heart problems had true cardiovascular disease. Variability also existed in the timing of the pre-9/11 health survey. However, we found no significant differences in the number of ailments reported by early (first 2 months) vs late (last 2 months) responders. Although our initial sample closely paralleled the US population census, small but significant trends to lose younger (aged <35 years), black, and less educated respondents over time makes generalization of our findings to these populations difficult. Finally, although attrition over time could introduce response bias (eg, illness behavior, help seeking) that might also explain our results, research has demonstrated that KN panelists are comparable to National Health Interview Survey respondents on prior year physician and emergency department visits and hospitalizations.[35] Because no substantial differences emerged on markers of health care use, this is not a likely explanation for our results.

In conclusion, many advances have been made in understanding the mental and physical health effects of extreme stress. We extend this work by linking acute stress responses to increases in physician-diagnosed cardiovascular ailments in a national sample of individuals following the 9/11 attacks, most of whom did not report preexisting cardiac disease. These findings highlight the possibility that acute stress reactions may indicate subsequent vulnerability to potentially serious health problems.

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Additional Information: The eTable is available at http://www.archgenpsychiatry.com.

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