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Risk terrain modeling predicts child maltreatment

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ABSTRACT

As indicated by research on the long-term effects of adverse childhood experiences (ACEs), maltreatment has far-reaching consequences for affected children. Effective prevention measures have been elusive, partly due to difficulty in identifying vulnerable children before they are harmed. This study employs Risk Terrain Modeling (RTM), an analysis of the cumulative effect of environmental factors thought to be conducive for child maltreatment, to create a highly accurate prediction model for future substantiated child maltreatment cases in the City of Fort Worth, Texas. The model is superior to commonly used hotspot predictions and more beneficial in aiding prevention efforts in a number of ways: 1) it identifies the highest risk areas for future instances of child maltreatment with improved precision and accuracy; 2) it aids the prioritization of risk-mitigating efforts by informing about the relative importance of the most significant contributing risk factors; 3) since predictions are modeled as a function of easily obtainable data, practitioners do not have to undergo the difficult process of obtaining official child maltreatment data to apply it; 4) the inclusion of a multitude of environmental risk factors creates a more robust model with higher predictive validity; and, 5) the model does not rely on a retrospective examination of past instances of child maltreatment, but adapts predictions to changing environmental conditions. The present study introduces and examines the predictive power of this new tool to aid prevention efforts seeking to improve the safety, health, and wellbeing of vulnerable children.

1. Introduction

The oftentimes lifelong, adverse physical, mental, and social health consequences of child maltreatment are well-documented in a growing body of literature (e.g., Felitti et al., 1998). The long-term health outcomes include shorter life expectancy (Brown et al., 2009; Campbell, Walker, & Egede, 2016), chronic disease and disability (Anda et al., 2008; Brown, Thacker, & Cohen, 2013; Campbell et al., 2016; Cunningham et al., 2014), obesity (Campbell et al., 2016; Williamson, Thompson, Anda, Dietz, & Felitti, 2002), smoking (Campbell et al., 2016; Edwards, Anda, Gu, Dube, & Felitti, 2007; Mersky, Topitzes, & Reynolds, 2013), alcohol and drug abuse (Campbell et al., 2016; Fergusson, Boden, & Horwood, 2008; Mersky et al., 2013), risk of intimate partner and sexual violence (Ports, Ford, & Merrick, 2016; Whitfield, Anda, Dube, & Felitti, 2003), depression and anxiety (Campbell et al., 2016; Fergusson et al., 2008; Mersky et al., 2013; Remigio-Baker, Hayes,

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& Reyes-Salvail, 2014), suicidality (Fergusson et al., 2008; McCauley et al., 1997), sexually transmitted diseases (Campbell et al., 2016; Hillis, Anda, Felitti, Nordenberg, & Marchbanks, 2000), unintended and teenage pregnancies (Anda et al., 2002; Dietz et al., 1999), low birth weight and fetal death (Hillis et al., 2004), psychological disorders and disturbances (Brown et al., 2007; De Venter, Demyttenaere, & Bruffaerts, 2013; Whitfield, Dube, Felitti, & Anda, 2005), and risk of aggressive and/or criminal behavior (Levenson & Socia, 2016; Reavis, Looman, Franco, & Rojas, 2013). The cost of child maltreatment to American society is estimated at $124 to $585 billion annually (Fang, Brown, Florence, & Mercy, 2012).

In Texas in 2014, more children were reported as abused or neglected in Tarrant County than in any other of its 254 counties (Texas Department of Family and Protective Services, 2015). Child Protective Services (CPS), a division of the Department of Family and Protective Services (DFPS), substantiated 6097 children as physically, sexually, or psychologically abused, neglected, or abandoned in Tarrant County in 2014, an increase of 408 from the previous year (DFPS, 2015). From 2013 to 2014 in Tarrant County, the rate of substantiated maltreatment increased from 10.9 to 11.5 victims per 1000 children (DFPS, 2014, 2015). For comparison, in 2014, the State of Texas had a substantiated maltreatment rate of 9.2 victims per 1000 children (DFPS, 2015) and the national rate was 9.4 victims per 1000 children (U.S. Department of Health & Human Services (HHS), 2016). Best estimates indicate that maltreatment will be confirmed for one in eight American children by 18 years of age, far greater than the one in 100 children whose maltreatment is currently included in annual social service agencies' records (Wildeman et al., 2014). Other data also suggests that the underreporting rates of crimes against children are exceedingly high. One strong indicator, for instance, is the fact that the majority of child maltreatment fatalities occur in families not known to the child welfare system (HHS, 2015).

1.1. Risk factors for child maltreatment

A review of the pertinent literature on child maltreatment and associated risk factors exposes the complexity of child maltreatment as a multi-system disease. Identified risk factors range from individual to societal levels, vary in level of influence, and may also have compounding effects on child maltreatment outcomes (Centers for Disease Control and Prevention (CDC), 2015; Diderich et al., 2013; Peterson, Joseph, & Feit, 2014; Stith et al., 2009; White, Hindley, & Jones, 2015). Some of the most well-documented risk factors for child maltreatment include parental substance abuse, family violence, and community poverty and instability.

Decades of research demonstrate that substance abuse (Kelleher, Chaffin, Hollenberg, & Fischer, 1994; Seay & Kohl, 2013; Smith, Johnson, Pears, Fisher, & DeGarmo, 2007; Sprang, Clark, & Staton-Tindall, 2010; Walsh, MacMillan, & Jamieson, 2003) and family violence (Appel & Holden, 1998; Cox, Kotch, & Everson, 2003; Diderich et al., 2013; Edleson, 1999; McGuigan and Pratt, 2001; Nicklas & Mackenzie, 2012) are significantly associated with a child's risk for maltreatment. Children of parents with any history of alcohol or substance abuse are at least five times more likely to experience abuse and nine times more likely to experience neglect than children of non-substance abusers (Kelleher et al., 1994). Even after adjusting for compounding effects of mental illness, these children were found to be nearly three to four times more likely to experience maltreatment than the control group (Kelleher et al., 1994). Children of women experiencing intimate partner violence are more than twice as likely to experience neglect by their mother (Nicklas & Mackenzie, 2012). Furthermore, the co-occurrence of child maltreatment and family violence is elevated by parental substance abuse (Hartley, 2002), which often occurs in a context of family dysfunction. In many instances, family dysfunction precipitates a child running away to escape a toxic environment (Kim, Tajima, Herrenkohl, & Huang, 2009). Investigations into child runaway cases refute conventional beliefs that children exhibit delinquent and rebellious behavior strictly due to hormonal changes. In a sample of 223 runaway and homeless children, Powers, Eckenrode, and Jaklitsch (1990) found that 60% of the children had been previously maltreated, similar to the 65–75% percent of runaway youth surveyed by Whitbeck, Hoyt, and Ackley (1997). Famularo, Kinscherff, Fenton, and Bolduc (1990) also found that children who demonstrated delinquent behaviors, such as running away or truancy, were seven times more likely to have experienced sexual abuse and twice as likely to have experienced physical abuse than their peers.

Beyond individual and familial risk factors, child maltreatment is influenced by the community and social context in which it occurs. Evidence shows that poverty and low socioeconomic status are strongly associated with neglect (Brown, Cohen, Johnson, & Salzinger, 1998; CDC, 2015; Drake and Pandey, 1996; Freisthler, Bruce, & Needell, 2007; Peterson et al., 2014), in part due to increased family stress and reduced parental capacity to provide a safe and nurturing environment. In addition to poverty and low socioeconomic status, the rate and severity of maltreatment are related to child-reported violence in their community (Lynch and Cicchetti, 1998). Although theories of social disorganization only provide a moderate explanation for child maltreatment (Mustaine, Tewksbury, Huff-Corzine, Corzine, & Marshall, 2014), incidence rates are correlated with indicators of a breakdown in community social control and organization (Coulton, Korbin, Su, & Chow, 1995; Felitti et al., 1998; Snowden & Pridemore, 2012). The most recent evaluation of child violence, based on the National Survey of Children's Exposure to Violence (NatSCEV), reveals that at least 40% of sampled children have witnessed or experienced violence, crime, and/or maltreatment more than once in their lifetime (Finkelhor, Turner, Shattuck, & Hamby, 2015).

Traditionally, maltreatment susceptibility has been understood by studying population-based, individual, and community-specific risk factors (see: Coulton, Crampton, Irwin, Spilsbury, & Korbin, 2007; Freisthler et al., 2007; McDonell & Skosireva, 2009; Parrish, Young, Perham-Hester, & Gessner, 2011; Schnitzer, Slusher, & Van Tuinen, 2004). Methods typically involved analyzing data sources including PRAMS (Pregnancy Risk Assessment Monitoring System) survey responses, CPS protective service report (PSR) records, medical and public health surveillance data, vital statistics, Census tract and

Table 1
List of Examined Risk Factors (in Alphabetical Order).

Risk Factor	Data Source
Aggravated Assaults	FWPD
Bars & Nightclubs	TABC
Murders	FWPD
Domestic Violence	FWPD
Drug Crimes	FWPD
Gang Presence	FWPD
Prostitution	FWPD
Poverty	Buxton
Robberies	FWPD
Runaways	FWPD
Dependent Variable	Data Source
Substantiated Cases of Child Maltreatment	DFPS

FWPD: Fort Worth Police Department; TABC: Texas Alcoholic Beverage Commission; DFPS: Department of Family and Protective Services.

neighborhood data, and subsets of large, multi-state databases such as NSCAW (National Survey of Child and Adolescent Well-being), LONGSCAN (Consortium of Longitudinal Studies on Child Abuse and Neglect), and NCANDS (The National Child Abuse and Neglect Data System), among others (see: Coulton et al., 2007; Freisthler et al., 2007; McDonell & Skosireva, 2009; McKenzie & Scott, 2011; Parrish et al., 2011; Schnitzer et al., 2004; White et al., 2015).

Building upon the established framework, the diagnostic and predictive model introduced in this study incorporates many of these established risk factors and, for the first time, examines their relative influence on child maltreatment rates in a comparative, systematic, and empirical way. This new approach has the potential to aid practitioners in finding the most vulnerable children before they are harmed and it enables intervention programs to concentrate and allocate limited resources in the most effective ways. The model is based on a relatively new statistical and geospatial analysis technique, Risk Terrain Modeling (RTM) (Caplan, Kennedy, & Miller, 2011), and this study is the first application of RTM to the context of child maltreatment. Risk Terrain Modeling was first developed by Rutgers University Center on Public Security (Kennedy, Caplan, & Piza, 2010) in the context of traditional criminal justice applications. Due to its success in accurately predicting shootings, robberies, and other crime events, the technique has quickly garnered widespread interest among criminologists and crime analysts (Caplan & Kennedy, 2011; Caplan, 2011). Different from traditional hotspot mapping, which relies on the retrospective analysis of past occurrences, RTM analyses the cumulative aggregation of environmental factors that are thought to be conducive for future occurrences of crime incidents in certain locations (Caplan & Kennedy, 2010). Driven by environmental criminological theory rather than simple, reactive density analyses, RTM offers numerous advantages over traditional hotspot maps. It examines the relative spatial influence of a multitude of factors on the dependent variable, thereby creating more robust models that have been shown to have greater predictive validity (Caplan & Kennedy, 2011).

Risk Terrain Modeling adds considerable benefit over other types of predictive analysis for child maltreatment. For instance, the identification of "risk clusters" (Kennedy et al., 2010), defined as locations of acute accumulations of problematic factors, allows prevention and health care providers to specifically gear targeted interventions to these areas. The identification of the relative influence of risk factors provides evidence-informed theoretical guidance for interventions to aid the prioritization of risk-mitigating efforts.

2. Method

A hospital Institutional Review Board (IRB) conducted a full review of the study proposal and approved the entire research study, including the collection and analysis of all data. The study operationalized data from multiple sources in an effort to provide a comprehensive empirical examination of the social and environmental factors commonly associated with child maltreatment (Coulton et al., 2007; Dubowitz et al., 2011; Duffy, Hughes, Asnes, & Leventhal, 2015; Freisthler et al., 2007; McDonell & Skosireva, 2009). Included sources were Department of Family and Protective Services (DFPS) for instances of substantiated child maltreatment, Fort Worth Police Department (FWPD) crime data for all offenses, Texas Alcoholic Beverage Commission (TABC) for all bar and nightclub locations, and Buxton consumer analytics for address-level information about households meeting federal poverty criteria. Buxton is a local marketing research company that analyses 250 databases to identify the full range of demographic, psychographic, financial, and healthcare-related attributes that can be ascribed to a household (Buxton Company, n.d.).

Address-level data for all established risk factors detailed in the introduction of this article were gathered for the years 2013 and 2014. Table 1 shows the ten included risk factors (commission of aggravated assaults, robberies, murders, domestic violence, and narcotics crimes, the presence of gangs and street prostitution, along with runaways, households living under the federal poverty line, and the presence of bars and nightclubs with a license to serve alcoholic beverages past midnight) in alphabetical order. Unduplicated addresses for substantiated instances of child maltreatment were also collected from DFPS for the years 2013 and 2014 as the dependent variable. The data included all forms of neglect, physical, emotional, and sexual abuse, abandonment, and trafficking of children ages zero to seventeen.

Table 2
Optimized RTM Model Specifications.

Risk Factor	Spatial Influence[a]	Coefficient[b]	Relative Risk Value
Poverty	780	1.598	4.94
Domestic Violence	780	1.422	4.15
Aggravated Assaults	400	0.732	2.08
Runaways	780	0.594	1.81
Murders	1560	0.442	1.56
Drug Crimes	780	0.224	1.25
Intercept		−4.703	
Overdispersion		1.428	

BIC Score = 19893.
[a] Expressed in U.S. feet.
[b] All variables included in the model demonstrated a p-value of <0.01.

2.1. Model design

All included variables were limited to the city boundaries of Fort Worth, the largest city in Tarrant County, Texas with an estimated population of 792,727 in 2013 and an area of nearly 350 square miles (Census, 2016). Fort Worth is the fifth largest city in Texas and the 16th most populous city in the United States (Census, 2016). The exact addresses for all included risk factors and the dependent variable for the year 2013 were pinpointed and entered into the Risk Terrain Modeling Diagnostics (RTMDx) professional utility. The RTMDx utility (Caplan and Kennedy, 2013) was developed by Rutgers Center on Public Security specifically for the purpose of conducting automated RTM analyses. The software examined the geographical distributions of all entered risk factors and created binary risk maps for each factor. All locations that were either within a certain distance of points or exhibited a point density above two standard deviations were coded as one for having elevated risk and all other locations were coded as zero. The RTMDx algorithm then identified the best-fit prediction model through a series of regression analyses using the statistical software R. The software selected the best model through optimization of the Schwartz's Bayesian Information Criteria (BIC), a statistic that balanced how well the model fit the data against the complexity of the model. It displayed the resulting geographical regression model on a rasterized cell map that showed the aggregate risk score for each raster cell dependent on how many of the included risk factors exhibited elevated risk levels within it. For the present study, the average block length across Fort Worth was calculated as 780 feet using ArcGIS 10.3, a popular geospatial information system software suite for working with maps and geographic information. Based on this information, approximately one half-block in length, or about 400 feet, was selected as the raster cell size for the model. This selection resulted in a total of 64,126 half-block cells in the final prediction map, 1845 of which contained incidents of substantiated child maltreatment.

3. Results

The regression process determined that the best-fitting risk terrain model was a Negative Binomial type II model that retained six of the initial 10 risk factors and yielded a BIC score of 19,863. The six most significant risk factors were (in order of decreasing importance): poverty, domestic violence, aggravated assaults, runaways, murders, and drug crimes. The model also included an intercept term that represented the background rate of events and an intercept term that represented overdispersion of the event counts.

The selected risk terrain model assigned relative risk scores to each raster cell that ranged from one for the lowest baseline risk to 150 for the highest risk in any cell, indicating that households in this cell exhibited a 150 times higher risk to experience instances of substantiated child maltreatment. Table 2 shows the relative influence and the optimized zones of spatial influence for each of the six factors that together comprised the best-fitting child maltreatment RTM model. The most influential factors were poverty with a relative risk value of 4.94 (meaning this factor was 4.94 times more influential than a factor with a value of one), closely followed by instances of domestic violence with a relative score of 4.15. Aggravated assaults had approximately half the relative risk with a score of 2.08, followed by runaways, murders, and drug crimes with relative factors of 1.81, 1.56, and 1.25 respectively.

3.1. Model testing

To test model fit, the resulting 2013 RTM model was overlaid with the actual locations of DFPS substantiated occurrences of child maltreatment during the year 2014. Fig. 1 demonstrates the fit of the calculated cumulative distribution of risk levels for the year 2013 and the distribution of actual incidents of substantiated child maltreatment during 2014 (N = 5391). Fig. 1 reveals a highly accurate fit between the RTM prediction and the actual cases in the subsequent year. A total of 52% of all future cases were accurately predicted in the 10% of highest risk cells and almost all observed incidents were located in cells that were predicted to have an elevated risk.

To examine the performance of RTM against a traditional hotspot (HS) model, a corresponding hotspot analysis was conducted based on 2013 DFPS data. The optimized fit of the search radius as suggested by the ArcGIS algorithm for the

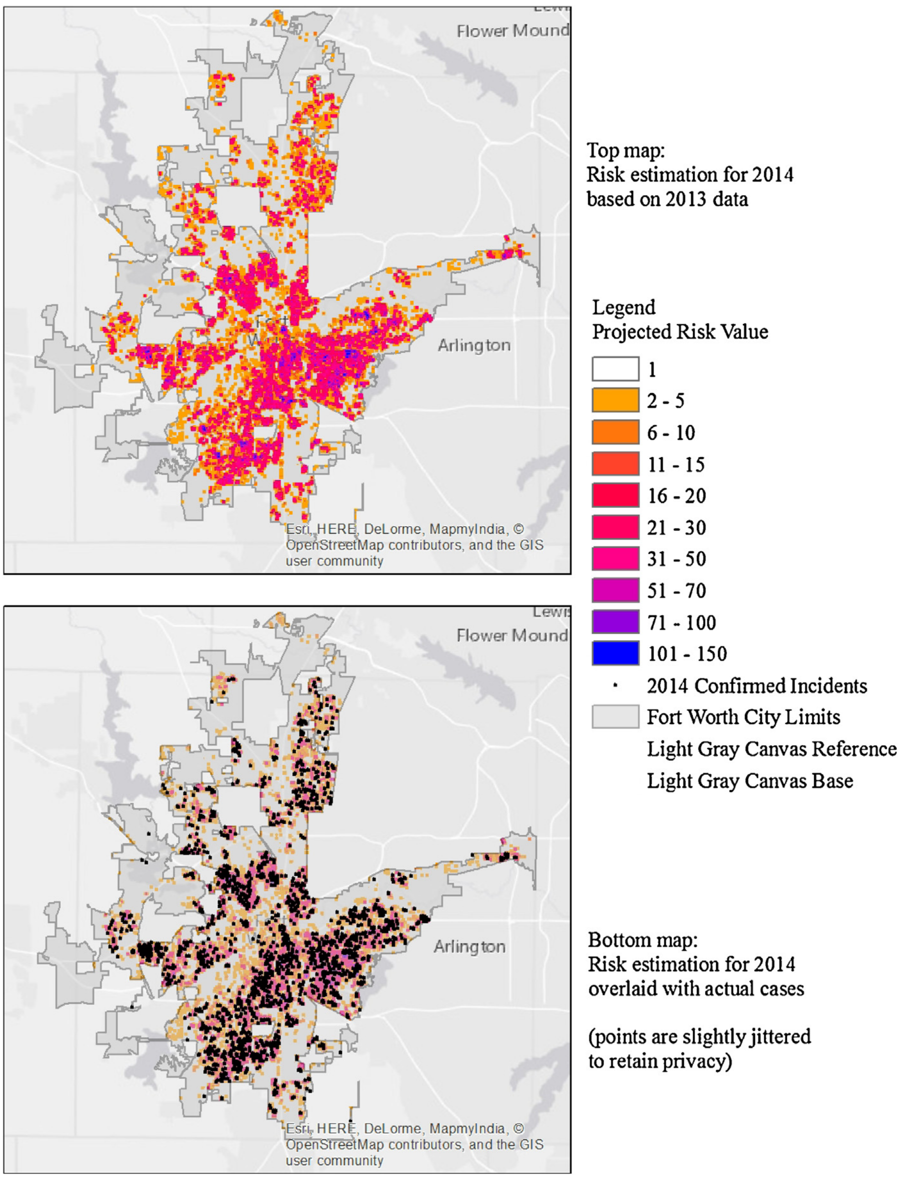

Fig. 1. Optimized Risk Prediction Map and Overlaid Actual Future Cases.

underlying kernel density estimation was confirmed through a series of Moran's I iterations that yielded the same optimal bandwidth. Fig. 2 shows that the RTM highest risk stratum (10% of the study area) included 52% of all future cases, almost 10% more than the HS model (43% of cases); the second risk stratum (20% of the study area) contained over 80% (HS 66%); and the third risk stratum (30% of the study area) predicted over 90% of 2014 cases (HS 81%). The total predicted areas with elevated risk (40% of the study area) correctly identified 98% of future cases. Only 133 of the 5391 or two percent of all instances occurred in areas that were not identified as having an elevated risk. In comparison, the highest 40% of the HS estimation missed a total of 474 or almost 9% of cases.

Fig. 3 further reveals that the RTM model, in addition to having higher predictive accuracy than the HS model, also produced a much more precise prediction. The total area flagged by RTM as exhibiting elevated risk levels was 37% smaller than that of the HS. Fig. 3 also shows that, where the HS model has a continuous slope of projected risk levels, the RTM model allows the identification of distinct risk-severity brackets. These brackets could potentially be useful as additional data points to aid prioritization decisions when allocating intervention resources.

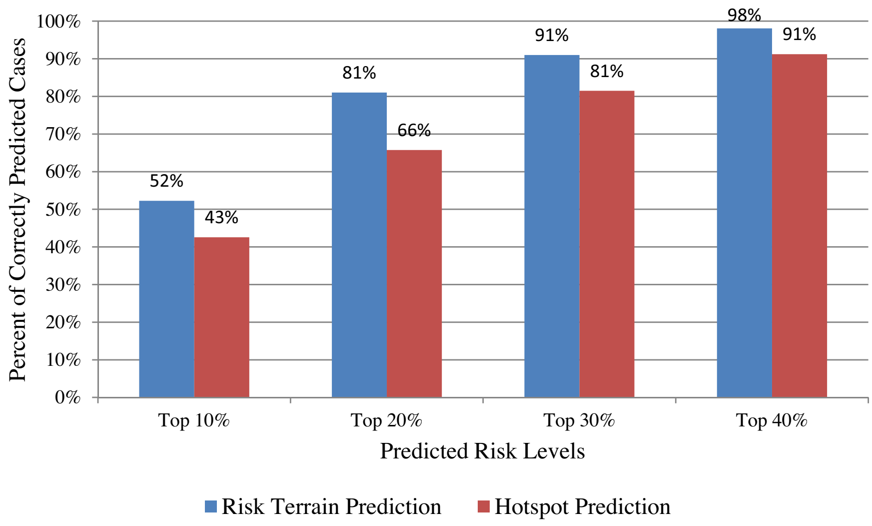

Fig. 2. Charted Percentage of Actual Child Maltreatment Cases in Predicted Risk Cells.
The RTM prediction was able to capture more than half of all future cases in the top 10% of identified highest risk cells. Only 133 cases (out of 5391) or less than 2% of future cases were outside the risk terrain prediction. The hotspot prediction missed 474 or almost 9% of cases.

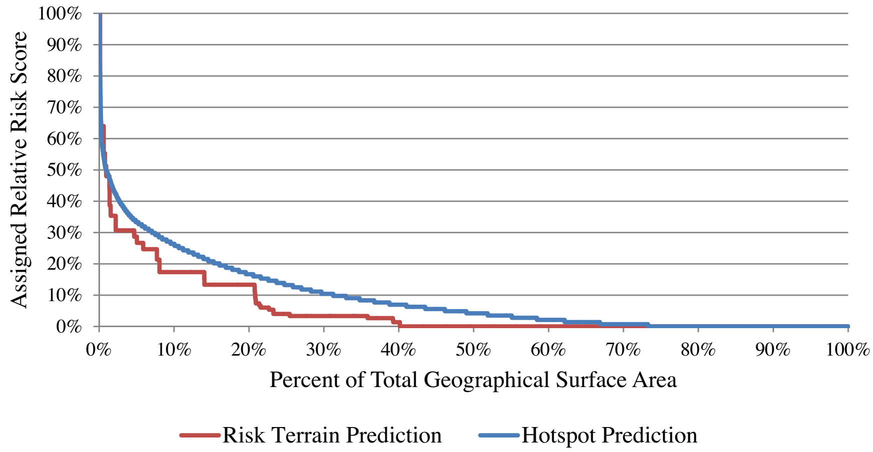

Fig. 3. Charted Risk Estimation Surface Coverage.
The geographical area estimated by the risk terrain prediction as having elevated risk was 37% smaller than that of the hotspot prediction.

4. Discussion

A risk terrain model was developed to predict future instances of substantiated child maltreatment, including neglect and physical and sexual abuse cases, within the City of Fort Worth, Texas. Consistent with previous examinations of RTM models (e.g., Kennedy et al., 2010), the model was found to have exceedingly higher predictive accuracy and power than traditional hotspot maps. It was able to accurately predict 52% of all instances during the subsequent year in only one-tenth of the city's area that was identified as having the most problematic aggregation of risk factors. Moreover, a total of 98% of all substantiated future cases occurred in discrete areas that were correctly flagged as having elevated risk. Only two percent of all future instances were outside of the predicted areas. In short, the model offers researchers and prevention and health care providers a predictive instrument that holds numerous advantages over traditional hotspot maps. Of considerable practical utility is the circumstance that all factors included in the model are relatively easily obtainable. The RTM prediction is not retrospective and does not assume a static environment, but instead is flexible and capable of adapting to relevant changes in the environment. Most importantly, the resulting risk map clearly identifies highest risk cluster areas.

This information will enable future interventions to optimize the allocation of scarce prevention and treatment resources in narrowly confined, highest need locations. In addition, aside from identifying the areas most affected, the model provides information about the relative importance of the factors comprising the risk. Simply put, the model identifies the locations that are at highest risk for future substantiated maltreatment cases, and informs about the relative importance of the factors creating this risk. Thus, it provides additional strategic information required for focused prevention and intervention strategies.

Risk Terrain Modeling changes the paradigm of how children can be located in discrete geographic areas before they are harmed by abuse and neglect. Theoretically grounded in the literature, this model provides additional empirical support for research that focuses on poverty (Brown et al., 1998; CDC, 2015; Drake and Pandey, 1996; Freisthler et al., 2007; Peterson et al., 2014), community instability and violence (Coulton et al., 2007; Lynch & Cicchetti, 1998; McDonell & Skosireva, 2009), family violence (Appel & Holden, 1998; Cox et al., 2003; Diderich et al., 2013; Edleson, 1999; McGuigan & Pratt, 2001; Nicklas & Mackenzie, 2012), runaways (Famularo et al., 1990; Kim et al., 2009; Powers et al., 1990; Whitbeck et al., 1997), and substance abuse (Hartley, 2002; Kelleher et al., 1994; Seay and Kohl, 2013; Smith et al., 2007; Sprang et al., 2010; Walsh et al., 2003) as risk factors significantly associated with child maltreatment. One new element this study adds to the body of knowledge is a comprehensive comparison of the relative importance of each of these factors. This comparatively large-scale empirical examination found poverty and domestic violence to exert an impact that is about double that of other violent or drug crimes in the household and its surrounding vicinity.

The results of this study point toward RTM as a valuable instrument for researchers and practitioners involved in the prevention of child maltreatment, the ultimate goal of which is to allow children to avoid needless, preventable suffering and the lifetime of negative consequences that often ensue. Still, the present study can only be the beginning of a line of research that should address some of the remaining limitations. Most importantly, the predictive ability of the model was examined for only one geographic location. Additional studies should apply the model to other geographies to examine its cross-territorial and cross-national generalizability. Provided such studies are able to establish transposability of model specifications across different geographical territories and contexts, prediction of child maltreatment in similar areas could be conducted without the need to solicit data on substantiated child maltreatment. Second, the consistency of risk factors across pediatric age ranges, as well as different types of child maltreatment, such as physical and sexual abuse and the various forms of neglect, should be examined to create an even more nuanced understanding of what exactly exposes children of various ages to risk for specific types of maltreatment. Third, the longitudinal robustness of obtained geographical regression equations should be studied by comparing them to newly calculated models for future years.

The pursuit of research seeking to predict child maltreatment and ultimately prevent it from occurring is critical because child maltreatment is estimated to affect at least 702,000 children per year in the United States alone according to official 2014 statistics (HHS, 2016). As Felitti et al. (1998) have shown in their pioneering Adverse Childhood Experiences (ACE) Study, a reduction in childhood trauma and stress-related maladaptations is likely to lead to lower rates of chronic diseases and mental health conditions that diminish the workforce, teen pregnancy-related loss of educational opportunities, and substance abuse disorders and related incarcerations, among other detrimental outcomes. The precise identification of block-level risk cluster groups with up to 150 times greater risk for future maltreatment cases allows child welfare professionals, community organizations, faith-based groups, and social services providers to concentrate resources and support where children and families need them the most. Researchers and providers no longer have to dilute the effectiveness of scarce resources by blanketing entire postal zip codes when they need only concentrate in a radius of several street blocks.

The ability to predict future instances before they occur offers an opportunity for social services and health care providers to reallocate some of their resources toward primary prevention. RTM enables primordial or contextual prevention approaches that address maltreatment and its related social determinants of health and it provides a data-driven and visually appealing argument for increased funding for prevention services. Moreover, the high degree of accuracy of this RTM model renders it an ideally-suited tool for the development of effective primary prevention strategies.

Once prospective geographic foci have been identified, numerous other strategies can be aligned there to alleviate existing risk factors. Such strategies for highest risk clusters could, for instance, entail the development of asset maps and determinations of specific prevention resource capacity needs based on population characteristics (e.g., mental health services or drug treatment clinics), the alignment of existing prevention services, and the development of infrastructures to promote community building and resilience (e.g., through Crime Prevention Through Environmental Design [CPTED]) (Jeffery, 1971). Other innovative approaches include efforts to increase the availability of high quality early learning centers staffed by well-trained and supported community members and to offer effective preventive health services such as wellness screenings, vaccines, and long-acting reversible contraceptives (LARC) via mobile or neighborhood health clinics. Additionally, systematic improvements to the recruitment and training of competent, trauma-informed foster and adoptive families within the neighborhood could provide an easier transition for children already within the child welfare system and could represent an effort aimed at changing social norms around effective parenting. An example of an even more inventive strategy could be the conduction of a market segmentation analysis of dominant household types in the highest risk cluster areas to target prevention and health education messaging, or to identify strategic business options for economic development.

Overall, RTM offers a new approach to finding the most vulnerable children and preventing their maltreatment. Once highest risk cluster areas are identified, limited funds and resources can be deployed where they are most needed. The ability to effectively direct interventions to the areas that need them most and help children living there before maltreatment occurs cannot be overstated. After all, as Frederick Douglass said, “It is easier to build strong children than to repair broken men” (Harvard Law Today, 2010).

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References

Anda, R. F., Chapman, D. P., Felitti, V. J., Edwards, V., Williamson, D. F., Croft, J. P., & Giles, W. H. (2002). Adverse childhood experiences and risk of paternity in teen pregnancy. *Obstetrics and Gynecology*, *100*(1), 37–45.
Anda, R. F., Brown, D. W., Dube, S. R., Bremner, J. D., Felitti, V. J., & Giles, W. H. (2008). Adverse childhood experiences and chronic obstructive pulmonary disease in adults. *American Journal of Preventive Medicine*, *34*(5), 396–403. http://dx.doi.org/10.1016/j.amepre.2008.02.002
Appel, A. E., & Holden, G. W. (1998). The co-occurrence of spouse and physical child abuse: A review and appraisal. *Journal of Family Psychology*, *12*(4), 578–599.
Brown, J., Cohen, P., Johnson, J., & Salzinger, S. (1998). A longitudinal analysis of risk factors for child maltreatment: Findings of a 17-year prospective study of officially recorded and self-reported child abuse and neglect. *Child Abuse & Neglect*, *22*(11), 1065–1078. http://dx.doi.org/10.1016/s0145-2134(98)00087-8
Brown, D. W., Anda, R. F., Edwards, V. J., Felitti, V. J., Dube, S. R., & Giles, W. H. (2007). Adverse childhood experiences and childhood autobiographical memory disturbance. *Child Abuse & Neglect*, *31*, 961–969.
Brown, D. W., Anda, R. F., Tiemeier, H., Felitti, V. J., Edwards, V. J., Croft, J. B., & Giles, W. H. (2009). Adverse childhood experiences and the risk of premature mortality. *American Journal of Preventive Medicine*, *37*(5), 389–396. http://dx.doi.org/10.1016/j.amepre.2009.06.021
Brown, M. J., Thacker, L. R., & Cohen, S. A. (2013). Association between adverse childhood experiences and diagnosis of cancer. *PLoS One*, *8*(6), e65524. http://dx.doi.org/10.1371/journal.pone.0065524
Buxton Company (n.d.). What is customer analytics? Retrieved February 10, 2016 from http://www.buxtonco.com/about/customer-analytics/.
Centers for Disease Control and Prevention. (2015). *Child maltreatment: Risk and protective factors*. Retrieved December 30, 2015 from. http://www.cdc.gov/violenceprevention/childmaltreatment/riskprotectivefactors.html
Campbell, J. A., Walker, R. J., & Egede, L. E. (2016). Associations between adverse childhood experiences, high-risk behaviors, and morbidity in adulthood. *American Journal of Preventive Medicine*, *50*(3), 344–352. http://dx.doi.org/10.1016/j.amepre.2015.07.022
Caplan, J., & Kennedy, L. (2010). *Risk terrain modeling manual*. Newark, NJ: Rutgers Center on Public Security.
Caplan, J., & Kennedy, L. (2011). *Risk terrain modeling compendium*. Newark, NJ: Rutgers Center on Public Security.
Caplan, J., & Kennedy, L. (2013). *Risk terrain modeling diagnostics utility (Version 1.0)*. Newark, NJ: Rutgers Center on Public Security.
Caplan, J., Kennedy, L., & Miller, J. (2011). Risk terrain modeling: Brokering criminological theory and GIS methods for crime forecasting. *Justice Quarterly*, *28*(2), 360–381. http://dx.doi.org/10.1080/07418825.2010.486037
Caplan, J. (2011). Mapping the spatial influence of crime correlates: A comparison of operationalization schemes and implications for crime analysis and criminal justice practice. *Cityscape*, *13*(3), 57–83.
U.S. Census Bureau. (2016). *American factfinder: Community facts for fort worth, texas [Data file]*. Retrieved from. http://factfinder.census.gov/faces/nav/jsf/pages/community_facts.xhtml
Coulton, C., Korbin, J., Su, M., & Chow, J. (1995). Community level factors and child maltreatment rates. *Child Development*, *66*(5), 1262–1276. http://dx.doi.org/10.2307/1131646
Coulton, C. J., Crampton, D. S., Irwin, M., Spilsbury, J. C., & Korbin, J. E. (2007). How neighborhoods influence child maltreatment: A review of the literature and alternative pathways. *Child Abuse & Neglect*, *31*, 1117–1142.
Cox, C. E., Kotch, J. B., & Everson, M. D. (2003). A longitudinal study of modifying influences in the relationship between domestic violence and child maltreatment. *Journal of Family Violence*, *18*(1), 5–17.
Cunningham, T. J., Ford, E. S., Croft, J. B., Merrick, M. T., Rolle, I. V., & Giles, W. H. (2014). Sex-specific relationships between adverse childhood experiences and chronic obstructive pulmonary disease in five states. *International Journal of Chronic Obstructive Pulmonary Disease*, *9*(1), 1033–1043. http://dx.doi.org/10.2147/COPD.S68226
Texas Department of Family and Protective Services. (2014). *2013 annual report and data book.*. Retrieved January 6, 2016 from https://www.dfps.state.tx.us/About_DFPS/Data_Books_and_Annual_Reports/2013/pdf/FY2013_AnnualRpt_Databook.pdf
Texas Department of Family and Protective Services. (2015). *2014 annual report and data book.*. Retrieved January 6, 2016 from https://www.dfps.state.tx.us/About_DFPS/Data_Books_and_Annual_Reports/2014/
De Venter, M., Demyttenaere, K., & Bruffaerts, R. (2013). The relationship between adverse childhood experiences and mental health in adulthood: A systematic literature review. *Tijdschrift Voor Psychiatrie*, *55*(4), 259–268.
Diderich, H., Fekkes, M., Verkerk, P., Pannebakker, F. D., Velderman, M. K., Sorenson, P. J., . . . & Oudesluys-Murphy, A. M. (2013). A new protocol for screening adults presenting with their own medical problems at the emergency department to identify children at high risk for maltreatment. *Child Abuse & Neglect*, *37*(12), 1122–1131. http://dx.doi.org/10.1016/j.chiabu.2013.04.005
Dietz, P. M., Spitz, A. M., Anda, R. F., Williamson, D. F., McMahon, P. M., Santelli, J. S., & Kendrick, J. S. (1999). Unintended pregnancy among adult women exposed to abuse or household dysfunction during their childhood. *Journal of the American Medical Association*, *282*, 1359–1364.
Drake, B., & Pandey, S. (1996). Understanding the relationship between neighborhood poverty and specific types of child maltreatment. *Child Abuse & Neglect*, *20*(11), 1003–1018. http://dx.doi.org/10.1016/0145-2134(96)00091-9
Dubowitz, H., Kim, J., Black, M., Weisbart, C., Semiatin, J., & Magder, L. (2011). Identifying children at high risk for a child maltreatment report. *Child Abuse & Neglect*, *35*(2), 96–104. http://dx.doi.org/10.1016/j.chiabu.2010.09.003
Duffy, J., Hughes, M., Asnes, A., & Leventhal, J. (2015). Child maltreatment and risk patterns among participants in a child abuse prevention program. *Child Abuse & Neglect*, *44*, 184–193. http://dx.doi.org/10.1016/j.chiabu.2014.11.005
Edleson, J. (1999). The overlap between child maltreatment and woman battering. *Violence Against Women*, *5*(2), 134–154. http://dx.doi.org/10.1177/107780129952003
Edwards, V. J., Anda, R. F., Gu, D., Dube, S. R., & Felitti, V. J. (2007). Adverse childhood experiences and smoking persistence in adults with smoking-related symptoms and illness. *The Permanente Journal*, *11*(2), 5–13.

Famularo, R., Kinscherff, R., Fenton, T., & Bolduc, S. (1990). Child maltreatment histories among runaway and delinquent children. *Clinical Pediatrics*, *29*(12), 713–718. http://dx.doi.org/10.1177/000992289002901207

Fang, X., Brown, D., Florence, C., & Mercy, J. (2012). The economic burden of child maltreatment in the United States and implications for prevention. *Child Abuse & Neglect*, *36*(2), 156–165. http://dx.doi.org/10.1016/j.chiabu.2011.10.006

Felitti, V. J., Anda, R. F., Nordenberg, D., Williamson, D. F., Spitz, A. M., Edwards, V., . . . & Marks, J. S. (1998). Relationship of childhood abuse and household dysfunction to many of the leading causes of death in adults. *American Journal of Preventive Medicine*, *14*(4), 245–258. http://dx.doi.org/10.1016/s0749-3797(98)00017-8

Fergusson, D. M., Boden, J. M., & Horwood, L. J. (2008). Exposure to childhood sexual and physical abuse and adjustment in early adulthood. *Child Abuse & Neglect*, *32*, 607–619.

Finkelhor, D., Turner, H. A., Shattuck, A., & Hamby, S. L. (2015). Prevalence of childhood exposure to violence, crime, and abuse. *The Journal of the American Medical Association (JAMA) Pediatrics*, *169*(8), 746–754. http://dx.doi.org/10.1001/jamapediatrics.2015.0676

Freisthler, B., Bruce, E., & Needell, B. (2007). Understanding the geospatial relationship of neighborhood characteristics and rates of maltreatment for Black, Hispanic, and White children. *Social Work*, *52*(1), 7–16.

U.S. Department of Health & Human Services, Administration for Children and Families, Administration on Children, Youth and Families, Children's Bureau. (2015). *Child maltreatment 2013*.. Retrieved from. http://www.acf.hhs.gov/programs/cb/research-data-technology/statistics-research/child-maltreatment

U.S. Department of Health & Human Services, Administration for Children and Families, Administration on Children, Youth and Families, Children's Bureau. (2016). *Child maltreatment 2014*.. Retrieved from. http://www.acf.hhs.gov/programs/cb/research-data-technology/statistics-research/child-maltreatment

Hartley, C. (2002). The co-occurrence of child maltreatment and domestic violence: Examining both neglect and child physical abuse. *Child Maltreatment*, *7*(4), 349–358. http://dx.doi.org/10.1177/107755902237264

Harvard Law Today. (2010). *It is easier to build strong children than fix broken men: At HLS summit, Edelman says we must move from punishment to justice (video)*. Retrieved from http://today.law.harvard.edu/it-is-easier-to-build-strong-children-than-fix-broken-men-at-hls-summit-edelman-says-we-must-move-from-punishment-to-justice-video/

Hillis, S. D., Anda, R. F., Felitti, V. J., Nordenberg, D., & Marchbanks, P. A. (2000). Adverse childhood experiences and sexually transmitted diseases in men and women: A retrospective study. *Pediatrics*, *106*(1), E11.

Hillis, S. D., Anda, R. F., Dube, S. R., Felitti, V. J., Marchbanks, P. A., & Marks, J. S. (2004). The association between adverse childhood experiences and adolescent pregnancy, long-term psychosocial outcomes, and fetal death. *Pediatrics*, *113*(2), 320–327.

Jeffery, C. R. (1971). *Crime prevention through environmental design*. Thousand Oaks, CA: Sage.

Kelleher, K., Chaffin, M., Hollenberg, J., & Fischer, E. (1994). Alcohol and drug disorders among physically abusive and neglectful parents in a community-based sample. *American Journal of Public Health*, *84*(10), 1586–1590. http://dx.doi.org/10.2105/ajph.84.10.1586

Kennedy, L., Caplan, J., & Piza, E. (2010). Risk clusters, hotspots, and spatial intelligence: Risk terrain modeling as an algorithm for police resource allocation strategies. *Journal of Quantitative Criminology*, *27*(3), 339–362. http://dx.doi.org/10.1007/s10940-010-9126-2

Kim, M. J., Tajima, E. A., Herrenkohl, T. I., & Huang, B. (2009). Early child maltreatment, runaway youths, and risk of delinquency and victimization in adolescence: A mediational model. *Social Work Research*, *33*(1), 19–28.

Levenson, J. S., & Socia, K. M. (2016). Adverse childhood experiences and arrest patterns in a sample of sexual offenders. *Journal of Interpersonal Violence*, *31*(10), 1883–1911. http://dx.doi.org/10.1177/0886260515570751

Lynch, M., & Cicchetti, D. (1998). An ecological-transactional analysis of children and contexts: The longitudinal interplay among child maltreatment, community violence, and children's symptomatology. *Development and Psychopathology*, *10*(2), 235–257. http://dx.doi.org/10.1017/s095457949800159x

McCauley, J., Kern, D. E., Kolodner, K., Dill, L., Schroeder, A. F., DeChant, H. K., & Bass, E. B. (1997). Clinical characteristics of women with a history of childhood abuse: Unhealed wounds. *Journal of the American Medical Association*, *277*, 1362–1368.

McDonell, J., & Skosireva, A. (2009). Neighborhood characteristics, child maltreatment, and child injuries. *Child Indicators Research*, *2*, 133–153. http://dx.doi.org/10.1007/s12187-009-9038-6

McGuigan, W. M., & Pratt, C. C. (2001). The predictive impact of domestic violence on three types of child maltreatment. *Child Abuse & Neglect*, *25*, 869–883.

McKenzie, K., & Scott, D. A. (2011). Using routinely collected hospital data for child maltreatment surveillance: Issues, methods and patterns. *BMC Public Health*, *11*(7), 1–10. http://dx.doi.org/10.1186/1471-2458-11-7

Mersky, J. P., Topitzes, J., & Reynolds, A. J. (2013). Impacts of adverse childhood experiences on health, mental health, and substance use in early adulthood: A cohort study of an urban, minority sample in the U.S. *Child Abuse & Neglect*, *37*, 917–925.

Mustaine, E., Tewksbury, R., Huff-Corzine, L., Corzine, J., & Marshall, H. (2014). Community characteristics and child sexual assault: Social disorganization and age. *Journal of Criminal Justice*, *42*(2), 173–183. http://dx.doi.org/10.1016/j.jcrimjus.2013.06.016

Nicklas, E., & Mackenzie, M. (2012). Intimate partner violence and risk for child neglect during early childhood in a community sample of fragile families. *Journal of Family Violence*, *28*(1), 17–29. http://dx.doi.org/10.1007/s10896-012-9491-8

Parrish, J. W., Young, M. B., Perham-Hester, K. A., & Gessner, B. D. (2011). Identifying risk factors for child maltreatment in Alaska: A population-based approach. *American Journal of Preventive Medicine*, *40*(6), 666–673.

Peterson, A. C., Joseph, K., & Feit, M. (2014). *New directions in child abuse and neglect research. Washington*. DC: National Academies Press.

Ports, K. A., Ford, D., & Merrick, M. T. (2016). Adverse childhood experiences and adult sexual victimization. *Child Abuse & Neglect*, *51*, 313–322.

Powers, J., Eckenrode, J., & Jaklitsch, B. (1990). Maltreatment among runaway and homeless youth. *Child Abuse & Neglect*, *14*(1), 87–98. http://dx.doi.org/10.1016/0145-2134(90)90084-7

Reavis, J. A., Looman, J., Franco, K. A., & Rojas, B. (2013). Adverse childhood experiences and adult criminality: How long must we live before we possess our own lives? *The Permanente Journal*, *17*(2), 44–48. http://dx.doi.org/10.7812/TPP/12-072

Remigio-Baker, R. A., Hayes, D. K., & Reyes-Salvail, F. (2014). Adverse childhood events and current depressive symptoms among women in Hawaii: 2010 BRFSS Hawaii. *Maternal Child Health Journal*, *18*(10), 2300–2308. http://dx.doi.org/10.1007/s10995-013-1374-y

Schnitzer, P. G., Slusher, P., & Van Tuinen, M. (2004). Child maltreatment in Missouri: Combining data for public health surveillance. *American Journal of Preventive Medicine*, *27*(5), 379–384.

Seay, K. D., & Kohl, P. L. (2013). Caregiver substance abuse and children's exposure to violence in a nationally representative child welfare sample. *Journal of Social Work Practice in the Addictions*, *13*(1), 70–90. http://dx.doi.org/10.1080/1533256X.2013.756335

Smith, D. K., Johnson, A. B., Pears, K. C., Fisher, P. A., & DeGarmo, D. S. (2007). Child maltreatment and foster care: Unpacking the effects of prenatal and postnatal parental substance use. *Child Maltreatment*, *12*(2), 150–160. http://dx.doi.org/10.1177/1077559507300129

Snowden, A., & Pridemore, W. (2012). Alcohol outlets, social disorganization, land use, and violence in a large college town: Direct and moderating effects. *Criminal Justice Review*, *38*(1), 29–49. http://dx.doi.org/10.1177/0734016812467198

Sprang, G., Clark, J. J., & Staton-Tindall, M. (2010). Caregiver substance use and trauma exposure in young children. *Families in Society*, *91*(4), 401–407. http://dx.doi.org/10.1606/1044-3894.4029

Stith, S. M., Liu, T., Davies, L. C., Boykin, E. L., Alder, M. C., Harris, J. M., . . . & Dees, J. (2009). Risk factors in child maltreatment: A meta-analytic review of the literature. *Aggression and Violent Behavior*, *14*(1), 13–29. http://dx.doi.org/10.1016/j.avb.2006.03.006

Walsh, C., MacMillan, H., & Jamieson, E. (2003). The relationship between parental substance abuse and child maltreatment: Findings from the Ontario Health Supplement. *Child Abuse & Neglect*, *27*(12), 1409–1425. http://dx.doi.org/10.1016/j.chiabu.2003.07.002

Whitbeck, L. B., Hoyt, D. R., & Ackley, K. A. (1997). Families of homeless and runaway adolescents: A comparison of parent/caretaker and adolescent perspectives on parenting, family violence and adolescent conduct. *Child Abuse & Neglect*, *21*, 517–528.

White, O. G., Hindley, N., & Jones, D. P. H. (2015). Risk factors for child maltreatment recurrence: An updated systematic review Medicine. *Science and the Law*, *55*(4), 259–277. http://dx.doi.org/10.1177/0025802414543855

Whitfield, C. L., Anda, R. F., Dube, S. R., & Felitti, V. J. (2003). Violent childhood experiences and the risk of intimate partner violence in adults: Assessment in a large health maintenance organization. *Journal of Interpersonal Violence*, *18*(2), 166–185.

Whitfield, C. L., Dube, S. R., Felitti, V. J., & Anda, R. F. (2005). Adverse childhood experiences and hallucinations. *Child Abuse & Neglect*, *29*(7), 797–810.

Wildeman, C., Emanuel, N., Leventhal, J., Putnam-Hornstein, E., Waldfogel, J., & Lee, H. (2014). The prevalence of confirmed maltreatment among U.S. children, 2004 to 2011. *The Journal of the American Medical Association (JAMA) Pediatrics*, *168*(8), 706–713. http://dx.doi.org/10.1001/jamapediatrics.2014.410

Williamson, D. F., Thompson, T. J., Anda, R. F., Dietz, W. H., & Felitti, V. J. (2002). Body weight, obesity: And self-reported abuse in childhood. *International Journal of Obesity*, *26*, 1075–1082.