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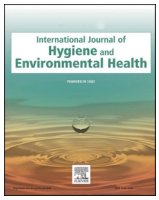

The effects of parental occupational exposures on autism spectrum disorder severity and skills in cognitive and adaptive domains in children with autism spectrum disorder

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1. Introduction

Autism spectrum disorder (ASD) is a group of neurobehavioral disorders characterized by poor social and communication skills, and repetitive behaviors (American Psychiatric Association [APA], 2013). However, the severity of these core symptoms can be highly variable. Both genetic and environmental factors play a role in the etiology of ASD and may modulate the phenotypic expression (Gialloreti et al., 2019). Although studies have linked parental occupational exposure (e.g. paints, xylene, solvents, exhaust and combustion products, pesticides) to ASD, to our knowledge there are no studies that have evaluated if parental occupational exposures are associated with common co-occurring behaviors or cognitive and adaptive skills in their children with autism (McCanlies et al., 2012, 2019; Schmidt et al., 2014; Windham et al., 2009, 2013; Windham et al., 2009).

Diagnostic criteria for ASD include persistent deficits in social-emotional reciprocity, in nonverbal communicative behaviors, and in understanding, developing and maintaining relationships (American Psychiatric Association [APA], 2013). They include repetitive and restrictive patterns of behavior and interests, and sensory dysfunction, such as sensitivity to touch or sounds. Individuals with ASD often have difficulty adjusting to changing social situations as well as appropriately responding to social cues (American Psychiatric Association [APA], 2013). They are often inflexible and can become extremely distressed if their routine is disrupted, and may or may not have intellectual impairment, language impairment, or other neurodevelopmental or behavioral disorders. ASD symptoms may be apparent in children prior to the age of two, but this varies depending on the severity of their symptoms. ASD severity is based on specific symptoms including impaired social response, deficits in nonverbal and verbal communication, and restricted and/or repetitive interests or patterns of behavior (American Psychiatric Association [APA], 2013). Besides genetic factors, research has demonstrated the importance of environmental exposures in the etiology of ASD, and related behaviors or cognitive and adaptive skills (Gialloreti et al., 2019; Kalkbrenner et al., 2014; Hertz-Picciotto et al., 2018; Philippat et al., 2015).

Studies evaluating pharmacokinetics indicate that the fetus and child can't clear toxicants as efficiently as adults, potentially affecting neurodevelopment, disrupting immune processes or endocrine hormones, or resulting in epigenetic changes (Ginsberg, 2004; Kalkbrenner et al., 2014; Mordaunt et al., 2019). Bisphenol A (BPA) levels were associated with the severity of social responsiveness in children with ASD (Rossignol et al., 2014). Metals measured in air pollution, diet, and dental amalgams during pregnancy suggested that chromium, mercury, and nickel exposure may be associated with ASD or ASD severity (Kalkbrenner et al., 2014). Rossignol et al. (2014) conducted a systematic review looking at environmental toxicants and the severity of ASD behaviors (Rossignol et al., 2014). These studies suggested that lead and mercury were associated with ASD severity or poor ASD outcomes (Rossignol et al., 2014). Similarly, p-cresol (4-methylphenol) measured in the urine of children with ASD compared to control children was associated with more severe ASD symptoms (Persico and Napolioni, 2013). Lead and mercury measured in the urine and red blood cells of children with ASD were associated with worse scores on the Social Responsiveness Scale (SRS) (Adams et al., 2013; Alabdali et al., 2014). Braun et al. (2014) measured endocrine disrupting chemicals (EDCs) in urine and plasma of pregnant mothers. Both polybrominated diphenyl ether-28 and trans-Nonachlor were associated with higher SRS scores, indicating more severe autistic behaviors. Braun et al. (2017) also showed that prenatal urinary levels of BPA in the mothers were

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associated with higher Social Responsiveness Scale™-2 (SRS-2) scores, and with boys more internalizing and somatizing behaviors measured using the Behavioral Assessment System for Children-2 (BASC-2). Although these were not studies of parental occupational exposures, these chemicals can be found in occupational environments such as automotive, paint manufacturing, construction, and appliance industries, or hospitals and in most cases, are likely to occur at higher concentrations than in the environmental setting. Thus, it is plausible that workplace exposures may be associated with more severe ASD.

Previously we found that parental occupational exposure to solvents may be associated with ASD (McCanlies et al., 2019), however our findings for parental occupational exposure to metals, pesticides, or pharmaceuticals in association with an ASD diagnosis were null, contrary to prior research (Kalkbrenner et al., 2014; McCanlies et al., 2019). We also did not evaluate the association between parental occupational exposures and ASD severity or other co-occurring developmental characteristics. Nor, to our knowledge, has this been investigated by others. Therefore, the aim of the current investigation is to fill this gap and determine if parental occupational exposures are associated with ASD severity, aberrant behaviors, or skills in cognitive and adaptive domains in their children with ASD.

2. Materials and methods

2.1. Study population

The CHARGE study is a population-based case-control study. A detailed description of the population has been previously published (Hertz-Picciotto et al., 2006). Briefly, the CHARGE study identified potential participants through the California Department of Developmental Services, California, USA enrolling children with a previous community diagnosis of autism. Children from the general population, selected from State Vital Statistics birth records were also recruited. Eligible children were between the ages of two and five, born in California, living with at least one biologic parent who speaks English or Spanish, and residing in the catchment areas of a geographically selected list of California Regional Centers that coordinate services for persons with developmental disabilities. Following clinical evaluation, the children were diagnosed as having ASD, developmental disorder or delay without ASD, or typical development (TD).

The National Institute for Occupational Safety and Health (NIOSH) received diagnosis, parental occupational, and basic demographic data on 976 children and one or both of their parents from the CHARGE study (UC Davis) team. Because this study specifically focused on children with ASD, and their aberrant behaviors and skills in cognitive and adaptive domains in relation to parental workplace exposures, we excluded children with TD or developmental delay. The final sample for this study consisted of 532 children with ASD and their parents, after excluding two children without Autism Diagnostic Observation Schedule-2 (ADOS-2) data, which prevented the calculation of autism severity scores. No children were excluded due to missing covariate data.

2.2. Demographic and lifestyle characteristics

Demographic, lifestyle, and medical data were collected through extensive questionnaires, parent interviews, and birth record review. Information collected for both mothers and fathers included age, level of education, race/ethnicity, birthplace, smoking history, regional center/geographic location of residence, and payment method used for the child's delivery. Level of education was reported as years of primary or secondary education, high school, high school/graduate equivalency degree, some college, and graduate or professional degree. A variable, total years of education was calculated by summing the two parents' education level. If mothers' or fathers' years of education was missing, the years of education for the non-missing parent was doubled to ensure that household education would be comparable to those families with both parents' data. Race/ethnicity was categorized as white non-Hispanic, Hispanic (any race), Black non-Hispanic, and other, which included American Indian/Alaska Native, Asian, Pacific Islander/Hawaiian Native, and multi-racial. Information about the children included their age at the time of the ADOS, sex, date of birth, race/ethnicity, and duration of breastfeeding.

2.3. Diagnostic criteria

All the children underwent cognitive, social, and medical evaluations at either the University of California, Davis, MIND Institute in Sacramento, CA or the University of California, Los Angeles (UCLA) Neuropsychiatric Institute. Children with a previous diagnosis of ASD were assessed using the Autism Diagnostic Observation Schedule-2 (ADOS-2) (Lord et al., 2003) and their parents completed the Autism Diagnostic Interview-Revised (ADI-R) (Lord et al., 1994) to confirm their child's ASD diagnosis. For children with a previous diagnosis of a neurodevelopmental delay other than ASD and children sampled from the general population, the parent completed the Social Communication Questionnaire (SCQ) (Rutter et al., 2003), a short screening instrument for ASD symptoms. If the score was $\geq$15, the child was evaluated for ASD on the full ADOS-2 as described above and their parents completed the ADI-R (Lord et al., 1994, 2003; Risi et al., 2006). The algorithm of Risi et al. (2006) was used to assign final diagnosis of ASD or not.

2.4. ASD severity score

ASD severity was measured using the Calibrated Severity Score (CSS) derived from the ADOS-2. The CSS indicates severity of the core features that are central to a diagnosis of ASD (Gotham et al., 2009; Wiggins et al., 2017). This metric was designed to be independent of age and of developmental level, including intellectual ability, language or motor skills, or behavioral problems. Because other measures of ASD severity have been highly influenced by developmental level and other factors that represent constructs far broader than ASD, the CSS is accepted as the best metric for severity of ASD (Wiggins et al., 2017). Development of the CSS was based on a dataset that contained 2195 ADOS-2 assessment results and clinical evaluations. The assessment results were divided into narrowly defined age and language skill categories. An algorithm was then used to create standardized raw total scores for age/language skill categories (Gotham et al., 2009). The CSS takes integer values and has a range of 1–10: most though not all children considered to be typically developing score in the range of 1–3, and most though not all children with ASD score in the range of 7–10, with 10 being the most severely affected.

2.5. Assessment of ASD behaviors and skills in cognitive and adaptive domains

The Aberrant Behavior Checklist (ABC) is an instrument designed to assess problem behaviors (Aman et al., 1985). It consists of 58 questions, scored from 0 (behavior is not at all a problem) to 3 (problem to a severe degree). The developers of the ABC identified five subscales from a factor analysis: irritability, social withdrawal, stereotypy, hyperactivity, and inappropriate speech. A higher score on the ABC indicates more problematic behaviors.

The Mullen Scales for Early Learning (MSEL) measures cognitive function (Mullen, 1995). It is administered by a professional and is composed of four subscales that measure developmental abilities including expressive language, receptive language, visual reception, and fine motor skills. These four subscales are also combined into a composite score for overall cognitive functioning. A higher score on the MSEL indicates a higher skill level.

The Vineland Adaptive Behavior Scales (VABS) also measures developmental abilities and adaptive capacity (Sparrow et al., 1984). It

is a semi-structured parent/caregiver interview. A composite score and four subscale scores: communication, socialization, daily living, and motor skills can be calculated. A higher score on the VABS indicates greater acquisition of social and adaptive skills. Thus, notably: scoring of the MSEL and VABS is reverse of the scoring for the CSS and the ABC.

2.6. Workplace exposure assessment

Workplace exposure assessment has been previously described in detail (McCanlies et al., 2019). Briefly, information on parental occupational history was collected during the CHARGE study telephone interview. Mothers were interviewed about their job histories and when possible, or if directed by the mother, the father was interviewed about his job history. Approximately 37 % of the fathers responded, otherwise the mothers reported the fathers' job history. For each job, occupational information included, the place of employment, the months and years of employment, which month(s) of pregnancy (or the postnatal period) the job was held, and the total hours worked per week. Information about what the company made or did, the parents' job titles, and their duties/responsibilities were also collected. For this study, the period spanning three months prior to pregnancy until birth of the study child was evaluated and referred to as the index period. This period was selected, because it encompasses a critical window in which parental occupational exposures may significantly impact the early stages of brain development such as synaptogenesis, cell differentiation and migration, organogenesis, and child neurodevelopment (Kuper-Sassé et al., 2024; Mattison, 2010).

These data were sent to NIOSH for exposure assessment and analyses. Each reported job was assigned a 2002 North American Industry Classification System (United States Census Bureau, 2007) and 2000 Standard Occupational Classification (U.S. Bureau of Labor Statistics, 2000) code. (Recruitment into the CHARGE study began in 2003. The earliest births of CHARGE children were in 1998.) These codes along with the parents' job history information were entered into an ACCESS database for two experienced industrial hygienists (IHs) to semi-quantitatively estimate occupational exposure levels to sixteen agents (anesthetic gas, asphalt, automobile/mechanic fluids, cutting/-machining fluids, disinfectants/cleaners, ethylene oxide, metals, polychlorinated biphenyls (PCBs), perchlorates, pesticides, pharmaceuticals/medicine, phenol, plastics/polymer chemicals, radiation, solvents, paint chemicals/lacquers). These agents were selected a priori based on evidence in peer-reviewed scientific reports indicating potential associations with adverse pregnancy outcomes such as low intellectual functioning, neurodevelopmental disorders, impaired social skills, or impulsivity (Grandjean and Landrigan, 2006; Wigle et al., 2008). The IHs were blinded to the severity of the children's ASD. An ordinal estimate for both the frequency (0 = unexposed to 3 = frequent exposure) and intensity (0 = unexposed to 3 = high intensity) of exposure to the 16 chemical and physical agents was assigned for each job. After each IH independently assigned exposure levels, these were compared, then discussed until a consensus was reached. Cumulative exposure for each chemical or chemical class was derived by multiplying the [frequency of exposure (0–3)] x [intensity of exposure (0–3)] x [work hours/week] for each agent for each job held during the index period. If a person had the same exposure to an agent from two or more different jobs, they were summed together. Because the distribution of cumulative exposures was left-skewed, all cumulative exposures were log-transformed ($\log_e$) after the addition of a constant to shift all values above zero, thereby avoiding undefined log-transformed values.

2.7. Ethics

This study complies with all applicable requirements. The CHARGE study protocol was approved by institutional review boards at the University of California, Davis, USA and the University of California, Los Angeles, USA and by the State of California Committee for the Protection of Human Subjects. Written informed consent was collected from all participants, prior to data collection. The NIOSH human subjects review board approved the protocol and plan for the study of occupational exposures (Morgantown, WV, USA).

2.8. Statistical analyses

Descriptive statistics were used to characterize the study population. Four outcomes were evaluated in this analysis; ASD severity measured using the CSS, problematic behaviors using the ABC, and skills in cognitive and adaptive domains measured using the MSEL and VABS respectively. Cumulative occupational exposures served as the primary predictor variables. Multiple linear regression was used to evaluate associations between each exposure and the scores for ASD severity, the ABC, MSEL, and VABS. Table 1

Weighted analysis was performed to adjust for lower participation from underserved and disadvantaged populations and possible selection bias as a consequence: the weights were derived by comparing sociodemographic factors in the CHARGE study sample with the distribution of those same factors in the pool of ASD children eligible for CHARGE, to obtain the inverse of the probability of participation for each sociodemographically defined participant group. Except for the means and standard deviations (Table 2) and histograms (Supplementary Fig. 1), all the tables, including the supplementary table and figures show the weighted results. In considering which variables to adjust for and which may lie along the causal pathway, we aimed to balance controlling for the appropriate confounding factors, without over-adjusting, which could hide true associations. For example, we believe controlling for length of breastfeeding is important because the literature does not provide clear evidence on whether occupational exposures do or do not influence breastfeeding, whereas another upstream factor is likely influencing both occupational exposure and duration of breastfeeding, namely the decision on whether, and how many hours per week, to work outside the home during the pregnancy and the breastfeeding period. This common ancestor of those two variables creates a backdoor path for which adjustment of breastfeeding duration would sufficiently control the confounding. Moreover, breastfeeding duration can influence developmental outcomes, independently of occupational exposures. More generally, confounders were selected based on prior knowledge in the published literature, the potential association of occupational exposures with the covariate evaluated by Pearson correlation analyses, and the criterion of a 10 % change or greater in the exposure beta coefficient. This approach is broadly consistent with recommendations from Weng et al. (2009) and Lash et al. (2021). This approach led to adjustment variables for models predicting each of the outcomes (CSS, ABC, MSEL, and VABS scores) as follows: mothers' models were adjusted for, mothers' age at time of delivery, mothers' smoking, total years of education, length of breast feeding (months), and regional center. Fathers' models were adjusted for fathers' age at delivery, fathers' race/-ethnicity, child gestational age, length of breast feeding, total years of education, and regional center. The models with mothers' or fathers' combined data were adjusted for mean age of father and mother at delivery, total years of education, mothers' smoking, length of breast feeding (months), and regional center.

Paint chemicals and solvents/degreasers were combined into one group referred to as solvents in this manuscript. This was done because there was a nearly complete overlap in the exposed parents and because the chemical agents in paint chemicals that are of greatest concern are principally solvents (Centre for Industry Education Collaboration, 2016; Park et al., 2016). For analysis combining mothers' and fathers' exposures, their respective cumulative exposures were summed together.

To facilitate interpretation of the multivariate results for multiple outcomes measured on different scales, in the presentation of results we have converted the beta coefficients that represent change in outcome for a one unit increase in cumulative exposure to a) the change in scores on the individual scales, and b) the change in units of one standard

Table 1
Characteristics of children with ASD and their parents.

		Sample (N = 532)	Weighted % Or Mean (SE)[a]
Children	Sex		
	Male	452	86.2 %
	Female	80	13.8 %
	Race/ethnicity		
	White, non-Hispanic	268	45.9 %
	African American, non-Hispanic	14	2.5 %
	Hispanic (any)	145	32.1 %
	Other[b]	105	19.5 %
	Gestational age	524	39.1 (0.1)
	Duration of breast feeding (month)	527	7.5 (0.4)
	ASD Severity Score[c]	532	7.4 (0.1)
Mothers	Age at delivery	532	30.4 (0.3)
	Ethnicity/Race		
	White, non-Hispanic	318	56.1
	African American, non-Hispanic	19	3.9
	Hispanic (any)	125	28.0
	Other[b]	70	12.1
	Educational level		
	High school/GED[d] or less	74	18.7
	Some college	214	48.8
	Bachelor's degree	165	22.8
	Graduate or professional	79	9.8
	Smoking before or during pregnancy		
	Yes	72	17.7
	No	449	82.3
	Alcohol consumption during 3 months before pregnancy through delivery		
	0–8 drinks/month	290	58.4
	8+ drinks/month	227	41.6
	Birthplace		
	USA	407	74.6
	Mexico	39	10.7
	Outside of USA and Mexico	86	14.8
Fathers	Age at delivery	519	33.2 (0.3)
	Ethnicity/Race		
	White, non-Hispanic	333	58.1
	African American, non-Hispanic	25	5.5
	Hispanic (any)	110	25.7
	Other[b]	64	10.8
	Educational level		
	High school/GED[d] or less	118	27.7
	Some College	161	32.9
	Bachelor's degree	156	25.8
	Graduate or professional	95	13.6
Mothers/ Fathers	Total years of education	532	28.3 (0.2)
	Mean of mother's age and father's age	532	31.7 (0.3)
	Regional Center		
	Alta, far Northern, and Redwood Coast	201	36.9
	North Bay	71	12.9
	East Bay, San Andreas, and Golden Gate	85	14.3
	Valley Mt, Central Valley, and Kern	92	20.1
	All Los Angeles RCs plus Orange, San Diego, Tricounties, and Inland	83	15.8

[a] SE = standard error.
[b] Other = American Indian/Alaska Native, Asian, Pacific Islander/Hawaiian Native, or multi-racial.
[c] ASD Severity score was calculated using ADOS-2.
[d] General Educational Development.

deviation (SD) for that scale.

3. Results

Most of the children were male (86.2 %) and either white, non-Hispanic (45.9 %) or Hispanic (32.1 %; Table 1). The overall mean ASD severity score was 7.4 ± 0.1 (range 4–10). On average, the mothers were 30 years old at the time of the birth of the study child, most were white, non-Hispanic (56.1 %) or Hispanic (28.0 %), nearly half had some college education (48.8 %), over four-fifths were non-smokers, and three quarters were born in the USA. Similarly, the fathers were, on average, 33 years old when the study child was born, most were white, non-Hispanic (58.1 %) or Hispanic (25.7 %), and about a third had some college education.

3.1. Mean cumulative chemical exposure for mothers, fathers, and mother or father

Table 2 shows descriptive statistics, specifically the mean cumulative exposure of each chemical for mothers, fathers, and mothers or fathers combined. The highest mean cumulative chemical exposure for the mothers' or fathers' combined data and the mothers alone were pharmaceuticals/medicine at 8.85 ± 0.99 and 8.67 ± 0.80, respectively. For fathers, the highest cumulative chemical exposure was anesthetic gas (9.39 ± 0.87), followed closely by pharmaceuticals/medicine (9.14 ± 1.01).

3.2. Mean child ASD severity score by mother, father, and mother or father combined occupational exposures

Table 2 also presents the mean child ASD severity score for each chemical exposure reported by the mothers, fathers, and both mothers or fathers. Examining mothers alone, child mean ASD severity scores were highest for mothers' exposed to phenol (7.48 ± 1.52) and ethylene oxide (7.35 ± 1.53), and lowest for anesthetic gases (6.81 ± 1.64). In fathers alone, the mean ASD severity score was highest for automobile/mechanic fluid exposure (7.68 ± 1.54), and among mothers or fathers combined (7.77 ± 1.52; Table 2), while the second highest severity score analyzing fathers' exposure alone was phenols (7.67 ± 1.84). The mean ASD severity scores in analyses of fathers alone were lowest for pesticides and cutting/machining fluids exposure (7.00 ± 1.11 and 7.15 ± 1.33, respectively).

3.3. Association between mothers', fathers' and mother' or fathers' cumulative chemical exposures and child ASD severity scores

Complete results for beta coefficients, 95 % CI's and p-values are found in Tables 3–5 for exposures of mothers, fathers and both parents combined. In models adjusted for confounders, a one point increase in the $\log_e$ cumulative exposure is associated with a higher ASD severity score as follows: mothers' occupational exposure to phenol is equivalent to an increase of 1.84 points on the CSS (range in this study population: 4–10), or 0.3 CSS SD (Tables 3 and 6); fathers' occupational ethylene oxide exposure (Tables 4 and 6) is equivalent to +1.25 CSS pts or 0.81 SD; and plastics/polymers equivalent to +0.83 CSS pts or 0.53 SD. As occupational exposure to pharmaceuticals/medicine and phenols in mothers or fathers combined increased, the ASD severity score rose, which is equivalent to increases of, respectively, +0.46 CSS points or +0.83 CSS SD and +1.28 CSS points or +0.83 CSS SD (Tables 5 and 6).

3.4. Parental occupational exposures and ABC scores in children with ASD

The ABC has five subscales. Complete results for beta coefficients, 95 % CI's and p-values are found in Fig. 1 and the Supplementary Tables 1–3. Significant findings (not including borderline ones) are presented in Table 6 in which beta coefficients are converted to outcome changes in raw scores and in SDs, per one unit $\log_e$ cumulative exposure increase; these final results are described below.

Greater irritability was significantly associated with automobile/mechanic fluids when fathers were exposed, with half an SD increase,

Table 2
Mothers', fathers', and mothers' or fathers' combined mean cumulative chemical exposure and child mean ASD severity score by mothers', fathers', and mothers' or fathers' combined occupational exposure.

	Mothers			Fathers			Mother or Father		
	N	Cumulative Chemical Exposure[a]	ASD Severity Score[b]	N	Cumulative Chemical Exposure[a]	ASD Severity Score[b]	N	Cumulative Chemical Exposure[a]	ASD Severity Score
Chemicals		Mean (SD[c])	Mean (SD)		Mean (SD)	Mean (SD)		Mean (SD)	Mean (SD)
Anesthetic Gas	16	7.23 (1.22)	6.81 (1.64)	<8[d]	–	–	22	7.81 (1.48)	6.86 (1.75)
Asphalt	<8[d]	–	–	<8[d]	–	–	<8[d]	–	–
Automobile/Mechanic Fluids	<8[d]	–	–	40	8.44 (1.10)	7.68 (1.54)	44	8.40 (1.09)	7.77 (1.52)
Cutting/Machining Fluids	<8[d]	–	–	41	8.67 (0.99)	7.15 (1.33)	42	8.65 (0.99)	7.17 (1.32)
Disinfectants	135	7.85 (1.12)	7.23 (1.64)	209	8.28 (0.91)	7.28 (1.54)	289	8.28 (1.01)	7.25 (1.56)
Ethylene Oxide	43	7.33 (0.67)	7.35 (1.53)	19	7.48 (0.80)	7.32 (1.73)	56	7.45 (0.75)	7.30 (1.61)
Metals	17	7.80 (0.89)	7.06 (1.30)	156	8.46 (0.93)	7.24 (1.56)	172	8.40 (0.95)	7.22 (1.54)
PCBs	<8[d]	–	–	<8[d]	–	–	<8[d]	–	–
Perchlorates	<8[d]	–	–	<8[d]	–	–	<8[d]	–	–
Pesticides	<8[d]	–	–	14	8.10 (1.19)	7.00 (1.11)	19	7.94 (1.23)	7.32 (1.29)
Pharmaceuticals/ Medicine	38	8.67 (0.80)	7.21 (1.45)	20	9.14 (1.01)	7.45 (1.67)	52	8.85 (0.99)	7.27 (1.57)
Phenol	31	7.22 (0.57)	7.48 (1.52)	15	7.38 (0.89)	7.67 (1.84)	42	7.32 (0.76)	7.48 (1.64)
Plastics/Polymers	<8[d]	–	–	20	8.74 (1.08)	7.35 (1.63)	24	8.78 (1.01)	7.25 (1.59)
Radiation	30	7.40 (0.78)	7.10 (1.63)	<8[d]	–	–	35	7.66 (0.98)	7.14 (1.68)
Solvents[e]	104	7.63 (1.18)	7.32 (1.63)	233	8.56 (1.08)	7.26 (1.57)	286	8.49 (1.16)	7.25 (1.58)
Any chemical exposure	146	8.69 (1.33)	7.25 (1.62)	251	9.52 (1.09)	7.29 (1.58)	319	9.51 (1.16)	7.28 (1.58)
No chemical exposure	386	n/a	7.47 (1.52)	281	n/a	7.52 (1.51)	213	n/a	7.60 (1.48)

[a] Logarithm (base e) of the cumulative chemical exposure score is shown.
[b] ASD severity (CSS) score calculated using ADOS-2.
[c] SD = standard deviation.
[d] Due to small sample size, beta coefficients could not be calculated.
[e] Solvents consists of paint chemicals and solvents/degreasers.

and also when mothers and fathers were both exposed. Irritability was also increased significantly with exposures to pharmaceuticals from both parents. In contrast, irritability was reduced in association with mothers' exposure to anesthetic gases and metals, with fathers' exposures to pesticides (−1.09 SD) and phenols, and with both parents' exposures to metals.

Social withdrawal increased with exposures to plastics/polymers by fathers alone and by both parents (+0.5 SD); but decreased with mothers' anesthetic gas exposure and fathers' pesticide exposure.

Stereotypies increased with fathers' exposure to metals (by +0.2 SD), and by phenols, and plastics/polymers (both by +0.7 SD), and with both parents' exposures to metals, and plastics/polymers. Stereotypy was lessened by fathers' exposures to pesticides and pharmaceuticals.

Hyperactivity was strongly associated with occupational exposures to pharmaceuticals/medicine resulting in a full +1.0 SD increase from mothers; and +0.5 from these same exposures when mother and father were both exposed (Fig. 1; Table 6; Supplementary Tables 1 and 3). Additionally, hyperactivity was increased with exposure of fathers only to phenols (+0.8 SD) and to automobile/mechanic fluids (+0.4 SD), or both parents' workplace exposures to pharmaceuticals (+0.5 SD), automobile/mechanic fluids (+0.5 SD), anesthetic gases, and ethylene oxide (+0.6 SD) (Table 6. Supplementary Tables 2 and 3). Oddly, fathers' exposure alone to ethylene oxide was associated with reduced hyperactivity of −1.6 SD, and pesticides, with reduced hyperactivity of −0.5 SD.

Lastly, inappropriate speech, a short subscale of only 4 items, was not increased by any of the exposures examined, but was decreased by: mothers' exposure to anesthetic gas, metals, and radiation exposure; fathers' ethylene oxide, pesticide exposure; and both parents' solvent exposure.

3.5. Occupational Exposures and MSEL scores in Children with ASD

The MSEL has four subscales and an overall composite score for cognitive skills. Complete results for beta coefficients, 95 % CI's and p-values are found in Fig. 2 and in Supplementary Tables 1–3 for exposures of mothers, fathers and both parents combined. Significant findings (not including borderline ones) are presented in Table 6 as outcome changes in T-scores and in SDs, per one unit exposure increase, which are described below.

Lower scores indicate poorer cognitive skills. No chemical exposures of mothers alone were associated with lower MSEL scores. Mothers' pharmaceutical exposure was associated with improved cognitive functioning in ASD children (Fig. 2, Supplementary Table 1) on both expressive and receptive language measures, as well as the composite score. In fathers alone, only exposure to phenols had any association with improved skills, in this case, visual reception, by +25.7 points or 2.6 SD (Table 6). In contrast, two different exposures for fathers alone—anesthetic gases and ethylene oxide—were significantly associated with poorer expressive language skills, with the largest decrease from the latter: 10.7 points, equivalent to 1.1 SD.

However, the strongest and most consistent deficits in cognition were with fathers' occupational exposures to plastics/polymers, which were associated with significantly reduced skills on all four subscales of the MSEL in children with ASD. These significantly poorer skills were observed for: expressive language by −13.5 points or −1.35 SD; receptive language, visual reception, and fine motor by −9.9 to −11.9 points or −0.99 to −1.19 SD. Additionally, the composite scores of children whose fathers had higher cumulative exposures to plastics/polymers were lower by −11.7 points or −0.78 SD of this overall outcome. These findings were similarly reflected in the analysis of combined exposures to plastics/polymers of both parents, which demonstrated robust, highly significant associations with the MSEL composite score and all four subscales. Scores were reduced by −9.5to −13.4 points or −0.73 to −1.33 SD.

No other exposures were associated with either reduced or increased scores on the MSEL. A total of 12 significant associations were observed between occupational exposures and reduced MSEL scores representing

Table 3
Results of weighted* linear regression models predicting the change in autism severity score for a 1-unit increase in the $\log_{(e)}$ cumulative exposure for each occupational chemical exposure to **mothers**.

Chemicals		Unadjusted Model		Adjusted Model[b]	
	N = 523	Beta (95 % C.I.)[c]	p-value	Beta (95 % C.I.)[c]	p-value
Anesthetic Gas	16[a]	−0.17 (−0.67, 0.32)	0.46	−0.20 (−1.26, 0.86)	0.69
Asphalt	<8[d]	–	–	–	–
Automobile/Mechanic Fluids	<8[d]	–	–	–	–
Cutting/Machining Fluids	<8[d]	–	–	–	–
Disinfectants & Cleaners	135	0.08 (−0.25, 0.41)	0.62	0.18 (−0.09, 0.45)	0.19
Ethylene Oxide	43	−0.12 (−0.86, 0.62)	0.75	0.16 (−0.73, 1.05)	0.72
Metals	17	−0.34 (−0.91, 0.23)	0.21	−0.64 (−1.83, 0.55)	0.26
PCBs	<8[d]	–	–	–	–
Perchlorates	<8[d]	–	–	–	–
Pesticides	<8[d]	–	–	–	–
Pharmaceuticals/Medicine	38	0.38 (−0.40, 1.16)	0.32	0.43 (−0.16, 1.02)	0.15
Phenol	31	0.74 (−0.10, 1.57)	0.08	1.05 (0.26, 1.84)	0.01
Plastics/Polymers	<8[d]	–	–	–	–
Radiation	30	0.13 (−0.43, 0.70)	0.63	−0.16 (−0.97, 0.65)	0.69
Solvents[e]	104	−0.09 (−0.39, 0.21)	0.57	−0.05 (−0.33, 0.22)	0.70

*Weights were used to adjust for selection bias by sociodemographic factors.
[a] ASD severity score calculated using ADOS-2.
[b] The regression model was adjusted for mother's age at time of delivery (years), mother's smoking, length of breastfeeding, total years of education, and regional center.
[c] C.I. – confidence interval.
[d] Due to small sample size, beta coefficients could not be calculated.
[e] Solvents consists of paint chemicals and solvents/degreasers.

impaired cognitive skills, while 4 significant associations were observed with increased scores.

3.6. Parent occupational exposures and VABS

The VABS has four subscales and an overall composite score for adaptive skills. Complete results for beta coefficients, 95 % CI's and p-values are found in Fig. 3 and in Supplementary Tables 1–3 for exposures of mothers, fathers and both parents combined. Significant findings (not including borderline ones) are presented in Table 6 as outcome changes in T-scores and in SDs and are described below.

Lower scores indicate poorer adaptive skills. In mothers, anesthetic gas was associated with poorer communication skills by −4.1 points or 0.41 SD, whereas disinfectant exposure was associated with fewer daily living skills in children with ASD (Fig. 3; Supplementary Table 1). In fathers, exposure to cutting/machining fluids was associated with the child having reduced VABS composite scores (by −7.2 pts or −0.48 SD); and both daily living skills and motor skills (respectively, by −6.7 and −6.8 pts or −0.67 and −0.68 SD), and motor skills. Results for metal exposure also showed reduced scores on the VABS daily living subscale (by −3.02 or −0.30 SD). Some of the strongest and the most consistent associations with VABS were from fathers' occupational exposures to plastics/polymers. These exposures were linked to declines in the VABS composite and three subscales: composite (by −6.2 pts or −0.41 SD); communication skills (by −9.9 points or −0.99 SD); socialization and motor skills (Fig. 3; Table 6; Supplementary Table 2).

Table 4
Results of weighted* linear regression models predicting the change in autism severity score for a 1-unit increase in the $\log_{(e)}$ cumulative exposure for each occupational chemical exposure to **fathers**.

Chemicals		Unadjusted Model		Adjusted Model[b]	
	Sample (n = 523)	Beta (95 % C.I.)[c]	p-value	Beta (95 % C.I.)[c]	p-value
Anesthetic Gas	<8[d]	–	–	–	–
Asphalt	<8[d]	–	–	–	–
Automobile/Mechanic Fluids	40[a]	−0.09 (−0.56, 0.37)	0.69	−0.21 (−0.71, 0.30)	0.42
Cutting/Machining Fluids	41	0.14 (−0.17, 0.44)	0.37	0.19 (−0.18, 0.56)	0.29
Disinfectants/Cleaners	209	0.22 (−0.018, 0.45)	0.07	0.17 (−0.08, 0.42)	0.17
Ethylene Oxide	19	0.77 (−0.054, 1.59)	0.06	1.00 (0.21, 1.78)	0.02
Metals	156	0.18 (−0.068, 0.43)	0.14	0.18 (−0.09, 0.46)	0.19
PCBs	<8[d]	–	–	–	–
Perchlorates	<8[d]	–	–	–	–
Pesticides	14	−0.004 (−0.78, 0.77)	0.99	−0.60 (−1.47, 0.26)	0.15
Pharmaceuticals/Medicine	20	−0.08 (−1.13, 0.97)	0.87	−0.11 (−0.47 0.26)	0.55
Phenol	15	0.74 (−0.46, 1.94)	0.20	0.94 (−0.12, 2.0)	0.08
Plastics/Polymers	20	0.31 (−0.27, 0.88)	0.27	0.89 (0.13, 1.64)	0.02
Radiation	<8[d]	–	–	–	–
Solvents[e]	233	0.13 (−0.07, 0.33)	0.19	0.17 (−0.04, 0.37)	0.11

*Weights were used to adjust for selection bias by sociodemographic factors.
[a] ASD severity score calculated using ADOS-2.
[b] The regression model was adjusted for father's age at delivery (years), father's race/ethnicity, gestational length (weeks), breastfeeding, total years of education, and regional center.
[c] C.I. – confidence interval.
[d] Due to small sample size, beta coefficients could not be calculated.
[e] Solvents consists of paint chemicals and solvents/degreasers.

Table 5
Results of weighted* linear regression models predicting the change in autism severity score for a 1-unit increase in the $\log_{(e)}$ cumulative exposure for each occupational chemical exposure to **mothers or fathers**.

Chemicals		Unadjusted Model		Adjusted Model[b]	
	Sample (n = 523)	Beta (95 % C.I.)[c]	p-value	Beta (95 % C.I.)[c]	p-value
Anesthetic Gas	22[a]	−0.06 (−0.50, 0.39)	0.79	0.04 (−0.60, 0.69)	0.89
Asphalts	<8[d]	–	–	–	–
Automobile/ Mechanic Fluids	44	−0.18 (−59, 0.22)	0.36	−0.05 (−0.51, 0.41)	0.82
Cutting/Machining Fluids	42	0.11 (−0.20, 0.42)	0.47	0.21 (−0.10, 0.51)	0.18
Disinfectants/ Cleaners	289	0.20 (−0.03, 0.42)	0.08	0.20 (−0.01, 0.42)	0.06
Ethylene Oxide	56	0.13 (−0.68, 0.93)	0.75	0.46 (−0.21, 1.13)	0.17
Metals	172	0.14 (−0.08, 0.37)	0.20	0.14 (−0.10, 0.39)	0.24
PCBs	<8[d]	–	–	–	–
Perchlorates	<8[d]	–	–	–	–
Pesticides	19	−0.46 (−1.08, 0.16)	0.13	−0.45 (−0.93, 0.03)	0.07
Pharmaceuticals/ Medicine	52	0.20 (−0.30, 0.70)	0.42	0.46 (0.02, 0.91)	0.04
Phenol	42	0.78 (0.08, 1.48)	0.03	0.97 (0.47, 1.47)	0.0004
Plastics/Polymers	24	0.21 (−0.43, 0.84)	0.50	0.37 (−0.10, 0.85)	0.12
Radiation	35	0.08 (−0.47, 0.63)	0.78	0.03 (−0.70, 0.76)	0.93
Solvents[e]	286	0.10 (−0.07, 0.26)	0.26	0.09 (−0.08, 0.26)	0.32

*Weights were used to adjust for selection bias by sociodemographic factors.
[a] ASD severity score calculated using ADOS-2.
[b] The regression model was adjusted for mean age of mother and father at delivery (years), total years of education, mother's smoking, length of breast-feeding, and regional center.
[c] C.I. – confidence interval.
[d] Due to small sample size, beta coefficients could not be calculated.
[e] Solvents consists of paint chemicals and solvents/degreasers.

These associations remained significant when mothers' or fathers' combined exposures to plastics/polymers were evaluated, showing similar, significant reductions in the composite score and the communications subscale (Supplementary Table 3). In analyses of the combined parents' exposures, ethylene oxide also stood out, being associated with decrements in the VABS communication and daily living skills, as did cutting/machine fluids with associated decreases in daily living skills and motor skills. Additionally, anesthetic gas, metals, and radiation exposure were each associated with a reduced score in at least one VABS subscale. Associations in the direction opposite to our hypotheses were observed as single subscales with pesticides, pharmaceuticals, phenols, and radiation.

Automobile/mechanic fluids and solvents were the two categories of exposures having no associations, either positive or negative, with the VABS. A total of 19 significant associations were observed between occupational exposures and reduced adaptive scores on the VABS, whereas only 4 significant associations were observed with increased scores.

4. Discussion

Previously, we found that children with an ASD diagnosis were more likely to have been exposed prenatally to solvents than those with typical development (McCanlies et al., 2019). In this study, we found that the outcomes of ASD severity and co-occurring behaviors as well as cognitive and adaptive skills in children were also associated with several parental occupational exposures. Parental occupational exposures were not necessarily associated with both ASD severity and developmental skills, for example, mothers' exposure to disinfectants was associated with lower daily living skills (VABS), but ASD severity was only marginally associated with disinfectants in the combined mother or father sample. However, some exposures, including ethylene oxide, plastics/polymers, and pharmaceuticals/medicines were associated with both ASD severity and ASD behaviors.

Some worksites may expose employees to multiple exposures (Rim, 2017). For example, ethylene oxide, pharmaceuticals/medicine, phenol, radiation, solvents, and disinfectants are often found in hospital settings. Similarly, solvents and metal exposure may co-occur in individuals who work with automobile fluids and/or cutting/machining fluids. Additionally, several exposures examined in this study may be experienced in varied occupational settings. Factory workers, farm workers, or hospital workers can all be exposed to ethylene oxide and solvents (National Institute for Occupational Safety and Health [NIOSH], 1981). Occupational exposure to many of these agents is associated with poor reproductive outcomes such as still birth, miscarriage, tubal pregnancy, and congenital malformation, and have previously been shown to be associated with both cognitive deficits and ASD (Connor et al., 2014; Scheftel et al., 2017; National Institute for Occupational Safety and Health, 1981; Ornoy et al., 2015).

Below, we highlight the salient findings of our analyses of occupational exposures and their associations with autism severity, behavioral scales from the ABC, cognition based on the MSEL and adaptive skills obtained from the VABS. We additionally compare our findings with the extant literature and elaborate on potential mechanistic pathways that might link these workplace exposures with the outcomes of interest.

Plastics/polymers stood out in this study as being associated with: poorer scores on all four subscales and the composite of the cognitive domain for fathers' alone and the combined exposure from both parents; three of the four adaptive skills subscales along with the composite; as well as three of the five aberrant behavior scales, including social withdrawal, stereotypy and hyperactivity. Plastics and polymers are composed of several different types of chemicals including phthalates, polyethylene, acrylics, tetrafluoro ethylene, polyvinyl chloride, and polychlorinated biphenyl (PCB) (Crinnion, 2010). These chemicals and micro/nano plastics can cross the placental and the blood brain barrier (Engdahl et al., 2021; Du et al., 2024) and have neurotoxic effects through different mechanisms including endocrine disruption, alterations in gene expression involved in neurodevelopment and synaptic plasticity, oxidative stress, and inflammation (Lauby et al., 2024; Welch and Mulligan, 2022; Fishburn et al., 2024; Almeida-Toledano et al., 2024; Liu et al., 2023; Liu et al., 2024). Consistent with our results, research has found that in children, these neurotoxic effects can result in synaptic defects, delayed language, altered exploratory behaviors, deficits in learning and memory, reduced social interaction, attention-deficit/hyperactivity disorder (ADHD), and ASD (Welch and Mulligan, 2022; Fishburn et al., 2024; Almeida-Toledano et al., 2024; Liu et al., 2023; Liu et al., 2024; Xia et al., 2025; Hlisníková et al., 2020; Bakoyiannis et al., 2021). For example, polycarbonate plastics, bisphenol A (BPA), and more generally, a large number of additives that go into plastic products, including phthalates, and chlorinated, brominated and generally halogenated compounds, as well as the micro/nano plastic particles proper, are associated with abnormal development of the embryo or fetus, and many have be associated with sequelae of neurodevelopmental abnormalities and behavior disorders such as learning deficits, ADHD, and ASD. Additionally, phthalates can modify the

Table 6
Magnitude of change in outcome for a 1 SD (Standard Deviation)* increase [a]n $\log_{(e)}$ cumulative exposure for all significant associations ($p < 0.05$). Grey background indicates that the direction of the effect is opposite to the study hypothesis (i.e., improved outcome for higher exposure).

Exposure				Change in Outcome for a 1 SD Increase in Exposure[b]					
				Beta	Behavioral Scores *Higher Scores = Worse Behavior* *(Lower Scores = Improvement, shaded)*		Beta	Developmental Skills (Cognitive & Adaptive) *Lower Scores = Poorer Skills (Higher Scores = Improvement, shaded)*	
Chemical or Source of Exposure	Parent[f] Mo, Fa, M/F	Mean (SD) of $\log_{(e)}$ cum. exposure	1 unit change converted to exp-osure SD's[a]	Slope for CSS or ABC scale	Change in ASD Calibrated Severity Scale (CSS) among ASD: on scale from 4 to 10, SD = 1.55	ABC subscales[c] *range* (SD) *Irritability: 0 to 45* (8.5) *Social Withdrawal: 0 to 48* (7.7) *Stereotypy: 0 to 21* (4.4) *Hyperactivity: 0 to 48* (10.6) *Inappropriate Speech: 0 to 11* (2.9)	Slope for MSEL or VABS	[d]MSEL Composite SD = 15, Subscale SD = 10: *Expressive Language* *Receptive Language* *Visual Perception* *Fine Motor*	[e]VABs Composite: SD = 15 Subscale SD = 10 *Communications* *Daily Living Skills* *Socialization* *Motor*
Anesthetic gases	Mo M/F	7.23 (1.22) 7.81 (1.48)	0.82 0.68	−3.53 −1.64 −1.69 +1.64		*Irrit* = −4.28 pts, −0.50 SD *Withdr* = −1.34 pts, −0.17 SD *InSpee* = −1.39 pts, −0.48 SD *Hyper* = +1.12 pts, +0.11 SD	−4.99 −5.14 −3.31	*Express = -3.5 pts, or -0.35 SD*	*Comms* = −4.1 pts or −0.41 SD *Comms* = −2.25 pts or −0.23 SD
Automobile/Mechanic fluids	Fa M/F	8.44 (1.10) 8.40 (1.09)	0.91 0.92	4.80 4.30 3.47 5.97		*Irrit* = +4.36 pts, +0.51 SD *Hyper* = +3.91 pts, +0.37 SD *Irrit* = +3.19 pts, +0.38 SD *Hyper* = +5.49 pts, +0.52 SD			
Cutting, machine fluids	Fa M/F	8.67 (0.99) 8.65 (0.99)	1.01 1.01				−7.16 −6.58 −6.77 −4.98 −4.46		*Composite* = −7.23 pts, −0.48 SD *Daily* = −6.65 pts or −0.67 SD *Motor* = −6.84 pts or −0.68 SD *Daily* = −4.93 pts, −0.49 SD *Motor* = −4.42 pts, −0.44 SD
Disinfectants	Mo	7.85 (1.12)	0.89				−3.13		*Daily* = −2.79 pts or −0.28 SD
Ethylene oxide	Fa M/F	7.48 (0.80) 7.45 (0.75)	1.25 1.33	+1.00 −13.86 −6.73 +5.14	= +1.25 pts, = 0.81 SD	*Hyper = -17.33 pts, -1.63 SD* *Inspee = -8.43 pts, -2.91 SD* *Hyper = +6.43 pts, +0.61 SD*	−8.55 −5.24 −4.64 −4.00	*Express* = 10.7 pts, 1.1 SD	*Composite* = −6.97 pt, −0.46 SD *Comms* = −6.17 pts, −0.62 SD *Daily* = −5.32 pts, −0.53 SD
Metals	Mo Fa M/F	7.80 (0.89) 8.46 (0.93 8.40 (0.95)	1.12 1.08 1.05	−8.10 −2.55 +0.91 −1.58 +0.77		*Irrit* = −9.07 pts, −1.07 SD *InSpee* = −2.86 pts, −0.98 SD *Stereo* = +0.98 pts, +0.22 SD *Irrit* = −1.66 pts, −0.20 SD *Stereo* = +0.81 pts, 0.18 SD	−2.81 −2.19		*Daily* = −3.02 pts or −0.30 SD *Daily* = −2.30 pts or −0.23 SD
Pesticides	Fa	8.10 (1.19)	0.84	−11.06 −8.80 −5.50 −10.78 −3.23		*Irrit* = −9.29 pts, −1.09 SD *Withdr* = −7.39 pts, −0.96 SD *Stereo* = −4.62 pts, −1.05 SD *Hyper* = −9.06 pts, −0.46 SD *InSpee* = −2.71 pts, −0.94 SD	+11.11		*Socializ* = +9.33 pts, +0.93 SD
Pharmaceut-ical	Mo Fa M/F	8.67 (0.80) 9.14 (1.01) 8.85 (0.99)	1.25 0.99 1.01	+8.53 −8.30 +0.46 +2.40 +5.32	= +0.46 pts, = 0.83 SD	*Hyper* = +10.7 pts, +1.01 SD *Stereo* = −8.22 pts, = −1.87 SD *Irrit* = +2.42 pts, +0.28 SD *Hyper* = +5.37 pts, +0.51 SD	+7.83 +9.72 +11.36 +6.70	*Compos* = +9.78 pts, 0.65 SD *Express* = +12.15 pts, 1.2 SD *Recept* = +14.2 pts, 1.4 SD	*Daily* = +6.63 pts, +0.66 SD

(*continued on next page*)

Table 6 (*continued*)

Exposure				Change in Outcome for a 1 SD Increase in Exposure[b]					
				Beta	Behavioral Scores *Higher Scores = Worse Behavior* *(Lower Scores = Improvement, shaded)*		Beta	Developmental Skills (Cognitive & Adaptive) *Lower Scores = Poorer Skills (Higher Scores = Improvement, shaded)*	
Phenols	Mo	7.22 (0.57)	1.75	+1.05	= +1.84 pts, = 0.30 SD	*Irrit* = −6.23 pts, −0.73 SD	+22.98	*Visual Rec* = +25.7, or 2.6 SD	
	Fa	7.38 (0.89)	1.12	−5.56	= +1.28 pts, = 0.83 SD	*Stereo* = +2.93 pts, +0.67 SD	+16.00		*Daily* = +17.9 pts, +1.79 SD
	M/F	7.32 (0.76)	1.32	+2.62		*Hyper* = +8.02 pts, +0.76 SD			
				+7.16					
Plastics/polymers	Fa	8.74 (1.08)	0.93	+0.89	= +0.83 pts, = 0.53 SD	*Withdr* = +3.58 pts, +0.47 SD	−12.62	*Compos* = −11.7 pts, −0.78 SD	*Composite* = −6.16 pts, −0.41 SD
	M/F	8.78 (1.01)	0.99	+3.85		*Stereo* = +3.11 pts, +0.71 SD	−14.54	*Express* = −13.5 pts, −1.35 SD	*Comms* = −9.85 pts, −0.99 SD
				+3.34		*Withdr* = +4.14 pts, +0.54 SD	−12.77	*Recept* = −11.9 pts, −1.19 SD	*Socializ* = −4.69 pts, −0.47 SD
				+4.18		*Stereo* = +3.01 pts, +0.68 SD	−12.58	*Visual* = -11.7 pts, −1.17 SD	*Motor* = −7.61 pts, −0.76 SD
				+3.04		*Hyper* = +3.76 pts, +0.35 SD	−10.60	*F Motor* = −9.86 pts, 0.99 SD	Composite = −5.68 pts, −0.38 SD
				+3.80			−6.62	*Compos* = −11.0 pt, −0.73 SD	Comms = −9.75 pts, −0.98 SD
							−10.59	*Express* = −13.4 pts, −1.33 SD	
							−5.04	*Recept* = −11.04 pts, −1.10 SD	
							−8.18	*Visual* = −9.48 pts, −0.95 SD	
							−11.12	*F Motor* = -10.42 pts, −1.04 SD	
							−13.52		
							−11.15		
							−9.58		
							−10.23		
							−5.74		
							−9.85		
Radiation	Mo	7.40 (0.78)	1.28	−2.11		*Inspee* = −2.71 pts, = −1.75 SD			
Solvents	M/F	8.49 (1.16)	0.86	−0.42		*Inspee* = −0.50 pts, = −0.17 SD			
Number of significant findings (p<0.05):					0 improved outcome 5 worse outcome	17 improved outcome 18 worse outcome		4 improved outcome 12 worse outcome	3 improved outcome 19 worse outcome

*Use of 1 S standardizes these calculations across the exposures, and allows comparison of the effect sizes across exposures.

[a] One unit change in log(e) cumulative exposure converted to exposure SD's.

[b] Beta X change in exposure SD = change in outcome per SD change of exposure.

[c] Abbreviations for ABC subscales: *Irrit*: irritability; *Withdr*: lethargy or withdrawal; *Stereo*: stereotypy; *Hyper*: hyperactivity; *InSpee*: inappropriate speech.

[d] Abbreviations for the MSEL and subscales: *Compos:* composite; *Express:* expressive language; *Recept:* receptive language; *Visual:* visual reception; *FMotor:* fine motor.

[e] Abbreviations for the VABS and subscales: *Compos:* composite; *Comms:* communication; *Daily:* daily living skills; *Socializ:* socialization; *Motor;* motor skills.

[f] Mo = mother; Fa = father; M/F = mother or father.

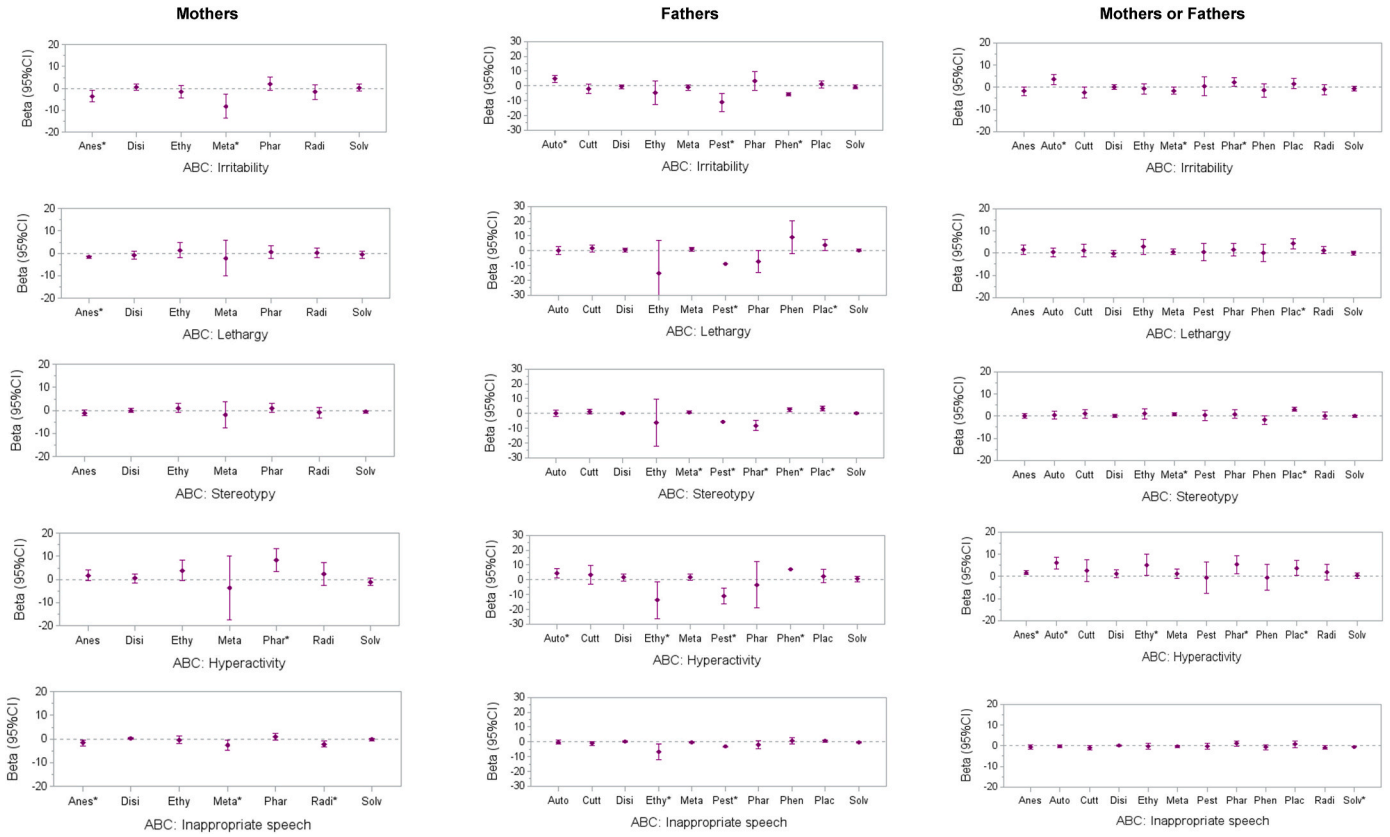

Fig. 1. Association between Mothers', Fathers', and Mothers' or Fathers' combined occupational exposures and scores on the Aberrant Behavior Checklist (ABC). Each figure shows the β-coefficient with its corresponding 95 % confidence interval for each occupational exposure. Occupational exposures followed by an asterisk are significant at a $p \leq 0.05$.

Mother's Models were adjusted for Mother's age at delivery, smoking, length of breast feeding, total years of education, and regional center. Father's models were adjusted for father's age at delivery (years), child gestation age, father's race/ethnicity, length of breast feeding, total years of education, and regional center. Models for Mother or Father combined were adjusted for mean age of mother and father at delivery (years), length of breast feeding, total years of education, mother's smoking, and regional center.

Anesthetic Gas (Anes), Automobile/Mechanic Fluids (Auto), Cutting/Machining Fluids (Cutt), Disinfectants/Cleaners (Disi), Ethylene Oxide (Ethy), Metals (Meta), Pesticides (Pest), Pharmaceuticals/Medicine (Phar), Phenol (Phen), Plastics/Polymer Chemicals (Plac), Radiation (Radi), Solvents (Solv).

hypothalamic-pituitary-gonadal axis, as well as the thyroid and adrenal axis, and can interfere with nuclear receptors in neural structures, affecting neurodevelopment (Hlisníková et al., 2020, 2021). Many of these chemicals are found in a variety of occupational settings, including automotive, PVC plastic manufacturers, food packaging, beauty care products, and pharmaceuticals. They can also be found in everyday products including flooring, medical devices, and personal-care products (Crinnion, 2010; Hauser and Calafat, 2005). Given not only the consistency across domains but also the magnitude of the deficits observed in the CHARGE/ReCHARGE cohort amounting to an approximate 1 or more SDs in the outcome per unit of exposure, further research evaluating the effects of parental occupational exposure to plastics/polymers on neurobehavioral and developmental outcomes in offspring is warranted.

Besides plastics, metal exposure, cutting/machining fluids, and automobile/mechanic fluids were associated with behavioral problems or poorer adaptive development, including increased stereotypy and a reduction in daily living and motor skills. Cutting/machining fluids and its waste contain metal particles along with lubricants, biocides, coolants, and corrosion inhibitors (Mirer, F.E, 2010). Automobile/mechanic fluids can also be composed of multiple hazardous chemicals including metals, volatile organic compounds (VOCs), paints, and solvents (Bartlet, G., 2013). Our metal results are consistent with some studies indicating that metal exposure is associated with higher scores on the CARS and SRS, as well as increased irritability and stereotypy (Adams et al., 2013; Lakshmi Priya and Geetha, 2011). Children with ASD have been found to have higher urinary levels of lead, thallium, tin, and tungsten compared to controls, which was associated with more severe ASD symptoms. Additionally, higher hair levels of metals including lead, mercury, chromium and nickel in children with ASD were associated with more severe ASD symptoms, including impaired verbal communication, higher CARS scores and difficulties with object use and auditory response (Adams et al., 2013; Blaurock-Busch et al., 2011). However, most of these studies of metals engaged small numbers of children affected with ASD. ASD severity and deficits in developmental skills or specific behaviors may result from the reduced ability to eliminate xenobiotics, like metals, mitochondrial dysfunction, or oxidative stress (Kalkbrenner et al., 2018; Rossignol et al., 2014).

Volatile organic compounds are a large group of chemicals that are generally found in mixtures and include solvents, paints, lubricants, and fuels. Previously we found that parental solvent exposure was associated with ASD (McCanlies et al., 2012). Here we found that occupational exposures (i.e. automobile/mechanic fluids, cutting/machining fluids) potentially composed of VOCs may be associated with ASD behaviors such as irritability, hyperactivity and poor expressive language. Research on the association between VOCs, paints, and solvents is mixed, showing both significant and null results, but trend toward a positive association, which is further supported by the results shown here (Kalkbrenner et al., 2014). VOCs can result in oxidative stress that interferes with cell membrane integrity which can affect multiple organ systems including the central nervous system potentially leading to the results we've observed. Additionally, further research should aim to

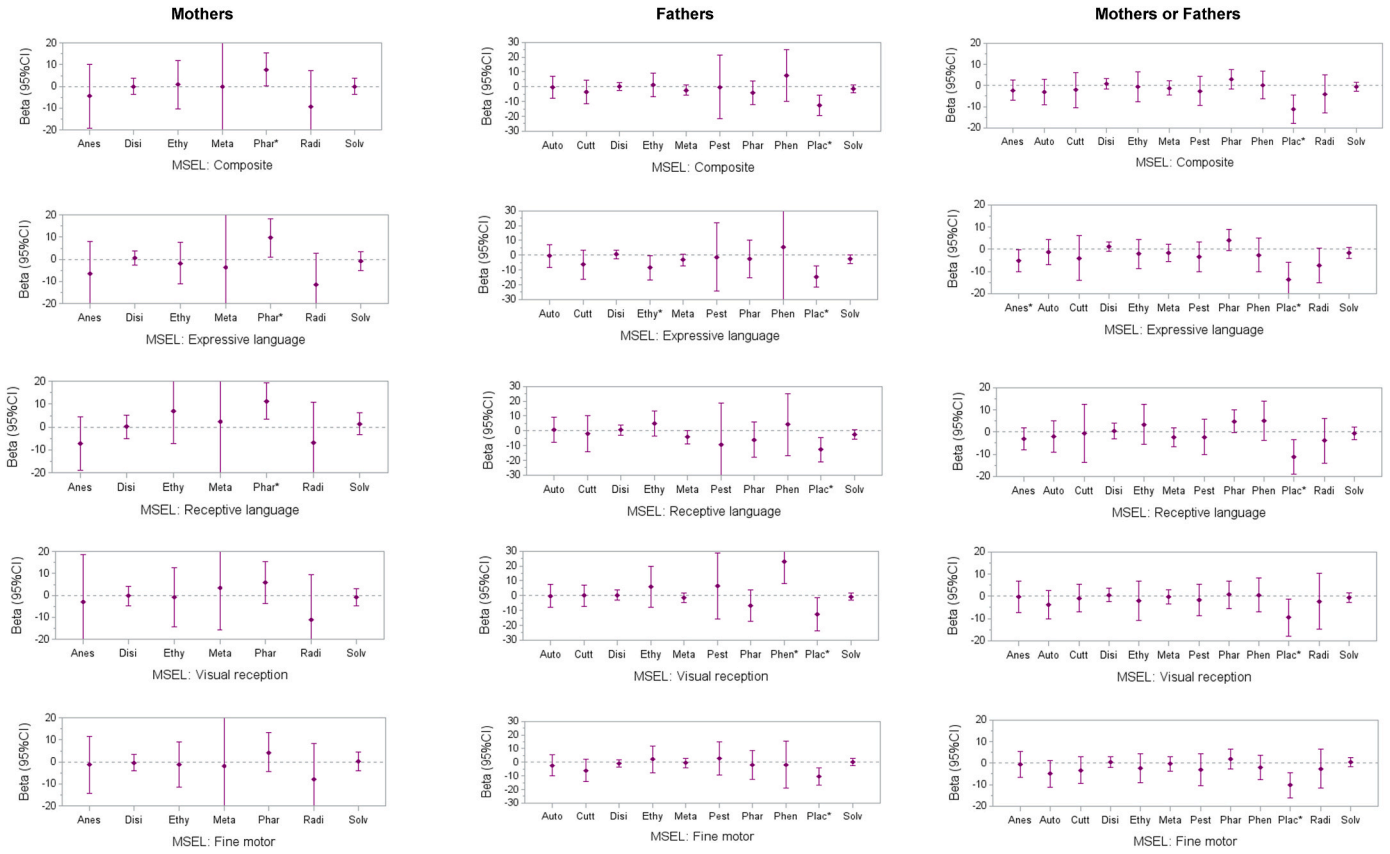

Fig. 2. Association between Mothers', Fathers', and Mothers' or Fathers' combined occupational exposures and scores on the Mullen Scales for Early Learning (MSEL). Each figure shows the β-coefficient with its corresponding 95 % confidence interval for each occupational exposure. Occupational exposures followed by an asterisk are significant at a $p \leq 0.05$.

Mother's Models were adjusted for Mother's age at delivery, smoking, length of breast feeding, total years of education, and regional center. Father's models were adjusted for father's age at delivery (years), child gestation age, father's race/ethnicity, length of breast feeding, total years of education, and regional center. Models for Mother or Father combined were adjusted for mean age of mother and father at delivery (years), length of breast feeding, total years of education, mother's smoking, and regional center.

Anesthetic Gas (Anes), Automobile/Mechanic Fluids (Auto), Cutting/Machining Fluids (Cutt), Disinfectants/Cleaners (Disi), Ethylene Oxide (Ethy), Metals (Meta), Pesticides (Pest), Pharmaceuticals/Medicine (Phar), Phenol (Phen), Plastics/Polymer Chemicals (Plac), Radiation (Radi), Solvents (Solv).

better understand the role of these chemicals in neurodevelopment and ASD.

Disinfectants includes ethylene oxide gas, formaldehyde, alcohols and phenolics (Anderson et al., 2019; National Institute for Occupational Safety and Health [NIOSH], 2019). In this study, ethylene oxide and phenol were significantly related to ASD severity, poorer expressive language (ethylene oxide, MSEL) and a lower degree of socialization (VABS). Occupations such as healthcare workers, veterinarians, hospital staff, or hotel housekeeping staff are at risk of disinfectant exposure. Our findings are consistent with Windham et al. (2013) who observed that parents of children with ASD were more likely to work in occupations with potential disinfectant exposure, although they did not assess ASD severity or behaviors. Disinfectants may trigger an immune response, or act as an endocrine disruptor (Gonsioroski et al., 2020; Shane et al., 2017). Several studies suggest that neuroinflammatory processes could play a role in the development and severity of ASD (Bjørklund et al., 2018; Krakowiak et al., 2017). EDCs can affect endogenous hormones that impact the developing nervous system and have been linked to ASD (Mari-Bauset et al., 2018).

Phenol, a derivative of benzene is used in the automotive, construction, appliance industry, and some personal care products (Barron et al., 2002). It can be absorbed via oral, dermal, or inhalation routes and has been detected in the general U.S. population including pregnant women and children. Previously, we found that solvents in general were linked to ASD (McCanlies et al., 2019), whereas this study indicates that phenol specifically may be linked to ASD severity, stereotypy, hyperactivity, and had a borderline but strong association with a lower socialization score. These results are consistent with research indicating urinary phenol levels in children from the CHARGE study were linked to an increased risk of ASD (Bennett et al., 2022), whereas these new results provide greater phenotypic specificity. Phenol's potential role in ASD may involve several mechanisms of action. As an EDC, phenol, including triclosan and BPA, can interfere with thyroid hormones and neurodevelopment signaling pathways (Mari-Bauset et al., 2018; Mustieles et al., 2015). Additionally, these chemicals may suppress the inflammatory response, disrupting immune mechanisms that are associated with ASD and ASD severity (Nowak et al., 2019; Bjørklund et al., 2018).

It is important to note that in a previous study, many of these occupational exposures (e.g. pharmaceuticals, ethylene oxide, and phenols) were not associated with ASD diagnosis (McCanlies et al., 2019). However, in this study, we identified associations between these exposures and ASD severity, deficits in cognitive or adaptive skills, or co-occurring problem behaviors. Thus, we've observed specificity in relationships between many occupational exposures and the outcomes we measured: ASD severity and the continuous distribution of behavioral symptoms, cognitive skills and adaptive function. In our previous study, ASD risk was measured as a dichotomous variable, defined by the presence of specific diagnostic symptoms. This distinction has allowed us to focus on nuances in symptom expression that may not be reflected

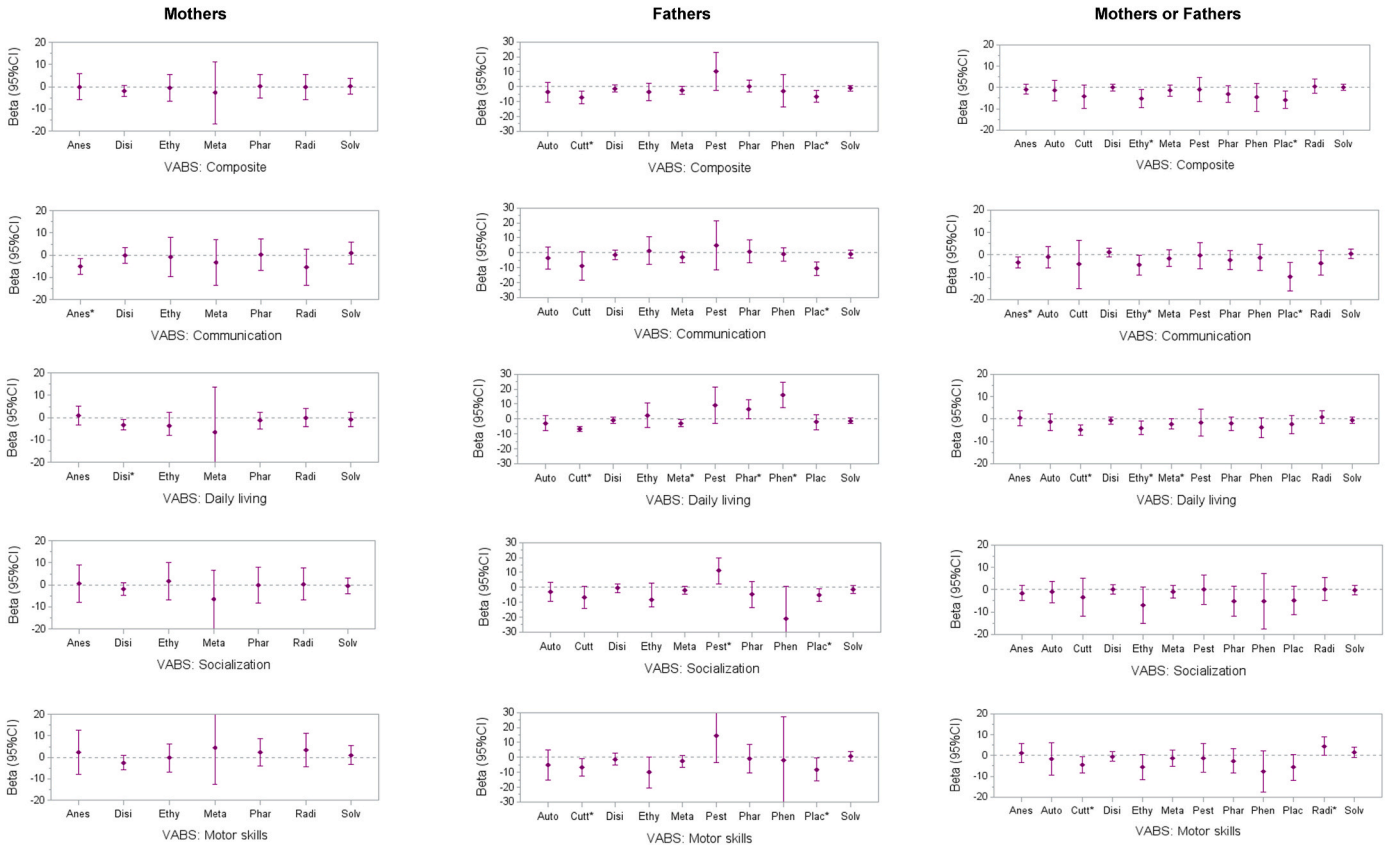

Fig. 3. Association between Mothers', Fathers', and Mothers' or Fathers' combined exposures and scores on the Vineland Adaptive Behaviors Scale (VABS). Each figure shows the β-coefficient with its corresponding 95 % confidence interval for each occupational exposure. Occupational exposures followed by an asterisk are significant at a $p \leq 0.05$.

Mother's Models were adjusted for Mother's age at delivery, smoking, length of breast feeding, total years of education, and regional center. Father's models were adjusted for father's age at delivery (years), child gestation age, father's race/ethnicity, length of breast feeding, total years of education, and regional center. Models for Mother or Father combined were adjusted for mean age of mother and father at delivery (years), length of breast feeding, total years of education, mother's smoking, and regional center.

Anesthetic Gas (Anes), Automobile/Mechanic Fluids (Auto), Cutting/Machining Fluids (Cutt), Disinfectants/Cleaners (Disi), Ethylene Oxide (Ethy), Metals (Meta), Pesticides (Pest), Pharmaceuticals/Medicine (Phar), Phenol (Phen), Plastics/Polymer Chemicals (Plac), Radiation (Radi), Solvents (Solv).

in a binary diagnosis, the latter requiring comparison with typical development, a qualitatively different research question. A similar pattern was observed with the association between ultrasound and ASD risk versus ASD severity (Webb et al., 2017). More research is needed to confirm and expand how workplace exposure impacts on child functioning.

There are both strengths and limitations associated with this study. The strengths include sampling frames that provided population-based controls and a close proxy to population-based cases (the California Department of Developmental Services client databases, supplemented by clinic and other referrals). Clinical evaluations by psychometricians with demonstrated research reliability on gold standard diagnostic instruments for both the ADI-R and ADOS-2, were used to determine a final diagnosis of ASD (Hertz-Picciotto et al., 2006). Moreover, frequency matching during recruitment along with systematic screening of many risk factors for ASD and variables correlated with occupational exposures during the preliminary analysis stage, and assignment of inverse probability weights were designed to reduce selection bias, minimize confounding, maximize precision, and increase the generalizability of the results. Finally, we 'translated' the model parameters into recognizable outcome changes per unit of exposure. Specifically, final results are presented as the increase or decrease, first, in points for each scale/subscale score examined, and secondly, in units of population standard deviations of the distributions for each neurodevelopmental/behavioral item or instrument (Table 6).

A potential weakness of this study is that despite a relatively large sample ($n > 500$) of ASD cases, it may still have been too small to see associations with agents to which only a small number of the parents were exposed. Obtaining accurate exposure data can also be challenging. In this study, we used IH-assessment based on the parents' job title, tasks, and responsibilities; a method that can be more accurate and less affected by recall bias than having parents report workplace exposures (Teschke et al., 2002). Nevertheless, there are several factors that can affect the accuracy of the IHs' estimate of workplace exposures including access to accurate job information, the IHs familiarity with specific jobs, potential solvent exposure within each job, and the use of personal protective equipment. However, whereas IH generated exposure is less sensitive, the specificity is generally more stable, resulting in less misclassification bias and attenuation of odds ratios (Benke et al., 2001). Misclassification bias is further reduced by using job tasks, responsibilities, and duties as was done in this study. Another potential limitation is that there may be more errors in the father's job histories completed by the mothers as compared to those completed by the father. These errors could have led to misclassification of exposure and decreased the precision of the measures of association.

Some of the results suggested possible beneficial impact of exposures. These were primarily found for specific behavioral concerns on the ABC, for which 17 significant associations (at $p < 0.05$) showed improved outcomes and 18 showed worsening of the behavior. In contrast, among associations with cognitive skills, 4 indicated

improvement and 12 demonstrated worsening of symptoms, and among associations with adaptive functional level, 4 improved and 19 worsened. Notably, the most well-powered analyses, which involved the combined exposures of mothers or fathers, rarely identified improvement: none for cognitive and none for adaptive skills; and two among the ABC scales: solvents associated with less inappropriate speech, and metals associated with decreased irritability, both of these amounting to small SD changes of 1/5th or less. These aspects of the results—the high ratios of associations with poorer skills vs. improvements for the MSEL and VABS, as well as the scarce evidence for benefits in the more statistically powered models with combined exposure of mothers or fathers—add to the credibility of evidence that parental workplace exposures in the pre-pregnancy and pregnancy periods could be harming the neurodevelopment of their children.

Lastly, although we did not use a panel of three or more IHs to assess occupational exposure, using more than one, which was done in this study, generally improves validity and reliability over a single IH (Siemiatycki et al., 1997). Furthermore, the IHs in this study have over 70 years of combined experience. Overall, the IHs were in good agreement 67 % of the time across all agents. Agreement increased to over 80 % for jobs with no exposures. Agreement varied when the IHs were estimating exposures across all agents. For example, the pre-consensus estimates of intensity and frequency of exposure to disinfectants/cleaners, metals, painting chemicals, pesticides, and solvents were in good agreement (about 60 %). They were in moderate to poor agreement (about 40 %–50 %) for agents such as ethylene oxide, pharmaceuticals/medicines, phenol, and plastics/polymer chemicals. Although consensus measures were used for this study, disagreement may have resulted in nondifferential (given that IHs were blinded to outcome data) misclassification for phenol, ethylene oxide, and disinfectants, pharmaceuticals/medicines - all found to be significant in this study. Nondifferential misclassification more commonly results in bias toward the null and may suggest that our results underestimate the true effect, though bias away from the null cannot be precluded (Benke et al., 2001).

5. Conclusion

The statistical analysis showed that ASD severity was most consistently associated with increasing estimates of exposures during the index period (three months prior to pregnancy until birth of the study child) to phenols, ethylene oxide, and pharmaceuticals. These findings suggest that each of these types of occupational exposures may play a role in severe ASD phenotypes. Furthermore, occupational exposures to plastics/polymers were consistently and significantly associated with poorer cognitive scores, deficits in adaptive skills, lower composite measures of both cognitive and adaptive functioning, and increases in several aberrant behaviors. With such robust findings, the evidence presented here indicates broad neurodevelopmental impact from workplace plastics/polymers. Additionally, five different occupational exposures were associated with significantly increased scores for hyperactivity: automobile/mechanic fluids, anesthetic gas, ethylene oxide, pharmaceuticals/medicine, and plastics/polymer chemicals, suggesting that this behavior is sensitive to early life neurotoxic exposures. Ethylene oxide was particularly associated with deficits in adaptive skills.

While all of these chemicals are of concern, we highlight plastics/polymers and ethylene oxide as being associated with the broadest set of outcomes. Nevertheless, future research could elucidate biologic mechanisms for any and all of these workplace chemicals. Collectively, these findings highlight the need to address exposure effects not just on employees, but on their family members, specifically, warranting attention among parents, future parents, and workplace management. Occupational safety officers and regulatory agencies should consider increasing awareness of these hazards and make clear recommendations for implementing protective measures at the worksite to reduce exposures. Given that these agents have been shown to be reproductive hazards and to interfere with neuronal migration (Mari-Bauset et al., 2018; Mustieles et al., 2015), provoke an immune or inflammatory response (Bjørklund et al., 2018; Nowak et al., 2019), and function as endocrine disruptors (Hlisníková et al., 2021; Mari-Bauset et al., 2018; Mustieles et al., 2015), all of which can influence brain development and impact cognition, adaptive capacity and behaviors, implementation of best practices and targeted interventions may be warranted in the workplace. For example, to mitigate potential risks, individuals who work in the automotive, paint manufacturing, construction, and appliance industries, pharmacies, veterinary clinics, hospitals, factories, or farms can exercise precaution by following recommended safety practices such as working in well-ventilated areas and wearing personal protective equipment. It is also important to note that many of the significant exposures identified occurred in fathers, an often-overlooked group in reproductive epidemiologic research. Future research should prioritize longitudinal studies investigating workplace environments and specific exposures that affect both mothers and fathers that may be associated with ASD and its severity or phenotypes. Lastly, research evaluating biological mechanisms linking these occupational hazards with neurodevelopmental disorders will be essential for confirming plausibility of causation and developing effective intervention and prevention methods.

CRediT authorship contribution statement

Erin C. McCanlies: Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **Ja Kook Gu:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation. **Claudia C. Ma:** Methodology, Formal analysis, Data curation. **Wayne T. Sanderson:** Methodology, Formal analysis, Data curation, Conceptualization. **Yunin J. Ludeña-Rodriguez:** Methodology, Investigation, Formal analysis, Data curation. **Irva Hertz-Picciotto:** Writing – review & editing, Writing – original draft, Resources, Methodology, Funding acquisition.

Niosh required statement

"The findings and conclusions in this report are those of the author(s) and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention."

Claudia Ma required statement

Although author Claudia C Ma is currently an FDA/CTP employee, this work was not done as part of her official FDA duties, but while she was at NIOSH. This article reflects the views of the author and should not be construed to represent FDA's.

Declaration of competing interest

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

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijheh.2025.114613.

References

Adams, J.B., Audhya, T., McDonough-Means, S., Rubin, R.A., Quig, D., Geis, E., Gehn, E., Loresto, M., Mitchell, J., Atwood, S., Barnhouse, S., Lee, W., 2013. Toxicological status of children with autism vs. neurotypical children and the association with autism severity. Biol. Trace Elem. Res. 151, 171–180.

Alabdali, A., Al-Ayadhi, L., El-Ansary, A., 2014. A key role for an impaired detoxification mechanism in the etiology and severity of autism spectrum disorders. Behav. Brain Funct. 10, 14.
Almeida-Toledano, L., Navarro-Tapia, E., Sebastiani, G., Ferrero-Martínez, S., Ferrer-Aguilar, P., Gomez-Roig, M., García-Algar, Ó., Andreu-Fernandez, V., Gómez-Roig, M., 2024. Effect of prenatal phthalate exposure on fetal development and maternal/neonatal health consequences: a systematic review. Sci. Total Environ. 950, 175080.
Aman, M.G., Singh, N.N., Stewart, A.W., Field, C.J., 1985. The aberrant behavior checklist: a behavior rating scale for the assessment of treatment effects. Am. J. Ment. Defic. 89, 485–491.
American Psychiatric Association [APA], 2013. Diagnostic and Statistical Manual of Mental Disorders, DSM-5, fifth ed. American Psychiatric Publishing, Washington, DC.
Anderson, S.E., Weatherly, L., Shane, H.L., 2019. Contribution of antimicrobials to the development of allergic disease. Curr. Opin. Immunol. 60, 91–95.
Bakoyiannis, I., Kitraki, E., Stamatakis, A., 2021. Endocrine-disrupting chemicals and behaviour: a high risk to take? Best Pract. Res. Clin. Endocrinol. Metabol. 35, 101517.
Barron, M.A., Haber, L., Maier, A., Zhao, J., Duourson, M., 2002. In: Agency, U.S.P. (Ed.), Toxicological Review of Phenol. Environmental Protection Agency, Washington, D. C.
Bartlet, G., 2013. The Negaive Effects and Recommendations for the Reduction of Exposure to Toxic Substances in the Auto Body and Auto Repair Industry, vol. 2. University at Albany, State University of New York Public Health Undergraduate Program.
Benke, G., Sim, M., Fritschi, L., Aldred, G., Forbes, A., Kauppinen, T., 2001. Comparison of occupational exposure using three different methods: hygiene panel, job exposure matrix (JEM), and self reports. Appl. Occup. Environ. Hyg 16, 84–91.
Bennett, D.H., Busgang, S.A., Kannan, K., Parsons, P.J., Takazawa, M., Palmer, C.D., Schmidt, R.J., Doucette, J.T., Schweitzer, J.B., Gennings, C., Hertz-Picciotto, I., 2022. Environmental exposures to pesticides, phthalates, phenols and trace elements are associated with neurodevelopment in the CHARGE study. Environ. Int. 161.
Bjørklund, G., Meguid, N.A., El-Ansary, A., El-Bana, M.A., Dadar, M., Aaseth, J., Hemimi, M., Osredkar, J., Chirumbolo, S., 2018. Diagnostic and severity-tracking biomarkers for autism spectrum disorder. J. Mol. Neurosci. 66, 492–511.
Blaurock-Busch, E., Amin, O.R., Rabah, T., 2011. Heavy metals and trace elements in hair and urine of a sample of Arab children with autistic spectrum disorder. Maedica (Bucur) 6, 247–257.
Braun, J.M., Muckle, G., Arbuckle, T., Bouchard, M.F., Fraser, W.D., Ouellet, E., Séguin, J.R., Oulhote, Y., Wester, G.M., Lamphear, B.P., 2017. Associations of prenatal urinary bisphenal A concentatrations with child behaviors and cognitive abilities. Environ. Health Perspect. 125, 067008.
Braun, J.M., Kalkbrenner, A.E., Just, A.C. Yolton, K., Calafat, A.M., Sjödin, A., Hauser, R., Webster, A.C., Chen, A., Lanphear, B.P., 2014. Gestational exposure to endocrine-disrupting chemicals and reciprocal social, repetitive, and stereotypic behaviors in 4- and 5-year-old children: The HOME Study. Environ. Health Perspect. 122, 513-520.
Centre for Industry Education Collaboration [CFIEC], 2016. The Essential Chemical Industry - Online. Department of Chemistry. University of York Centre for Industry Education Collaboration, University of York, UK.
Connor, T.H., Lawson, C.C., Polovich, M., McDiarmid, M.A., 2014. Reproductive health risks associated with occupational exposures to antineoplastic drugs in health care settings: a review of the evidence. J. Occup. Environ. Med. 56, 901–910.
Crinnion, W.J., 2010. The CDC fourth national report on human exposure to environmental chemicals: what it tells us about our toxic burden and how it assists environmental medicine physicians. Alternative Med. Rev. 15, 101–108.
Du, B., Deng, Q., Luo, D., Chen, H., Wu, W., Liang, B., Zhu, H., Zeng, L., 2024. Ubiquity of synthetic phenolic antioxidants in children's cerebrospinal fluid from south China: first evidence for their penetration across the blood-cerebrospinal fluid barrier. Environ. Sci. Technol. 58, 8289–8298.
Engdahl, E., van Schijndel, M.D.M., Voulgaris, D., Di Criscio, M., Ramsbottom, K.A., Rigden, D.J., Herland, A., Rüegg, J., 2021. Bisphenol a inhibits the transporter function of the blood-brain barrier by directly interacting with the abc transporter breast cancer resistance protein (bcrp). Int. J. Mol. Sci. 22, 5534.
Fishburn, J.L.A., Larson, H.L., Nguyen, A., Welch, C.J., Moore, T., Penn, A., Newman, J., Mangino, A., Widman, E., Ghobashy, R., Witherspoon, J., Lee, W., Mulligan, K.A., 2024. Bisphenol F affects neurodevelopmental gene expression, mushroom body development, and behavior in Drosophila melanogaster. Neurotoxicol. Teratol. 102, 107331.
Gialloreti, E.L., Mazzone, L., Benvenuto, A., Fasano, A., Alcon, A.G., Kraneveld, A., Moavero, R., Raz, R., Riccio, M.P., Siracusano, M., Zachor, D.A., Marini, M., Curatolo, P., 2019. Risk and protective environmental factors associated with autism spectrum disorder: evidence-based principles and recommendations. J. Clin. Med. 8.
Ginsberg, G., 2004. Pediatric pharmacokinetic data: implications for environmental risk assessment for children. Pediatrics 113, 973–983.
Gonsioroski, A., Mourikes, V.E., Flaws, J.A., 2020. Endocrine disruptors in water and their effects on the reproductive system. Int. J. Mol. Sci. 21, 1929.
Gotham, K., Pickles, A., Lord, C., 2009. Standardizing ADOS scores for a measure of severity in autism spectrum disorders. J. Autism Dev. Disord. 39, 693–705.
Grandjean, P., Landrigan, P.J., 2006. Developmental neurotoxicity of industrial chemicals. Lancet 368, 2167–2178.
Hauser, R., Calafat, A.M., 2005. Phthalates and human health. Occup. Environ. Med. 62, 806–818.
Hertz-Picciotto, I., Croen, L.A., Hansen, R., Jones, C.R., van de Water, J., Pessah, I.N., 2006. The CHARGE study: an epidemiologic investigation of genetic and environmental factors contributing to autism. Environ. Health Perspect. 114, 1119–1125.
Hertz-Picciotto, I., Krakowiak, P., Schmidt, R., 2018. Understanding environmental contributions to autism: causal concepts and the state of the science. Autism Res Apr 11, 554–586.
Hlisníková, H., Petrovičová, I., Kolena, B., Šidlovská, M., Sirotkin, A., 2020. Effects and mechanisms of phthalates' action on reproductive processes and reproductive health: a literature review. Int J Environ Res Public Health 17, 6811.
Hlisníková, H., Petrovičová, I., Kolena, B., Šidlovská, M., Sirotkin, A., 2021. Effects and mechanisms of phthalates' action on neurological processes and neural health: a literature review. Pharmacol. Rep. 73, 386–404.
Kalkbrenner, A.E., Schmidt, R.J., Penlesky, A.C., 2014. Environmental chemical exposures and autism spectrum disorders: a review of the epidemiological evidence. Curr. Probl. Pediatr. Adolesc. Health Care 44, 277–318.
Kalkbrenner, A.E., Windham, G.C., Zheng, C., McConnell, R., Lee, N.L., Schauer, J.J., Thayer, B., Pandey, J., Volk, H.E., 2018. Air toxics in relation to autism diagnosis, phenotype, and severity in a U.S. family-based study. Environ. Health Perspect. 126, 037004.
Krakowiak, P., Goines, P.E., Tancredi, D.J., Ashwood, P., Hansen, R.L., Hertz-Picciotto, I., Van de Water, J., 2017. Neonatal cytokine profiles associated with autism spectrum disorder. Biol. Psychiatry 81, 442–451.
Kuper-Sassé, M., El-Metwally, D.E., Bearer, C.F., 2024. Adverse exposures to the fetus, fanaroff and martin's neonatal-perinatal medicine, 2-Volume set. Diseases of the Fetus and Infant, pp. 240–258.
Lakshmi Priya, M.D., Geetha, A., 2011. Level of trace elements (copper, zinc, magnesium and selenium) and toxic elements (lead and mercury) in the hair and nail of children with autism. Biol. Trace Elem. Res. 142, 148–158.
Lash, T.L., VanderWeele, T.J., Haneuse, S., Rothman, K.J., 2021. Modern Epidemiology, fourth ed. Wolters-Kluwer.
Lauby, Samantha C., Lapp, Hannah E., Salazar, Melissa, Semyrenko, Sofiia, Chauhan, Danyal, Margolis, Amy E., Champagne, Frances A., 2024. Postnatal maternal care moderates the effects of prenatal bisphenol exposure on offspring neurodevelopmental, behavioral, and transcriptomic outcomes. PLoS One, 0305256.
Liu, Y., Guo, Z., Zhu, R., Gou, D., Jia, P.-P., Pei, D.S., 2023. An insight into sex-specific neurotoxicity and molecular mechanisms of DEHP: a critical review. Environmental Pollution 316, 120673.
Liu, Shuang, He, Yinling, Yin, Jia, Zhu, Qingqing, Liao, Chunyang, Jiang, Guibin, 2024. Neurotoxicities induced by micro/nanoplastics: a review focusing on the risks of neurological diseases. J. Hazard Mater. 469, 134054.
Lord, C., Rutter, M., DiLavore, P.C., Risi, S., 2003. Autism Diagnostic Observation Schedule Manual. Western Psychological Services, Los Angeles.
Lord, C., Rutter, M., Le Couteur, A., 1994. Autism diagnostic interview-revised: a revised version of a diagnostic interview for caregivers of individuals with possible pervasive developmental disorders. J. Autism Dev. Disord. 24, 659–685.
Mari-Bauset, S., Donat-Vargas, C., Llopis-Gonzalez, A., Mari-Sanchis, A., Peraita-Costa, I., Llopis-Morales, J., Morales-Suarez-Varela, M., 2018. Endocrine disruptors and autism spectrum disorder in pregnancy: a review and evaluation of the quality of the epidemiological evidence. Children 5.
Mattison, D.R., 2010. Environmental exposures and development. Curr. Opin. Pediatr. 22, 208–218.
McCanlies, E.C., Fekedulegn, D., Mnatsakanova, A., Burchfiel, C.M., Sanderson, W.T., Charles, L.E., Hertz-Picciotto, I., 2012. Parental occupational exposures and autism spectrum disorder. J. Autism Dev. Disord. 42, 2323–2334.
McCanlies, E.C., Ma, C.C., Gu, J.K., Fekedulegn, D., Sanderson, W.T., Ludena-Rodriguez, Y.J., Hertz-Picciotto, I., 2019. The CHARGE study: an assessment of parental occupational exposures and autism spectrum disorder. Occup. Environ. Med. 76, 644–651.
Mirer, F.E., 2010. New evidence on the health hazards and control of meetalworking fluids since completion of the OSHA advisory committee report. AJIM 53, 792–801.
Mordaunt, C.E., Park, B.Y., Bakulski, K.M., Feinberg, J.I., Croen, L.A., Ladd-Acosta, C., Newschaffer, C.J., Volk, H.E., Ozonoff, S., Hertz-Picciotto, I., LaSalle, J.M., Schmidt, R.J., Fallin, M.D., 2019. A meta-analysis of two high-risk prospective cohort studies reveals autism-specific transcriptional changes to chromatin, autoimmune, and environmental response genes in umbilical cord blood. Mol. Autism 10, 36.
Mullen, E.M., 1995. Mullen's Scales of Early Learning. American Guidance Services Inc., Circle Pines, MN.
Mustieles, V., Perez-Lobato, R., Olea, N., Fernandez, M.F., 2015. Bisphenol A: human exposure and neurobehavior. Neurotoxicology 49, 174–184.
Xia, G., Wan, T., Chen, Z., Liu, C., Li, R., 2025. Developmental toxicity of micro (nano) plastics (MNPs) exposure in mammals: a mini-review. Toxics 13, 224.
National Institute for Occupational Safety and Health [NIOSH], 1981. Ethylene oxide (EtO): Evidence of Carcinogenicity, Current Intelligence Bulletin. DHHS (NIOSH).
National Institute for Occupational Safety and Health [NIOSH], 2019. Chemical Disinfectants and Sterilants, Reproductive Health and the Workplace. U.S. Department of Health & Human Services/CDC. https://www.cdc.gov/niosh/topics/repro/disinfectants.html.
Nowak, K., Jablonska, E., Ratajczak-Wrona, W., 2019. Immunomodulatory effects of synthetic endocrine disrupting chemicals on the development and functions of human immune cells. Environ. Int. 125, 350–364.
Ornoy, A., Weinstein-Fudim, L., Ergaz, Z., 2015. Prenatal factors associated with autism spectrum disorder (ASD). Reprod. Toxicol. 56, 155–169.
Park, H., Park, H.D., Jang, J.K., 2016. Exposure characteristics of construction painters to organic solvents. Safety and Health at Work 7, 63–71.
Persico, A.M., Napolioni, V., 2013. Urinary p-cresol in autism spectrum disorder. Neurotoxicol. Teratol. 36, 82–90.

Philippat, C., Bennett, D., Krakowiak, P., Rose, M., Hwang, H.-M., Hertz-Picciotto, I., 2015. Phthalate concentrations in house dust in relation to autism spectrum disorder and developmental delay in the CHildhood autism risks from genetics and the environment (CHARGE) study. Environ Health Jun 26 (14), 56.
Rim, K.T., 2017. Reproductive toxic chemicals at work and efforts to protect workers' health: a literature review. Safety and Health at Work 8, 143–150.
Risi, S., Lord, C., Gotham, K., Corsello, C., Chrysler, C., Szatmari, P., Cook Jr., E.H., Leventhal, B.L., Pickles, A., 2006. Combining information from multiple sources in the diagnosis of autism spectrum disorders. J. Am. Acad. Child Adolesc. Psychiatry 45, 1094–1103.
Rossignol, D.A., Genuis, S.J., Frye, R.E., 2014. Environmental toxicants and autism spectrum disorders: a systematic review. Transl. Psychiatry 4, e360.
Rutter, M., Bailey, A., Berument, S.K., Lord, C., Pickles, A., 2003. Social Communication Questionnaire (SCQ). Western Psychological Services, Los Angeles.
Scheftel, J.M., Elchos, B.L., Rubin, C.S., Decker, J.A., 2017. Review of hazards to female reproductive health in veterinary practice. J. Am. Vet. Med. Assoc. 250, 862–872.
Schmidt, R.J., Lyall, K., Hertz-Picciotto, I., 2014. Environment and autism: current state of the science. Cut Edge Psychiatry Pract 1, 21–38.
Shane, H.L., Lukomska, E., Stefaniak, A.B., Anderson, S.E., 2017. Divergent hypersensitivity responses following topical application of the Quaternary ammonium compound, didecyldimethylammonium bromide. J Immunotoxicol 14, 204–214.
Siemiatycki, J., Fritschi, L., Nadon, L., Gerin, M., 1997. Reliability of an expert rating procedure for retrospective assessment of occupational exposures in community-based case-control studies. Am. J. Ind. Med. 31, 280–286.
Sparrow, S.S., Balla, D.A., Cicchetti, D.V., 1984. Vineland Adaptive Behavior Scales. American Guidance Services, Inc, Circle Pines, MN.
Teschke, K., Olshan, A.F., Daniels, J.L., De Roos, A.J., Parks, C.G., Schulz, M., Vaughan, T.L., 2002. Occupational exposure assessment in case-control studies: opportunities for improvement. Occup. Environ. Med. 59, 575–593. ; discussion 594.
United States Census Bureau, 2007. North American Industry Classification System (NAICS). Retreived from Census.gov.
U.S. Bureau of Labor Statistics, 2000. Standard Occupational Classification (SOC). www.bls.gov/SOC.
Webb, S.J., Garrison, M.M., Bernier, R., McClintic, A.M., King, B.H., Mourad, P.D., 2017. Severity of ASD symptoms and their correlation with the presence of copy number variations and exposure to first trimester ultrasound. Autism Res. 10, 472–484.
Welch, C., Mulligan, K., 2022. Does bisphenol A confer risk of neurodevelopmental disorders? What we have learned from developmental neurotoxicity studies in animal models. Int. J. Mol. Sci. 23, 2894.
Weng, H.-Y., Hseuh, Y.-A., Messam, L.L.M., Hertz-Picciotto, I., 2009. Methods of covariate selection: Directed acyclic graphs and the change-in-estimate procedure. Amer J Epidemiology. May 16, 1182–1190.
Wiggins, L.D., Barger, B., Moody, E., Soke, G., Pandey, J., Levy, S., 2017. Brief report: the ADOS calibrated severity score best measures autism diagnostic symptom severity in pre-school children. J. Autism Dev. Disord. 49, 2999–3006.
Wigle, D.T., Arbuckle, T.E., Turner, M.C., Berube, A., Yang, Q., Liu, S., Krewski, D., 2008. Epidemiologic evidence of relationships between reproductive and child health outcomes and environmental chemical contaminants. J. Toxicol. Environ. Health B Crit. Rev. 11, 373–517.
Windham, G.C., Fessel, K., Grether, J.K., 2009. Autism spectrum disorders in relation to parental occupation in technical fields. Autism Res. 2, 183–191.
Windham, G.C., Sumner, A., Li, S.X., Anderson, M., Katz, E., Croen, L.A., Grether, J.K., 2013. Use of birth certificates to examine maternal occupational exposures and autism spectrum disorders in offspring. Autism Res. 6, 57–63.

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Corrigendum to: "The effects of parental occupational exposures on autism spectrum disorder severity and skills in cognitive and adaptive domains in children with autism spectrum disorder" [Int. J. Hyg Environ. Health 268 (2025) 25 114613]

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We have identified substantial print errors in Table 6 in the manuscript named above. The errors are the result of some of the grey areas not printing in the software, and the data being shifted across and within the cells where there were intentional blanks in the row. This completely shifted the data, so that the data representing outcomes are no longer aligned with the correct corresponding exposure and/or parent. The table describes the change in ASD outcomes for each 1 standard deviation increase in exposure for each exposure for the mother, father, and mother/father combined. Because the table only shows the significant findings, as you read across the table some columns have blank spaces because the outcome for those columns were not significantly associated with the exposures, but outcomes in other columns of the same row, were significantly associated with the exposures. The specific rows within each 'box' are for which parent(s) had the exposures (see 2nd column within "Exposure"). To facilitate comprehension of the table, we have split each of the exposure rows according to the parent exposures. We believe that besides cleaning up/replacing the table with a correct layout and introducing a color shading for results consistent with our hypotheses, a more informative description of how to read the table is apparently needed: the technical/formatting details are now provided in the text (title) describing the Table; additionally we also include key notes for a clear bulleted explanation of what this summary table provides that cannot be directly gleaned from any other table or figure.

The updated Table 6 is as follows.

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Table 6: All significant associations (p<0.05): magnitude of change in behavioral or developmental outcome for a 1 SD (Standard Deviation) increase in $\log_{(e)}$ cumulative exposure. Each row outlined by solid borders contains results for a specific exposure, and is subdivided by the parent(s) whose exposure was analyzed. The four major outcomes are in the four columns, two under Behavioral Scores (the CSS and the ABC) and two under Developmental Skills (MSEL for cognitive and VABs for adaptive skills). The two shaded headings describe how to interpret positive vs. negative slopes. Beta coefficients can be for either of the two outcomes that follow the Beta column (e.g., ethylene oxide has significant—but different sized—associations with CSS and ABC). Blue shading indicates significant associations consistent with the *study hypothesis: a worse outcome for higher exposure*. Shaded dashes in parent box (----) indicate mixed significant associations (both improved and worse outcomes). Blank boxes indicate no outcome was significantly associated with that row's exposure of any parent (e.g., for Cutting, machine fluids, neither paternal nor M/F exposures were significantly associated with either CSS or any ABC subscale). Non-significant associations are not presented in this Table (e.g., the absence of a row for paternal exposures to anesthetic gases indicates no significant association of paternal exposures to those gases, with any of the outcomes).

	Exposure			Change in Outcome for a 1 SD Increase in Exposure[a]					
				Beta: CSS or ABC	Behavioral Scores **Higher** Scores = **Worse** Behavior *(shaded blue)* Lower Scores = Improvement *(no shading)*		Beta: MSEL or VABS	Developmental Skills (Cognitive & Adaptive) **Lower** Scores = **Poorer** Skills *(shaded blue)* Higher Scores = Improvement *(no shading)*	
Chemical or Source of Exposure	Parent: Mo, Fa, M/F[b]	Mean (SD) of log(e) cum. Exposure	1 unit change converted to exposure SD's[c]	Slope for CSS or ABC scales	Change in ASD **CSS** (Calibrated Severity Scale), among children with ASD: on scale form 4-10, SD = 1.55	Change in **ABC** subscales[d] *range* (SD): ***Irrit****ability:* *0 to 45* (8.5) *Social* ***Withdr****awal:* *0 to 48* (7.7) ***Stereo****typy:* *0 to 21* (4.4) ***Hyper****activity:* *0 to 48* (10.6) ***In****appropriate* ***Spee****ch:* *0 to 11* (2.9)	Slope for MSEL or VABS sub-scales	Change in **MSEL**[e] **Compos**ite SD = 15 pt All subscales SD = 10 pt: ***Express****ive Language* ***Recept****ive Language* ***Visual*** *Perception* ***Fine Motor***	Change in **VABS**[f] **Compos**ite SD = 15 pt All Subscales SD=10 pt: ***Comm****unications* ***Daily*** *Living Skills* ***Social****ization* ***Motor***
Anesthetic gases	Mo----	7.23 (1.22)	0.82	-3.53 -1.64 -1.69		*Irrit* = -2.89 pts, -0.34 SD *Withdr* = -1.34 pts, -0.17 SD *InSpee* = -1.39 pts, -0.48	-4.99		*Comm*: = -4.1 pts or -0.41 SD
	M/F	7.81 (1.48)	0.68	+1.64		*Hyper* = +1.12 pts, +0.11 SD	-5.14 -3.31	*Express* = -3.5 pts or -0.35 SD	*Comms* = -2.25 pts or -0.23 SD
Automobile / Mechanic fluids	Fa	8.44 (1.10)	0.91	+4.80 +4.30		*Irrit* = +4.36 pts, +0.51 SD *Hyper* = +3.91 pts, +0.37 SD			
	M/F	8.40 (1.09)	0.92	+3.47 +5.97		*Irrit* = +3.19 pts, +0.38 SD *Hyper* = +5.49 pts, +0.52 SD			
Cutting, machine fluids	Fa	8.67 (0.99)	1.01				-7.16 -6.58 -6.77		*Compos* = -7.23 pts, -0.48 SD *Daily* = -6.65 pts or -0.67 SD *Motor* = -6.84 pts or -0.68 SD
	M/F	8.65 (0.99)	1.01				-4.98 -4.46		*Daily* = -4.93 pts, -0.49 SD *Motor* = -4.42 pts, -0.44SD
Disinfectants	Mo	7.85(1.12)	0.89				-3.13		*Daily* = -2.79 pts or -0.28 SD

	Parent	Mean (SD) Cum Exposure	Change in SD	Beta: CSS or ABC	Behavioral Scores Change in ASD severity scale (4-10)	Behavioral Scores Change in ABC scales	Beta: MSEL or VABS	Developmental Skills **Change in** MSEL: Composite SD=15 Subscales SD=10	Developmental Skills **Change in** VABS: Composite SD=15 Subscales SD=10
Ethylene oxide	Fa----	7.48 (0.80)	1.25	+1.00 -13.86 -6.73	= +1.25 pts, =0.81 SD	*Hyper* = -17.33 pts, -1.63 SD *Inspee* = -8.43 pts, -2.91 SD	-8.55 -5.24	*Express* = 10.7 pts, 1.1 SD	*Compos* = -6.97 pt, -0.46 SD
	M/F	7.45 (0.75)	1.33	+5.14		*Hyper* = +6.43 pts, +0.61 SD	-4.64 -4.00		*Comms* = -6.17 pts, -0.62 SD *Daily* = -5.32 pts, -0.53 SD
Metals	Mo	7.80 (0.89)	1.12	-8.10 -2.55		*Irrit* = -9.07 pts, -1.07 SD *InSpee* = -2.86 pts, -0.98 SD			
	Fa	8.46 (0.93)	1.08	+0.91		*Stereo* = +0.98 pts, +0.22 SD	-2.81		*Daily* = -3.02 pts or -0.30 SD
	M/F----	8.40 (0.95)	1.05	-1.58 +0.77		*Irrit* = -1.66 pts, -0.20 SD *Stereo* = +0.81 pts, 0.18 SD	-2.19		*Daily* = -2.30 pts or -0.23 SD
Pesticides	Fa	8.10 (1.19)	0.84	-11.06 -8.80 -5.50 -10.78 -3.23		*Irrit* = -9.29 pts, -1.09 SD *Withdr* = -7.39 pts, -0.96 SD *Stereo* = -4.62 pts, -1.05 SD *Hyper* = -9.06 pts, -0.46 SD *InSpee* = -2.71 pts, -0.94 SD	+11.11		*Socializ* = +9.33 pts, +0.93 SD
Pharmaceutical	Mo----	8.67 (0.80)	1.25	+8.53		*Hyper* = +10.7 pts, +1.01 SD	+7.83 +9.72	*Compos* = +9.78 pts, 0.65 SD *Express* = +12.15 pts, 1.2 SD	
	Fa	9.14 (1.01)	0.99	-8.30		*Stereo* = -8.22 pts, = -1.87 SD	+11.36	*Recept* = +14.2 pts, 1.4 SD	
	M/F----	8.85 (0.99)	1.01	+0.46 +2.40 +5.32	= +0.46 pts, = 0.83 SD	*Irrit* = +2.42 pts, +0.28 SD *Hyper* = +5.37 pts, +0.51 SD	+6.70		*Daily* = +6.63 pts, +0.66 SD
Phenols	Mo	7.22 (0.57)	1.75	+1.05	= +1.84 pts, = 0.30 SD				
	Fa----	7.38 (0.89)	1.12	-5.56 +2.62 +7.16		*Irrit* = -6.23 pts, -0.73 SD *Stereo* = +2.93 pts, +0.67 SD *Hyper* = +8.02 pts, +0.76 SD	+22.98 +16.00	*Visual* = +25.7, +2.6 SD	*Daily* = +17.9 pts, +1.79 SD
	M/F	7.32 (0.76)	1.32	+0.97	= +1.28 pts, = 0.83 SD				
Plastics / polymers	Fa	8.74 (1.08)	0.93	+0.89 +3.85 +3.34	= +0.83 pts, = 0.53 SD	*Withdr* = +3.58 pts, +0.47 SD *Stereo* = +3.11 pts, +0.71 SD	-12.62 -14.54 -12.77 -12.58 -10.60 -6.62 -10.59 -5.04 -8.18	*Compos* = -11.7 pts, -0.78 SD *Express* = -13.5 pts, -1.35 SD *Recept* = -11.9 pts, -1.19 SD *Visual* = -11.7 pts, -1.17 SD *F Motor* = -9.86 pts, -0.99 SD	*Compos* = -6.16 pts, -0.41 SD *Comms* = -9.85 pts, -0.99 SD *Socializ* = -4.69 pts, -0.47 SD *Motor* = -7.61 pts, -0.76 SD
	M/F	8.78 (1.01)	0.99	+4.18 +3.04 +3.80		*Withdr* = +4.14 pts, +0.54 SD *Stereo* = +3.01 pts, +0.68 SD *Hyper* = +3.76 pts, +0.35 SD	-11.12 -13.52 -11.15 -9.58 -10.23 -5.74 -9.85	*Compos* = -11.0 pts, -0.73 SD *Express* = -13.4 pts, -1.33 SD *Recept* = -11.0 pts, -1.10 SD *Visual* = -9.48 pts, -0.95 SD *F Motor* = -10.4 pts, -1.04 SD	*Compos* = -5.68 pts, -0.38 SD *Comms* = -9.75 pts, -0.98 SD

	Parent	Mean (SD) Cum Exposure	Change in SD	Beta: CSS or ABC	Behavioral Scores		Beta: MSEL or VABS	Developmental Skills	
					Change in ASD severity scale (4-10)	Change in ABC scales		Change in MSEL: Composite SD=15 Subscales SD=10	Change in VABS: Composite SD=15 Subscales SD=10
Radiation	Mo	7.40 (0.78)	1.28	-2.11		*Inspee* = -2.71 pts, = -1.75 SD			
Solvents	M/F	8.49 (1.16)	0.86	-0.42		*Inspee* = -0.50 pts, = - 0.17 SD			
Summary of Findings: Improved Outcome (contrary to hyptheses) vs. Worse Outcome (consistent with hypothesis):									
Number of Significant Findings ($p<0.05$):					0: improved outcome 5: worse outcome	17: improved outcome 18: worse outcome		4: improved outcome 12: worse outcome	3: improved outcome 19: worse outcome.

Abbreviations:

[a] Beta-X-change in exposure SD = change in outcome per SD change in exposure

[b] Parent category: Mo = mother; Fa = father; M/F = mother or father combined = mother or father or both

[c] One unit change in $\log_{(e)}$ cumulative exposure converted to exposure SD's; Use of 1 SD standardizes calculations across all exposures, allowing comparison of effect sizes across exposures

[d] ABC (Aberrant Behavior Checklist) subscales: *Irrit* (Irritability); *Withdr* (Withdrawal or lethargy); *Stereo* (stereotypy); *Hyper* (Hyperactivity); *Inspee* (Inappropriate speech)

[e] MSEL (Mullen Scales of Early Learning) subscale abbreviations: *Compos* (Composite); *Express* (Expressive language); *Recept* (Receptive language); *Visual* (Visual perception); *F Motor* (Fine Motor)

[f] VABS (Vineland Adaptive Behavior Scales) abbreviations: *Compos* (Composite); *Comms* (Communications); *Daily* (Daily Living Skills); *Social* (Socialization); *Motor* (Motor)

Notes on Table 6

Synopsis of the take-aways:

1. For three of the four outcomes, the number of significant confirmatory findings of harm (our hypotheses) far outweighed the number of significant inverse findings. As summarized numerically (bottom of Table 6): Autism severity, cognitive domains and adaptive skills all demonstrated a preponderance of adverse associations, visually represented by the preponderance of results in blue shading for those three columns.
2. The exception was the ABC. Here there were approximately equal numbers of outcomes that were contrary to our hypothesized direction of associations, compared with outcomes that confirmed our hypotheses.
3. Nevertheless, even on the ABC, some findings of adverse outcomes were largely consistent with our hypothesis: Hyperactivity—the most common of all neurobehavioral outcomes in the U.S. population—increased in 8 parent exposure/outcome analyses, and decreased in two. Stereotypy similarly showed increases in 5 versus decreases in two.
4. Plastics and polymers stand out for being associated with the largest number of adverse outcomes, far more than any other class of exposures. This table highlights that all four outcome domains had significant associations that were exclusively consistent with our hypotheses, a phenomenon not observed for any other exposure. (Ethylene oxide has significant associations with all four developmental domains but also has significant inverse associations on ABC subscales.)
5. In contrast, pesticides had no significant associations with adverse outcomes.
6. The number of significant findings for mothers' exposures was lower than for fathers' exposures, but the largest number were for M/F combined. Even so, two exposures were exclusively significant with maternal exposures: Disinfectants and Radiation. Findings were similar for maternal Phenol exposures in association with greater autism severity, though not with other outcomes. Additionally, although not represented in Table 6, Figure 3 shows the borderline association of maternal Ethylene Oxide Exposure with Hyperactivity, which drove the significant finding for the M/F exposures to this sterilizing agent.
7. For many exposures/outcomes, fathers' exposures were the main driver of the M/F findings: Automobile/ mechanic fluids in associations with ABC scales for irritability and hyperactivity; Cutting/machine fluids for adaptive skills; Ethylene Oxide for adaptive skills; Phenols in relation to ABC scales for stereotypy and hyperactivity; and Plastics/Polymers for all four sets of outcomes: autism severity (CSS), ABC scales, and multiple cognitive (MSEL) and adaptive (VABS) skills.