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Title:
Coping with oil spills: oil exposure and anxiety among residents of Gulf Coast states after the Deepwater Horizon oil spill

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Abstract:
Introduction: In April 2010, a fatal explosion on the Deepwater Horizon drilling rig in the Gulf of Mexico resulted in the largest accidental marine oil spill in history. This research describes the association of oil exposure with anxiety after the Deepwater Horizon oil spill and evaluates effect modification by self-mastery, emotional support, and cleanup participation.
Methods: To assess the impacts of the Deepwater Horizon oil spill, the Centers for Disease Control and Prevention conducted the Gulf States Population Survey, a random-digit-dial telephone cross-sectional survey completed between December 2010 and December 2011 with 38,361 responses in four different Gulf Coast states: Louisiana, Florida, Alabama, and Mississippi. Anxiety severity was measured using the Generalized Anxiety Disorder symptom inventory. We used Tobit regression to model underlying anxiety as a function of oil exposure and hypothesized effect modifiers, adjusting for socio-demographics.
Results: Latent anxiety was higher among those directly exposed to oil than among those who were not directly exposed to oil in confounder-adjusted models (β=2.84, 95% CI: 0.78, 4.91). Among individuals exposed to oil, there was no significant interaction between participating in cleanup activities and emotional support for anxiety (*P*=0.16). However, among those directly exposed to oil, in confounder-adjusted models, participation in oil spill cleanup activities was associated with lower latent anxiety (β=-3.50, 95% CI: -6.10, -0.90).
Conclusion: Oil contact was associated with greater anxiety, but this association appeared to be mitigated by cleanup participation.

Keywords:
Generalized anxiety; disaster recovery; mental health; emergency response; Gulf States Population Survey (GSPS)

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The authors declare no conflicts of interest with this work.

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Coping with oil spills: oil exposure and anxiety among residents of Gulf Coast states after the Deepwater Horizon oil spill

ABSTRACT

Introduction: In April 2010, a fatal explosion on the Deepwater Horizon drilling rig in the Gulf of Mexico resulted in the largest accidental marine oil spill in history. This research describes the association of oil exposure with anxiety after the Deepwater Horizon oil spill and evaluates effect modification by self-mastery, emotional support, and cleanup participation.

Methods: To assess the impacts of the Deepwater Horizon oil spill, the Centers for Disease Control and Prevention conducted the Gulf States Population Survey, a random-digit-dial telephone cross-sectional survey completed between December 2010 and December 2011 with 38,361 responses in four different Gulf Coast states: Louisiana, Florida, Alabama, and Mississippi. Anxiety severity was measured using the Generalized Anxiety Disorder symptom inventory. We used Tobit regression to model underlying anxiety as a function of oil exposure and hypothesized effect modifiers, adjusting for socio-demographics.

Results: Latent anxiety was higher among those directly exposed to oil than among those who were not directly exposed to oil in confounder-adjusted models (β=2.84, 95% CI: 0.78, 4.91). Among individuals exposed to oil, there was no significant interaction between participating in cleanup activities and emotional support for anxiety (*P*=0.16). However, among those directly exposed to oil, in confounder-adjusted models, participation in oil spill cleanup activities was associated with lower latent anxiety (β=-3.50, 95% CI: -6.10, -0.90).

Conclusion: Oil contact was associated with greater anxiety, but this association appeared to be mitigated by cleanup participation.

1. INTRODUCTION

1.1 Impacts and health effects of the Deepwater Horizon oil spill

In April 2010, a fatal explosion on the Deepwater Horizon drilling rig in the Gulf of Mexico resulted in the largest accidental marine oil spill in history.[1] The explosion killed 11 workers and released over 4 million barrels of oil into the Gulf, and in an effort to remediate the spill, an additional 2.1 million gallons of dispersants were released onto the ocean surface to break up the crude oil.[2, 3] Over a span of three months, the spill contaminated more than 68,000 square miles, ranging from Texas to Florida.[4-6] This resulted in damages to ecosystems in affected areas, causing widespread impacts on both the tourism and fishing industries.[3]

Several thousand workers and volunteers helped with oil spill cleanup activities.[3] As a result of exposure to the oil spill, an increased prevalence of physical symptoms such as shortness of breath, wheezing, coughing, headaches, painful joints, and chest pain have been found in these participants.[6] Qualitative studies of exposed fishermen, families, and oil industry workers on the Gulf Coast also reported that exposed individuals described uncertainty about the future and developed generalized anxiety, stress reactions, and posttraumatic stress disorder months after the explosion.[1]

1.2 Evidence of oil-induced associations before this study and added value

Previous studies of cleanup participation during the Deepwater Horizon oil spill have found that participants involved in cleanup operations had a significantly higher prevalence of

mental health impacts, including depression and PTSD.[7] After accounting for demographic characteristics and other predictors such as pre-existing conditions, residential proximity to the oil spill, and previous experience of disasters, results still provide evidence of mental health consequences for cleanup participants.[7] Several studies have focused on the associations of mental health and response workers by comparing cleanup participants to populations not involved with the disaster.[7-9] Few studies have compared cleanup participants to non-cleanup participants among populations impacted by the disaster. A recent study on the associations of oil contact and depression found that respondents with oil contact had lower depression severity if they participated in cleanup activities, compared to exposed individuals who did not participate in cleanup activities.[10]

The objective of this cross-sectional study was to test the hypotheses that oil exposure was associated with anxiety after the Deepwater Horizon oil spill and that there was effect modification of that association by self-mastery (coping ability), emotional support, and cleanup participation. To the best of our knowledge, studies to date have not examined the associations of anxiety and individuals participating in oil spill cleanup activities compared to individuals not participating in oil spill cleanup activities within populations directly affected by the oil spill.

2. METHODS

2.1 Study population

Following the Deepwater Horizon oil spill, the Substance Abuse and Mental Health Services Administration and the Centers for Disease Control and Prevention published a report

titled, "*Behavioral Health in the Gulf Coast Region Following the Deepwater Horizon Oil Spill*" that described the behavioral health of residents impacted by the Deepwater Horizon oil spill.[11] Included in the report was the Gulf States Population Survey, a random-digit-dial telephone survey conducted between December 2010 and December 2011 to assess the impacts of the Deepwater Horizon oil spill.[11] The survey was created to provide information on the mental health status of the coastal population in areas affected by the oil spill.[12] The Gulf States Population Survey, a publicly available, coded dataset, included 38,361 responses from individuals aged ≥18 years old residing in Louisiana, Florida, Alabama, and Mississippi.[12] The majority of the interviews were conducted in 25 coastal counties or parishes within 32 miles of fishing locations closed due to the oil spill.[12] To compare the results from coastal counties to noncoastal counties, 27,947 interviews were conducted in coastal counties, and 10,414 interviews were conducted in noncoastal counties.[12]

2.2 Data description

There were 16 questions found in the Gulf States Population Survey that measured contact with oil from the Deepwater Horizon oil spill. Direct oil contact was assessed by the question, "Did you have direct contact with the oil from the Gulf oil spill? (yes/no). Questions from the 7-item Generalized Anxiety Disorder (GAD-7) questionnaire were also used to self-screen for moderate to severe cases of generalized anxiety.[12] Of the individuals contacted for the Gulf States Population Survey, 44.2% completed the interview.[13] The data for the Gulf States Population Survey was weighted to adjust for United States Census population estimates, and the survey design, sampling methods, and weights were based on methods used for the Behavioral

Risk Factor Surveillance System.[14] Analysis of this resource does not qualify as Human Subjects Research under 45 CFR 46.102 because this is a publicly available deidentified dataset.

2.3 Analysis

In the Gulf States Population Survey, the observed GAD-7 scores of survey respondents could range from 0 to 21 for anxiety symptom severity.[12] We conceptualized mental health as being on a continuous gradient and therefore assumed there to be left-censoring of "negative" anxiety (e.g., calmness, confidence) and right-censoring of extreme anxiety by the GAD-7 psychometric instrument. Tobit regression is a tool for modeling a latent dependent variable assumed to be normally-distributed whose true values are censored by the measurement instrument.[15] Therefore, under the assumption that latent anxiety in the population was normally distributed rather than bounded between 0 and 21, Tobit regression was used to model underlying latent anxiety as a latent variable. Figure 1 presents a histogram of observed GAD-7 scores along with modeled Tobit latent anxiety severity.

We adjusted models for age (continuous), gender (male/female), race (white/black/other), Hispanic ethnicity (yes/no), smoking status (never/former/current), binge drinking (yes/no), exercise (yes/no), marital status (married/not currently married), and employment status (employed [employed for wages, self-employed] / not employed [out of work, unable to work] / other [homemaker, student, retired]). We further added interaction terms with how often people felt they had the emotional support they needed (always/usually/sometimes/rarely/never), and perceived self-mastery, a confirmatory factor analysis score derived from 5 items (strength of agreement with "I have little control over the things that happen to me," "What happens to me in

the future mostly depends on me," "I can do just about anything I really set my mind to do," "I am confident in my ability to handle unexpected problems," and "When I need suggestions about how to deal with a personal problem, I know there is someone I can turn to").[16]

In fully adjusted models, we tested for an interaction between direct contact with oil and participation in oil spill cleanup efforts. We also examined the association of cleanup participation with anxiety, controlling for the same confounders among the subpopulation with direct oil exposure, and tested for interactions with emotional support and self-mastery.

Survey estimation methods were used to account for the survey design with singleton primary sampling units treated as certainty units.[17, 18] Missing data were handled by multiple imputation by chained equations with 80 imputations.[19] All analyses were conducted using Stata/IC 16.1. The Stata code used for all of the analyses can be found in Appendix A.

3. RESULTS

3.1 Population and sample demographics

Characteristics of the population are provided in Table 1, according to whether they had direct contact with oil from the Deepwater Horizon oil spill, and whether they participated in cleanup activities. These estimates incorporate multiple imputation and survey estimation for population inference. Characteristics of the sample population according to direct oil contact and participation in cleanup activities during the Deepwater Horizon oil spill are provided in Table 2.

3.2 Oil contact with anxiety

In fully adjusted models, latent anxiety was higher (β = 2.84, 95% CI: 0.78, 4.91, Wald test *P* = 0.01) among individuals directly exposed to oil compared to individuals not exposed to oil (Table 3). There was no heterogeneity in the oil-anxiety association across levels of emotional support (always, usually, sometimes, and rarely or never) (4-degrees-of-freedom F test: *P* = 0.97), with the lowest β-coefficient of 0.98 (95% CI: -0.86, 2.82) for "usually supported" and the highest β-coefficient of 4.65 (95% CI: 0.41, 8.89) for "always supported" (Table 4). There was also no significant modification of the association between oil exposure and anxiety by self-mastery (Wald test *P* = 0.12). Among those exposed to oil, individuals with lower self-mastery scores (minimum in sample: -4.04) had higher latent anxiety (β = 9.24, 95% CI: 0.12, 18.36) compared to individuals with higher self-mastery scores (maximum in sample: 3.31) (β = -3.22, 95% CI: −9.81, 3.38).

3.3 Cleanup participation and anxiety among those with oil contact

There was, however, a significant antagonistic interaction between direct oil exposure and participation in cleanup activities for latent anxiety (Wald test *P* = 0.01). Among individuals directly exposed to oil in fully adjusted models, cleanup participation was associated with lower latent anxiety (β = -3.50, 95% CI: -6.10, -0.90) (Table 5). Among individuals directly exposed to oil, there was no significant interaction between participating in cleanup activities and levels of emotional support (always, usually, sometimes, rarely or never) (4-degrees-of-freedom F test: *P*

= 0.07), with the lowest β-coefficient of -3.90 (-8.36, 0.57) for "sometimes" and the highest β-coefficient of 1.55 (-2.07, 5.17) for "sometimes" (Table 6).

Among those exposed to oil and participated in cleanup activities, individuals with lower self-mastery scores (minimum in sample: -4.04) had less latent anxiety (β = -12.86, 95% CI: −24.54, -1.18) compared to individuals with higher self-mastery scores (maximum in sample: 3.31) (β = 4.77, 95% CI: −5.36, 14.91). Thus, although the interaction term between cleanup participation with self-mastery among those directly exposed to oil was not statistically significant (Wald test $P = 0.11$), there is suggestive evidence that participation may have had a larger benefit among individuals with lower self-mastery. Among individuals exposed to oil in fully adjusted models, there was no significant interaction between participating in cleanup activities and being paid for cleanup activities for anxiety (β = -0.88, 95% CI: -7.19, 5.24, Wald test $P = 0.79$).

4. DISCUSSION

4.1 Oil contact and increased anxiety

This study found positive associations of oil contact with anxiety in residents of Gulf States subsequent to the Deepwater Horizon oil spill. These results are consistent with previous findings from studies examining the associations of oil exposure and mental health impacts.[7, 10, 20-22] Our findings that exposed individuals with lower self-mastery scores had greater mental health impacts also agree with studies demonstrating the positive associations between high levels of self-mastery and improved mental health.[23]

4.2 Oil contact, cleanup participation, and anxiety

We found that the association of oil exposure with latent anxiety is diminished among participants in oil cleanup activities. To the best of our knowledge, this is the first study to examine associations of anxiety and participation in oil spill cleanup activities within populations directly affected by the oil spill. These findings agree with a recent study examining the associations of depression and individuals participating in oil spill cleanup activities compared to individuals not participating in oil spill cleanup activities within populations directly affected by the oil spill.[10] This previous study also found associations of oil contact and mental health effects that were attenuated among the persons who participated in oil spill cleanup efforts.[10]

4.3 Volunteering, cleanup participation, and mental health; similar findings in literature

Although this paper is the first to examine the relationship between oil exposure and anxiety by cleanup participation, prior studies have shown associations between general volunteering and mental health. In a longitudinal study conducted in the United Kingdom, individuals who engaged in volunteering regularly appeared to have higher levels of mental well-being compared to those who never volunteered.[24] A 2017 cross-sectional study found that combat veterans who volunteered in disaster relief social service organizations reported positive mental health responses as a result of helping those in need.[25] A previous study examining public servants working in the area affected from the Great East Japan Earthquake of 2011 also reported that engaging in disaster-related work may reduce mental health distress among workers.[26]

4.4 Study strengths and limitations

The main strengths of this paper were the use of a large, representative sample and the ability to compare different populations affected by the oil spill. However, because this was a cross-sectional survey, there was potential for reverse causality between cleanup participation and anxiety symptoms, both assessed after the oil spill.[27] It is also unknown whether respondents who participated in oil spill cleanup activities were healthier at baseline and had fewer mental health conditions. As the Gulf States Population Survey was a random-digit-dial telephone survey, the associations may introduce bias due to potential effects of recall bias or social desirability bias among the study participants.[28]

Although the associations between cleanup participation and anxiety were adjusted for several factors relating to anxiety and socio-demographics, uncontrolled confounders such as specific subgroups may have been present during analysis. A recent study examining determinants of participation in cleanup activities found positive associations of participation and proximity of affected areas.[29] Approximately 4.7% of residents in affected Gulf communities participated in the oil spill cleanup activities, and most were young men in excellent physical health.[29] These individuals residing in affected communities may have been easily mobilized and motivated to help their affected communities by participating in cleanup activities.[29] Future longitudinal cohort studies would allow researchers to compare exposed and unexposed populations on short-term and long-term health effects, validating prior cross-sectional studies.[30]

4.5 Implications and Conclusions

From a public health perspective, volunteering in disaster-relief could provide an intervention for mental health impacts after disasters occur. By responding to major disasters and working as a community, a sense of belonging or contribution may create a protective response for mental health.[26] Additionally, it has been shown that individuals who experience a disaster may benefit from the resources of their social networks.[31] We postulate that participation of disaster-related activities may give people some control over an event that was otherwise out of their control. Increasing participation in disaster-related cleanup activities could also increase resilience and recovery of individuals and the surrounding community.[29]

Although this cross-sectional study is limited in its ability to draw firm causal inferences, the findings from this paper raise the possibility that encouraging affected individuals to volunteer in times of need may mitigate the harmful effects of oil exposure. Further research, such as trials evaluating post-oil exposure cleanup participation as an intervention, is needed.

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Table 1. Estimated Characteristics of the Population According to Direct Oil Contact and Participation in Cleanup Activities During the Deepwater Horizon Oil Spill. These estimates incorporate MI and survey estimation for population inference.

Characteristic	Direct oil contact	No direct oil contact	Participated in cleanup activities	Did not participate in cleanup activities
Gender (%)				
Female	46 (38, 54)	52 (50, 54)	44 (34, 55)	52 (50, 54)
Male	54 (46, 62)	48 (46, 50)	56 (45, 66)	48 (46, 50)
Mean age (years)	43 (40, 46)	49 (48, 49)	39 (33, 43)	49 (48, 50)
Mean GAD-7 Score	6 (5, 7)	4 (3, 4)	4 (3, 5)	4 (3, 4)
Race (%)				
White	76 (67, 85)	69 (67, 72)	72 (61, 82)	70 (67, 72)
Black	11 (7, 15)	20 (19, 22)	18 (8, 28)	20 (18, 22)
Other	13 (4, 23)	10 (8, 12)	11 (4, 18)	10 (9, 12)
Hispanic Ethnicity (%)				
Yes	13 (3, 23)	11 (9, 13)	8 (1, 16)	12 (10, 13)
No	87 (77, 97)	89 (87, 91)	92 (84, 99)	88 (87, 90)
Employment (%)				
Employed	60 (52, 68)	52 (50, 54)	64 (52, 75)	52 (50, 54)
Not Employed	15 (10, 21)	16 (14, 17)	12 (6, 19)	16 (14, 17)
Other	25 (18, 32)	32 (30, 35)	24 (13, 35)	32 (30, 34)
Marital status (%)				
Married	51 (43, 59)	52 (50, 54)	43 (32, 53)	52 (50, 55)
Not Married	49 (41, 57)	48 (46, 50)	57 (47, 68)	48 (45, 50)
Exercise (%)				
Yes	81 (75, 88)	73 (71, 75)	89 (83, 95)	73 (71, 75)
No	19 (12, 25)	27 (25, 29)	11 (5, 17)	27 (25, 29)
Binge drinking (%)				
Yes	22 (17, 28)	15 (13, 17)	29 (19, 38)	15 (13, 16)
No	78 (72, 83)	85 (83, 87)	71 (62, 81)	85 (84, 87)
Smoking (%)				
Never	52 (44, 60)	55 (52, 57)	49 (39, 60)	55 (52, 57)
Former	21 (15, 27)	24 (22, 26)	22 (13, 32)	24 (22, 25)
Current	27 (20, 33)	22 (20, 24)	29 (20, 38)	22 (20, 24)
Emotional support (%)				
Always	40 (32, 48)	50 (48, 52)	53 (42, 63)	49 (47, 51)
Usually	33 (26, 40)	27 (25, 29)	32 (23, 41)	27 (25, 29)
Sometimes	16 (11, 21)	14 (13, 16)	6 (3, 10)	15 (13, 17)
Rarely and Never	11 (6, 16)	9 (7, 10)	9 (3, 15)	9 (7, 10)

Table 2. Characteristics of the Sample Population According to Direct Oil Contact and Participation in Cleanup Activities During the Deepwater Horizon Oil Spill.

Characteristic	Direct oil contact	No direct oil contact	Participated in cleanup activities	Did not participate in cleanup activities
Gender (%)				
Female	1,985 (55%)	21,300 (63%)	740 (47%)	22,698 (63%)
Male	1,640 (45%)	12,578 (37%)	835 (53%)	13,459 (37%)
Mean age (years)	3,625 (50)	33,878 (56)	1,575 (48)	1,548 (59)
Mean GAD-7 Score	3,539 (5)	33,108 (3)	36,157 (1)	35,318 (3)
Race (%)				
White	2,983 (82%)	26,160 (77%)	1,289 (82%)	28,005 (78%)
Black	428 (12%)	5,910 (17%)	172 (11%)	6,234 (17%)
Other	210 (6%)	1,751 (5%)	112 (7%)	1,860 (5%)
Hispanic Ethnicity (%)				
Yes	3,496 (97%)	32,749 (97%)	1,518 (97%)	34,948 (97%)
No	111 (3%)	962 (3%)	52 (3%)	1,024 (3%)
Employment (%)				
Employed	2,063 (57%)	15,510 (46%)	1,033 (66%)	16,654 (46%)
Not Employed	615 (17%)	4,423 (13%)	215 (14%)	4,879 (14%)
Other	938 (26%)	13,856 (41%)	323 (21%)	14,531 (40%)
Marital status (%)				
Married	2,114 (59%)	17,709 (52%)	882 (56%)	19,045 (53%)
Not Married	1,496 (41%)	16,027 (48%)	683 (44%)	16, 963 (47%)
Exercise (%)				
Yes	2,868 (80%)	24,251 (72%)	1,299 (83%)	25,992 (72%)
No	732 (20%)	9,400 (28%)	265 (17%)	9,925 (28%)
Binge drinking (%)				
Yes	2,857 (80%)	29,550 (88%)	1,229 (80%)	31,366 (88%)
No	706 (20%)	3,889 (12%)	314 (20%)	4,322 (12%)
Smoking (%)				
Never	1,754 (49%)	17,927 (54%)	777 (50%)	19,018 (53%)
Former	939 (26%)	9,003 (27%)	368 (24%)	9,627 (27%)
Current	882 (25%)	6,513 (19%)	405 (26%)	7,053 (20%)
Emotional support (%)				
Always	1,570 (44%)	16,622 (50%)	743 (48%)	17,556 (49%)
Usually	1,114 (31%)	9,526 (28%)	494 (32%)	10,203 (29%)
Sometimes	543 (15%)	4,864 (15%)	208 (13%)	5,237 (15%)
Rarely and Never	365 (10%)	2,490 (7%)	119 (8%)	2,760 (8%)

Table 3. Associations Between Direct Contact with Oil and Anxiety in Communities Participating in the Gulf States Population Survey.

Model	Differences in Anxiety (95% CI)
Model 1: Unadjusted association	3.53 (1.77, 5.28)
Model 2: Adjusted for age, race, Hispanic ethnicity, gender	3.36 (1.60, 5.11)
Model 3: Further adjusted for exercise, smoking, and binge drinking	3.42 (1.60, 5.25)
Model 4: Further adjusted for employment and marital status	3.34 (1.50, 5.17)
Model 5: Further adjusted for self-mastery and emotional support	2.84 (0.78, 4.91)

Note: CI, confidence intervals.

Table 4. Associations Between Direct Contact with Oil and Anxiety, by Frequency of Emotional Support, in Communities Participating in the Gulf States Population Survey.

Emotional Support	Percent of Population (95% CI)	Differences in Anxiety (95% CI)
Always	0.49 (0.47, 0.52)	4.65 (0.41, 8.89)
Usually	0.27 (0.26, 0.29)	0.98 (-0.86, 2.82)
Sometimes	0.15 (0.13, 0.16)	1.89 (-0.54, 4.32)
Rarely or never	0.09 (0.07, 0.10)	3.28 (-0.56, 7.11)

Note: CI, confidence intervals.

Table 5. Differences in Anxiety between Individuals Participating in Oil Spill Cleanup Activities Compared to Individuals Not Participating in Oil Spill Cleanup Activities, among Individuals with Direct Contact With Oil, in Communities Participating in the Gulf States Population Survey.

Model	Differences in Anxiety (95% CI) among persons exposed	Differences in Anxiety (95% CI) among persons not exposed
Model 1: Unadjusted association	-3.46 (-6.71, -0.22)	-0.26 (-2.36, 1.84)
Model 2: Adjusted for age, race, Hispanic ethnicity, gender	-3.13 (-6.10, -0.16)	-0.76 (-2.94, 1.42)
Model 3: Further adjusted for exercise, smoking, and binge drinking	-3.18 (-6.11, -0.25)	-0.53 (-2.49, 1.44)
Model 4: Further adjusted for employment and marital status	-3.43 (-6.10, -0.76)	-0.28 (-2.17, 1.62)
Model 5: Further adjusted for self-mastery and emotional support	-3.50 (-6.10, -0.90)	0.33 (-1.56, 2.21)

Note: CI, confidence intervals.

Table 6. Associations between Oil Spill Cleanup Participation and Anxiety, by Frequency of Emotional Support, in Communities Participating in the Gulf States Population Survey.

Emotional Support	Percent of Population (95% CI)	Differences in Anxiety (95% CI)
Always	0.49 (0.47, 0.52)	-3.84 (-7.44, -0.24)
Usually	0.27 (0.26, 0.29)	-3.90 (-8.36, 0.57)
Sometimes	0.15 (0.13, 0.16)	1.55 (-2.07, 5.17)
Rarely or never	0.09 (0.07, 0.10)	-3.38 (-9.03, 2.28)

Note: CI, confidence intervals.

Figure 1. Latent anxiety and observed anxiety symptom scores in the Gulf States Population Survey