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Deepwater Horizon oil spill exposure and child health: a longitudinal analysis

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Abstract

The BP Deepwater Horizon oil spill (DHOS) created widespread concern about threats to health among residents of the Louisiana Gulf Coast. This study uses data from the Resilient Children, Youth, and Communities study—a longitudinal cohort survey of households with children in DHOS-affected areas of South Louisiana—to consider the effect of DHOS exposure on health trajectories of children, an especially vulnerable population subgroup. Results from latent linear growth curve models show that family DHOS exposure via physical contact and job/income loss both negatively influenced initial child health. However, the effects of physical exposure dissipated over time while the effects of job/income loss persisted. This pattern holds for both general child health and the number of recent physical health problems children had experienced. These findings help to bridge the literature on disaster impacts and resilience/vulnerability, with the literature on socioeconomic status as a fundamental cause of health outcomes over the life course.

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

The Deepwater Horizon oil spill (DHOS) ranks as the largest accidental marine oil spill in history by volume[1] and length of shoreline oiled (Nixon et al. 2016). The disaster was set in motion on April 20, 2010, when the BP-leased Deepwater Horizon oil rig

[1]The DHOS is surpassed in volume only by the Persian Gulf oil spill of 1991, when Iraqi forces intentionally released over 300 million gallons of oil (CNN 2018). This was a purposeful action in the context of war; a disaster, but not an accident.

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exploded about 50 miles offshore of Southeast Louisiana, killing 11 workers aboard the structure. The rig subsequently sank, breaching the wellhead and creating a seafloor blowout that spewed crude oil into the Gulf of Mexico for the next 3 months. It is estimated that over 200 million gallons of oil were released before the well was brought to a static state. The cleanup and mitigation response to the crisis was immense. Several thousand workers were engaged in cleanup efforts, in addition to many volunteers. Floating booms and controlled burns were used to contain and eliminate the oil, along with nearly two million gallons of chemical dispersants applied to the water to break up the crude. Despite the scope of the response, the DHOS resulted in severe and cascading damage to natural ecosystems and coastal human populations, with the most severe oiling occurring in South Louisiana (National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling 2011).

As the disaster unfolded, there was widespread concern about the threats posed by the DHOS to the health and livelihoods of Gulf Coast residents. In South Louisiana, the Gulf is central to the economy and culture (Austin et al. 2014; Henry and Bankston 2002). Coastal Louisiana accounts for over one quarter of commercial fishing landings in the continental USA and supports the infrastructure responsible for 90% of the nation's outer continental shelf oil and gas production (Louisiana Coastal Protection and Restoration Authority 2018). Drilling and fishing moratoria following the spill caused economic hardship, as did damage to fishing grounds, public concerns over seafood safety, and decreased regional tourism. Moreover, fears about health threats were not unwarranted, as adverse impacts of oil spills on human health are well-documented (Aguilera et al. 2010; Laffon et al. 2016). Both crude oil and chemical dispersants contain properties that are toxic to humans (Laffon et al. 2016; Solomon and Janssen 2010). Oil spill exposure through physical contact and inhalation can cause dermatological and respiratory problems, depression of the central nervous system, and, in some cases, cancer (Solomon and Janssen 2010). In addition to physical contact, oil spill exposure can occur via social and economic disruption. These types of exposures also have well-established negative impacts on human health, especially as related to psychosocial stress (e.g., Gill et al. 2016; Palinkas et al. 1993). Indeed, in the aftermath of the DHOS, various forms of spill exposure have been linked to increased physical health symptoms, including wheezing and shortness of breath, headaches, skin rashes, and burning of the eyes, nose, throat, and lungs (D'Andrea and Reddy 2013; Fan et al. 2015; Peres et al. 2016). Among cleanup workers, illness symptoms—including hematological, hepatic, pulmonary, and cardiac functions—have been worsening over time (D'Andrea and Reddy 2018).

While most research on health impacts from DHOS exposure has focused on adults, these concerns are especially salient for children due to physiologic and behavioral characteristics that put them at greater risk for toxic exposure during oil spills, including higher respiratory and metabolic rates, smaller physical stature, and inquisitive play (Murray 2011; National Commission on Children and Disasters 2010). In addition, both toxic exposure and economic adversity during childhood can have noxious impacts at important stages of social, physical, and cognitive development that result in long-term consequences for health and well-being over the life course (Hayward and Gorman 2004; Kousky 2016; Lanphear 2015). Research in the context of Hurricane Katrina also points to unique contours of disaster vulnerability among children (Fothergill and Peek 2015; McLaughlin et al. 2009).

In this study, we address two major gaps in the extant literature on public health impacts related to DHOS exposure. First, we focus on the health implications of oil spill exposure for children, an especially vulnerable population subgroup (Fothergill and Peek 2015; McLaughlin et al. 2009; Murray 2011; National Commission on Children and Disasters 2010). Second, we address the paucity of research on oil spill impacts using longitudinal cohort data—most research to date has been cross-sectional and therefore precludes examination of health trajectories over time (Aguilera et al. 2010; Laffon et al. 2016). More specifically, using data from the Resilient Children, Youth, and Communities (RCYC) study, we analyze three waves of data from a longitudinal cohort of households with children in DHOS-affected areas of South Louisiana. Drawing on the longitudinal design, we employ latent linear growth curve models to examine the effect of oil spill exposure on both initial child health and change in child health following the DHOS.

Background

Social scientists have historically framed disasters as a severe form of social disruption (e.g., Bucher 1957; Sorokin 1942). Nearly six decades ago, Fritz (1961: 655) suggested conceptualizing disasters as circumstances when all or part of society "undergoes severe danger and incurs such losses to its members and physical appurtenances that the social structure is disrupted and the fulfillment of all or some of the essential functions of the society is prevented." Common to sociological framings of disasters developed in the ensuing years are notions that loved ones have been harmed and personal property has been damaged, and that everyday social relations are inadequate to cope with the emergent context. This inability to cope disrupts the typical social order and necessitates the development of new behaviors to adapt to the crisis (Drabek 1986; Dynes and Tierney 1994; Kreps 1989; Quarantelli 1989, 2000).

Adaptive capacity in such circumstances is not monolithic. Disaster resilience refers to individual and systemic capacity for successful adaptation and coping in the face of disaster-related adversity, and the ability to advance along a positive trajectory in the aftermath of the disturbance (Abramson et al. 2015; Norris et al. 2008). Disaster vulnerability, in contrast, refers to individual and systemic factors that constrain adaptive capacity and make people more susceptible to negative disaster impacts over time (Wisner et al. 2004). All these ideas encourage thinking about disasters not as single-point-in-time events, but as social processes that are temporal in nature.

Research also suggests that the consequences of disaster for individual well-being depend in part on the "definition of the situation" (Thomas and Thomas 1928). Disasters that are viewed as being of a natural origin or "Acts of God" tend to engender feelings that no one is at fault that victims are equally deserving of aid, and generally support the emergence of "therapeutic communities" that mitigate and ameliorate disruption (Erikson 1994). In contrast, disasters that are viewed as being of a technological origin or "human-made" have the potential to "create a far more severe and long-lasting pattern of social, economic, cultural and psychological impacts than do natural ones" (Freudenburg 1997: 26). In such cases, "corrosive communities" often emerge: contexts defined by chronic uncertainty, competing narratives of impacts and blame, deterioration in the trust of institutions tasked with protecting the public from the risks of modern technology (i.e., recreancy), and protracted litigation (Cope et al. 2016; Erikson 1994; Freudenburg 1993, 2000; Gill and Picou 1998; Gill et al. 2016; Kroll-Smith and Couch 1993; Picou et al. 2004; Ritchie et al. 2018). These dynamics have been evident since the Exxon Valdez oil spill of 1989 in Prince William Sound, Alaska (see Gill et al. 2016), and there is growing evidence that in terms of its psychosocial consequences, the DHOS is in many respects an "Exxon Valdez rerun" (Ritchie et al. 2011; see also Cope et al. 2016; Gill et al. 2012; Gill et al. 2014; Lee and Blanchard 2012; Parks et al. 2018; Parks et al. 2020). Notably, Erikson (1994) termed these types of disasters a "new species of trouble," while Perrow (1984) warned that "normal accidents" would become more common in complex and tightly coupled systems managing catastrophic risk (see also Beck 1992). Indeed, it seems clear that the DHOS was not only the result of a technological failure, but also a series of human errors embedded in a complex and tightly coupled structure of multiple firms, onshore and offshore entities, and contractual relationships (Hammer 2010).

This study bridges the research on disaster impacts and resilience/vulnerability with the sociology of health literature on the "fundamental cause" perspective. Over 20 years ago, Link and Phelan (1995) formulated a theory of social conditions as fundamental causes of health disparities (see also Phelan et al. 2010). Their central aim was to explain why the association between socioeconomic status (SES) and health has persisted over time despite tremendous changes in the threat of various diseases and related risk factors. Their explanation rests on the notion that "the enduring association results because SES embodies an array of resources, such as money, knowledge, prestige, power, and beneficial social connections that protect health no matter what mechanisms are relevant at any given time" (Phelan et al. 2010: S28). The "fundamental cause" perspective provides an important linkage for thinking about the relationships between disasters and health, and resilience and vulnerability therein. Not only is there reason to believe that lower SES will act as a form of vulnerability and higher SES as a form of resilience to negative health effects in the wake of disaster, but also that SES-related disaster losses, such as job or income loss, may serve as powerful drivers of enduring negative health impacts.

Research questions and expectations

In the analysis that follows, our objective is to examine the relationship between DHOS exposure and child health over time. We analyze the relationships between self-reported *physical DHOS exposure* and *job/income loss due to the DHOS* as predictors of *current general child health* and *number of recent physical child health problems*. Specifically, we ask:

> Q1. Is physical and economic DHOS exposure associated with lower initial levels of general child health?
> Q2. Is physical and economic DHOS exposure associated with a greater initial number of recent physical child health problems?
> Q3. Is physical and economic DHOS exposure associated with change in general child health over time?

Q4. Is physical and economic DHOS exposure associated with change in the number of recent physical child health problems over time?

The extant literature suggests that oil spill exposure, both physical and economic, will be associated with lower initial levels of general child health and a greater number of initial child health problems. Due to the paucity of longitudinal health research in oil spill contexts, the impact of these exposures on child health over time is speculative. We do, however, believe it is reasonable to expect that health trajectories will differ depending on DHOS exposure experiences. We do not hold firm expectations regarding the relative impacts of physical versus economic exposure on child health outcomes, although our analysis does allow us to speak to this question.

Data and methods

The present study uses data from the RCYC survey to examine the relationship between oil spill exposure and child health following the DHOS. The RCYC effort is informed by previous studies conducted by researchers at the National Center for Disaster Preparedness (NCDP), Earth Institute, Columbia University (Abramson et al. 2010; Abramson et al. 2013). A 2010 random-digit dial survey of coastal Louisiana and Mississippi households revealed significant worry about the health impacts of the DHOS and motivated more in-depth study. Subsequently, in 2012, NCDP researchers used a multi-stage sampling design to select communities, census blocks, and households with children to build a dataset concerning the impacts of the DHOS in Louisiana, Mississippi, Alabama, and Florida. An impact index was calculated to identify spill-affected communities using three sources of data: (1) individual claims data from the Gulf Coast Claims Facility (zip code), (2) business claims data from the Gulf Coast Claims Facility (zip code), and (3) aggregated coastline oiling data from the National Oceanic and Atmospheric Administration's Shoreline Cleanup and Assessment Technique (latitude/longitude). *Z* scores were calculated for each of the three variables by zip code and then summed to create a standardized index where higher values indicated more impacted areas. Within highly impacted areas, a two-stage cluster sampling design was utilized to randomly select census blocks, and within these blocks to randomly select households with children. Household eligibility was determined by the presence of at least one child between the ages of 3 and 18 years old and a parent or caregiver age 18 years or older.[2] Participants identified through this process were then surveyed about oil spill exposure, health status, and related topics.[3]

In 2014, researchers from the NCDP returned to the DHOS-affected areas in South Louisiana and conducted a face-to-face household survey ($N = 717$). Since the initial surveys conducted in 2012 were anonymous, the research team revisited the previously interviewed addresses and collected identifiable information to populate a cohort database going forward. From each household, one adult age 18 years or older who was the parent or caregiver of a child in the household provided information for themselves, the focal child, and characteristics of their household. In cases where there

[2] Henceforth we use the term *parent* for ease of expression.

[3] For further methodological information, see Abramson et al. (2013).

was more than one child in the household, the child with the most recent birthday was identified. Adult respondents were selected based on their self-reported ability to be the caregiver best able to answer questions about the focal child's health. Of those surveyed, 655 agreed to be followed up for subsequent waves of data collection. The RCYC study then conducted follow-up interviews with the same adults, and centered on the same focal children, in 2016 and 2018.[4] Out of the 655 respondents from 2014, approximately 74% were re-interviewed in 2016 ($N = 482$) and 2018 ($N = 481$). Reasons for attrition included inability to relocate respondents, refusals, mortality, and incarceration.[5] The survey instrument covered topics such as direct and indirect oil spill exposure, physical and mental health status, perceptions of recovery, demographic data, and a range of characteristics theoretically linked to social vulnerability and resilience. The data collection and study procedures were approved by the Institutional Review Boards at Columbia University and Louisiana State University.

For the current study, our analytic method requires non-missing data on the outcome measures for at least three time points. A total of 420 parents were interviewed at all three points in time. Of these, 27 were missing data on one or both of our outcome measures at one or more time points. When comparing those with missing data to their counterparts with data on both dependent variables at all three time points ($n = 393$), there were no significant differences in: child health at baseline, DHOS exposure (via physical contact or job/income loss), number of people in the household, child gender, child age, parent gender, parent race/ethnicity, or parent marital status. However, those with missing data were significantly older (51 vs. 42 years; $p < .01$) and had lower college completion (8% vs. 22%; $p < .05$) when compared to those with full data on the outcome measures. In all analyses, missing data on the predictor variables ($n = 88$ on household income, $n = 1$ on parent education, $n = 2$ on DHOS exposure via physical contact) were handled via full information maximum likelihood (FIML). Therefore, our analytic sample consists of the 393 parents with non-missing values on the outcome variables at all three time points.

Outcome variables

We consider two outcomes, both of which were assessed in 2014, 2016, and 2018.[6]

Current general child health (range 1–5) At each time point, parents were asked how they would describe their child's current general health. Response options included poor, fair, good, very good, and excellent. The variable was coded such that higher values indicated better health.

[4] In rare cases a new caregiver was selected due to chronic unavailability of the original adult respondent.

[5] In a supplemental analysis (not shown), we examined correlations of all Time 1 outcome and exposure variables with study attrition. One component of physical DHOS exposure (whether the parent could smell the oil in the first 6 months following the oil spill) carried a negative and association at the $p = .039$ level, whereas the other components of physical DHOS exposure (parent or child direct contact with the oil) did not carry significant associations, nor did spill-related job/income loss, general child health, or recent physical child health problems. That the outcome variables were not significantly associated with study attrition, provides added confidence in the results.

[6] Correlations between the two outcomes at each time point are shown in Appendix 1.

Number of recent physical child health problems (range 0–5) At each time point, parents were asked whether in the past 2 months their child had the following: (1) respiratory symptoms such as shortness of breath, wheezing, or tightness in the chest, burning in the nose, throat, or lungs; (2) vision problems such as watery, burning or itchy eyes, blurred, or distorted vision; (3) skin problems such as a skin rash, sore, or blister that lasted three or more days; (4) headaches; (5) unusual bleeding, such as nosebleeds or ear bleeds, or—for girls only—excessive menstrual bleeding. For each health problem, a code of 1 was assigned if a child experienced the problem in the past 2 months, and a code of 0 if the problem was not present. The outcome variable reflects the total number of physical health problems the child experienced in the past 2 months.[7] It is important to note that this measure is not a comprehensive account of all types of physical child health problems; it is a discrete list of specific symptoms. Moreover, it also does not measure other domains of health (e.g., mental, social) that are often considered in rating general health. While these two outcomes are significantly (negatively) correlated, the associations are not strong (see Appendix 1).

Predictor variables

Physical DHOS exposure (1 = yes; 0 = no) In 2014, parents were asked whether they had direct physical contact with the oil, tar balls, or any material put into the water to clean up the oil within 6 months of the DHOS (from April–November 2010). A parallel question was also asked regarding the focal child. In addition, parents were asked whether they could smell the spill within 6 months of the DHOS. Families were considered to have had physical oil spill exposure if the parent answered affirmatively to at least one of these three questions. The range of questions allows for the assessment of various types of physical exposure and helps to reduce potential social desirability bias associated with any one item (e.g., conflating child oil spill exposure with irresponsible parenting).

Job/income loss due to DHOS (1 = yes; 0 = no) In 2014, parents were asked whether anyone in the household had lost income as a result of the oil spill, and whether anyone in the household had lost their job as a result of the DHOS. Families were considered to have experienced job/income loss due to the oil spill if the parent answered affirmatively to either of these questions.[8]

Controls

We include a range of control variables in the models to account for differences in the sociodemographic profiles of households. All regression analyses control for the following variables, measured in 2014: *total number of people in the*

[7] Two months is a standard for recent health recollections used elsewhere in the literature. See, for example, the National Health Interview Survey (National Center for Health Statistics 2019).

[8] There were approximately 50 people who in 2016 or 2018 who reported losing job/income due to the DHOS since the prior wave. Allowing these individuals to affect the slope once they had been exposed does not change our results.

household (range 2 to 13); *child is male* (1 = yes; 0 = no); *child age* (range 4 to 18); *parent is male* (1 = yes; 0 = no); *parent age* (range 19 to 81); *parent race/ethnicity* (categories for Non-Hispanic Black, Other, and Non-Hispanic White as the reference); *parent is unmarried* (1 = yes; 0 = no); *parent has bachelor's degree or more* (1 = yes; 0 = no); and *household income* (range 1–8; 1 = under \$10k; 2 = \$10–20k; 3 = \$20–30k; 4 = \$30–40k; 5 = \$40–50k; 6 = \$50–60k; 7 = \$60–70k; 8 = above \$70k).[9,10]

Analytic method

We employ latent linear growth curve models to consider the effects of oil spill exposure on both initial child health and change in child health following the DHOS. Growth curve models are well suited for modeling the effects of time-invariant predictors on both initial values and change in time-varying outcomes. In addition, likelihood ratio tests showed a superior fit to the data for this model compared with an OLS regression (which does not address within-person clustering on time-varying outcomes) and a random intercept model (which combines all the between-person variance into one component). Additionally, IC criteria showed that the presented model fits the data better than a growth curve allowing separate slopes for each time period. For each child health outcome, our models are based on the following equation:

$$
\begin{gathered}
Y_{it} = I_i + S_i x_t + e_{it}, \;\; i = 1, \ldots n \;\; t = 1, 2, 3 \\
I_i = \alpha_I + \gamma_I W_i + u_{Ii}, \\
S_i = \alpha_S + \gamma_I W_i + u_{Si},
\end{gathered}
$$

where y_{it} is the child health outcome for individual i at time t; I_i is the latent intercept (i.e., the initial value of the child health outcome) for individual i; S_i is the latent slope (i.e., the rate of change in child health over the study period) for individual i; x_t is the time score equal to 0 when $t = 1$ (i.e., 2014), equal to 1 when $t = 2$ (i.e., 2016), and equal to 2 when $t = 3$ (i.e., 2018); and e_{it} is the residual variance for individual i at time t. For equations predicting I_i and S_i, α is the fixed subject-specific intercept, γ is the vector of effects of the predictors and covariates, and u_i is the random effect for individual i. In addition to estimating random effects for I_i and S_i, we also estimate their covariance. Finally, initial analyses indicated that the residual variance did not significantly differ across time points. Therefore, for a more parsimonious model, we constrain the residual variance e_{it} to be equal across time points. For each outcome, we present two models: Model 1 shows the unconditional growth

[9] In our analysis child age is modeled age as a linear relationship. Sensitivity analysis modeling child age as curvilinear or categorical (i.e., quartiles) yielded similar results.

[10] Ancillary analyses controlling for whether the respondent had moved during the survey yielded similar results.

curve, and Model 2 includes effects for the DHOS exposure variables and covariates. All models were estimated in Stata 16.1.

Results

Descriptive statistics for child health, DHOS exposure, and the control variables are shown in Table 1. On average, children were in good health, with general health scores showing modest improvement at later time points. Specifically, the average general child health score was 3.69 in 2014, 3.79 in 2016, and 3.85 in 2018. Regarding physical health problems in the past 2 months, children had 1.06 in 2014, 1.17 in 2016, and 1.26 in 2018, a modest increase in number of recent physical health problems over time. Importantly, DHOS exposure was not uncommon. Overall, 51% of children were in households with physical

Table 1 Descriptive statistics on child health, DHOS exposure, and controls

	Mean	SD	Min	Max
Current general child health				
Time 1 (2014)	3.69	1.10	1	5
Time 2 (2016)	3.79	1.10	1	5
Time 3 (2018)	3.85	1.14	1	5
Number of recent physical child health problems				
Time 1 (2014)	1.06	1.29	0	5
Time 2 (2016)	1.17	1.36	0	5
Time 3 (2018)	1.26	1.48	0	5
Physical DHOS exposure[a]	0.51	0.50	0	1
Job/income loss due to DHOS[a]	0.37	0.48	0	1
Controls[a]				
Total people in household	4.32	1.39	2	13
Child is male	0.57	0.50	0	1
Child age	11.66	4.18	4	18
Parent is male	0.38	0.49	0	1
Parent age	42.35	10.72	19	81
Parent race-ethnicity				
Non-Hispanic Black	0.25	0.43	0	1
Other race-ethnicity	0.13	0.34	0	1
Non-Hispanic White	0.62	0.49	0	1
Parent is unmarried	0.29	0.45	0	1
Parent has bachelor's degree	0.22	0.42	0	1
Household income	5.11	2.37	1	8

Source: RCYC survey ($N = 393$; N based on respondents with non-missing information on the dependent variable at all three waves)

[a] Measured at Time 1 (in 2014); *SD* standard deviation

DHOS exposure, and 37% were in households with job/income loss due to the DHOS.

With respect to the control variables, over half (57%) of children were male. At the initial interview in 2014, children were an average of about 12 years old and lived in 4-person households where the average income was between $40 and 50k. Sixty-two percent of parents were female. Just over 60% of parents were Non-Hispanic White and another 25% were Non-Hispanic Black. At the initial interview in 2014, parents were an average of 42 years old, about 70% were married, and 22% had a bachelor's degree or more.

Table 2 shows the means for the child health outcomes and all covariates by DHOS exposure. Wald tests were used to test for significant differences between those with and without physical DHOS exposure, and those with and without job/income loss due to DHOS. The results indicate that those with either exposure type (physical or economic) had poorer general health and more physical health problems. Children in households with physical DHOS exposure also had a greater prevalence of job/income loss due to the DHOS when compared with children without physical DHOS exposure (52% vs 21%; $p < .001$). Similarly, children in households with job/income loss due to the DHOS had a higher prevalence of physical DHOS exposure (72% vs. 38%; $p < .001$). Both exposure types were tied to significantly lower average household incomes ($p < .001$). Finally, fewer parents in households with job/income loss due to DHOS had college degrees when compared with parents in households without economic exposure (9% vs. 30%, $p < .001$).

Table 3 presents results from latent linear growth curve models estimating the effects of DHOS exposure on initial values of, and rate of change in, general child health. Model 1 shows results for the unconditional model. The results indicate an average initial general child health value of 3.69 ($p < .001$) and a significant and positive average rate of change in general child health ($b = .08$; $p < .01$). While the coefficients for the latent intercept and slope reflect the average person-specific values for initial child health and rate of change in child health, respectively, the variance components represent the amount of between-person variation in the initial status and/or rate of change in child health. Likelihood ratio tests demonstrated significant between-person variation in the initial status, the rate of change, and their covariance.[11]

Model 2 shows results for the full model. The rate of change in child general health when both exposure variables and all covariates are at 0 is not significant. The results indicate that physical DHOS exposure significantly affects both initial values of general child health and the rate of change in general child health. After adjusting for job/income loss due to the DHOS and controls, physical DHOS exposure is associated with lower initial general child health scores ($b = -.52$; $p < .001$). Yet, the negative effect of physical DHOS exposure on general child health dissipates with time, as indicated by the significant and positive effect of

[11] Likelihood ratio (LR) test for OLS vs. unconditional means model: $\chi2 = 310.12$, $p < .001$; LR test for unconditional means vs. unconditional growth curve without covariance between random intercept and random slope: $\chi2 = 16.31$ $p < .001$; LR test for adding covariance between random intercept and random slope: 6.74; $\chi2 = p < .01$.

Table 2 Means on child health and controls by DHOS exposure

	Physical DHOS exposure	No physical DHOS exposure	b	Job/income loss due to DHOS	No job/income loss due to DHOS	c
Current general child health						
Time 1 (2014)	3.32	4.07	***	3.32	3.90	***
Time 2 (2016)	3.52	4.08	***	3.37	4.04	***
Time 3 (2018)	3.61	4.13	***	3.55	4.03	***
Number of recent physical child health problems						
Time 1 (2014)	1.47	0.63	***	1.45	0.84	***
Time 2 (2016)	1.50	0.80	***	1.69	0.86	***
Time 3 (2018)	1.46	1.02	**	1.64	1.04	***
Physical DHOS exposure[a]	1.00	0.00		0.72	0.38	***
Job/income loss due to DHOS[a]	0.52	0.21	***	1.00	0.00	
Controls[a]						
Total people in household	4.31	4.34		4.47	4.24	
Child is male	0.53	0.61	+	0.52	0.60	
Child age	11.81	11.54		10.99	12.05	*
Parent is male	0.36	0.40		0.41	0.35	
Parent age	43.64	41.01	*	41.81	42.66	
Parent race-ethnicity						
Non-Hispanic Black	0.26	0.22		0.27	0.23	
Other race-ethnicity	0.15	0.12		0.17	0.11	+
Non-Hispanic White	0.59	0.66		0.56	0.66	+
Parent is unmarried	0.31	0.27		0.34	0.26	+
Parent has bachelor's degree	0.20	0.25		0.09	0.30	***
Household income	4.64	5.70	***	4.26	5.65	***

Source: RCYC survey ($N = 393$; N based on respondents with non-missing information on the dependent variable at all three waves)

$^{+}p < .10$, $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$

[a] Measured at Time 1 (in 2014)

[b] Significance of Wald tests comparing those with and without physical exposure

[c] Significance of Wald tests comparing those with and without economic exposure

physical DHOS exposure on the rate of change in general child health ($b = .16$; $p < .05$). In contrast, after adjusting for the effects of physical DHOS exposure and controls, job/income loss due to the DHOS is associated with lower initial general child health ($b = -.30$; $p < .01$) but does not significantly affect the rate of change in general child health. That DHOS-related job/income loss significantly affects initial values of general child health, but not the rate of change, is indicative of persistent general child health disparities over the study period between children in households with economic exposure to the DHOS versus those without such impacts.

Table 3 Latent linear growth curve models estimating the effects of DHOS exposure on initial values of and rate of change in general child health

	Model 1				Model 2			
	Latent intercept		Latent slope		Latent intercept		Latent slope	
	b	s.e.	*b*	s.e.	*b*	s.e.	*b*	s.e.
Constant	3.694***	0.05	0.084**	0.03	4.001***	0.12	− 0.062	0.08
Physical DHOS exposure					− 0.524***	0.10	0.163*	0.07
Job/income loss due to DHOS					− 0.298**	0.11	0.004	0.07
Total people in household[a]					− 0.031	0.04	0.027	0.02
Child is male					− 0.047	0.10	0.136*	0.06
Child age[a]					− 0.017	0.01	− 0.007	0.01
Parent is male					0.159	0.10	0.019	0.07
Parent age[a]					− 0.004	0.01	− 0.001	0.00
Parent race-ethnicity								
Non-Hispanic Black					− 0.003	0.12	− 0.033	0.07
Other race-ethnicity					− 0.144	0.15	− 0.094	0.09
Non-Hispanic White[b]								
Parent is unmarried					− 0.079	0.13	0.077	0.08
Parent bachelor's or more					0.341*	0.13	− 0.126	0.08
Household income[a]					0.070*	0.03	0.035	0.02
Variance components								
Random intercept		0.768				0.507		
Random slope		0.133				0.118		
Covariance (intercept, slope)		− 0.096				− 0.077		
Residual error		0.445				0.445		

Source: RCYC survey ($N = 393$). Likelihood ratio (LR) test for OLS vs. unconditional means model: $\chi2 = 310.12$, $p < .001$; LR test for unconditional means vs. unconditional growth curve without covariance between random intercept and random slope: $\chi2 = 16.31$ $p < .001$; LR test for adding covariance between random intercept and random slope: 6.74; $\chi2 = p < .01$

+$p < .10$, *$p < .05$, **$p < .01$, ***$p < .001$. *b* coefficient; s.e. standard error

[a] Centered

[b] Reference category

Figure 1 elucidates these trends, showing predicted general child health over time for children in households with and without physical DHOS exposure (Panel A), and for children in households with and without job/income loss due to the DHOS (Panel B).[12] Specifically, in each panel, Fig. 1 shows predicted child health values for those exposed

[12] All figures were estimated using the margins command. While the sem command allows for FIML estimation of missing values it does not provide predicted values for any of the cases missing on model predictors. Further, the sem command does not allow factor notation, which is required for margins to provide valid estimates. Therefore, we estimated margins from multilevel models using the mixed command, which does not use FIML, so for these models we handled missing data on income by using mean imputation and including a dichotomous indicator of whether cases were missing data on income.

and not exposed, holding the values of the other exposure variable and all covariates at their means. For instance, Panel A of Fig. 1 presents predicted child health values over time by physical DHOS exposure when holding job/income loss due to the DHOS and the covariates at their mean values.

At the initial observation period in 2014, predicted child health is .55 units lower for children in households with versus without physical DHOS exposure (3.43 vs. 3.97; $p < .001$). For those without physical DHOS exposure, predicted child health remains stable—at about 3.98—across the study period. Yet for those with physical DHOS exposure, predicted child health improves over the study period, such that by 2018 the predicted child health score for those with physical exposure is 3.76. This pattern of

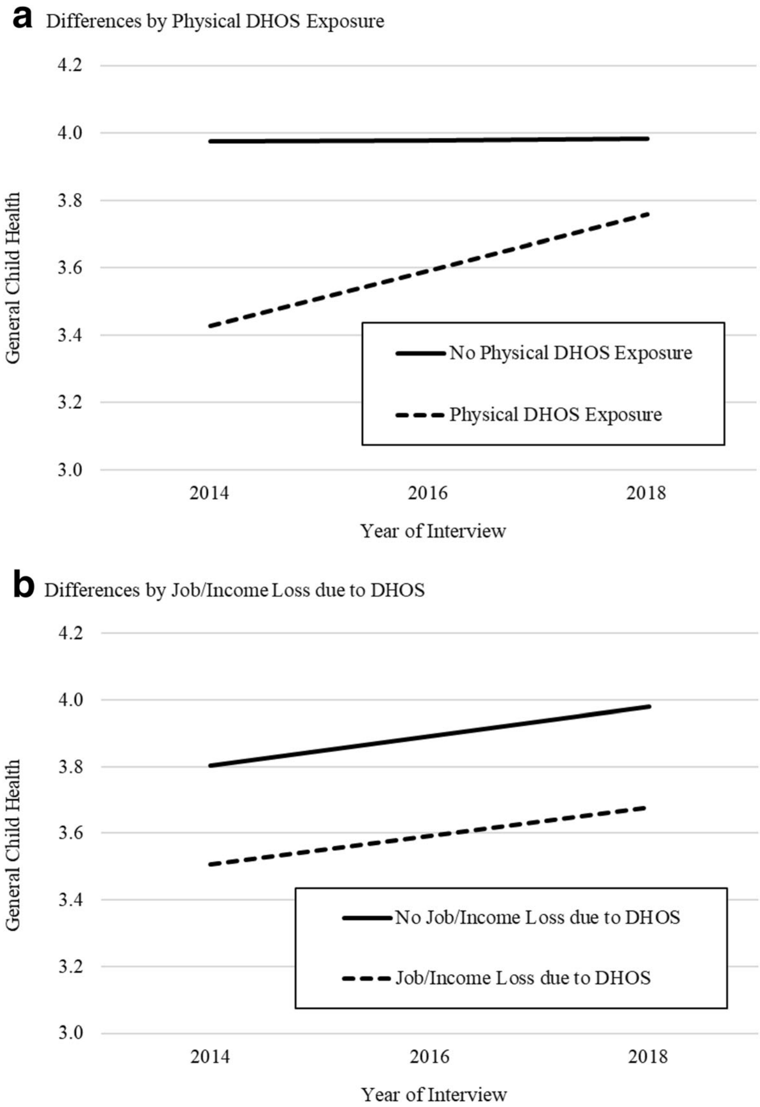

Fig. 1 Predicted general child health over time, adjusting for DHOS exposure and mean values of covariates

results leads to a significantly smaller disparity ($p < .05$) in predicted child health for those with versus without physical DHOS exposure at the final observation period (about .22) compared with the initial observation period (about .55). These results suggest that over time children recover from physical DHOS exposure with respect to general health. Panel B of Fig. 1 presents predicted child health values over time by job/income loss due to the DHOS at average levels of physical DHOS exposure and average values of the covariates. In contrast to Panel A, Panel B indicates a stable disparity in predicted child health for those with versus without economic exposure to the DHOS that stays at about .30 over the entire study period.

Table 4 presents results from latent linear growth curve models estimating the effects of DHOS exposure on initial values of, and rate of change in, the number of recent physical child health problems. Model 1 shows results for the unconditional model. The results indicate an average initial value of 1.06 ($p < .001$) recent physical child health problems and a significant and positive average rate of change in the number of recent physical child health problems ($b = .10$; $p < .01$). This suggests that physical health problems such as headaches, respiratory issues, and vision or skin problems increased for children over the study period. Likelihood ratio tests demonstrated significant between-person variation in the initial status and the rate of change.[13]

Model 2 shows results for the full model. Like the findings for general child health presented in Table 2, the results indicate that physical DHOS exposure significantly affects both initial values and the rate of change in the number of recent physical health problems experienced by a child. Specifically, physical DHOS exposure is associated with a greater initial number of recent physical child health problems ($b = .64$; $p < .001$), adjusting for the effects of job/income loss due to DHOS and controls. Yet, physical DHOS exposure also has a significant negative effect on the rate of change in the number of recent physical child health problems ($b = -.21$; $p < .01$). Given that the rate of change in the number of recent physical child health problems when both exposure variables and all covariates are at 0 is positive and significant (.25, $p < .01$), the negative effect of physical DHOS exposure on the rate of change suggests that those with physical DHOS exposure experience fewer increases in physical health problems over time. In contrast, adjusting for the effects of physical DHOS exposure and controls, DHOS-related job/income loss is associated with a greater initial number of recent physical child health problems ($b = .38$; $p < .01$), but does not significantly affect the rate of change in the number of recent physical child health problems. That DHOS-related job/income loss significantly affects the initial number of recent physical child health problems, but not the rate of change over time, is suggestive of persistent disparities over the study period in the number of physical health conditions experienced between children in households with economic exposure to the DHOS versus those without such impacts.

These trends are illustrated in Fig. 2, which shows the predicted number of recent physical child health problems over time for children in households with and without physical DHOS exposure (Panel A), as well as for children in households with and

[13] Likelihood Ratio (LR) test for OLS vs. unconditional means model: $\chi2 = 321.19$, $p < .001$; LR test for unconditional means vs. unconditional growth curve without covariance between random intercept and random slope: $\chi2 = 14.39$; $p < .001$; LR test for adding covariance between random intercept and random slope: $\chi2 = 0.80$; $p = .372$.

Table 4 Latent linear growth curve models estimating the effects of DHOS exposure on initial values of and rate of change in number of recent physical child health problems

	Model 1				Model 2			
	Latent intercept		Latent slope		Latent intercept		Latent slope	
	b	s.e.	*b*	s.e.	*b*	s.e.	*b*	s.e.
Constant	1.064***	0.06	0.099**	0.04	0.737***	0.14	0.254**	0.09
Physical DHOS exposure					0.639***	0.12	− 0.213**	0.07
Job/income loss due to DHOS					0.384**	0.13	0.088	0.08
Total people in household[a]					0.039	0.04	− 0.028	0.03
Child is male					− 0.206+	0.11	− 0.151*	0.07
Child age[a]					0.042**	0.01	− 0.021*	0.01
Parent is male					− 0.237+	0.12	− 0.025	0.07
Parent age[a]					0.003	0.01	− 0.003	0.00
Parent race-ethnicity								
Non-Hispanic Black					0.304*	0.14	− 0.106	0.08
Other race-ethnicity					0.240	0.17	− 0.201+	0.10
Non-Hispanic White[b]								
Parent is unmarried					0.093	0.15	0.063	0.09
Parent bachelor's or more					− 0.293+	0.16	0.235*	0.09
Household income[a]					− 0.021	0.04	− 0.009	0.02
Variance components								
Random intercept	0.877				0.550			
Random slope	0.085				0.043			
Covariance (intercept, slope)	0.049				0.110			
Residual error	0.785				0.785			

Source: RCYC survey ($N = 393$). Likelihood ratio (LR) test for OLS vs. unconditional means model: $\chi2 = 321.19$, $p < .001$; LR test for unconditional means vs. unconditional growth curve without covariance between random intercept and random slope: $\chi2 = 14.39$; $p < .001$; LR test for adding covariance between random intercept and random slope: $\chi2 = 0.80$; $p = .372$

+$p < .10$, *$p < .05$, **$p < .01$, ***$p < .001$; *b* coefficient; *s.e* standard error

[a] Centered

[b] Reference category

without job/income loss due to the DHOS (Panel B). In 2014, the predicted number of recent physical child health problems is about .61 units higher for children in households with versus without physical DHOS exposure (1.36 vs. .75; $p < .001$). For those without physical DHOS exposure, the predicted number of health problems increases over time, which is likely reflective of the tendency for children to acquire more health problems as they age. Yet, for those with physical DHOS exposure, the predicted number of health problems remains stable across the study period. This pattern of results leads to a significantly smaller disparity ($p < .01$) in predicted health problems for those with versus without physical exposure at the final observation period (.22) compared with the initial observation period (.61). In contrast, Panel B indicates a stable disparity in the predicted number of recent physical child health problems for those with versus without economic exposure to the DHOS that stays at about .49 over the study period.

Supplemental analyses

Supplemental analyses (not shown) assessed whether results were sensitive to the way we operationalized physical DHOS contact. First, we separated child/parent direct physical DHOS contact (henceforth, “direct contact”) from the indicator for whether

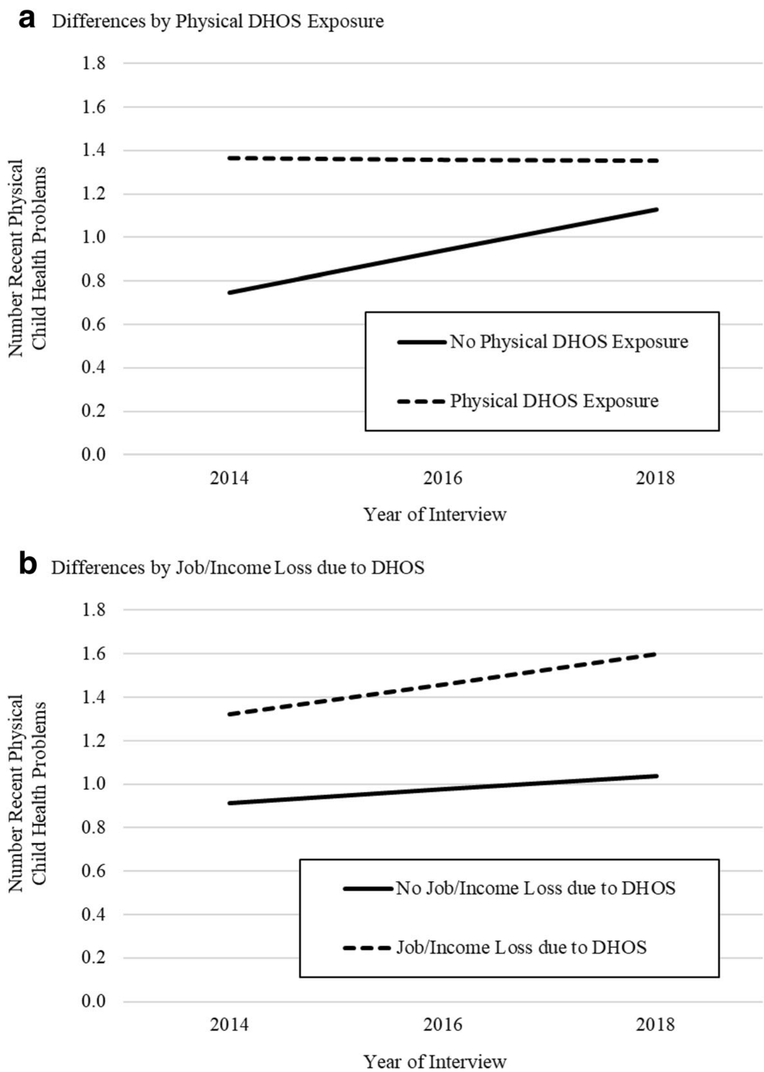

Fig. 2 Predicted number of recent physical child health problems over time, adjusting for DHOS exposure and mean values of covariates

the parent smelled the DHOS and used information from both indicators to create an ordinal variable for level of physical exposure: 0 = no exposure; 1 = one exposure (direct or smell); 2 = two exposures (direct and smell). In regressions controlling for covariates, results were similar to the physical exposure indicator in the main analysis, both in terms of direction and significance of the ordinal physical exposure variable. We also entered the ordinal physical exposure as a categorical variable (reference = no exposure). Again, results were consistent with the main analysis, except that "one exposure" was marginally significant for general child health. We then modeled the "direct contact" indicator by itself with covariates and results were similar to the main analysis in terms of direction and significance, except that the effect of direct contact on the rate of change for physical health did not reach significance. Finally, results modeling the smelled spill indicator by itself with covariates were also similar to the main analysis, except that smelled spill was not significant for general child health ($p = .12$). Overall the supplementary analyses were consistent with and provided support for our main findings, although in some cases the coefficients failed to reach statistical significance. This is likely because of the smaller cell sizes and larger standard errors that occurred when modeling the ordinal physical exposure variable as categorical or when modeling direct contact and smelled spill as separate indicators entirely. We do not have a theoretical guide as to whether these differences in operationalization are distinctions with a difference in relation to the outcomes.

Discussion

The purpose of this study was to assess the relationship between DHOS exposure and child health trajectories over time. The results showed the following: (1) physical DHOS exposure is associated with lower initial levels of general child health and a greater initial number of recent physical child health problems; (2) economic DHOS exposure is associated with lower initial levels of general child health and a greater initial number of recent physical child health problems; (3) the negative effect of physical DHOS exposure on general child health and the positive effect of physical DHOS exposure on the number of child health problems dissipates over time; and (4) economic DHOS exposure does not affect the rate of change in general child health or recent physical child health problems, indicating a persistent health disparity over the study period for children with this type of exposure.

The main contributions of these findings are twofold. First, while most of the research on DHOS-related health consequences has focused on adults, our results point to serious consequences of DHOS exposure for child health that, in the case of job/income loss, persist even 8 years after the disaster. These results underscore children as an especially vulnerable population subgroup in the context of oil spills that merit further attention in future research (Murray 2011; National Commission on Children and Disasters 2010). Second, and in contrast to most prior research based on cross-sectional data, our use of prospective cohort data allowed us to assess child health trajectories over time (Aguilera et al. 2010; Laffon et al. 2016). This approach enabled us to corroborate associations found in prior research and led to new insights regarding the long-term health implications of different types of exposure to oil spills.

The results of this study contribute to the literature on the health effects of oil spills broadly (e.g., Gill et al. 2016; Palinkas et al. 1993), as well as to the growing body of research on the health effects related to the DHOS specifically (e.g., Ayer et al. 2019; Cope et al. 2013; D'Andrea and Reddy 2013, 2018; Fan et al. 2015; Gill et al. 2014; Lee and Blanchard 2012; Osofsky et al. 2011;Parks et al. 2020; Peres et al. 2016; Ramchand et al. 2019; Rung et al. 2016; Rung et al. 2017). In addition, our pattern of results showing that the negative effects of oil spill exposure via job/income loss—but not physical exposure—on child health persist over time, help to link the literature on disaster impacts and resilience/vulnerability with the literature on SES as a fundamental cause of health outcomes (Link and Phelan 1995; Phelan et al. 2010). More specifically, our results suggest that SES-related disaster losses, such as job or income loss, may serve as powerful drivers of enduring negative health impacts for children.

Several additional strengths and limitations of the current study are worth noting. First, while our focus on child health is important because of scant research on this vulnerable population, a limitation of the data is that parents were asked to assess a child's current overall health and physical health symptoms. Self-rated health is used by groups such as the World Health Organization as a reliable and valid measure of psychological, social, and biological dimensions of health (Boardman 2004; Ferraro and Farmer 1999), and is one of the strongest correlates of physical health, healthcare utilization, objective health measures, and life expectancy (Frankenberg and Jones 2004; Idler and Benyamini 1997; Jylhä 2009). However, while self-rated health has known qualities, researchers have yet to conduct comparable analyses of parent reports of general child health and physical health symptoms. For example, in this case, it is possible that those whose children suffered DHOS exposure may have been more attuned to their child's health status than those whose children were not exposed. Future research can extend the current study by relying on more direct forms of child health assessment, including biomarker measurement.

Relatedly, the current study relies on two child health outcomes measured over a 3-year time span. While researchers do not know the best time horizon over which to observe these outcomes, research on the Exxon Valdez oil spill continues to document negative impacts nearly 25 years after the initial event (Gill et al. 2016). The implication is that continuing to assess these outcomes over a longer timeframe is merited. Moreover, the use of a diverse array of physical health measures in future work could deepen our understanding of the range of exposure impacts and help elucidate mechanisms. In addition, among adults, DHOS exposure has been associated with adverse mental health outcomes, including depression, anxiety, and psychosocial stress related to lifestyle disruption (Ayer et al. 2019; Cope et al. 2013; Gill et al. 2014; Lee and Blanchard 2012; Osofsky et al. 2011; Parks et al. 2018; Parks et al. 2020; Ramchand et al. 2019; Rung et al. 2016; Rung et al. 2017). One potentially fruitful path for research going forward could involve replicating this study with a focus on child mental and behavioral health outcomes.

While we use a variety of measures to assess DHOS exposure, these measures also have limitations. For example, our DHOS exposure variables (physical and economic) are based on self-reports and thus subject to recall bias, attribution error, and subjective interpretations of experiences. Moreover, it is important to note that the people in this region of the country are subject to chronic environmental risk associated with the petrochemical industry. The implication is that the DHOS was not the only potential source of toxic exposure for study participants, and that the risks associated with exposure to pollution from chemical releases and other industrial incidents are somewhat normalized (Slack et al. 2020; Thomas et al. 2018).

The probability sample design of the RCYC study is a strength over non-probability studies. Although the sample size is typical of cohort studies using a probability sample, future research using a larger sample can build on the strengths of the current study. Specifically, a larger sample could enable the detection of greater health variability over time and reduce the possibility of a type II error. Southeast Louisiana is a unique place in many respects. Only larger samples and replication across different settings will allow for a determination of the generalizability of the findings presented here. Additionally, although Gould et al. (2015) note the drawbacks of larger population-based surveys in disaster studies (e.g., potentially casting “too wide a net” when the impacts are more geographically delimited), a larger sample among impacted populations could facilitate analyses of important population subgroups. A notable group in this regard on the Louisiana Gulf Coast are Vietnamese Americans, a community with high involvement in the fishing industry (VanLandingham 2017). The RCYC data does not allow for the examination of the Vietnamese American experience specifically.

Finally, it is worth noting that the geography identified for the probability sample design was informed in part by data from the Gulf Coast Claims Facility (i.e., BP claims). Claims processes are known to be socially uneven in terms of engagement and almost certainly underestimate impact. On the other hand, protracted claims and litigation processes following oil spills have also been shown to be a major source of psychosocial stress (Ritchie et al. 2018). Given that the sample was drawn from Louisiana parishes highly impacted by the oil spill, measurement of the probability of respondent impact could yield further insights in future research and its omission is a limitation of the current analysis.

The impacts of a disaster like the DHOS can be expected to unfold over many years, and for people living along the Louisiana Gulf Coast, this process has occurred alongside other types of environmental shocks and stressors. The State of Louisiana continues to invest in major, long-term planning, implementation, and monitoring of restoration activities since the DHOS, some of which include efforts to better understand and support resilient coastal communities and economies (Louisiana Coastal Protection and Restoration Authority 2013). This is consistent with the notion that human resilience to disaster must be supported holistically, with policy and practice that considers dimensions such as natural resources, infrastructure, economies, political resources, and social and cultural characteristics, including physical, mental, and behavioral health services (National Academies of Sciences, Engineering, and Medicine 2019). In its report to the President and Congress, the National Commission on Children and Disasters (2010) highlighted children’s unique needs, offering many recommendations for disaster management and recovery. Among these recommendations is a need for policy and programming tailored to better support the long-term health of children who have experienced disaster. The present study offers insight into the differential impacts of DHOS exposure for children over time and highlights the utility of longitudinal methods in answering questions about the long-term social, public health, and economic impacts of a complex technological disaster. These findings may be useful for a variety of stakeholders, including parents and other child caretakers, practitioners who work directly with families and children, and decision makers responsible for policies and funding that support disaster resilience among children and families.

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Appendix. Correlations for outcome variables

		Current general child health			Number of recent physical child health problems		
		Time 1	Time 2	Time 3	Time 1	Time 2	Time 3
Current general child health	Time 1	1.00	–	–	–	–	–
	Time 2	.55	1.00	–	–	–	–
	Time 3	.43	.62	1.00	–	–	–
Number of recent physical child health problems	Time 1	− .53	− .37	− .36	1.00	–	–
	Time 2	− .32	− .48	− .35	.52	1.00	–
	Time 3	− .30	− .38	− .42	.51	.60	1.00

RCYC survey ($N = 393$)

All correlations are significant ($p < .001$)

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