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Development of a Phthalate Environmental Reproductive Health Literacy (PERHL) Scale

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Background: Substantial evidence exists linking phthalate exposure to adverse reproductive health outcomes. Current US federal regulations of consumer product chemicals place the onus on individuals to mitigate their exposure to phthalates, with assumptions of sufficient environmental health literacy (EHL). Few validated scales for people of reproductive age exist to evaluate phthalate-specific EHL.

Objectives: Our objective is to develop a multidimensional scale characterizing latent factors of phthalate knowledge, risk perception, and self-efficacy to inform individual-level interventions for reducing phthalate exposure.

Methods: We distributed a survey with 31 items to 117 participants in the Environmental Reproductive and Glucose Outcomes (ERGO) cohort who gave birth within the last 5 years. Exploratory factor analysis (EFA) was used to identify underlying latent factors. Internal reliability was assessed via omega hierarchical coefficient. Average sum scores for each latent factor and the overall Phthalate Environmental Reproductive Health Literacy (PERHL) score were calculated. Associations between latent factors, overall PERHL score, and sociodemographic characteristics were explored using linear models.

Results: Six latent factors were identified as follows: "Awareness of Phthalate Reproductive Health Impacts," "Uncertainty," "Protective Behavior/Risk Control," "Regulatory Interest," "Awareness of Phthalate Exposure Pathways," and "General Phthalate Knowledge." Each factor demonstrated acceptable to strong internal reliability, with coefficients ranging between 0.63 and 0.93. Non-white participants had lower scores for the "Awareness of Phthalate Reproductive Health Impacts" [β: −0.35, 95% confidence interval (CI): −0.63, −0.07], "Awareness of Phthalate Exposure Pathways" (β: −0.32, 95% CI: −0.57, −0.07), and "General Phthalate Knowledge" (β: −0.36, 95% CI: −0.66, −0.06), but no significant difference in scores on "Uncertainty" (β: 0.17, 95% CI: −0.16, 0.50), "Protective Behavior/Risk Control" (β: −0.04, 95% CI: −0.36, 0.28), or "Regulatory Interest" (β: −0.21, 95% CI: −0.51, 0.09). No associations were seen for age or educational attainment and latent or sum factors.

Discussion: Six latent factors were identified for the PERHL scale. Non-white race and ethnicity was associated with lower scores for knowledge-related scale factors. https://doi.org/10.1289/EHP13128

Introduction

Environmental health literacy (EHL) is a process and methodology that evaluates and characterizes the ways in which environmental health information is attended, conceptualized, contextualized, and used to inform behaviors.[1–3] Early attempts to characterize EHL largely focused on measurement of participants' topical environmental health knowledge and skills.[4–6] However, the definition of EHL continues to evolve, and various social and structural factors have been posited as critical influences on the ways in which people attend to and act on environmental health information, making EHL a multidisciplinary construct.[1,2,7,8] Further, EHL is often concept- and context-specific, necessitating tools specific to a given population and topic.[3,9]

Pregnancy is a sensitive window of exposure for both a parent's and child's health.[10] Exposure to endocrine disrupting chemicals (EDCs) can perturb physiological changes during pregnancy, with adverse health impacts for both parent and child.[11–14] Among the different types of EDCs, phthalates have been well-studied and linked to a variety of adverse reproductive and child health outcomes. Phthalates are a group of EDCs commonly used as plasticizers, in personal care products, and building materials.[15] Due to their widespread use, phthalates are a ubiquitous and frequent exposure, with >95% of the US population having detectable urinary concentrations of phthalate metabolites.[16] Phthalates are able to cross the placenta, resulting in fetal exposure that is strongly correlated with parental phthalate exposure.[17] Prenatal phthalate exposure has been associated with multiple adverse outcomes for the fetus, including shorter anogenital distance and reduced penile size and impaired neurodevelopment.[18–20] Phthalate exposure has also been associated with increased body size and risk of type 2 diabetes in pregnant individuals.[11,21–23] There is also evidence indicating that higher urinary phthalate metabolite concentrations during pregnancy are associated with risk for gestational diabetes, preterm birth, and hypertensive disorders of pregnancy.[24–27] Thus, reducing phthalate exposures during pregnancy provides clear health benefits for both the pregnant individual and child.

In the US, regulation of consumer product chemicals, including phthalates, is limited, with personal care product chemical regulations remaining unchanged at the federal level since the 1930s. Consumers often presume personal care products are tested for safety before release on the market.[28,29] However, these products and their ingredients (except color additives) are not required to undergo safety testing.[29] Thus, the onus is on consumers to be aware of possible exposures and associated health effects from personal care products. These limited regulations assume individuals are knowledgeable of their exposures, have awareness of health risks, and have the ability to adjust behaviors to reduce exposure. Collectively, this knowledge, awareness, and behavior suggest a need for EHL as it relates to phthalate exposure. Yet, little is known about EHL as it relates to phthalate exposure in pregnant people and individuals with younger children, despite the pervasive exposure and associated health risks. Understanding knowledge, perceived risk, and behaviors associated with phthalate exposures could provide an opportunity to

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increase agency for engaging in health-protective behaviors.[30] There are often competing contextual, behavioral, social, and structural factors also at play that may influence uptake of health-protective behaviors to reduce environmental exposures.[31] However, it has been well documented that information alone is often insufficient to inspire behavior change.[32] Characterizing the complex factors at play, in addition to phthalate knowledge, may provide insight as to how to communicate phthalate information to pregnant individuals and parents of young children in such a way that does not rely on the science literacy/information deficit model.[1] Specifically, better characterization of EHL may provide opportunity for targeted intervention to reduce exposures in pregnant people and children—groups that are sensitive to phthalate exposures.

Two overarching models have been proposed to conceptualize EHL and outline the field's objectives, including development of measurement tools for EHL.[1,3] Presently, there is a scarcity of tools developed to assess individual EHL, and the available tools are characterized by a broad focus, aiming to asses overall EHL or EHL related to certain media such as air or water.[4,33] Despite their utility, these tools exhibit limitations in their ability to finely characterize EHL tailored to a specific exposure within a targeted audience, as proposed by Finn and O'Fallon.[3]

Development of scales to measure EHL specific to a given exposure and context is critical to measure efficacy of educational environmental health interventions. Development of scales that can measure individual EHL and extent of engagement in health-protective behaviors afford the opportunity to quickly identify those who may be at risk of elevated environmental exposures in a noninvasive manner.

We sought to develop a tool to characterize the underlying factors contributing to phthalates and reproductive health EHL via the Phthalate Environmental Reproductive Health Literacy (PERHL) scale. We sought to understand the latent factors that contribute to phthalate-specific EHL. Furthermore, we sought to understand the associations between these factors and sociodemographic factors linked to disparities in urinary phthalate metabolite concentrations.[21–23,34] We hypothesized that in addition to knowledge of phthalates, other underlying factors would contribute to overall phthalate EHL. Additionally, we anticipated that there would be differences in EHL along demographic markers that can capture social differences in access to environmental health information.

Methods

Item Generation and Review

Twenty-seven items were adapted from a previously validated scale assessing awareness, risk acceptance, perceived uncertainty, and protective behaviors in relation to EDCs.[35] This scale was selected due to the inclusion of topical knowledge, uncertainty, risk perception/acceptability, and interest in engaging in self-protective behavior. We specifically selected this scale because it differed from other existing EHL scales by encompassing constructs beyond knowledge and behavioral intent. By incorporating these other constructs, the scale offers a more comprehensive assessment of individuals' attitudes and responses toward EDCs. The previous scale was validated with participants ($n = 331$) who identified as Vietnamese citizens ages 18 years or older living in the Ho Chi Minh metro area.[36] Items from that scale were based on the Health Belief Model, which broadly explains health-protective behaviors via four factors: perception of susceptibility, perception of severity, perception of barriers, and perception of benefits.[36] Structural equation modeling (SEM) was implemented to test the scale's performance. The fit indices indicated that a final version of the scale had acceptable fit [comparative fit index (CFI) = 0.95, Tucker-Lewis index (TLI) = 0.93, standardized root mean squared error (SRMR) = 0.05, root mean square error of approximation (RMSEA) < 0.05].[36] Since its development, that scale has been used to explore whether perceived uncertainty mediates the relationship of awareness of EDCs with risk concern, risk acceptability, and self-protective responses.[36]

For the present study, all items were adapted to be specific to the topic of phthalates (rather than EDCs in general), with items on awareness, risk acceptance, perceived uncertainty, and protective behaviors based on the original scale being maintained. These items were reviewed by two experts in environmental reproductive epidemiology (T.J.T.) and environmental exposure assessment (G.A.) from Harvard T.H. Chan School of Public Health Department of Environmental Health. Each expert independently reviewed the items for clarity, scope, and redundancy, and provided feedback in writing. Two items were removed from the original scale ("I believe that nature is valuable for its own sake" and "I believe that to protect the environment unconditionally is important") due to their broad nature. Six new items were added, bringing the total to 31 items in all. The new items were added to clarify barriers to communication and to distinguish potential health impacts and associated perceived risks to parent and child. The item "I am uncertain about the adverse effects of phthalates on humans and the environment because of ineffective or difficulty understanding of science communication" was added to capture challenges related to environmental health communications. The following three items were added so as to address distinct concerns about health implications of phthalate exposure for birthing people and children: "Reproductive health problems are possibly caused by using personal care products (such as perfumes, deodorants, and soaps) that contain phthalates," "Reproductive health problems for women trying to get pregnant are possibly caused by using personal care products (such as perfumes, deodorants, and soaps) that contain phthalates," and "Reproductive health problems for children are possibly caused by their mother's exposure during pregnancy to personal care products (such as perfumes, deodorants, and soaps) that contain phthalates." Finally, the following two items were added to address protective behaviors' importance for the parent and child's health: "I think reducing my use of personal care products that may contain phthalates (such as certain perfumes, deodorants, or soaps) is important for my child's health" and "I think reducing my use of personal care products that may contain phthalates (such as certain perfumes, deodorants, or soaps) is important for my health."

Participants and Sampling

Participants ($n = 117$) who completed the PERHL scale were a subset of participants from the Environmental Reproductive and Glucose Outcomes (ERGO) study, a pregnancy cohort focused on understanding the role of EDCs on reproductive and later-life cardiometabolic health outcomes in pregnant people and their offspring.[35] More details about the ERGO study have been described elsewhere.[35] In brief, participants in the ERGO study were recruited during early pregnancy at routine prenatal visits beginning in 2016.[35] Eligibility criteria for the ERGO study included being at least 18 years of age, being <15 weeks of gestation at the time of enrollment, speaking English, and having plans to receive prenatal care and deliver at either Beth Israel Deaconess Medical Center or Brigham and Women's Hospital in Boston, Massachusetts. To be eligible to complete the PERHL survey, participants must have been a member of the ERGO cohort who were at least 15 weeks but less than 5 years postpartum. PERHL surveys were completed via online questionnaire between March 2021 and June 2022.[37] Prior to completing the

PERHL survey, ERGO participants were not engaged in conversations about phthalates as part of the study. Study protocols were approved by the institutional review boards of Harvard T.H. Chan School of Public Health and Mass General Brigham, and all participants provided written informed consent.

Suitability for Exploratory Factor Analysis

Eighty seven percent of the data were complete cases.[38] Missing values were imputed using predictive mean matching (PMM) to ensure that imputed values were plausible.[38] We assessed sampling adequacy using the Kaiser-Meyer-Olkin (KMO) test. KMO values below 0.5 are generally undesirable for factor analysis, with scores closer to 1 indicating the sampling is adequate.[37,39] Additionally, we assessed whether the correlation matrix indicated that the variables were unrelated (and therefore unsuitable for factor analysis) via Bartlett's test of sphericity.[39] A significant test (<0.05) indicates that factor analysis is appropriate.[39]

Exploratory Factor Analysis: Factor Retention and Rotation

Horn's parallel analysis was used to determine the number of factors to retain for exploratory factor analysis (EFA).[40] In parallel analysis, correlation matrices of random variables are constructed based on the same sample size and number of variables in the observed data set. Eigenvalues from the random matrices are compared to eigenvalues from the true data correlation matrix. The statistical package "paran" (version 1.5.2) was used to complete parallel analysis by creating random permutations of data sets with the same number of variables and observations in keeping with the structure of the experimental dataset (i.e., Likert scale-like variables). Factors with eigenvalues greater than the random matrix eigenvalues are retained. This approach adjusts for effects of sampling error (as compared to the K1 criteria, retaining factors with eigenvalues above 1.0).[39]

Principal axis factoring was implemented for factor extraction.[41] We anticipated that our factors would correlate and therefore applied Promax oblique rotation.[39] Each item was evaluated based on its factor loadings, and items with loadings equal to or above 0.3 were retained. Cross-loaded factors (those items with loadings of 0.3 or greater on two or more factors) were removed.[42] All analyses were performed in R version 4.21.

Internal Reliability

We assessed the internal reliability of the scale factors via the omega hierarchical reliability measure.[43] Omega hierarchical is more appropriate than Cronbach's alpha for scales that are congeneric and may contain minor dimensions.[43] Cronbach's alpha statistic assumes that individual items on a scale contribute equally (tau equivalence).[43] When this assumption is violated, alpha does not represent a true estimate of internal consistency but rather the lower bound estimate.[43] There are no universally accepted guidelines for measures of reliability; however, omega coefficients range from 0 to 1, with values closer to 1 (typically above 0.75) preferred.[44,45] Omega hierarchical is a measure of the proportion of variance in observed variables explained by the group factors, with higher scores indicating greater contribution to the observed variable variance and indicating reliability of the construct.[45]

Criterion Validity: Associations Between PERHL Scale and Self-Report of Phthalate Avoidance

Scores for each latent factor were calculated by summing the score for each individual item that loaded onto the relevant factor and averaged by the number of items assigned to the factor. Four factor questions were reverse coded to prevent straight-line responding. Scores were averaged for each latent factor to account for the variability in the number of items that loaded onto each factor. Total PERHL scores were calculated by summing the latent factor scores.

To preliminarily determine whether the PERHL scale was associated with behaviors associated with phthalate avoidance, we conducted several secondary analyses using data from the ERGO study. At the time of PERHL assessment, we asked study participants which chemicals, if any, they avoid in their personal care products via the following question: "I try to avoid the following chemicals in my own personal care products (please select all that apply)." Response options: UV filters, cyclosiloxanes, glycol ethers, fragrances, alkylphenols, ethanolamines, antimicrobials, bisphenol A, phthalates, parabens, formaldehyde, silicones. We used logistic regression models to assess the association between the latent factor scores and the self-reported measure of avoiding phthalates in personal care products, controlling for educational attainment [less than a college degree vs. college degree or above (reference)], race [non-white vs. non-Hispanic white (reference)], and age at consent (continuous). Although the field of EHL is nascent, there is preliminary evidence that knowledge and risk perception of endocrine disrupting chemicals (specifically among women of reproductive age) is associated with increased age, being non-Hispanic white, and having higher educational attainment.[46] Age, race/ethnicity, and educational attainment are also associated with urinary biomarkers of phthalate exposure among women of reproductive age. Specifically, women with lower educational attainment tend to have higher biomarkers of phthalate exposure as do non-white women.[47] Finally, shifts in temporal trends of phthalate use over time have led to differences in phthalate exposures over time that can lead to differences in exposures across the lifespan.[48] Thus, we sought to control for each of these covariates when exploring the associations between latent factor scores and avoidance of personal care products. In all statistical analyses, a significance level of $\alpha = 0.05$ was employed to assess statistical significance. p-Values of <0.05 were considered to be statistically significant for interpretation of our results.

Statistical Analyses Evaluating the PERHL Scale with Sociodemographic Factors

In addition to the analysis evaluating the PERHL scale and behaviors associated with phthalate avoidance, we also preliminarily explored associations between sociodemographic factors (age calculated from self-reported date of birth, self-reported race and ethnicity, and self-reported educational attainment) collected at the first prenatal visit via questionnaire and six latent factors identified in the PERHL scale using linear models. Race is a socially constructed variable that can contribute to different patterns in product usage associated with endocrine disrupting chemicals and health disparities.[13,21,22,49–51] As such, we decided to examine racial and ethnic differences in PERHL scale scores as an opportunity to assess potential disparities in EHL that may be amenable to intervention to reduce health disparities. Participants were asked to select all race/ethnicities that apply to themselves from the following: white/Caucasian, black/African American, Haitian/Caribbean, Native Hawaiian or other Pacific Islander, South Asian, East Asian, American Indian/Alaskan Native, other, Hispanic or Latino, or refuse to answer. Due to limited sample size, we evaluated this as non-Hispanic white (reference) or non-white participants. Education was categorized as less than a college degree and college degree or above (reference).

Results

For this pilot study, one hundred and seventeen participants completed the PERHL survey. The sociodemographic characteristics of the participants who completed the survey are presented in Table 1. The majority of participants (71.8%) were non-Hispanic white, the mean age was 33.1 years old, and a majority of participants (86.3%) had a college degree or beyond. All but one ERGO participant identified as female. In comparison, the Vietnamese participants who contributed to the original scale, were mostly (55%) early adults, 26–40 years of age, with the majority (64%) being female. Additionally, most (74%) had achieved an undergraduate degree.[36]

Suitability for Factor Analysis

The KMO measure of sampling adequacy was 0.90, indicating that data were suitable for EFA.[41] Additionally, Bartlett's test of sphericity was significant (p-value of <0.001), indicating that the data were factorable.[41]

Exploratory Factor Analysis & Internal Reliability

Horn's parallel analysis specified that six factors should be retained, as demonstrated in Figure 1. Eigenvalues for each of the retained factors are shown in Table S1.

Two items cross-loaded across factors with values more than 0.3 and were subsequently removed. Four items did not load onto any factor. Upon review of the items that loaded onto each of the six factors, we labeled them as "Awareness of Phthalate Reproductive Health Impacts," "Uncertainty," "Protective Behavior/Risk Control," "Regulatory Interest," "Awareness of Phthalate Exposure Pathways," and "General Phthalate Knowledge." An overview of the six factors is provided in Table 2. All items are listed in Table S2 along with their standardized factor loadings and omega coefficients. Omega coefficients ranged between 0.63 and 0.93.

"Awareness of Phthalate Reproductive Health Impacts" consisted of eight items that explained 30.3% of the variance with factor loadings from 0.574 to 1.034. "Uncertainty" consisted of four items that explained 12.9% of the variance with factor loadings from 0.701 to 0.963. "Protective Behavior/Risk Control" consisted of five items that explained 18% of the variance with factor loadings from 0.553 to 1.037. "Regulatory Interest" consisted of three items that explained 12.1% of the variance with factor loadings from 0.86 to 0.944. "Awareness of Phthalate Exposure Pathways" consisted of four items that explained 14% of the variance with factor loadings from 0.651 to 0.81, "General Phthalate Knowledge" consisted of three items that explained 12.7% of the variance with factor loadings from 0.682 to 0.716. Sum PERHL scores ranged from 11.21 (indicating lower phthalate and reproductive health EHL) to 29.8 (indicating higher phthalate and reproductive health EHL). Table 3 displays the summary of overall PERHL scale scores. Count and percent responses for each item are summarized in Figures S1–S6 and Tables S3–S8, grouped by the latent factors onto which they loaded.

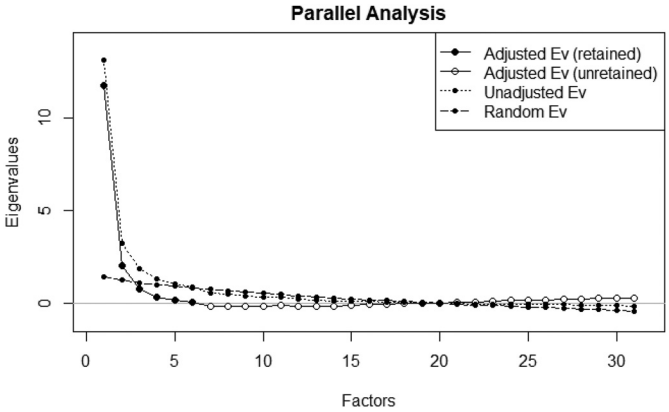

Figure 1. Results from parallel analysis factor retention for exploratory factor analysis to develop the Phthalate Environmental Reproductive Health Literacy scale. Data were collected from a subset of the Environmental Reproductive Glucose Outcomes (ERGO) cohort ($n = 117$) who had given birth within the past 5 years at either Beth Israel Deaconess Medical Center or Brigham and Women's Hospital in Boston, Massachusetts. Corresponding numerical data [eigenvalues (Ev)] can be found in Table S1.

Table 1. Participant demographics for all ($n = 117$) ERGO cohort participants who completed the PERHL survey between March 2021 and June 2022 and full ERGO cohort.

Demographic	PERHL participants ($n = 117$)	Overall ERGO cohort ($n = 653$)
Age at consent (years)	$n = 117$	$n = 653$
Mean ± SD	33.1 ± 4.26	32.9 ± 4.8
Median (minimum, maximum)	32.0 (22.8, 42.9)	33 (16.8, 56.5)
Race and ethnicity	($n = 117$)	($n = 651$)
Non-Hispanic white [n (%)]	84 (71.8%)	377 (58%)
Non-white [n (%)]	33 (28.2%)	274 (42%)
Education	($n = 117$)	($n = 629$)
Less than college degree [n (%)]	16 (13.7%)	132 (21%)
College degree or beyond [n (%)]	101 (86.3%)	497 (79%)

Note: ERGO, Environmental Reproductive and Glucose Outcomes; PERHL, Phthalate Environmental Reproductive Health Literacy; SD, standard deviation.

Table 2. Overview of six PERHL latent constructs.

Latent factor	Description	Number of items[a]
Awareness of phthalate reproductive health impacts	These items address the extent to which respondents believe that exposure to phthalates may be associated with reproductive health impacts. Additionally, items address whether respondents believe that timing of exposure to phthalates during pregnancy may affect maternal and child health.	8
Uncertainty	These items address to what extent respondents feel uncertain about the adverse effects of phthalates on environmental and human health due to varied possible sources of uncertainty.	4
Protective behavior/ risk control	These items address whether respondents try to minimize their use of certain personal care and household products due to concern of phthalate exposure, and to what degree they believe reducing their phthalate exposures is beneficial to their health.	5
Regulatory interest	These items address the respondents' belief that phthalates should be regulated based on their potential impacts to the environment and human health.	3
Awareness of phthalate exposure routes	These items address respondents' understanding of sources of phthalates into the environment, and possible exposure pathways that may affect reproductive health outcomes.	3
General phthalate knowledge	These are very general items addressing the respondents' belief that phthalates are in personal care products, that people can be exposed to phthalates by using personal care products, and that they may have adverse human health impacts.	3

Note: PERHL, Phthalate Environmental Reproductive Health Literacy.
[a]All individual items are provided in the Supplementary Materials, Table S2.

Table 3. Distribution of overall PERHL scale scores as completed by members of the ERGO cohort ($n = 117$) between March 2021 and June 2022.

Minimum	1st Quartile	Median	Mean	3rd Quartile	Maximum
11.21	21.09	22.93	23.08	25.12	29.8

Note: ERGO, Environmental Reproductive and Glucose Outcomes; PERHL, Phthalate Environmental Reproductive Health Literacy.

The factor correlations are shown in Table 4. All factors were positively correlated with one another, with the exception of "Uncertainty." "Uncertainty" was negatively correlated with "Awareness of Reproductive Health Impacts," "Protective Behavior/Risk Control," "Awareness of Phthalate Exposure Pathways," and "General Phthalate Knowledge."

Criterion Validity

When estimating the associations of our latent factors with self-report of avoiding products with phthalates (Table 5), we observed greater odds of self-reporting avoidance of phthalates in personal care products for participants with higher scores for "Protective Behavior/Risk Control" [odds ratio (OR) = 21.21 (95% confidence interval (CI): 6.16, 98.34)], "Awareness of Exposure Pathways" [OR = 5.45 (95% CI: 1.57, 23.78)], and "General Phthalate Knowledge" [OR = 4.79 (95% CI: 1.26, 19.51)]. These odds ratios can be interpreted as the increase in odds of reporting avoiding phthalates in personal care products per one unit increase on each subscale. Participants with higher scores of "Awareness of Reproductive Impacts" had reduced odds [OR = 0.14 (95% CI: 0.03, 0.60)] of self-reporting that they avoid phthalates in personal care products. Odds of self-reporting phthalate avoidance for race, education, age at consent, "Uncertainty," and "Regulatory Interest" were null. Higher overall PERHL score was associated with slightly lower odds of self-reporting avoiding products with phthalates [OR = 0.63 (95% CI: 0.41, 0.89)].

Demographic Associations

We found no significant associations between age or education and the six latent factors. β values for race (non-white vs. non-Hispanic white) represent the difference in latent factor scores of non-white participants compared to non-Hispanic white participants on the individual subscales. Non-white participants had lower scores for the "Awareness of Phthalate Reproductive Health Impacts" (β: −0.35; 95% CI: −0.63, −0.07), "Awareness of Phthalate Exposure Pathways" (β: −0.32; 95% CI: −0.57, −0.07), and "General Phthalate Knowledge" (β: −0.36; 95% CI: −0.66, −0.06), but no significant difference in scores on "Uncertainty" (β: 0.17; 95% CI: −0.16, 0.50), "Protective Behavior/Risk Control" (β: −0.04; 95% CI: −0.36, 0.28), or "Regulatory Interest" (β: −0.21; 95% CI: −0.51, 0.09) (Table 6).

Discussion

Pregnancy is a sensitive window of exposure for health, and as such, pregnant individuals often seek information to increase their confidence in decision-making during the perinatal period.[52] Risks from environmental exposures pose a unique challenge for pregnant individuals, given the sensitive window of exposure for later-life health. Indeed, pregnancy requires profound physiological change with altered lipid and glucose metabolism, vasculature, inflammatory, and coagulation responses.[53–55] Exposure to EDCs can perturb these normal physiologic changes, resulting in an increased risk of adverse pregnancy and child health outcomes, including gestational diabetes and hypertensive disorders in pregnancy and childhood obesity and altered cardiometabolic health in children. Of concern, trying to mitigate exposure to these chemicals can be challenging due to lack of knowledge regarding identification of strategies for avoiding these chemicals due to their ubiquity.[56]

Through EFA, we identified six underlying latent constructs related to phthalate reproductive environmental health literacy: "Awareness of Phthalate Reproductive Health Impacts," "Uncertainty," "Protective Behavior/Risk Control," "Regulatory Interest," "Awareness of Phthalate Exposure Pathways," and "General Phthalate Knowledge." Each of the six constructs demonstrated acceptable to strong internal reliability via omega coefficient. We found statistically significant associations between scores on the "Protective Behavior/Risk Control," "Awareness of Exposure Routes," and "General Phthalate Knowledge" factors with self-reporting avoiding personal care products with phthalates. These findings may suggest that the PERHL scale could predict environmental health literacy most linked with phthalate avoidance behaviors, as well as the possibility that certain groups, such as racial/ethnic minorities, may have lower EHL in some domains. Additionally, we found that three constructs, "Uncertainty," "Regulatory Interest," and "Awareness of Phthalate Reproductive Health Impacts" were associated with decreased odds of avoidance of personal care products with phthalates. Previous work has suggested that EHL must consider the context and competing factors that contribute to the decision-making process as to whether to engage in health-protective behaviors (or not).[2] These findings support the notion that there are constructs that will both push and pull individuals from engaging in specific health-protective behaviors.

When examining participant characteristics and associations with the latent factors, we found associations with race and ethnicity and three of the latent factors. Specifically, non-white participants had lower scores for "Awareness of Phthalate Reproductive Health Impacts," "Awareness of Phthalate Exposure Pathways," and "General Phthalate Knowledge." These three constructs largely capture topical phthalate information, suggesting a possible racial/ethnic disparity in access to phthalate information. On the other hand, no associations were seen between race and ethnicity and

Table 4. PERHL latent factor correlations.

	Awareness of phthalate reproductive health impacts	Protective behavior/risk control	Awareness of phthalate exposure pathways	Uncertainty	General phthalate knowledge	Regulatory interest
Awareness of phthalate reproductive health impacts	1.00	0.65	0.66	−0.26	0.68	0.41
Protective behavior/risk control	0.65	1.00	0.50	−0.02	0.47	0.51
Awareness of phthalate exposure pathways	0.66	0.50	1.00	−0.01	0.60	0.42
Uncertainty	−0.26	−0.02	−0.01	1.00	−0.23	0.13
General phthalate knowledge	0.68	0.47	0.60	−0.23	1.00	0.39
Regulatory interest	0.41	0.51	0.42	0.13	0.39	1.00

Note: PERHL, Phthalate Environmental Reproductive Health Literacy.

Table 5. Covariate-adjusted[a] odds (calculated via logistic regression) of self-reporting avoidance of personal care products with phthalates for increases in averaged latent factor scores among a subset of participants ($n = 117$) in the ERGO cohort who had given birth within the past 5 years at either Beth Israel Deaconess Medical Center or Brigham and Women's Hospital in Boston, Massachusetts.

	Avoids phthalates in personal care products	
Predictor	Odds ratios	95% Confidence interval
Race/ethnicity (non-Hispanic white)	Ref	Ref
Race/ethnicity (non-white)	1.05	(0.29, 3.89)
Education (less than college degree)	Ref	Ref
Education (college degree or beyond)	0.30	(0.04, 2.07)
Age at consent	1.10	(0.95, 1.30)
Uncertainty	0.59	(0.24, 1.39)
Protective behavior/risk control	21.21	(6.16, 98.34)
Regulatory interest	0.80	(0.30, 2.06)
Aware of reproductive impacts	0.14	(0.03, 0.60)
Aware of exposure pathways	5.45	(1.57, 23.78)
General phthalate knowledge	4.79	(1.26, 19.51)
Total PERHL score	0.63	(0.41, 0.89)

Note: ERGO, Environmental Reproductive and Glucose Outcomes; PERHL, Phthalate Environmental Reproductive Health Literacy; Ref, reference.
[a]Adjusted for race/ethnicity, educational attainment, and age at enrollment.

"Uncertainty," "Protective Behavior/Risk Control," or "Regulatory Interest" latent factors. Thus, it may be that many people, regardless of sociodemographic characteristics or background, share similar risk perceptions and desire to engage in health-protective behaviors, but may have disparate access to high-quality, accessible environmental health information and materials. Confirmation is needed for these findings, and further exploration is needed to determine what may drive the possible racial/ethnic disparities in information (such as inadequate communication channels or inaccessible materials). Of particular interest is that racial and ethnic disparities in urinary phthalate metabolite concentrations exist, with non-whites having higher use of many of the phthalate-containing consumer products. While EHL has not been evaluated in terms of social constructs such as race/ethnicity, the field of health literacy has demonstrated differences with regards to sociodemographics such as race/ethnicity. If racial/ethnic differences in information related to phthalates drives some of these exposure disparities, then it is plausible that improving clarity and accessibility of information could aid in reducing exposure to these chemicals.

Previous EHL scales have been developed to assess general environmental health literacy, air EHL, water EHL, and food EHL.[4,33] Four scales (general, food, air, and water EHL) were developed collectively via exploratory and confirmatory factor analyses.[33] An abbreviated, general EHL scale (the Short Assessment of EHL, or SA-EHL) was developed by adapting the Short Assessment of Health Literacy to the environmental health context.[4] To complete this assessment, participants are asked to match environmental health-relevant terms to one of two words that are most related. Scores are then summed (with higher scores indicating higher EHL). However, this scale is suggested to be used as a tool to screen whether written materials are suitable for the EHL of an intended audience.[4] To our knowledge, there does not exist a validated scale assessing phthalate literacy or phthalate reproductive environmental health literacy. It has been suggested that EHL may not be a phenomenon encompassing understanding of all environmental exposures but may instead be context and topic-specific.[2,3] The PERHL scale builds upon the existing literature by tailoring a scale to measure EHL relevant to a specific exposure and associated health outcomes. Additionally, it includes constructs, such as risk control and behaviors, and scientific

Table 6. Associations between sociodemographic factors and phthalate environmental health literacy latent construct score (assessed via linear regression) among a subset of participants ($n = 117$) in the ERGO cohort who had given birth within the past 5 years at either Beth Israel Deaconess Medical Center or Brigham and Women's Hospital in Boston, Massachusetts.

	Awareness of phthalate reproductive health impacts		Uncertainty		Protective behavior/risk control		Regulatory interest		Awareness of phthalate exposure pathways		General phthalate knowledge		PERHL total sum	
Predictor	Est. (95% CI)	*p*-Value[a]	Est. (95% CI)	*p*-Value	Est. (95% CI)	*p*-Value	Est. (95% CI)	*p*-Value	Est. (95% CI)	*p*-Value	Est. (95% CI)	*p*-Value	Est. (95% CI)	*p*-Value
Age (years)	0 (−0.03, 0.03)	0.931	−0.01 (−0.05, 0.02)	0.469	0.02 (−0.01, 0.05)	0.228	0.02 (−0.01, 0.06)	0.069	−0.01 (−0.04, 0.02)	0.282	0.01 (−0.02, 0.04)	0.457	0.04 (−0.09, 0.16)	0.58
Race[b]														
Non-Hispanic white	Ref	—	Ref	—	Ref	—	Ref	—	Ref	—	Ref	—	Ref	—
Non-white	−0.35 (−0.63, −0.07)	0.014	0.17 (−0.16, 0.50)	0.327	−0.04 (−0.36, 0.28)	0.819	−0.21 (−0.51, 0.09)	0.097	−0.32 (−0.57, −0.07)	0.014	−0.36 (−0.66, −0.06)	0.014	−1.17 (−2.35, 0.01)	0.052
Education[c]														
College degree or higher	Ref	—	Ref	—	Ref	—	Ref	—	Ref	—	Ref	—	Ref	—
Less than college degree	0.09 (−0.28, 0.47)	0.628	−0.14 (−0.57, 0.29)	0.531	0.24 (−0.16, 0.65)	0.24	−0.16 (−0.55, 0.23)	0.423	−0.08 (−0.41, 0.25)	0.622	−0.17 (−0.58, 0.24)	0.408	−0.21 (−1.78, 1.36)	0.789

Note: —, no data; CI, confidence interval; ERGO, Environmental Reproductive and Glucose Outcomes; Est., estimate; PERHL, Phthalate Environmental Reproductive Health Literacy; Ref, reference.
[a]*p*-Values calculated using the Wald test for logistic regression coefficients.
[b]Estimates for race (non-white vs. non-Hispanic white) represent the difference in latent factor scores of non-white participants compared to non-Hispanic white participants.
[c]Estimates for education (college degree or higher vs. less than a college degree) represent the difference in latent factor scores of participants with less than a college degree compared to those with a college degree or higher.

uncertainty, which may allow for evaluation of behavior-related factors that are useful for intervention development. The overall PERHL score offers a simple metric of EHL, which if replicated in other contexts, can be helpful in measuring overall EHL for trend or comparative analyses. However, the subscale scores provided further value via insight into the varied latent constructs that may be contributing to overall EHL. Therefore, when possible, both the overall and PERHL scores should be assessed.

We found no evidence of associations for six latent factors or the overall PERHL scale with age or educational attainment. In previous work, overall SA-EHL score was found to be positively associated with education.[4] The lack of an association between age or educational attainment may suggest little difference in phthalate environmental health literacy regardless of older or younger age, as well as level of educational attainment. For the latter, the lack of environmental health in traditional educational venues may make it so the average public has less knowledge and awareness of phthalates, which could subsequently impact limited uncertainty and behavior changes associated with phthalate knowledge. Indeed, studies evaluating knowledge and behavior change as it relates to environmental chemicals have found that both youths and adults have limited understanding of environmental health risks or prevention strategies.[1] Further, those who have a better understanding of the link between exposure and health outcomes are more likely to adapt their behaviors to reduce exposures.[1] However, a challenge with the present study population is that there may be limited association with these variables due to a greater proportion of the study population having higher educational attainment and being non-Hispanic white. Future studies will need to evaluate PERHL in populations with greater diversity as it relates to these sociodemographic variables.

A main finding from this study is the association between the PERHL scale and avoiding personal care products with phthalates. Indeed, the strongest association was seen between the latent factor of "Protective Behavior/Risk Control" and avoidance of phthalates in personal care products, followed by "General Phthalate Knowledge" and "Awareness of Exposure Pathways" latent factors. While these findings require further validation, these three factors, together, could provide the basis for an abbreviated scale, given they collectively had the highest odds of predictive phthalate-avoidant behaviors. These findings may also suggest that the PERHL scale, when used in a similar study population, may be particularly informative of behavior-associated phthalate risk control. If replicated, this scale may be especially useful in ascertaining information on behavior-related literacy that would be valuable for intervention development for the reduction of phthalate exposure in individuals of reproductive age.

Our study had several limitations. First, the sample was fairly homogenous, with most participants being non-Hispanic white and having a college degree or beyond. Additionally, all participants were initially recruited into the ERGO study from obstetrics clinics during routine prenatal care. This may affect the generalizability of these findings to the broader United States population of individuals of reproductive age, and as such, the scale's performance should be tested in more diverse populations. Second, this was a cross-sectional study, and the PERHL scale, along with behavior-related questions, were collected at the same time. Based on this study design, we only evaluated concurrent criterion validity, rather than predictive validity. Due to limited sample size, we were unable to better characterize race beyond the binary categorization. However, relying solely on the binary categorization of participants as non-Hispanic white or non-white limits the nuanced understanding of diversity and EHL within the sample, hindering comprehensive analysis and interpretation. Our sample size was sufficient only for EFA, and we could not split the sample in half to additionally perform confirmatory factor analysis (CFA). Future work should include a CFA for additional indices of the scale performance. Finally, we did not evaluate associations between the overall scale and latent variables with urinary phthalate metabolite concentrations or adverse health outcomes. However, we did assess sociodemographic factors linked to phthalate exposure, as well as phthalate avoidance behavior.

Despite these limitations, our study had several strengths. First, we designed a new scale to evaluate phthalate environmental health literacy. As this class of chemicals is ubiquitous, identifying the degree to which the general public, and particularly individuals of reproductive age, are knowledgeable, aware, and seek to alter behaviors related to these chemical exposures can be particularly useful for intervention development. Second, we evaluated this scale to see if higher levels of EHL were associated with different sociodemographic factors known to be linked to urinary phthalate metabolite concentrations. This is one of the first studies to show associations between EHL of phthalates and race/ethnicity, suggesting an important potentially modifiable factor to reduce health disparities. Third, we evaluated phthalate avoidance behavior finding that the scale was strongly associated with this factor. As such, this scale may be particularly useful around identification of knowledge and behavior modification as it relates to phthalate EHL in individuals of reproductive age.

Understanding pregnant individuals' knowledge, awareness, and behaviors related to phthalates and their impact on reproductive health is critical to identifying means of successfully communicating phthalate information to improve health outcomes. Access to information alone is often insufficient for protective behavior adoption and characterizing the various factors influencing pregnant individuals' phthalate awareness and protective behaviors can inform environmental health message creation and dissemination.[32] This work lays the foundation for developing a reliable scale to assess phthalate-specific EHL in people of reproductive age, requiring further testing in additional populations. We find suggestion that there may be racial/ethnic disparities in access to phthalate information, which may be a modifiable driver of socially driven phthalate exposure disparities. Additional work is needed to confirm the PERHL scale's performance in other populations. If replicated, this scale could offer a solution-oriented assessment for identifying populations with lower phthalate EHL, with implications for EHL interventions that could reduce phthalate exposure and associated adverse health outcomes.

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