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Asthma at mid-life is associated with physical activity limits but not obesity after 10 years using matched sampling in a nationally representative sample

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Abstract
Asthma and obesity are both prevalent conditions that appear related, but the etiology for this association remains unclear. This study examines whether asthma is associated with obesity and physical activity limits 10 years later among a subsample from the National Longitudinal Survey of Youth 1979 who were age 40 at baseline. We addressed selection bias using inverse-propensity score weighting (N = 5077), and confirmed the results with full matching (N = 5041), and with both methods we estimated new sampling weights so that the sample would remain nationally representative. Both matched sampling methods balanced adults with asthma versus those without asthma on all 7 covariates: baseline obesity, sex, race/ethnicity, family income, poverty status, general health status and physical activity limits. Before matching, baseline asthma was significantly associated with developing obesity 10 years later in an unadjusted model [OR = 1.44 (1.10–1.90)], but not in the multivariable model [OR = 1.15 (0.80–1.67)]. Baseline asthma was not associated with obesity 10 years later after inverse propensity weighting [OR (95% CI = 1.03 (0.69–1.53)] and full matching [1.16 (0.75–1.80)]. Results remained similar after excluding subjects with baseline obesity. In a cumulative logistic model using complex survey and full matching weights, those with baseline asthma had 83% greater odds of reporting physical activity limits compared to those without asthma, OR = 1.83 (1.21–2.76). Baseline asthma was not associated with obesity among either a nationally representative sample of middle-aged adults or a non-obese subset. However, asthma was associated with physical activity limits in the full matched sample. Asthma disease management programs should communicate that asthma does not imply obesity and also encourage exercise within the physical limitations of their populations. Selection bias on factors such as low socioeconomic status may explain previous asthma-obesity associations.

Keywords Inverse propensity score weighting (IPW) · Full matching · Causal mediation · Asthma · Obesity · National longitudinal survey

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1 Introduction

Asthma is one of the most common chronic conditions in the United States, with prevalence of 8% among adults (CDC 2018a). Obesity is reaching epidemic proportions, and the current 33% prevalence among US adults is predicted to increase to 42% by 2030 (Akinbami et al. 2001; CDC 2018a, b; Flegal et al. 2012; Finkelstein et al. 2012). Associations between asthma and obesity have been identified in both cross-sectional (Akerman et al. 2004; Baffi et al. 2015; Gwynn 2004) and longitudinal studies (Castro-Rodriguez et al. 2001; Hasler et al. 2006; Sood et al. 2013). Because asthma and obesity are prevalent, the associations between them must be examined using longitudinal evidence to clarify whether asthma preceded obesity and reduced physical activity, or whether the association may be attributed to selection bias, for instance, whether a third factor such as poverty status is associated with both asthma and obesity.

Using data collected from the Coronary Artery Risk Development in Young Adults (CARDIA) study (Beckett et al. 2001), authors of CARDIA study investigated whether asthma is associated with weight gain and physical activity. The study included n = 4547 subjects, aged 18–30 year black and white men and women with a 10-year follow-up period. These participants decreased physical activity and gained weight over time. This study concluded that asthma incidence showed a J-shaped pattern of association with change in BMI. The incidence of asthma was associated with highest and lowest baseline and change in BMI, but stratified analysis found that this association exists only in females. Physical activity did not explain the association between asthma and increased BMI. The Zurich cohort study of 591 subjects aged between 20 and 40 years found an association between asthma and obesity both cross-sectionally and longitudinally (Hasler et al. 2006). Earlier longitudinal studies have also found that weight gain precedes and predict the incidence of asthma (Camargo et al. 1999; Castro-Rodriguez et al. 2001).

Exercise improves quality of life among people with asthma and reduces airway inflammation and responsivity (Del Giacco and Garcia-Larsen 2016; Eichenberger et al. 2013). However, exercise is underutilized as a strategy for asthma control: data from an online survey of adults with self-reported physician diagnosed asthma showed that poor control was frequently reported (75%) and that many adults reduced the amount of time spent exercising to avoid asthma symptoms (Price et al. 2014). Adults with asthma may reduce exercise because it may trigger bronchoconstriction. Exercise-Induced constriction (EIC) occurs in approximately 90% of people with asthma and is more likely to be associated with poor control, during high intensity or high endurance sports and in cold or dry air settings (Bonini and Silvers 2018). The goal of asthma management is to control symptoms so that individuals with asthma can participate in exercise without interference from asthma symptoms. Effective therapies for both control of persistent asthma and EIC prevention help asthmatics to live an active life style. Despite the evidence, some patients will still limit exercise. Physicians and asthma educators should advocate to dispel the myth that asthmatics should not exercise (Rubin 2015).

Although asthma had been associated with obesity and overall health status in previous research, it remains unclear if associations between asthma and subsequent obesity and physical activity limits are attributable to selection bias. The primary research aim of the current study is to evaluate if asthma precedes obesity and limited physical activity in a nationally representative sample of middle-aged US adults after adjusting for potential confounding using matched sampling.

2 Materials and methods

2.1 Inclusion and exclusion criteria

We tested these hypotheses in a subsample of the National Longitudinal Survey of Youth 1979 (NLSY79), a nationally representative sample of Americans born between 1957 and 1964. This was a prospective longitudinal cohort design. We used data from 1998 to 2000 survey period as baseline, when participants were ages 34–43. The endpoint was in the survey year after participants turned 50: 2008, 2010, or 2012. We excluded participants who were not yet 50 in 2012 (i.e., born in 1963–1964). Our analysis dataset included N = 5077 subjects with complete baseline asthma, sex, race/ethnicity, Body Mass Index (BMI), poverty status, physical activity limits, general health, and net family income, and follow-up BMI (Fig. 1).

2.2 Custom sampling weights

NLSY79 is a complex longitudinal survey designed to be nationally representative of US adolescents in 1979, born in 1963–1964. Because of this complexity the NLS staff creates a set of cross-sectional weights for each survey round. Longitudinal aspects of our study

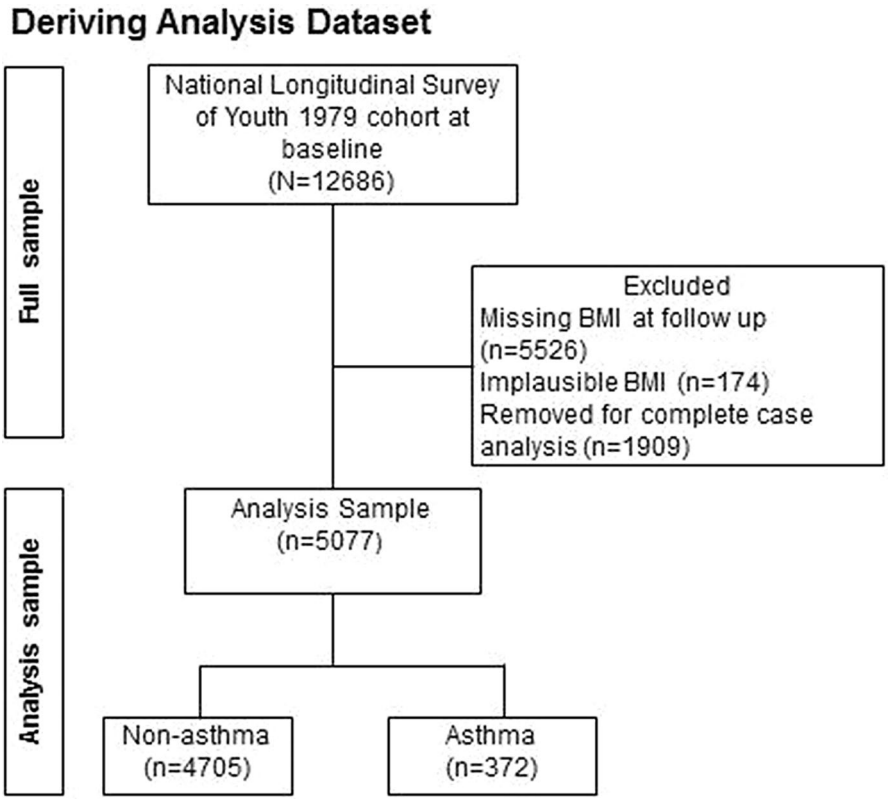

Fig. 1 Creating the analysis dataset

required multiple survey years, so, we used custom weighting procedure suggested by NLS for the subjects in our dataset (N = 5077) (NLSY79 2018b).

2.3 Measures

The main predictor variable was baseline self-reported asthma, measured in an inventory of health problems as endorsing "Asthma (Shortness of breath, chronic cough)".

One of the main endpoints was BMI at age 50, which was computed from self-reported height and weight. Height was only measured once during midlife, during the 2006 survey wave. Weight was available both at baseline (1998) and follow-up (2012). Participants' obesity status was coded as 1 for BMI > 30 kg/m^2 (Flegal et al. 2012). To address measurement error in BMI due to misreported height, weight, or data entry error, we used Tukey's method (5) of outlier detection to remove 174 participants who reported implausible BMI values more than 1.5 times the interquartile range from median. Prior to removing outliers, the BMI range was 13–366.2 kg/m^2. After removing outliers, the BMI range was 14.6–53.8 kg/m^2.

The other endpoint was self-reported physical activity limitation due to health reason. Physical activity limitations measured whether subjects' health limited their ability to engage in moderate physical activity 'Not limited at all', 'Yes, limited a little or 'Yes, limited a lot', and was coded as 1–3 respectively. In general, self-reported asthma and physical activity limitations were previously validated and concluded to be reliable measures (Gill et al. 2012; Mirabelli et al. 2014; Senthilselvan et al. 1993). However, we have not found a study specifically validating these self-rated questions from NLSY79 data.

Control variables were identified from previous research as potential confounders between asthma and obesity (Ampon et al. 2005; Beckett et al. 2001; Hasler et al. 2006; Luder et al. 2004). The 7 control variables were baseline obesity, sex, race/ethnicity, family income, poverty status, general health status (measured whether subjects' overall health was 'Excellent', 'Very good', 'Good', 'Fair' or 'Poor' condition, and was coded as 1–5), and how much health conditions limited moderate physical activity (physical activity limits.) Respondents with baseline total net family income for the last calendar year below the 1998 poverty income guidelines for their family size were coded as in poverty. In 1998, poverty guidelines cutoffs were $7890 for an individual and $16,050 for a family of four (NLSY79 2018a).

2.4 Statistical methods

We display categorical variables as weighted percentages, and continuous variables as mean ± standard error (SE). We performed bivariate comparisons using Rao-Scott Chi Square and t-test for complex survey sample, implemented with SAS PROC SURVERYFREQ and SURVEYREG.

Observational studies are subject to confounding on both observed and unobserved variables: people with asthma may differ from those without asthma in terms of the demographics and clinical characteristics and some of the characteristics may also be associated with developing obesity. For instance, poverty status was associated with baseline asthma and obesity 10 years later. To minimize confounding on observed characteristics, we used matched sampling methods to identify people without asthma with similar background characteristics as those with asthma. Only 372 people in our sample reported having

asthma, so we chose matching procedures that preserve sample size as much as possible to maximize statistical power: inverse propensity score weighting and full matching.

For inverse propensity weighting, we estimated the propensity of having asthma in 1998 ($\hat{p}$) using a multiple logistic regression model using baseline obesity, sex, race/ethnicity, poverty, general health status, physical activity limits, family income, and sampling weight as the predictor variables (Austin and Stuart 2015; Dugoff et al. 2014). Subjects with baseline asthma (N = 372) were assigned weights of the estimated inverse propensity of having asthma ($1/\hat{p}$) and the subjects without asthma (N = 4705) were assigned weights of the inverse propensity of not having asthma $1/(1-\hat{p})$. After inverse propensity weighting, we tested balance using weighted t-tests and Chi square tests and found that asthma and non-asthma groups were balanced on all 7 covariates.

Full matching creates a series of matched set by selecting subclasses with at least one person with asthma and at least one person without asthma, which reduces the need to potentially discard participants (Hansen 2004; Rosenbaum 2002, 1991). We implemented full matching with the R MatchIt package (Ho et al. 2011) using the same set of variables as the inverse propensity weighting. This is an optimal method in terms of minimizing the distances between individuals with and without asthma within each matched set (Hansen 2004). Full matching makes use of many more observations than other comparable methods. In our study, full matching discarded only 36 highly dissimilar subjects from the without-asthma group and none from the asthma group. After full matching, we evaluated balance using Cohen's effect size, a measure of the differences in means for people with asthma versus without asthma divided by the standard deviation. Cohen's effect size is classified as inconsequential (0.0–0.2), small (0.2–0.5), medium (0.5–0.8), and large (larger than 0.8, with no upper bound) (Cohen 1988). Full matching balanced the groups on all covariates plus sampling weights, displayed in a Love plot (Love 2002) (Fig. 2).

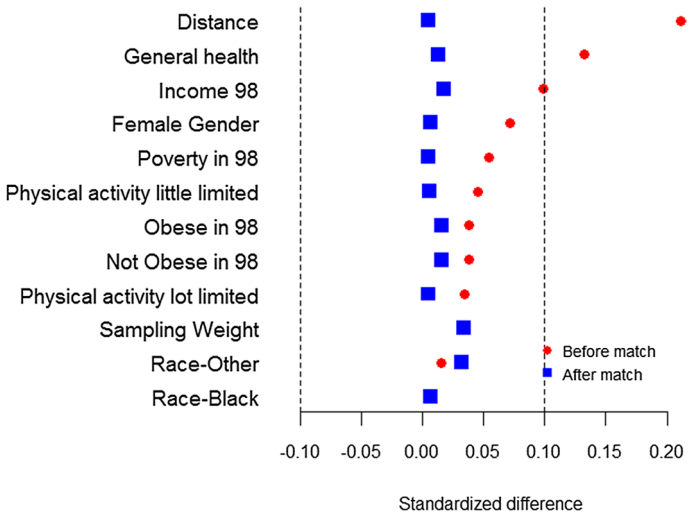

Fig. 2 Love plot depicting standardized differences before and after full matching. The blue squares indicate after matching standardized differences and red circular dots indicate before matching differences. *Blue squares are close to zero for all the variables, which suggest a good match*. Most of the red dots are seen away from the standardized difference of zero for the raw data

For both matched sampling methods, we created a combined weight variable by multiplying matched sampling weights and complex survey sampling weight (Dugoff et al. 2014). This combined weight variable was used for all outcome models.

We performed multivariable logistic regression analysis in the matched samples to examine association between obesity and other covariates using complex survey design. We assessed the goodness of fit of the logistic regression model using a C-statistic (Hosmer and Lemeshow 2000). We used cumulative logistic regression models with complex survey design to assess relationships between physical activity limits and other covariates. We implemented these models using SAS PROC SURVEYLOGISTIC.

We repeated the above inverse-propensity and full matching and regression procedures in a subsample of participants without obesity at baseline (N = 2188 for IPW and N = 2159 for full-matching.) After inverse propensity score weighting, the sample size was balanced on all 7 covariates, and comprised 2188 non-obese participants at baseline (balance not shown). After full matching, the sample size was balanced on all 7 covariates, and comprised 2159 non-obese participants at baseline (balance not shown).

Results were considered significant if $p < 0.05$. We conducted analyses in R 3.2.3 (https://www.r-project.org) and SAS 9.4 (SAS Institute Inc. Cary, NC).

3 Results

3.1 Baseline characteristics and bivariate analysis before matching

In the sample, 7% (N = 372) had asthma. Baseline factors associated with greater risk of asthma included female gender, obesity, higher body mass index, lower household income, household poverty status, poor health status, and physical activity limits (Table 1). Race/ethnicity distribution among the groups were similar ($p = 0.295$).

Among participants with asthma at age 40, 73% (SE = 2.7) had obesity at age 50 compared to 65% (SE = 0.82) in subjects without asthma ($p = 0.0.009$), corresponding to 44% greater odds of obesity at age 50 (unadjusted OR = 1.44, 95% confidence interval (1.10–1.90)). Participants with asthma at age 40 were also more likely than those without asthma to report that their health limited moderate physical activity "a lot" 17% (SE = 2.7) versus 16% (SE = 8.9) or "a little" 18.4% (SE = 2.8) versus 6.4% (SE = 0.81) ($p = 0.044$).

Asthma is associated with factors that predict poor health, so people with asthma at age 40 may have had greater risk of obesity, physical activity limits, and poor health at age 50 even if they did not have asthma. To reduce confounding, we use matching in order to identify a group of people without asthma with similar background factors as those with asthma. Inverse propensity score weighting yielded balance on all 7 variables (Table 1). Full matching yielded balance on all 7 variables plus survey sampling weights (Fig. 2).

3.2 Regression models for obesity and physical activity limits before matched sampling

Prior to matched sampling, asthma at age 40 was not associated with obesity at age 50 in this nationally representative sample using survey-weighted multiple logistic regression; however, baseline obesity, race, and net family income were independent predictor of obesity (C-statistic = 0.85). Prior to matched sampling, asthma at age 40 was not associated with health-related physical activity limitations at age 50 using survey-weighted

Table 1 Baseline characteristics measured in 1998, comparing subjects who had asthma in 1998 with those who did not have asthma, before and after inverse propensity score weighting

	Before matching			After matching		
	Asthma			Asthma		
	Yes (N = 372)	No (N = 4705)	*p* value§	Yes (N = 372)	No (N = 4705)	*p* value‡
Gender, weighted % (SE)			<0.0001			0.763
Male	36.7 (2.9)	51.9 (0.85)		49.8 (3.7)	50.9 (0.85)	
Female	63.3 (2.9)	48.1 (0.85)		50 (3.7)	49.1 (0.85)	
Race/ethnicity, weighted % (SE)			0.295			0.188
Hispanic	7.8 (1.0)	6.5 (0.26)		9.4 (1.9)	6.5 (0.26)	
Black	15.4 (1.6)	14.1 (0.43)		14.5 (2.0)	14.2 (0.43)	
Other	76.8 (2.0)	79.4 (0.51)		76.1 (2.7)	79.3 (0.51)	
In poverty, weighted % (SE)			<0.0001			0.382
Yes	21.7 (2.4)	10.7 (0.47)		12.9 (1.8)	11.3 (0.50)	
No	78.3 (2.4)	89.3 (0.47)		87.1 (1.8)	88.7 (0.50)	
Obese (BMI > 30 kg/m^2)			0.008			0.944
Yes	61.3 (2.9)	53.0 (0.85)		53.2 (3.8)	53.5 (0.85)	
No	38.7 (2.9)	47.0 (0.85)		46.8 (3.8)	46.5 (0.85)	
Family income (USD), mean ± SE	42,624 ± 2145	55,363 ± 807	<0.0001	52,937 ± 3700	54,557 ± 790	0.668
General health status, % (SE)			<0.0001			0.846
Excellent	11.7 (2.0)	24.8 (0.74)		25.6 (3.9)	23.9 (0.72)	
Very good	27.8 (2.7)	41.5 (0.84)		37.2 (3.6)	40.8 (0.83)	
Good	35.9 (2.9)	25.0 (0.73)		27.2 (2.9)	25.5 (0.74)	
Fair	18.0 (2.3)	7.5 (0.43)		8.5 (1.3)	8.2 (0.47)	
Poor	6.6 (1.4)	1.2 (0.20)		1.6 (0.39)	1.6 (0.23)	
Health limits activity 98, % (SE)			<0.0001			0.748
Not limited at all	77.0 (2.5)	92.8 (0.43)		90.8 (1.4)	91.7 (0.48)	

Table 1 (continued)

	Before matching			After matching		
	Asthma			Asthma		
	Yes (N = 372)	No (N = 4705)	*p* value§	Yes (N = 372)	No (N = 4705)	*p* value‡
Yes, little limited	13.8 (2.1)	4.5 (0.34)		5.3 (0.99)	5.1 (0.39)	
Yes, limited a lot	9.2 (1.7)	2.8 (0.27)		3.9 (1.0)	3.2 (0.31)	

‡*p* values are from Rao-Scott Chi square and independent samples t-test using complex survey weights

The goal of propensity score weighting was to make the groups similar ($p > 0.05$) in terms of the characteristics

cumulative logistic regression; however, gender, general health status and baseline physical activity were independent predictor of physical activity limitations (C-statistic = 0.65) (Table 2). Prior to matched sampling, asthma at age 40 was not associated with general health status 10 years later in an adjusted model (result not shown).

3.3 Regression models for obesity and physical activity limits in the inverse propensity weighted sample

In the inverse propensity-weighted sample using combined survey and propensity weights, baseline asthma was not associated with developing obesity 10 years later [OR = 1.03 (0.69–1.53)] in a multivariable regression model (Table 3). Baseline obesity and race were the only independent predictors of obesity at the age 50. Similarly, baseline asthma was not associated with health-related physical activity limitations in this inverse propensity weighted sample. Sex, race, general health status and baseline limited physical activity were independent predictors of physical activity limits at 10-year follow-up (Table 4).

3.4 Regression models for obesity and physical activity limits in the full matching sample

After full matching, baseline asthma was not associated with obesity at age 50 [OR = 1.16 (0.75–1.80)], concurring with inverse propensity weighted findings. Only baseline obesity predicted subsequent obesity (Table 3). However, baseline asthma was an independent predictor of limited physical activity due to health at the follow-up in the full matching sample. Those with baseline asthma had 83% greater odds of reporting limited physical activity due their health compared to those without asthma [OR = 1.83 (1.21–2.76)] in a cumulative logistic regression using combined weights (Table 4).

Table 2 Initial survey logistic regression models before propensity weights

Variable	Outcome: obesity at follow-up†		Outcome: limited physical activity at follow-up‡	
	Odds ratio (95% CI)	*p* value	Odds ratio (95% CI)	*p* value
Asthma (1998)	1.15 (0.80–1.7)	0.446	1.03 (0.52–2.03)	0.928
Obese (BMI > 30) 1998	22.8 (18.6–28.0)	< 0.0001	0.42 (0.17–1.07)	0.07
Race (Black vs. Hispanic)	1.02 (0.79–1.3)	0.203	1.25 (0.68–2.29)	0.592
Race (Other vs. Hispanic)	0.80 (0.63–1.0)	0.008	2.18 (1.02–4.70)	0.077
Sex (Female)	0.84 (0.70–1.0)	0.05	3.12 (1.15–8.50)	0.026
In poverty 1998	0.95 (0.70–1.3)	0.76	1.08 (0.68–1.72)	0.751
General health status 1998	1.08 (0.98–1.2)	0.129	1.45 (1.27–1.66)	< 0.0001
Health limit moderate activity 1998				
Little limited versus not limited at all	0.96 (0.64–1.44)	0.56	2.29 (1.10–4.79)	0.871
Lot limited versus not limited at all	1.22 (0.68–2.2)	0.47	4.79 (2.47–9.28)	< 0.0001
Family Income (in $10,000) 1998	0.96 (0.94–0.98)	< 0.001	1.01 (0.96–1.05)	0.794

†Binary logistic regression model with complex sampling design ‡Cumulative logistic regression model with complex sampling design

Table 3 Regression models for obesity in the inverse propensity score weighted and full matched samples, using survey logistic regression

Variable	Inverse propensity sample (N = 5077)		Full matching sample (N = 5041)	
	Odds ratio (95% CI)	*p* value	Odds ratio (95% CI)	*p* value
Asthma (1998)	1.03 (0.69–1.53)	0.884	1.16 (0.75–1.80)	0.508
Obese (BMI > 30) 1998	21.0 (13.5–32.9)	< 0.0001	21.8 (13.0–36.4)	< 0.0001
Sex (female)	1.05 (0.70–1.56)	0.831	0.95 (0.58–1.53)	0.820
Race/ethnicity				
Black versus Hispanic	0.52 (0.22–1.24)	0.580	1.25 (0.68–2.29)	0.299
Other Versus Hispanic	0.38 (0.17–0.85)	0.015	0.89 (0.53–1.49)	0.321
In poverty 1998	1.21 (0.70–2.1)	0.493	0.60 (0.29–1.28)	0.187
General health status 1998	1.05 (0.83–1.33)	0.665	0.95 (0.72–1.25)	0.713
Health limit moderate activity 1998				
Little limited vs not limited at all	1.29 (0.64–2.59)	0.844	0.78 (0.41–1.47)	0.177
Lot limited versus not limited at all	1.91 (0.97–3.75)	0.142	1.64 (0.60–4.5)	0.219
Family Income (in $10,000) 1998	0.99 (0.95–1.03)	0.670	0.92 (0.81–1.03)	0.156

*C-statistic 0.84 for both models

Table 4 Regression models for limited physical activity due to health reason in the inverse propensity score weighted and full matched samples, using survey logistic regression

Variable	Inverse propensity sample (N = 3771)		Full matching sample (N = 3731)	
	Odds ratio† (95% CI)	*p* value	Odds ratio† (95% CI)	*p* value
Asthma (1998)	0.75 (0.29–1.90)	0.540	1.83 (1.21–2.76)	0.004
Obese (BMI > 30) 1998	0.68 (0.30–1.55)	0.360	1.05 (0.59–1.86)	0.871
Sex (female)	2.63 (1.27–5.46)	0.009	2.15 (1.34–3.45)	0.002
Race/ethnicity				
Black versus Hispanic	1.53 (0.79–2.98)	0.947	0.85 (0.48–1.51)	0.414
Other versus Hispanic	2.26 (1.20–4.24)	0.026	1.06 (0.61–1.84)	0.542
In poverty 1998	0.92 (0.51–1.67)	0.778	1.19 (0.58–2.43)	0.630
General health status 1998	1.46 (1.13–1.88)	0.003	1.41 (1.05–1.89)	0.023
Health limit moderate activity 1998				
Little limited versus not limited at all	2.85 (1.39–5.84)	0.639	2.96 (1.47–6.0)	0.345
Lot limited versus not limited at all	11.8 (3.8–36.8)	0.001	4.61 (1.95–10.88)	0.015
Family Income (in $10,000) 1998	0.95 (0.87–1.04)	0.246	0.93 (0.86–1.01)	0.073

†Odds ratios are from cumulative logit model. Probabilities are modeled in the order that physical activities are "lot limited", "little limited" and "not limited" due to health reason

3.5 Replicating analysis among participants without baseline obesity

Our full sample reported BMIs that were at median obese: over half of the sample had obesity, a higher prevalence of obesity than the general population of 40–50 year olds in 1998

(Flegal et al. 2002; Mokdad et al. 1999). As a robustness check, we evaluated the association between asthma and incident obesity by excluding participants who were obese at baseline. Among non-obese participants, baseline asthma was not associated with incident obesity 10 years later after either inverse propensity weighting or full matching. Baseline physical activity limited a lot compared to not at all limited due to health was positively associated with developing obesity [OR = 2.6 (1.2–5.6) and OR = 2.6 (1.02–6.5) for inverse propensity and full matching sample, respectively].

We also examined the association between asthma and our other outcome—physical activity limitations—after excluding subjects who were obese at baseline and adjusting for all covariates. In the non-obese subsample, baseline asthma was not associated with later physical activity limitations, but female gender and baseline poor health score were positively associated with physical activity limitations.

4 Discussion

A nationally representative sample of people with asthma at age 40 were not more likely to have obesity at age 50, both before and after matched sampling, and both in the full nationally representative sample and a non-obese subsample. Past findings of associations between asthma and subsequent obesity were not conducted in nationally representative samples, and relied on regression to reduce confounding.

A nationally representative sample of people with baseline asthma were more likely to have health-related physical activity limitations at age 50 after matched sampling, but not before matched sampling.

In the non-obese subsample, people with asthma were not more likely to have health-related physical activity limitations at age 50. People with asthma who have reached age 40 without becoming obese may have better health habits, more favorable genetics, and fewer comorbidities that enable them to avoid health-related activity limitations than people in a nationally representative sample, despite their asthma.

Prior researchers have explained associations between asthma and obesity by hypothesizing that asthma medications may lead to weight gain (Hedberg and Rossner 2000), especially long-term oral steroid usage (Lee 2018; Partners Asthma Center 2018). However, our nationally representative sample lacked associations between asthma and later obesity, suggesting that asthma medications may not cause obesity on average, even though evidence suggests some subpopulations gain weight or even become obese with steroid medication usage.

Both the full matching and inverse propensity weighted models for obesity yielded similar results in the full sample and in a subsample of participants not obese at baseline. In the full sample, baseline obesity was the only factor associated with obesity 10 years later in both models; in the sub-analysis, no factor predicted obesity 10 years later in both matching models. However, the models yielded different results when the outcome was physical limitations: with full matching but not inverse propensity weighting, asthma was associated with later physical limitations. Relationships between physical activity limits and all other variables were comparable in both matching models.

These findings suggest no association between asthma and obesity, which may help in the development of asthma disease management programs, which often have dual goals of physical activity and weight management. Given the high prevalence of obesity in the US population, participants in physical activity interventions may feel more encouraged

by being motivated by goals unrelated to weight, including strength, endurance, mood, improved quality of life, and reduced risks of frailty in old age. Past research suggests that exercise alone is not sufficient for weight loss, and people who attempt to lose weight through exercise may feel discouraged and give up on physical activity (Luke and Cooper 2013; Pontzer et al. 2016). People with asthma face additional barriers to physical activity compared with similar people without asthma. Disease management programs that encourage physical activity for health and quality of life reasons may be more successful in prompting people to continue with physical activity, even if it does not lead to weight loss.

This study also highlights the usefulness of replicating findings in specialized health datasets using economics datasets such as the National Longitudinal Studies that have nationally representative samples followed for long time periods.

5 Strengths and limitations

This study used follow-up data from a nationally representative sample of adolescents in 1979 and estimated survey sampling weights so that the results remain nationally representative. Previous samples used to examine the association between asthma and obesity were not nationally representative.

Body weight was self-reported, and almost half of the participants (N = 5516) did not report their weights at age 50+. People tend to under-report their actual weights (Jayawardene et al. 2014), especially women and overweight people, but self-reported body weight correlates with actual weights, so even if overweight participants were more likely to under-report their weights, we do not expect differential under-report of weight by asthma status. Even if subjects who did not report their weights were disproportionately overweight, we expect similar levels of non-response by asthma status: overweight/obese people with asthma would likely report their weights just as much as overweight/obese people without asthma.

We minimized potential confounding between asthma and the outcomes by using two matched sampling methods to balance the asthma and non-asthma groups on potential confounders. The matching methods produced similar outcomes, suggesting that our results are not sensitive to the matching method.

NLSY did not collect the date of asthma diagnosis, so we could not establish that the matching variables preceded the asthma diagnosis. Comparing people with and without asthma at the same age and observe their health outcomes 10 years later does yield meaningful information about how asthma proceeds during midlife. Many people with asthma use oral steroids, so that would likely be true for this sample, although NLSY did not collect information about asthma medication usage. Usage of long-term asthma medications may contribute to weight gain among people with asthma, but we could not demonstrate associations between long-term asthma treatment and weight.

Asthma and physical activity limitations data were based on self-rated single-item questions, which may have added noise to the data. However, any bias related to this noise is probably towards the null.

Race/ethnicity categories were coded in 1979 as mutually exclusive categories of White, Black, Hispanic, and Other. This standard conflates race and ethnicity and does not allow categorization of multiple identities, so that Hispanic Blacks must choose only one of those identities.

6 Conclusion

Our study establishes that asthma was not associated with obesity 10 years later, but it was associated with limited physical activity due to health. Asthma disease management programs that encourage physical activity and weight loss as separate goals may encourage people with asthma to maintain physical activity even in the absence of weight loss.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interests.

Ethical approval This article does not contain any studies with human participants performed by any of the authors. The data was publicly available.

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