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ORIGINAL RESEARCH

Deepwater Horizon Oil Spill Exposure, Industry Sector, and Child Health

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Abstract
The historic 2010 BP Deepwater Horizon Oil Spill (DHOS) led to public distress regarding potential impacts on children in nearby Gulf Coast communities. Using a community-based South Louisiana panel study of households with children, we examined the effect of fishing industry employment on changes in a subjective measure of general child health and whether economic and physical DHOS exposures played a mediating role. Fishing industry employment had a negative effect on child health compared to other industries. Economic exposure and physical exposure both mediated the effects of the fishing industry on child health, with economic exposure mediating a larger share (49.3%) of the relationship compared to physical exposure (40.5%). The importance of economic oil spill exposure in these findings highlights the significance of social determinants of health at the intersection of disasters and child vulnerability.

Keywords Deepwater Horizon · Oil spill · Disaster · Child health · Occupation

Introduction

The 2010 BP Deepwater Horizon oil spill (DHOS) was the largest marine oil spill in world history by length of shoreline oiled (Nixon et al. 2016). The DHOS began on April 20, 2010, when an explosion on a BP-leased oil rig in the Gulf of Mexico killed 11 people, subsequently sinking the structure and releasing approximately 200

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million gallons of oil from the seafloor over the following months. South Louisiana coastal ecosystems and communities experienced the greatest oiling impacts from the DHOS (National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling 2011). Controlled burns and millions of gallons of toxic chemical dispersants were subsequently deployed by cleanup workers to mitigate the spill (National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling 2011).

Prior research on the health effects of the DHOS has largely focused on adult residents of affected communities (e.g., Cope et al. 2013; Drakeford et al. 2020; Fan et al. 2015; Gould et al. 2015; Osofsky et al. 2011; Parker et al. 2019; Parks et al. 2018, 2020; Peres et al. 2016). However, because they are dependent on the adult caregivers in their lives for safety and well-being, children are uniquely vulnerable in disaster contexts (King et al. 2015; Osofsky and Osofsky 2018; Peek 2008; Williams et al. 2008). Moreover, children's health post-disaster has been suggested as a "bellwether indicator of successful recovery or as a lagging indicator of system dysfunction and failed recovery" (Abramson et al. 2010). Negative child health impacts in the wake of oil spills are likely, not only from direct physical exposure to toxins but also economic hardship and psychosocial stress stemming from resource loss and from parental post-disaster psychopathology (i.e., through household job or income loss) (Slack et al. 2020). Children are likely to have more harmful physical exposures because of their shorter height, greater metabolism, elevated respiratory rate, and the ways they play (i.e., crawling or playing on the ground and placing things in their mouths) (Kousky 2016; Murray 2011). Understanding disaster impacts on child health and development is critical to population health. Researchers estimate that as much as half of adult health status is established by school age, underscoring health and development in childhood as a critical juncture in the life course (Currie 2011; Hayward and Gorman 2004; Lanphear 2015; Newnham and Ross 2009). Additionally, research has shown that adverse childhood experiences (or ACEs) not only cause psychosocial stress in the present but have consequences for health that persist for years (Centers for Disease Control and Prevention 2019).

The current study contributes to prior research on the DHOS and health by using data from the 2014 Gulf Coast Population Impact (GCPI) study and the 2016 and 2018 waves of Resilient Children, Youth, and Communities (RCYC) study to assess the effect of fishing industry employment on parent-reported general child health and the role of economic and physical exposure in that relationship. We advance prior research by: (1) extending past studies of oil spills and adult health by examining child health; (2) improving on extant cross-sectional research by using longitudinal methods to assess health changes in a three-wave cohort of children; and (3) assessing mechanisms that connect vulnerable group membership to poor health (i.e., parental industry of employment, economic, and physical exposures).

Fishing Industry Sector, Economic Exposure, and Physical Exposure

While environmental disasters can impact virtually all ecosystems and human populations, renewable resource communities (RRCs)—people characterized by reliance on a stable environment and renewable natural resources for their livelihoods and lifeways—are particularly vulnerable to environmental disasters (Arata et al. 2000; Cope et al. 2013; Gill et al. 2016; Oberg et al. 2016). The fishing communities in South Louisiana are quintessential RRCs (Henry and Bankston 2002). Moratoria on fishing were implemented following the DHOS, placing fishers' means of making a living in direct jeopardy (Holloway et al. 2018; Sumaila et al. 2012). Long after the moratoria, chronic impacts on families tied to the fishing industry remained. These impacts stemmed from public fears regarding food safety, concern over polluted fishing grounds, effects on fish stocks, lifeway disruption, and litigation, all of which amplified psychosocial stress for fishers compared to non-fishers (Cope et al. 2013, 2016; Gilbert 2013; Gill et al. 2012; Lee and Blanchard 2012; Parks et al. 2018, 2020; Ritchie et al. 2018; Simon-Friedt et al. 2016; Singleton et al. 2016).

Conservation of resources (COR) theory maintains that stable employment and finances are key human resources in Western societies. Fishing is often informal and precarious in nature and households tied to fishing for their livelihoods can be particularly vulnerable to environmental shocks. COR holds that people with lower levels of resources to begin with will have a higher probability of immediate and future resource loss in the face of crisis (Hobfoll 1989). COR further argues that "resources are necessary and stress will occur where resources are threatened, lost, believed to be unstable, or where individuals and groups cannot see a path to the fostering and protection of their resources" (Hobfoll 2001, p. 340). In addition to loss of material resources, technological environmental disasters can lead to spirals of psychosocial stress within communities and families through disputes surrounding fault-finding, financial/legal processes, institutional cynicism, and ongoing worry (Baum et al. 1983; Cope et al. 2016; Freudenburg 1993; Kroll-Smith et al. 1991; Mayer et al. 2015; Parker et al. 2019; Picou et al. 2004; Ritchie et al. 2018). For example, oil spill research following the Exxon Valdez oil spill applied the COR model to understand psychosocial outcomes and found disproportionately high and chronic distress among fishers (Arata et al. 2000; Gill et al. 2016; Palinkas 2012). In short, economic loss can lead to negative impacts on child health through material deprivation and psychosocial stress in family units, and these considerations combined with broader lifeway disruption and protracted litigation are especially pronounced for fishers following marine oil spills. Anxiety and depression, uncertainty and recreancy, social disruption, and avoidance coping behaviors are more prevalent and chronic among fishers and their families in the aftermath of such disasters (Cope et al. 2016; Gill et al. 2016; Parks et al. 2018, 2020; Ritchie et al. 2018).

Child health impacts in fishing households may also derive from physical exposure to DHOS toxins. Studies have demonstrated the deleterious health effects of crude oil and chemical dispersant exposure, substances carrying toxic elements such as sulfonic acid, hydrogen sulfide gas, and aliphatic hydrocarbons (Laffon et al. 2016; Solomon and Janssen 2010). Documented DHOS-related health effects have included hepatic and hematological alterations and somatic symptoms such as chest pain, joint pain, headache, skin rash, wheezing, and burning in the lungs, nose, throat, and eyes (D'Andrea and Reddy 2013; Peres et al. 2016). COR maintains that threats/harm to family members' health is a form of resource loss leading to health-damaging psychosocial stress (Hobfoll 2001). As such, physical exposure may not

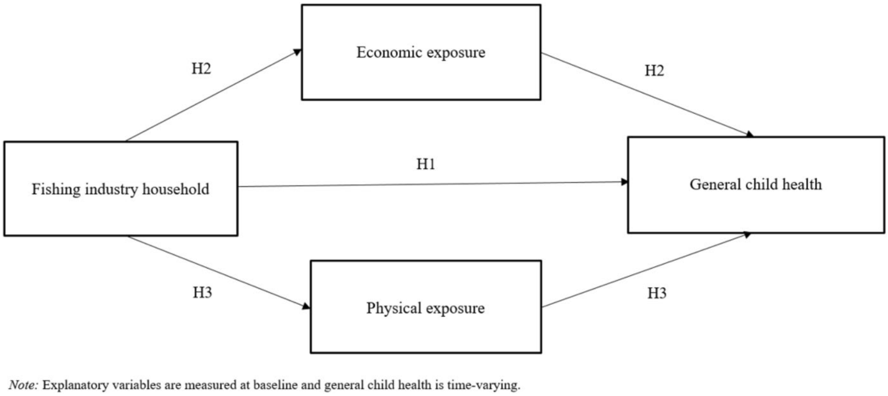

Fig. 1 Conceptual model of industry sector, DHOS exposures, and general child health

only directly impact one's own health, but may indirectly affect one's health through a family member's physical exposure to toxins. Indeed, as compared with economic exposure, past research has found that physical DHOS exposure was the greatest correlate of variation in health outcomes in a large sample of Gulf Coast adults that assessed exposures 8–20 months after the DHOS (Fan et al. 2015).

Based on prior evidence and theory, the current analysis assessed the following hypotheses for families in the wake of the DHOS:

Hypothesis 1 Children in fishing industry households have more negative changes in health compared to children in other types of households.

Hypothesis 2 DHOS economic exposure mediates the relationship between fishing industry sector and changes in child health.

Hypothesis 3 DHOS physical exposure mediates the relationship between fishing industry sector and changes in child health.

Hypothesis 4 Comparing DHOS economic and physical exposures, physical exposure mediates a greater proportion of the relationship between fishing industry sector and changes in child health.

Figure 1 shows a visual representation of this study's conceptual model and Hypotheses 1–3.

Methods

Data

We analyzed three waves of cohort data from the GCPI/RCYC studies. In 2012, the National Center for Disaster Preparedness (NCDP), Earth Institute, Columbia University (Abramson et al. 2013), used a multi-stage sampling design to identify households with children in coastal areas of Louisiana, Mississippi, Alabama, and Florida highly impacted by the DHOS per BP assistance claims, Shoreline Cleanup and Assessment Technique (SCAT), and National Oceanic and Atmospheric Administration oiling data (Michel et al. 2013). The NCDP returned to these households, in Louisiana specifically, in 2014, to field a household survey. To draw the sample, a two-stage cluster sampling design was implemented. In total, 720 households with children were randomly selected within a randomly selected set of census blocks in areas of South Louisiana highly impacted by the DHOS. Of these, 655 households agreed to be followed up with subsequent surveys. A self-identified parent or guardian respondent (henceforth parent) from each household provided personal, household, and focal child information. Where multiple children were present, the most recent birthday was used to select the focal child. The RCYC followed up with the same households again in 2016 ($N=484$) and 2018 ($N=485$). In the current study's analysis, independent variables were measured in 2014 and the outcome variable was measured in 2014, 2016, and 2018. Further sample and methodological information are detailed in Abramson et al. (2013).

Outcome Variable

General Child Health

The outcome investigated in this study was a subjective measure of general child health. Using the following question, the study elicited the parent's assessment of their child's current overall health at each wave of analysis: "In general, how would you describe {child name}'s health now? Would you say it is…" Response options were ordered such that higher values indicated better health: (1) "poor," (2) "fair," (3) "good," (4) "very good," and (5) "excellent."[1,2]

[1] In supplemental linear probability models, we use a dichotomous version of the dependent variable where excellent health is equal to 1, else 0. Results were not substantively changed in comparison to the main results, both in terms of direction of effects and statistical significance. Also, economic exposure mediated a larger portion of excellent child health (73.6%) compared to physical exposure (53.2%).

[2] In a random-effects model with covariates seen in Table 2, female parent and being an older parent (>40 years of age) where negatively and significantly associated with child health.

Primary Explanatory Variables

Industry of household employment and DHOS exposures were measured at wave 1 of the study. In addition to temporal proximity to the DHOS, focusing on these wave 1 measures had the added benefit of enabling a temporally parallel comparison of economic exposure and physical exposure in the mediation analysis described in the "Analytic Strategy" section below.

Industry

Respondents were asked about their household's industry sector with a question that asked: "We are interested in the sectors where people work. I am going to read a list of sectors where people work. Please tell me if anyone in your household, including you, is presently employed in any of these industries or work sectors." Responses were coded into a four-category variable. First, one response option including "fishing, agriculture, forestry, hunting," was retained as an industry category and labeled "fishing." Fishing is a major industry in the spill-affected region. Indeed, in an open-ended employment question in the survey, 71% of employed men in this category reported fishing industry employment. The second category, labeled "oil," included oil and gas extraction and mining, which were listed together as a single response option in the survey. "Other industry" was a third category constructed from individuals working in manufacturing, retail, government, education, tourism, real estate, or other industries. Finally, a fourth category comprised respondents with no paid employment and a small number of indeterminate responses. Those without paid employment could be disabled, retired, electing to not work, discouraged and thus not searching for a job, or unemployed. Of these four binary variables, "other industry" was the largest and thus set as the omitted reference in regression analyses. While not a focus of our analysis, it is reasonable to expect that families lacking adults with paid employment are likely to be facing economic hardship and other types of adversity which in turn hold negative implications for child well-being (Coelli 2011; Isaacs 2013).

Economic and Physical Exposure

To measure exposure to economic loss as a result of the DHOS, the study asked, "Did anyone in the household lose his or her job as a result of the oil spill" and "Did anyone in the household lose income as a result of the oil spill?" Economic exposure was coded as "yes" if an affirmative response was given to either question (1 = yes, 0 = no). We combined these items into a single indicator because: (1) collinearity was problematic when comparing the items separately and (2) in order to maintain comparability with previous research (Slack et al. 2020). While it is true that losing a job may have been positive for some people, we were interested in exposure to economic disruption and its relationship to child health, not whether the job loss was deemed positive or negative by the respondent. Physical exposure (1 = yes, 0 = no) was an indicator comprised of two classes of questions (three items): (1) whether the parent or child came into direct physical contact with the oil, tar balls, or any oil spill cleanup chemical dispersants; and (2) whether the parent could smell the oil spill. Both types of questions were prefaced with a time period of "within 6 months of the oil spill" (April–November 2010).

Covariates

Based on prior research, we controlled for several potentially confounding covariates. Unless otherwise indicated, all measures refer to the parent. We included a measure of the total number of household members at the time of the baseline survey (range 2–13). The sex (1 = female) and years of age reported in 2014 (range 4–18 [child], 18–84 [parent]) were controlled for both child and parent. Race-ethnicity was measured in three categories: non-Hispanic White, non-Hispanic Black, and other race-ethnicity. Married referred to current marital status (1 = married, 0 = unmarried), a bachelor's degree or greater indicator measured educational attainment (1 = bachelor's or more, 0 = less than a bachelor's degree). The data were restricted to individuals with at least two waves of data on the dependent variable ($N = 529$).[3] Four more cases were dropped due to missing values on independent variables, resulting in an analytic sample of 525. Of the final analytic sample, 21% of individuals contributed two waves of data, and 79% contributed three waves of data. Descriptive statistics for study variables are shown in Table 1.

Analytic Strategy

We tested hypotheses and assessed whether physical exposure or economic exposure mediated an association between the fishing industry and general child health in several steps (Baron and Kenny 1986; Judd and Kenny 1981). First, we tested whether fishing industry status was significantly associated with the mediator variables (economic exposure and physical exposure). Second, if there was a significant association, we predicted general child health with industry sector and covariates, but not the mediator variables. The second step established whether there was a significant fishing industry effect that could be mediated. Third, we added mediator variables and observed whether the fishing industry effect was diminished. Fourth, we tested whether the mediation was statistically significant. Finally, we calculated the proportion of the fishing industry effect mediated by economic and physical exposure and compared the relative size of mediation.

Step 1 used standard binary logistic regression to assess the relationship between industry indicators and mediator variables (economic exposure and physical exposure), with all variables measured at wave 1. Steps 2 and 3 were estimated using econometric random-effects regression for panel data (Allison 2009). Specifically,

[3] Econometric random-effects regression requires at least two waves of data (Allison 2009).

Table 1 Descriptive statistics for study variables

Variable	*n* (%) or Mean ± SD
General child health 2014	3.7 ± 1.1
General child health 2016	3.8 ± 1.1
General child health 2018	3.8 ± 1.1
Industry	
Fishing	67 (13%)
Oil	95 (18%)
Other industry	280 (53%)
No paid employment	83 (16%)
Economic exposure	194 (37%)
Physical exposure	257 (49%)
Total people in household	4.3 ± 1.4
Female (child)	231 (44%)
Age (child)	11.7 ± 4.2
Female	324 (62%)
Age	42.1 ± 11.5
Race-ethnicity	
Non-Hispanic White	314 (60%)
Non-Hispanic Black	138 (26%)
Other race-ethnicity	73 (14%)
Married	354 (67%)
Bachelor's degree or greater	104 (20%)

Source RCYC study ($n = 525$)

SD = standard deviation; variables refer to parents unless otherwise indicated; independent variables were measured in 2014 and general child health was measured in 2014, 2016, and 2018; 2016 general child health $n = 460$; 2018 general child health $n = 457$

we estimated random intercept models to assess time-varying child health as a function of time, the focal predictors, and covariates, adjusted for both the occasion-specific error and the person-specific effects on child health. Our models can be summarized with the following equation:

$$y_{it} = \beta_0 + \beta_t T_{it} + \beta_x X_{i1} + \alpha_i + \varepsilon_{it}, \tag{1}$$

where y_{it} is child health reported by parent i at time t, β_0 is the intercept, β_t indicates the effect of survey wave on child health and T_{it} is a continuous indicator for wave of interview (equal to 1 at time 1 [in 2014], equal to 2 at time 2 [in 2016], and equal to 3 at time 3 [in 2018]), β_x is the vector of effects of the predictors for person i reported at time 1, α_i is the person-specific error, and ε_{it} is the occasion-specific error for person i at time t.

Random-effects models for panel data were well-suited for the child health outcome in the current study, in that child health changed over time and was measured on at least two occasions. The model assessed whether fishing industry status was associated with the level of child health, and by drawing on multiple waves of data minimized the chance that an association was due to error. In addition, while the outcome was time-varying, all predictors were measured at wave 1 and were therefore time-invariant. Because random-effects regression models treat the person-specific error as exogenous to any time-varying indicators, the random-effects estimator directly estimates the effects of time-invariant predictors. We chose random-effects regression instead of growth curve modeling for two reasons. First, about 20% of our sample had data for only two occasions, and growth curves require at least three waves of data on all observations. In addition, ancillary analyses (not shown) indicated that change in child health across survey waves within industries and exposure categories did not result in adequate cell sizes for growth curve models. Second, the current study was not focused on modeling trajectories of child health over time. Instead, we tested whether fishing industry status was associated with the level of child health net of any time trend and covariates.

To facilitate tests for statistically significant mediators, in steps 4 and 5, we estimated models identical to those in steps 2 and 3 but using a structural equation modeling framework. Postestimation tests for the structural equation modeling command in Stata (sem) produced estimates and *p*-values for the direct and indirect effects of mediators, which allowed the assessment of the indirect effects of fishing industry household status (via economic and physical exposure). Analyses were conducted in Stata 13.1 (StataCorp 2013).

Results

The percentage of respondents reporting economic DHOS exposure in each industry category was as follows: fishing (78%), oil (37%), other industry (31%), and no paid employment (25%). The industry breakdown for physical DHOS exposure was: fishing (79%), oil (38%), other industry (47%), and no paid employment (45%). In binary logistic regressions of economic exposure and physical exposure to the DHOS, industry sector was significantly associated with both (results shown in Appendix Table 3). Compared to "other industry" households, children in fishing industry households had significantly higher odds of economic exposure and physical exposure to the spill, net of covariates. In sensitivity analyses with fishing set as the reference category (not shown), all industry sectors had significantly lower odds of economic and physical exposure to the DHOS compared to fishing.

Next, we used random-effects regression for panel data (described in the "Analytic Strategy" section) to examine associations between industry and changes in child health over time and to assess whether fishing industry effects were mediated by physical or economic DHOS exposure. As shown in Table 2, Model 1 regressed child health on industry type and covariates. Results show that, compared to "other" industry households, children in fishing industry households ($b = -0.35$; $p < .01$) and children in households with no paid employment ($b = -0.26$; $p < .05$) had significantly lower levels of health. Child health in oil industry households was not statistically different from "other" industry households. In sensitivity analyses with fishing set as the reference category (not shown), oil and "other" industry

Table 2 Random-effects panel models of time-varying general child health regressed on industry, DHOS economic exposure, and DHOS physical exposure

	Model 1	Model 2	Model 3
Industry (ref. = other industry)			
Fishing	− 0.35**	− 0.18	− 0.21†
	(0.12)	(0.12)	(0.12)
Oil	− 0.06	− 0.05	− 0.09
	(0.10)	(0.10)	(0.10)
No paid employment	− 0.26*	− 0.31**	− 0.29**
	(0.11)	(0.11)	(0.11)
Economic exposure		− 0.42***	
		(0.08)	
Physical exposure			− 0.43***
			(0.08)
Total people in household	− 0.01	− 0.01	− 0.02
	(0.03)	(0.03)	(0.03)
Female (child)	− 0.13†	− 0.12	− 0.10
	(0.08)	(0.07)	(0.07)
Age (child)	− 0.01	− 0.01	− 0.01
	(0.01)	(0.01)	(0.01)
Female	− 0.27***	− 0.26***	− 0.23**
	(0.08)	(0.08)	(0.08)
Age	− 0.01***	− 0.01**	− 0.01**
	(0.00)	(0.00)	(0.00)
Race-ethnicity (ref. = Non-Hispanic White)			
Non-Hispanic Black	− 0.05	− 0.05	− 0.04
	(0.09)	(0.09)	(0.09)
Other race-ethnicity	− 0.20†	− 0.19†	− 0.19†
	(0.11)	(0.11)	(0.11)
Married	0.18†	0.15†	0.18*
	(0.09)	(0.09)	(0.09)
Bachelor's degree or greater	0.48***	0.40***	0.46***
	(0.10)	(0.10)	(0.10)
Time	0.08**	0.08**	0.08**
	(0.02)	(0.02)	(0.02)
Constant	4.41***	4.60***	4.49***
	(0.22)	(0.22)	(0.22)

Source RCYC study ($n = 525$)

Unstandardized coefficients and standard errors presented; variables refer to parents unless otherwise indicated; independent variables were measured in 2014 and child health was measured in 2014, 2016, and 2018

***$p < 0.001$, **$p < 0.01$, *$p < 0.05$, †$p < 0.10$

households had significantly higher levels of child health and households with no paid employment were not significantly different from fishing households.

In Model 2, we added economic DHOS exposure, which had a significantly negative effect on child health ($b = -0.42$; $p < .001$) and reduced the effect of fishing industry employment on child health to nonsignificance ($b = -0.18$; $p = .143$). Then in Model 3, we removed economic exposure and added physical DHOS exposure. Physical exposure was significantly and negatively associated with child health ($b = -0.43$; $p < .001$), and also attenuated the fishing industry coefficient to nonsignificance ($b = -0.21$; $p = .08$).

As shown in Appendix Table 4, analyses estimating the indirect effects of the fishing industry via economic and physical DHOS exposures demonstrated that both significantly mediated the association between fishing industry and child health ($p < .001$). Economic DHOS exposure mediated 49.3% of the child health effect of being in a fishing industry household and physical DHOS exposure mediated 40.5% of the effect of being in a fishing industry household.[4] The independent and significant effects of economic and physical DHOS exposure net of each other can be seen in the model shown in Appendix Table 5. To understand the relative contribution of each to child health, standardized coefficients are reported which show that effect sizes are similar, although the effect for physical exposure ($\beta = .16$) is slightly larger than that of economic exposure ($\beta = .14$). The two DHOS exposure indicators, along with college education, have the largest standardized coefficients in the model.

Discussion

The purpose of this study was to examine the relationship between fishing industry sector and changes in general child health and assess the role of DHOS economic exposure and physical exposure in that relationship. COR theory (Hobfoll 1989) and past research on exposure to oil spills and other technological disasters informed the development of four hypotheses, three of which were supported: (Hypothesis 1) children in fishing industry households had more negative changes in health compared to children in households in other industry sectors; (Hypothesis 2) DHOS economic exposure mediated the relationship between fishing industry sector and child health; and (Hypothesis 3) DHOS physical exposure mediated the relationship between fishing industry sector and child health. Hypothesis 4 was not supported—physical

[4] In ancillary analyses, we coded physical exposure excluding the DHOS smell indicator. This indicator had a significant direct effect on child health ($b = -.274$; $p = .002$) and significantly mediated 20% of the effect of fishing industry employment. We also separated child physical exposure, parent physical exposure, and parent report of DHOS smell. Child physical exposure had a significant direct effect on child health ($b = -.383$; $p = .001$) but did not have a significant indirect association mediating the relationship between fishing industry employment and child health ($p = .127$). Parent physical exposure had a significant direct effect on child health ($b = -.271$; $p = .003$) and significantly mediated 19.1% of the effect of fishing industry. DHOS smell had a significant direct effect on child health ($b = -.433$; $p < .001$) and significantly mediated 19.2% of the effect of fishing industry.

exposure did not mediate a greater proportion of the relationship between the fishing industry sector and general child health. Rather, we found that economic exposure mediated a greater proportion of the effect of a child's membership in a fishing household on their general health.

These analyses contribute to the extant research and advance our understanding of occupations and child health in the context of the largest accidental oil spill in history. Most prior oil spill research has focused on adult health. We extended past studies by examining child health, a key point of oil spill vulnerability and biological development in the life course (Murray 2011; Newnham and Ross 2009). Prior studies have typically relied on cross-sectional data; we advanced this work by studying a cohort of children assessed at three time points across 4 years. Our findings based on cohort data and econometric random-effects analysis offer greater confidence in the temporal ordering and causal inference regarding the child health impacts of the DHOS stemming from the fishing industry and economic and physical DHOS exposures. Our analysis went beyond a description of patterns and points to dynamic causal mechanisms linking fishing industry households to poorer child health in the aftermath of the DHOS, showing that economic and physical exposures explained substantial parts of that relationship.

The current study adds to research on DHOS health impacts (Ayer et al. 2019; Cope et al. 2013; D'Andrea and Reddy 2013, 2018; Drescher et al. 2014; Fan et al. 2015; Gill et al. 2014; Gould et al. 2015; Lee and Blanchard 2012; Osofsky et al. 2011; Parks et al. 2020; Peres et al. 2016; Ramchand et al. 2019; Rung et al. 2016, 2017; Singleton et al. 2016; Slack et al. 2020), adverse childhood experiences (Williams and Finch 2019), disasters and child health (Abramson et al. 2013; Osofsky et al. 2015; Weems and Graham 2014; Williams et al. 2008), and literature on oil spills, technological disasters, and health (Couch and Coles 2011; Gill et al. 2016; Laffon et al. 2016). More broadly, health research increasingly supports the contention that "the primary determinants of disease are mainly economic and social" (Rose 2008, p. 161). This study's finding that oil spill economic exposure—job or income loss—explained a greater proportion of the fishing-child health relationship than physical exposure contributes to growing research on the importance of the social determinants of health.

Our results qualify the findings from some prior research. For example, Fan et al. (2015) found that economic exposure to the DHOS was only significantly associated with one of three adult health outcomes, whereas physical exposure was associated with all three. Substantial differences in study design may help account for differences in results. Fan et al. (2015) used a cross-sectional sample of adults, whereas the current study used longitudinal data on child health. Measurement of physical contact was also more expansive in the current study as it included not just physical contact with oil, but also contact with tar balls, chemical dispersants, or associated smell, and was conceptualized at the household versus individual level.[5] Additionally, the current study asked respondents about their exposures with more temporal uniformity.

[5] Ancillary analyses showing that parent physical exposure (both physical contact and smell) act as a significant mediator, but not child exposure, indicate the need for further research examining potential mechanisms (e.g., parent health) linking parent physical exposure and child health.

Finally, differences in the health outcome measurement between studies may have contributed to divergences in findings.

Several strengths and limitations of the current study and areas for further research should be noted. While the focus on general child health is a strength of our study, relying on parent report of children's health is not without limitations. As with self-rated health, potential limitations such as information loss and recall bias in the current study's outcome measure cannot be excluded given surveys were done 4–8 years after the disaster. However, just as limitations of self-rated health may apply to parent-reported subjective child health, so too may its strengths (e.g., it is among the strongest predictors of mortality). Self-rated health is utilized by organizations such as the World Health Organization as a valid and reliable measure of biological, physical, mental, and social aspects of health (Jylhä 2009). Parent-reported child health has received less validation compared to adult self-rated health; future attention should be devoted to assessing the strengths and limitations of parent-reported child health. Additionally, subsequent longitudinal oil spill and child health research can build on the current analysis by using a broader array of more direct measures of health. While a strength of the current study is its use of a probability sample, future studies employing a substantially larger sample could enable the study of important population subgroups. Analysis of populations such as Vietnamese Americans—a group with substantial involvement in the Louisiana Gulf Coast fishing industry—would be especially relevant (VanLandingham 2017).

Given demonstrated child health impacts from oil spills, one major policy implication from this and other research includes strengthening state and federal requirements for oil extraction permitting, and ongoing review of drilling and production regulations with the goal of preventing such incidents in the future (National Academy of Engineering and National Research Council 2012). Spill response planning at all levels should integrate findings that highlight the unique physical and social vulnerabilities of children in the immediate and long-term aftermath of an oil spill.

Additionally, for children, it is not just those in households with physical exposure who are in greatest need of public health and policy interventions, but also those in households with economic exposure. Specifically, the current study's findings show greater child health impacts for fishing industry households through economic oil spill exposure. The implication is that targeted policies that mitigate economic exposure for such families stand to have health promoting consequences for children. In addition, health interventions aimed at children cannot ignore children's or caregivers' broader household contexts. This implies the need for integrated healthcare services that address both psychosocial and physical health needs in the aftermath of oil spills (Osofsky et al. 2014; Williams et al. 2008). Interventions geared towards bolstering resilience for vulnerable households could include expanding social programming in fishing communities (e.g., medical supplies, housing aid, unemployment insurance, employment training, family leave), direct monetary transfers to fishing industry households with children, and facilitating women's educational attainment in these households (Conti et al. 2010; Currie 2011).

Beyond targeting fishing households, it is also important to note that negative disaster impacts extend to a larger share of the population in the affected area (Arata et al. 2000; Norris and Wind 2009; Palinkas 2012). As such, it is critical to consider policy interventions that may blanket large populations of children who are economically vulnerable to direct or indirect environmental exposures. Due to burgeoning evidence and relatively lower costs, many countries and locales have increased health and social spending as it relates to early life and child health and development (e.g., medical home-visiting, and quality center-based early-childhood care and education) (Currie 2011). Such spending among renewable resource communities in South Louisiana could yield a boon in child health resilience in the face of future environmental disasters and threats. Interventions must also address the cumulative impacts of the DHOS along with the traumas of other major disasters that have affected families in coastal Louisiana (Osofsky and Osofsky 2018). Indeed, the cumulative and long-term health effects of adverse childhood experiences are implied here (Centers for Disease Control and Prevention 2019). Oil and gas industry taxes, fines, and other mechanisms that capture the full costs of the industry to the environment and society could be important sources of revenue for such programs. In sum, a suite of policy interventions for children and their families is particularly critical given how determinative childhood conditions are for health across the life course.

Appendix

See Appendix Tables 3, 4 and 5.

Table 3 Binary logistic regression models of DHOS exposure

	Model 1 Outcome: economic exposure	Model 2 Outcome: physical exposure
Industry (ref. = other industry)		
Fishing	1.88***	1.56***
	(0.34)	(0.34)
Oil	0.18	− 0.30
	(0.26)	(0.26)
No paid employment	− 0.59†	− 0.24
	(0.30)	(0.27)
Total people in household	0.00	− 0.04
	(0.07)	(0.07)
Female (child)	0.19	0.31†
	(0.20)	(0.19)
Age (child)	− 0.05†	0.01
	(0.02)	(0.02)
Female	0.13	0.40*
	(0.22)	(0.20)
Age	0.01	0.02*
	(0.01)	(0.01)
Race-ethnicity (ref. = Non-Hispanic White)		
Non-Hispanic Black	− 0.05	0.07
	(0.24)	(0.23)
Other race-ethnicity	0.13	0.14
	(0.29)	(0.28)
Married	− 0.32	0.05
	(0.23)	(0.22)
Bachelor's degree or greater	− 1.09***	− 0.23
	(0.30)	(0.24)
Time		
Constant	− 0.18	− 1.39*
	(0.57)	(0.55)

Source RCYC study ($n = 525$)

Unstandardized coefficients and standard errors presented; variables refer to parents unless otherwise indicated; all variables were measured in 2014

***$p < 0.001$, **$p < 0.01$, *$p < 0.05$, †$p < 0.10$

Table 4 Estimates from linear mediation analyses

	Fishing industry → economic exposure → general child health		Fishing industry → physical exposure → general child health	
	Model 1 Outcome: economic exposure	Model 2 Outcome: general child health	Model 3 Outcome: physical exposure	Model 4 Outcome: general child health
	b (SE)	*b* (SE)	*b* (SE)	*b* (SE)
Direct effects				
Fishing[a]	.42*** (.06)	− .18 (.12)	.34*** (.07)	− 0.21† (0.12)
Economic exposure		− .42*** (.08)		
Physical exposure				− .43*** (.07)
Indirect effect of fishing industry on general child health		− .18*** (.04)		− .14*** (.04)
Total effect of fishing industry on general child health		− .36** (.12)		− .36** (.12)
Percent mediated		49.3%		40.5%

Source RCYC study ($n = 525$)

[a]Reference = other industry; SE = standard errors; analyses control for oil industry, no paid employment, total people in household, female (child), age (child), female, age, race-ethnicity, married, bachelor's degree or greater, and time; variables refer to parents unless otherwise indicated; independent variables were measured in 2014 and child health was measured in 2014, 2016, and 2018

***$p < 0.001$, **$p < 0.01$, *$p < 0.05$, †$p < 0.10$

Table 5 Random-effects panel model of time-varying general child health regressed on industry, DHOS economic exposure, and DHOS physical exposure

	Unstandardized coefficient	Standard error	Standardized coefficient	Standard error
Industry (ref. = other industry)				
Fishing	− 0.10	(0.12)	− 0.03	(0.04)
Oil	− 0.07	(0.10)	− 0.03	(0.03)
No paid employment	− 0.32**	(0.11)	− 0.11	(0.04)
Economic exposure	− 0.32***	(0.08)	− 0.14	(0.04)
Physical exposure	− 0.35***	(0.08)	− 0.16	(0.03)
Total people in household	− 0.02	(0.03)	− 0.02	(0.03)
Female (child)	− 0.09	(0.07)	− 0.04	(0.03)
Age (child)	− 0.01	(0.01)	− 0.04	(0.03)
Female	− 0.23**	(0.08)	− 0.10	(0.03)
Age	− 0.01**	(0.00)	− 0.10	(0.04)
Race-ethnicity (ref. = Non-Hispanic White)				
Non-Hispanic Black	− 0.04	(0.09)	− 0.02	(0.04)
Other race-ethnicity	− 0.18†	(0.11)	− 0.06	(0.03)
Married	0.16†	(0.09)	0.07	(0.04)
Bachelor's degree or greater	0.40***	(0.10)	0.14	(0.03)
Constant	4.69***	(0.21)	4.27	(0.20)

Source RCYC study ($n = 525$)

Variables refer to parents unless otherwise indicated; independent variables were measured in 2014 and child health was measured in 2014, 2016, and 2018

***$p < 0.001$, **$p < 0.01$, *$p < 0.05$, †$p < 0.10$

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Compliance with Ethical Standards

Conflict of interest The authors declare they have no actual or potential competing financial interests.

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