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Contributions of obesity and cigarette smoking to incident disability: A longitudinal analysis

Tarlise N. Townsend[a,b,*], Neil K. Mehta[a]

[a] University of Michigan, Department of Health Management and Policy, 1415 Washington Heights, Ann Arbor, MI 48109, United States
[b] University of Michigan, Department of Sociology, 500 S. State St., Ann Arbor, MI 48109, United States

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ABSTRACT

Downward trends in U.S. disability levels are stagnating. Assessing the key contributors to U.S. disability incidence is critical to improving the functional status of the U.S. population. Using longitudinal, nationally representative data from waves 2003–2015 of the Panel Study of Income Dynamics (PSID), we estimated age-specific U.S. disability incidence and quantified the individual and joint contributions of obesity (contemporaneous and earlier-life; BMI ≥ 30) and cigarette smoking to disability incidence. Participants were adults ages 33–96 who participated in PSID in 1986 and at least two consecutive waves 2003–2015 (N = 3247). We conducted age-stratified logistic regressions to predict incident disability at middle and older ages (33–69 years, 70–96 years). Next, counterfactual scenarios were used to estimate the contributions of each risk factor to incident disability. Disability incidence was greater in women than men (5.8 and 4.5 cases per 100 person-years, respectively) and increased with age. Obesity and cigarette smoking jointly explained 17–38% of disability incidence; each factor contributed roughly equal amounts in all groups but older men, for whom smoking history appeared more important. Obesity and smoking appeared to explain more of disability at younger ages (women: 33.1%, 95% CI: 25.1 to 41.0%; men: 37.6%, 95% CI: 28.8 to 46.5%) than at older ages (women: 16.5%, 95% CI: 8.2 to 24.9%; men: 24.5.%, 95% CI: 12.7 to 36.3%). This study provides a benchmark for monitoring trends in U.S. disability incidence. Obesity and smoking are key contributors to disability, accounting for 17–38% of incident disability in U.S. adults.

1. Introduction

U.S. surveillance studies document rising age-adjusted disability prevalence among Americans under age 70 beginning in the early 2000s (Choi et al., 2016; Freedman et al., 2013; Lakdawalla et al., 2004; Martin et al., 2010; Seeman et al., 2010), as well as a stall in declining prevalence among Americans at older ages (Freedman et al., 2013). These alarming trends follow a secular decline in U.S. disability prevalence during the 1980s and 1990s (Freedman et al., 2002, 2004; Manton et al., 2006; Schoeni et al., 2008). It is unclear why these long-run declines in disability ended. Understanding the main contributors to disability at the population level is critical to efforts to improve the functional status of the American population and to better understand secular trends.

In this study, we evaluated the individual and joint contributions of two key behavioral risk factors, obesity and cigarette smoking, to U.S. disability incidence between 2003 and 2015. Obesity is associated with increased risk of disability, and obesity levels have nearly doubled since the 1980s (Alley and Chang, 2007; Chang et al., 2017). Current and former smoking are also important risk factors for disability (Altarac, 2000; Claessen et al., 2010; Husemoen, 2004; Lee et al., 2013; Lincoln et al., 2003). Although smoking levels have declined, in 2018 17% of American adults smoked cigarettes, and an additional 23% were former smokers (Blewett et al., 2018). Nearly 80% of middle-aged American adults have either been obese or smoked cigarettes at some point in their life (Mehta and Myrskylä, 2017)—yet the contribution of these risk factors to recent disability levels has not been established.

We thus quantify for the first time the percentage of national disability incidence attributable to obesity and cigarette smoking, singly and jointly. While prior research has attempted to estimate the contribution of excess weight to disability (Waidmann et al., 2008), smoking is a likely confounder of this relationship that, if not explicitly accounted for, may cause downward bias in these estimates. In addition, by incorporating data on both earlier-life and contemporaneous body mass index (BMI), we estimate the effect of obesity on disability risk more accurately than much existing research (Abdullah et al.,

* Corresponding author at: 180 E. Madison Ave., New York, NY 10016, United States.
E-mail addresses: tarlise.townsend@nyulangone.org (T.N. Townsend), nkmehta@umich.edu (N.K. Mehta).

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Table 1
Weighted sample characteristics.

	Ages 33–69				Ages 70–96			
	Women		Men		Women		Men	
	Estimate	(95% CI)	Estimate	(95% CI)	Estimate	(95% CI)	Estimate	(95% CI)
Individuals	1537	–	1209	–	284	–	217	–
Characteristics at study entry[a]								
Age (years)	51.6	(51.08 to 52.06)	51.9	(51.36 to 52.36)	77.2	(76.49 to 77.87)	76.3	(75.50 to 77.01)
BMI[b] at study entry, kg/m^2								
Mean	26.6	(26.26 to 26.93)	27.8	(27.50 to 28.01)	25.4	(24.83 to 25.90)	26.4	(25.93 to 26.95)
Percentage obese class I	14.4	(12.45 to 16.51)	18.8	(16.46 to 21.32)	8.4	(5.55 to 12.56)	11.8	(8.01 to 16.98)
Mean if obese class I	32.4	(32.20 to 32.62)	32.0	(31.78 to 32.18)	31.5	(31.03 to 32.03)	31.6	(31.13 to 32.02)
Percentage obese class II+	8.7	(7.19 to 10.58)	6.3	(4.91 to 7.94)	2.8	(1.28 to 5.88)	2.8	(1.28 to 6.17)
Mean if obese class II+	39.3	(38.57 to 39.99)	37.9	(37.22 to 38.52)	39.0	(36.99 to 40.95)	38.0	(36.16 to 39.92)
Smoking status (%)								
Never	54.0	(51.06 to 56.93)	45.4	(42.27 to 48.49)	62.3	(55.88 to 68.23)	35.0	(28.65 to 41.86)
Former	26.9	(24.32 to 29.62)	32.3	(29.42 to 35.24)	32.0	(26.36 to 38.23)	60.5	(53.50 to 67.02)
Current	19.1	(16.89 to 21.52)	22.4	(19.89 to 25.06)	5.7	(3.37 to 9.60)	4.6	(2.46 to 8.35)
Ever obese or smoked[c] (%)	77.0	(74.54 to 79.44)	77.4	(74.72 to 80.00)	63.3	(57.06 to 69.49)	81.9	(76.45 to 87.25)
Race/ethnicity (%)								
Non-Hispanic white	79.5	(77.03 to 81.75)	88.3	(86.06 to 90.13)	87.2	(82.31 to 90.83)	89.8	(84.74 to 93.30)
Black	14.2	(12.42 to 16.24)	7.5	(6.15 to 9.05)	9.0	(6.07 to 13.05)	4.5	(2.51 to 8.03)
Hispanic non-Black	3.9	(2.80 to 5.51)	2.1	(1.31 to 3.47)	2.9	(1.28 to 6.47)	2.5	(1.00 to 6.31)
Non-Hispanic other	2.3	(1.54 to 3.55)	2.1	(1.25 to 3.65)	1.0	(0.24 to 3.83)	3.1	(1.37 to 7.02)
Educational attainment (%)								
Less than high school	8.7	(7.21 to 10.37)	8.0	(6.54 to 9.80)	21.3	(16.27 to 27.28)	20.9	(15.80 to 27.05)
High school degree	66.2	(63.40 to 68.96)	59.3	(56.18 to 62.30)	61.8	(55.36 to 67.88)	50.1	(43.13 to 56.97)
College degree	25.1	(22.61 to 27.77)	32.7	(29.84 to 35.71)	16.9	(12.73 to 22.14)	29.1	(23.18 to 35.78)
Calendar year of entry	2003.6	(2003.5 to 2003.7)	2003.3	(2003.2 to 2003.4)	2004.0	(2003.8 to 2004.3)	2003.6	(2003.4 to 2003.8)
BMI in 1986, kg/m^2								
Mean	23.1	(22.86 to 23.35)	25.3	(25.12 to 25.56)	24.1	(23.58 to 24.59)	25.9	(25.45 to 26.43)
Percentage obese class I	5.7	(4.47 to 7.27)	8.2	(6.64 to 10.04)	4.2	(2.33 to 7.49)	7.6	(4.69 to 12.21)
Mean if obese class I	31.9	(31.56 to 32.23)	31.7	(31.43 to 31.95)	31.4	(30.81 to 31.94)	31.5	(30.92 to 32.05)
Percentage obese class II+	1.7	(1.12 to 2.67)	1.5	(0.91 to 2.45)	1.6	(0.50 to 4.92)	3.1	(1.45 to 6.34)
Mean if obese class II+	38.7	(37.34 to 40.03)	39.3	(37.46 to 41.11)	40.2	(37.08 to 43.28)	37.7	(36.26 to 39.22)
Follow-up								
Person-years, total[d]	12,416	–	10,414	–	2332	–	1996	–
Person-years, per person[d]	8.1	–	8.6	–	8.2	–	9.2	–
Disability cases, total	608	–	369	–	287	–	210	–
Disability incidence, per 100 person-year	9.8	–	7.1	–	24.6	–	21.0	–

Notes: Data source: Panel Study of Income Dynamics, 1986 and 2003–2015.
[a] Study entry refers to the first wave the individual was eligible for the analytic subpopulation, between 2003 and 2015.
[b] BMI refers to body mass index.
[c] Ever obese refers to BMI during the analyzed years, 2003–2015; ever smoked refers to reporting lifetime history of smoking.
[d] Person-years in which incident disability (i.e., a switch to disability following no disability in the prior wave) was assessed; this equals twice the number of assessed waves.

2011; Preston et al., 2013). National surveillance studies of disability have typically been cross-sectional, relying on prevalence measures of disability. In contrast, we analyze a long-running, high-quality, nationally representative panel to identify new disability cases, thereby ameliorating methodological concerns such as reverse causality and Neyman bias (Grimes and Schulz, 2002; Mehta, 2015). This allows us to provide the first national estimates of U.S. disability incidence attributable to these risk factors over the 2003–2015 period. In contrast with mediation percentages and similar measures, these estimates take into account both the associations of the risk factors with incident disability and the prevalence of the risk factors in the U.S. population. Finally, while prior research has tended to focus on disability in older adults, we conduct this analysis for adults at both middle and older ages, thus helping to elucidate drivers of early-onset disability.

2. Methods

2.1. Data and sample

The Panel Study of Income Dynamics (PSID) is the world's longest-running household panel survey and collects data on myriad social, behavioral, and health indicators [dataset] (University of Michigan Institute for Social Research, 2020). It was initiated in 1968 with a nationally representative sample of over 18,000 individuals. PSID followed core sample members and their decedents annually until 1997 and then biennially thereafter. Response rates in PSID have equaled or exceeded response rates in other panel studies globally (McGonagle et al., 2012). At the time of this study, the most recent wave available was 2015. In 2003, PSID began including 13 items on activities of daily living limitations (ADLs) and instrumental activities of daily living limitations (IADLs). PSID collected self-reported height and weight information in 1986 and then biennially beginning in 1999. It is funded by the National Institute on Aging.

Respondents were included in the analytic subpopulation if they appeared in the panel and reported complete ADL and IADL information for at least two consecutive waves between 2003 and 2015 and—to obtain earlier-life BMI—participated in the panel in 1986. The youngest and oldest individuals meeting these criteria were ages 16 and 76 in 1986, resulting in an age group ranging from 33 to 96 years old during the 2003–2015 analytic period. Individual observations were included if contemporaneous BMI was < 50. The subpopulation consisted of 3247 respondents (1821 women; 1426 men) followed for a mean of 8.4 years.

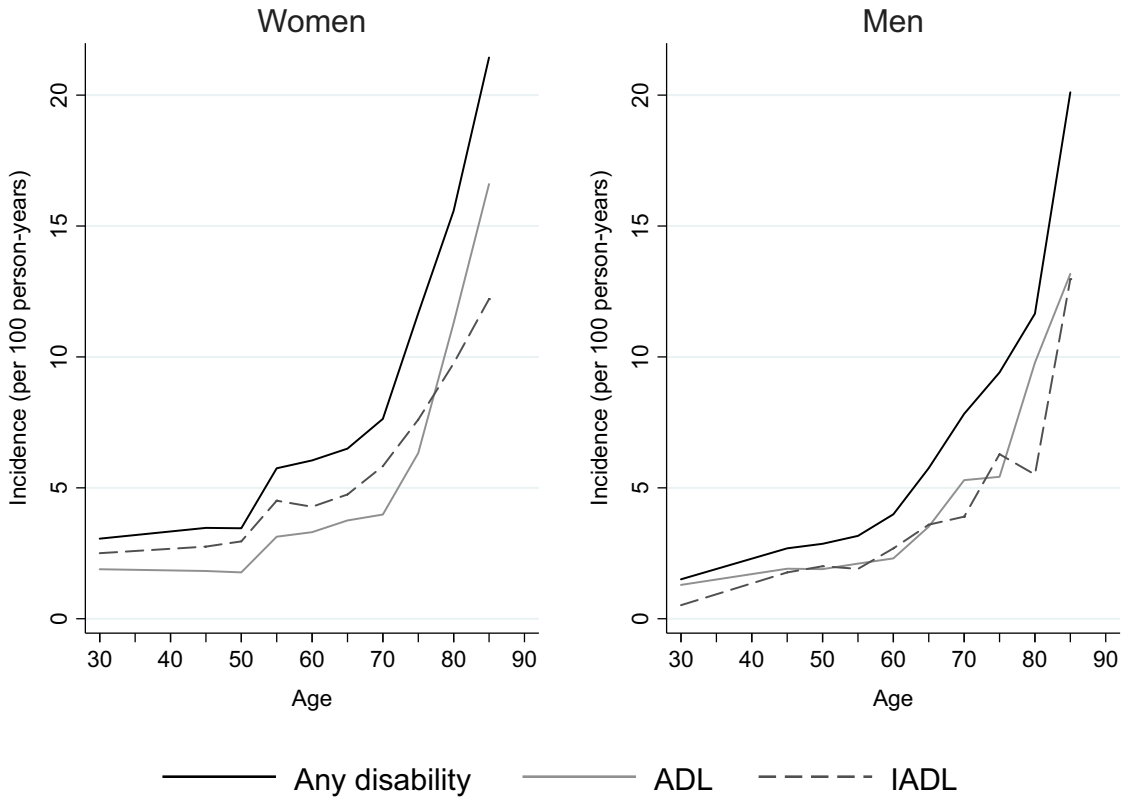

Fig. 1. Disability incidence by age and gender.
Five-year age intervals. Due to small sample sizes, individuals under age 45 years are coded as 30 and those over age 85 years are coded as 85. Solid Black indicates any incidence of any (ADL or IADL) disability; solid gray line indicates incidence of ADL disability; dashed gray line indicates incidence of IADL disability. ADL refers to activities of daily living; IADL refers to instrumental activities of daily living.

2.2. Disability and disability incidence

Following prior research (Cutler and Lleras-Muney, 2010; Iezzoni et al., 2014; Laditka and Laditka, 2016; Martin and Schoeni, 2014; Schoeni et al., 2005), we classified respondents as experiencing disability in a given wave if they reported at least one ADL limitation (difficulty bathing or showering; dressing; eating; getting in or out of a bed or a chair; walking; getting outside; using or getting to the toilet) or IADL limitation (difficulty preparing meals; shopping for personal toilet items or medicines; managing money; using the telephone; doing heavy housework; doing light housework). Disability incidence was defined as a switch from reporting no disability in one wave to reporting disability in the subsequent wave.

2.3. BMI, cigarette smoking, and sociodemographic characteristics

BMI and cigarette smoking were treated as time-varying and categorical. BMI was calculated as self-reported weight in kilograms divided by self-reported height in meters-squared. BMI from the 1986 wave (earlier-life BMI) and from the 2003–2015 waves (contemporaneous BMI) was used. Following standard guidelines, we defined underweight status as BMI < 18.5, healthy weight as BMI 20–24.9, overweight as 25–29.9, obesity class I as BMI 30–34.9, and obesity class II and above as BMI 35 and over. Examination of the correlation between the continuous 1986 and contemporaneous BMI measures (Pearson's r of 0.623, $p < 0.001$) and of model coefficient stability and standard error size alleviated concerns about multicollinearity in the earlier-life and contemporaneous measures. Smoking status was reported as current smoker, former smoker, and never smoker, and status was updated each wave (2003–2015).

Age was measured in single years and ascertained from birthdate and date of interview. Educational attainment was categorized as: less than high school, high school degree, and college degree. Race/ethnicity was categorized as: non-Hispanic white, Hispanic and non-Hispanic Black, Hispanic non-Black, and non-Hispanic other. Hispanic and non-Hispanic Black individuals were combined into one category given new and growing evidence of poorer health among Hispanic Black individuals compared to Hispanic non-Black individuals (Chinn and Hummer, 2016; Elo et al., 2011).

Several conservative methods of imputation were selected to reduce missing data on covariates while preserving the validity of the data and associations. In all variables, a missing value was imputed if sandwiched between two waves with identical values. In addition, a "years of education" variable was used to reduce missingness in the categorical education variable: fewer than 12 years of education was coded as "less than high school", 12–14 years as "high school degree", and 16 years as "college degree". Finally, information from past and future waves was used to impute race/ethnicity and education, which are unlikely to vary over time in the age groups studied. 90 observations were excluded due to missing data.

2.4. Statistical analysis

We estimated logistic regression models predicting disability incidence in a wave for each individual, using a person-wave file. Observations were included in regression analyses if the respondent was at risk for incident disability, with an indicator of whether incidence occurred in the following survey wave. If a respondent reported disability and was therefore not at risk for disability onset, subsequent person-waves were excluded from the analysis as long as they continued to report disability. If the respondent reported no disability in a subsequent wave (indicating recovery), the respondent reentered the

Table 2
Disability incidence by age and gender (per 100 person-years).

Age	Any disability[a]	(95% CI)	ADL disability[b]	(95% CI)	IADL disability[c]	(95% CI)
A. Women						
< 45	3.1	(1.99 to 4.13)	1.9	(1.02 to 2.76)	2.5	(1.57 to 3.44)
45–49	3.5	(2.63 to 4.31)	1.8	(1.22 to 2.43)	2.8	(2.01 to 3.51)
50–54	3.5	(2.68 to 4.23)	1.8	(1.21 to 2.33)	3.0	(2.23 to 3.68)
55–59	5.7	(4.63 to 6.86)	3.1	(2.28 to 3.99)	4.5	(3.49 to 5.52)
60–64	6.0	(4.74 to 7.35)	3.3	(2.31 to 4.30)	4.3	(3.17 to 5.38)
65–69	6.5	(4.97 to 8.03)	3.8	(2.56 to 4.95)	4.7	(3.39 to 6.10)
70–74	7.6	(5.92 to 9.35)	4.0	(2.68 to 5.29)	5.8	(4.27 to 7.38)
75–79	11.7	(9.23 to 14.11)	6.3	(4.47 to 8.18)	7.6	(5.52 to 9.69)
80–84	15.6	(12.23 to 18.94)	11.3	(8.28 to 14.31)	9.8	(6.93 to 12.58)
85+	21.4	(15.81 to 27.06)	16.6	(11.52 to 21.69)	12.2	(7.61 to 16.81)
< 70	**4.6**	**(4.13 to 5.11)**	**2.5**	**(2.17 to 2.90)**	**3.6**	**(3.16 to 4.01)**
70+	**11.7**	**(10.21 to 13.12)**	**7.3**	**(6.09 to 8.45)**	**7.7**	**(6.51 to 8.91)**
All ages	**5.8**	**(5.35 to 6.33)**	**3.4**	**(2.98 to 3.72)**	**4.3**	**(3.88 to 4.72)**
B. Men						
< 45	1.5	(0.65 to 2.37)	1.3	(0.48 to 2.11)	0.5	(0.04 to 0.99)
45–49	2.7	(1.90 to 3.48)	1.9	(1.23 to 2.59)	1.8	(1.12 to 2.42)
50–54	2.9	(2.10 to 3.63)	1.9	(1.26 to 2.53)	2.0	(1.36 to 2.66)
55–59	3.2	(2.38 to 3.96)	2.1	(1.44 to 2.77)	1.9	(1.30 to 2.50)
60–64	4.0	(2.93 to 5.05)	2.3	(1.48 to 3.13)	2.7	(1.81 to 3.57)
65–69	5.8	(4.31 to 7.20)	3.5	(2.36 to 4.67)	3.6	(2.45 to 4.74)
70–74	7.8	(5.83 to 9.83)	5.3	(3.66 to 6.93)	3.9	(2.51 to 5.29)
75–79	9.4	(7.09 to 11.73)	5.4	(3.52 to 7.33)	6.3	(4.37 to 8.20)
80–84	11.7	(8.46 to 14.85)	9.8	(6.81 to 12.75)	5.5	(3.12 to 7.89)
85+	20.1	(14.85 to 25.36)	13.2	(8.79 to 17.56)	13.0	(8.28 to 17.67)
< 70	**3.3**	**(2.90 to 3.75)**	**2.2**	**(1.82 to 2.49)**	**2.1**	**(1.79 to 2.44)**
70+	**10.2**	**(8.77 to 11.68)**	**6.9**	**(5.73 to 8.14)**	**5.8**	**(4.77 to 6.88)**
All ages	**4.5**	**(4.05 to 4.96)**	**3.0**	**(2.62 to 3.34)**	**2.8**	**(2.41 to 3.09)**

Notes: Data source: Panel Study of Income Dynamics, 1986 and 2003–2015.
Bold indicates estimates for all individuals under age 70, ages 70 and older, and for all ages, respectively.
[a] Any disability refers to any ADL or IADL disability.
[b] ADL refers to activities of daily living.
[c] IADL refers to instrumental activities of daily living.

risk set at that wave. Multiple disability incident events for an individual were therefore possible. By assessing repeated incidence, we were able to model all incident disability and examine the real fluctuation in disability status throughout the life course. All person-time prior to entering the risk set was censored, as was person-time after death, loss to follow-up, or the end of the study period.

Given potential age and cohort differences in associations between the predictors and disability, we stratified the regression analyses by age at exposure (under 70 years, 70 years and above). For each age group, the regression model comprised:

$$\log\left(\frac{p_{it}}{1-p_{it}}\right) = \beta_0 + \beta_1 Age_{it} + \beta_2 Female + \sum_{j=1}^{4}\beta_{3j}1986BMI_{ij} + \sum_{j=1}^{4}\beta_{4j}ContempBMI_{ij} + \sum_{j=1}^{2}\beta_{5j}Smoke_{ij} + \sum_{j=1}^{2}\beta_{6j}Education_{ij} + \sum_{k=1}^{3}\beta_{7k}Race_{ik} + \beta_8 Yeara_{it}; \quad (1)$$

where *it* denotes individual *i* at *t* waves since 2003 and p_{it} is the individual-level annual probability of disability incidence. Contemporaneous BMI and smoking status measures were lagged one wave to ameliorate reverse causation.

Analyses were conducted using Stata 15.0 and the svy extension package. Estimates were weighted using PSID population weights that were adjusted to address selective, non-mortality censoring (Appendix A). Because the aim was to model disability incidence in the population alive at a given time, no adjustments were made for censoring due to mortality. Observations were clustered to account for intra-individual correlation. Taylor series linearization was used to account for unequal clustering.

2.5. Counterfactuals

Using a counterfactual approach, we estimated the percentage of disability in each age group individually and jointly attributable to obesity (any class) and cigarette smoking. We first estimated national disability incidence for each age group over the 2003–2015 period, using the observed distribution of covariates in the regression model. We then re-estimated disability incidence under three counterfactual scenarios: (1) elimination of obesity of any class (earlier-life and contemporaneous), (2) elimination of current and former smoking, and (3) elimination of both risk factors simultaneously. The resulting reduction in incidence provided an estimate of disability incidence attributable to the risk factors. These estimates share empirical and theoretical foundations with conventional formulas of the population attributable risk fraction (Elo et al., 2017; Greenland and Drescher, 1993; Tanuseputro et al., 2015).

2.6. Supplementary analyses

We conducted six supplementary analyses. First, we separately examined the contributions of current and former smoking to disability incidence. Second, we estimated the contributions of each risk factor to first observed incidence—i.e., excluding individuals from the risk set once an incident event was observed. Because the disability data were truncated prior to 2003, we were unable to conclude that a first observed incidence was truly an individual's first disability event. Third, we examined persistent disability, defined as disability reported in at least two consecutive waves. Fourth, we examined the risk factors' contributions to ADLs and IADLs separately. Fifth, we estimated the contribution of sedentariness at study entry (fewer than 10 min of heavy exercise per week) to incident disability alongside obesity and smoking. Finally, we included household income as percent of the

Table 3
Results of logistic regression predicting disability incidence[a,b].

	Ages 33–69 years		Ages 70–96 years	
	Odds ratio	95% C.I.	Odds ratio	95% C.I.
Contemporaneous BMI				
Underweight	1.312	(0.519 to 3.317)	0.601	(0.218 to 1.658)
Healthy weight	*Ref.*	–	*Ref.*	–
Overweight	1.034	(0.814 to 1.312)	0.968	(0.727 to 1.290)
Obese class I	1.764	(1.308 to 2.378)	1.865	(1.183 to 2.939)
Obese class II+	2.378	(1.645 to 3.438)	2.897	(1.297 to 6.468)
BMI in 1986				
Underweight	0.841	(0.473 to 1.497)	0.514	(0.0696 to 3.795)
Healthy weight	*Ref.*	–	*Ref.*	–
Overweight	0.871	(0.677 to 1.121)	0.889	(0.653 to 1.209)
Obese class I	1.357	(0.955 to 1.928)	1.116	(0.588 to 2.118)
Obese class II+	2.578	(1.478 to 4.497)	0.665	(0.198 to 2.233)
Smoking				
Never	*Ref.*	–	*Ref.*	–
Former	1.299	(1.060 to 1.591)	1.509	(1.148 to 1.983)
Current	1.890	(1.489 to 2.398)	1.073	(0.573 to 2.009)
Age	1.047	(1.033 to 1.060)	1.098	(1.073 to 1.124)
Education				
< High school	*Ref.*	–	*Ref.*	–
High school degree	0.673	(0.490 to 0.924)	0.798	(0.553 to 1.151)
College degree	0.521	(0.367 to 0.740)	0.815	(0.542 to 1.225)
Female	1.468	(1.202 to 1.793)	1.289	(0.967 to 1.720)
Race/ethnicity				
Non-Hispanic white	*Ref.*	–	*Ref.*	–
Black	1.381	(1.091 to 1.749)	1.226	(0.688 to 2.184)
Hispanic non-Black	1.304	(0.737 to 2.307)	0.901	(0.388 to 2.093)
Non-Hispanic other	0.772	(0.402 to 1.485)	0.515	(0.236 to 1.122)
Constant	0.00535	(0.00239 to 0.0120)	0.000193	(2.81e-05 to 0.00133)
Observations	11,415	–	2164	–

Notes: Data source: panel study of income dynamics, 1986 and 2003–2015.
[a] Year fixed effects were also included in the regression.
[b] Incidence was per 100 person-years.

federal poverty line in the regressions, to address the potential for residual confounding of the risk factor-disability relationship.

3. Results

The analytic subpopulation comprised 2746 individuals ages 33–69 years (1537 women; 1209 men) and 501 ages 70–96 years (284 women; 217 men; Table 1). Between 2003 and 2015, 977 incident disability events occurred at younger ages (women: 608; men: 369) and 497 at older ages (women: 287; men: 210). Table 1 provides weighted characteristics of the subpopulation. In each of the four age-gender subgroups, the majority of individuals were non-Hispanic white (80–90%) and had obtained a high school but not a college degree (50–66%).

In 1986, mean BMI was lower in women than men. Mean BMI at study entry (i.e., in the first wave eligible for the analytic subpopulation, 2003–2015) was higher than in 1986 (1986: 23–26; study entry: 25–28); the gender gap was narrower at study entry but remained. 23–25% of the younger group and 11–15% of the older group experienced class I obesity at study entry. Overall, women were more likely to report never smoking (women: 54–62%; men: 35–45%). 77% of younger women, 77% of younger men, 63% of older women, and 82% of older men were either obese during any of the analyzed years or reported ever having smoked. Fig. B.1 in the appendix shows mean BMI and percentage reporting ever having smoked from 2003 to 2015, by age and gender group.

Fig. 1 depicts disability incidence by age and gender, overall and by ADL and IADL difficulty separately; Table 2 provides point estimates and confidence intervals. Overall, disability incidence was greater among women (5.8 cases per 100 person-years; 95% CI: 5.35–6.33 per 100 person-years) than men (4.5 cases per 100 person-years; 95% CI: 4.05, 4.96) and rose with age (under age 70: 4.0 cases per 100 person-years; 95% CI: 3.66, 4.31; age 70 and over: 11.0; 95% CI: 9.93–11.99). Under age 70, disability incidence was 4.6 per 100 person-years in women (95% CI: 4.13, 5.11) and 3.3 per 100 person-years in men (95% CI: 2.90, 3.75). Age 70 and over, disability incidence was 11.7 per 100 person-years in women (95% CI: 10.21, 13.12) and 10.2 per 100 person-years in men (95% CI: 8.77, 11.68).

Table 3 provides regression results. In adults ages 33–69 years, earlier-life and contemporaneous obesity were positively associated with incidence (1986, obese class I: OR = 1.357, 95% CI: 0.955 to 1.928; 1986 obese class II+: OR = 2.578, 95% CI: 1.478 to 4.497; contemporaneous, obese class I: OR = 1.764, 95% CI: 1.308–2.378; contemporaneous, obese class II+: OR = 2.378, 95% CI: 1.645–3.438). Neither underweight nor overweight were clearly associated with incident disability. Current smoking (vs. never: OR = 1.890, 95% CI: 1.489–2.398) and former smoking (vs. never: OR = 1.299, 95% CI: 1.060–1.591) were positively associated with incident disability, as were age, female, and being Black (vs. non-Hispanic white). Having obtained a high school or college degree (vs. neither) negatively predicted incidence.

In adults ages 70–96 years, contemporaneous but not earlier-life obesity predicted disability incidence (1986, obese class I: OR = 1.116, 95% CI: 0.588 to 2.118; 1986 obese class II+: OR = 0.665, 95% CI: 0.198 to 2.233; contemporaneous, obese class I: OR = 1.865, 95% CI: 1.183–2.939; contemporaneous, obese class II+: OR = 2.897, 95% CI: 1.297–6.468). Neither underweight nor overweight were clearly associated with incident disability. Former but not current smoking predicted incidence (former: OR = 1.509, 95% CI:1.148–1.983; current: OR = 1.073, 95% CI: 0.573–2.009), as did age and being female.

Table 4 provides population attributable fractions by age-gender group. Obesity and smoking jointly accounted for 17–38% of disability incidence in the four subgroups. The risk factors' joint contribution appeared to be larger at younger ages (women: 33.1%, 95% CI: 25.1 to

Table 4
Observed disability incidence and estimated population attributable fractions[a].

A. Women

	Incidence[a,b]		Amount explained[b]		Percent explained (%)	
	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI
Ages 33–69						
Observed	4.6	(4.1 to 5.1)				
Smoking	3.9	(3.4 to 4.4)	0.7	(0.4 to 1.1)	15.7	(8.8 to 22.7)
Obesity	3.7	(3.2 to 4.2)	0.9	(0.6 to 1.2)	19.6	(13.8 to 25.5)
Both	3.1	(2.6 to 3.6)	1.5	(1.1 to 1.9)	33.1	(25.1 to 41.0)
Ages 70–94						
Observed	11.7	(10.2 to 13.1)				
Smoking	10.5	(9.0 to 12.1)	1.1	(0.3 to 2.0)	9.7	(2.5 to 16.9)
Obesity	10.8	(9.4 to 12.3)	0.8	(0.3 to 1.4)	7.2	(2.8 to 11.6)
Both	9.7	(8.2 to 11.3)	1.9	(0.9 to 2.9)	16.5	(8.2 to 24.9)

B. Men

	Incidence[a,b]		Amount Explained[b]		Percent explained (%)	
	Estimate[b]	95% CI	Estimate	95% CI	Estimate[b]	95% CI
Ages 33–69						
Observed	3.3	(2.9 to 3.7)				
Smoking	2.7	(2.2 to 3.1)	0.6	(0.4 to 0.9)	19.3	(10.8 to 27.8)
Obesity	2.6	(2.2 to 3.0)	0.7	(0.5 to 0.9)	21.4	(14.9 to 27.9)
Both	2.1	(1.7 to 2.5)	1.2	(0.9 to 1.6)	37.6	(28.8 to 46.5)
Ages 70–94						
Observed	10.2	(8.8 to 11.7)				
Smoking	8.4	(6.8 to 10.1)	1.8	(0.6 to 2.9)	17.4	(6.3 to 28.6)
Obesity	9.4	(8.0 to 10.8)	0.8	(0.3 to 1.4)	8.1	(2.8 to 13.4)
Both	7.7	(6.1 to 9.3)	2.5	(1.2 to 3.8)	24.5	(12.7 to 36.3)

Notes: Data source: panel study of income dynamics, 1986 and 2003–2015.
[a] Rows indicate observed disability incidence followed by estimated incidence under the counterfactual scenarios: if smoking were eliminated in the subpopulation; if obesity were eliminated; and if both were eliminated.
[b] Per 100 person-years.

41.0%; men: 37.6%, 95% CI: 28.8 to 46.5%) versus older ages (women: 16.5%, 95% CI: 8.2 to 24.9%; men: 24.5.%, 95% CI: 12.7 to 36.3%). The risk factors also appeared to explain a larger proportion of incidence in men versus women. While confidence intervals overlapped, point estimates of obesity's contribution to incidence were larger than those for smoking in the younger groups but smaller in the older groups.

Tables B.1–B.6 in the appendix present results of the supplementary analyses. Among individuals under age 70 years, current and former smoking contributed roughly equally to disability incidence (Table B.1). In the older group, former smoking explained nearly all of smoking's contribution. In the analysis of first incidence rather than repeated incidence, estimated incidence rates fell by 0.4–1.4 per 100 person-years, while the estimated contributions of obesity and smoking varied minimally from the repeated incidence analysis (Table B.2).

In the younger group, the risk factors jointly explained roughly 9 percentage points more of persistent disability than all incident disability, primarily driven by a larger contribution of obesity to persistent disability (Table B.3). In the older group, the factors appeared to explain 2–8 percentage points less of persistent disability than all incident disability, driven by a smaller role of smoking to persistent disability. The risk factors jointly explained 4–7 percentage points more of IADL disability than ADL disability; this difference appeared driven by a larger contribution of smoking to IADL disability (Table B.4). Estimating the contribution of sedentariness at study entry alongside obesity and smoking increased the total amount of incidence explained by 4–5 percentage points in the younger group, driven by the apparent contribution of sedentariness and mitigated by a 0.2–2 percentage point decrease in the apparent contribution of obesity and smoking (Table B.5). In the older group, the total estimated percent explained rose by 21 percentage points when sedentariness was considered, while the apparent contributions of obesity and smoking changed very little. Finally, inclusion of an income measure in the statistical models had negligible effects on the percent explained estimates and did not change the substantive conclusions (Table B.6).

4. Discussion

After decades of improvement, declines in U.S. disability began to stall in the early 2000s (Choi et al., 2016; Freedman et al., 2013; Lakdawalla et al., 2004; Martin et al., 2010; Seeman et al., 2010). The reasons for this interruption are not known. Understanding the contributions of key risk factors to disability helps explain these shifting trends and offers insight into means for improving disability levels in the future. We quantified the respective contributions of obesity and cigarette smoking to incident disability (i.e., onset of difficulty with any ADL or IADL) among U.S. adults ages 33 and over between 2003 and 2015. These risk factors jointly explained an estimated 33% and 38% of incident disability among women and men under age 70, respectively. At older ages, when physical frailty increasingly contributes to disability, obesity and smoking explained an estimated 17% of incident disability among women and 25% among men. For all groups except older men, the estimated contribution of obesity was greater than that of smoking, although these differences were not statistically significant. Further research is needed to quantify the contributions of other preventable risk factors to disability incidence. Candidates include manual labor involvement (Cutler and Lleras-Muney, 2010; Li, 2000; Townsend and Mehta, 2020), inadequate exercise independent of its effects on BMI (Penninx et al., 2001), adverse environmental exposures (Ferkol and Schraufnagel, 2014), and alcohol consumption (Samokhvalov

et al., 2010).

We offer several contributions to the existing literature on U.S. disability. First, prior national-level studies have estimated disability prevalence using cross-sectional data (Alley and Chang, 2007; Chang et al., 2017; Iezzoni et al., 2014; Martin and Schoeni, 2014), while we use longitudinal data and model incident events. Analysis of incidence minimizes the effects of reverse causation—in this case, the pathway from disability status to behavioral status. Reverse causation is a key threat to validity in disability research, as disability may lead to changes in physical activity, diet, and cigarette consumption (Stokes and Preston, 2016). Second, we include earlier-life BMI in order to capture the effects of long-run exposure to high BMI. Incorporation of weight histories has been shown to improve the predictive power of weight-related outcomes (Abdullah et al., 2011; Mehta, 2015; Mehta et al., 2014). Our results confirm this pattern in younger adults, demonstrating that earlier-life BMI predicts disability risk independent of contemporaneous BMI. Third, prior studies have examined the individual-level associations between obesity and cigarette smoking and disability. We take the further step of translating individual-level relative risks to population attributable risk fractions, thereby providing the first set of estimates of the contributions of these risk factors to national-level disability incidence.

Finally, we examine early-onset disability in addition to that occurring at older ages. Early-onset disability has received little attention but is of particular concern, given evidence of its rising prevalence (Iezzoni et al., 2014; Martin and Schoeni, 2014). It may interfere with the ability to work and save for retirement, care for children and aging parents, and engage in other activities important in middle life. Our results suggest that obesity and smoking are key contributors to disability occurring before age 70, and especially to disability lasting multiple years. Although cigarette smoking levels have been declining, obesity rates among younger Americans continue to rise, adversely affecting disability trends among those under age 70. Moreover, the rise in electronic cigarette use among young people may begin to offset the benefits of declines in combustible cigarette smoking (McMillen et al., 2015). The consequences for early-onset disability will depend on the extent to which nicotine and other chemicals present in electronic cigarettes contribute to adverse health outcomes (Stratton et al., 2018). Research tracking these trends and their health consequences is imperative, as are careful policy responses.

Obesity is associated with an array of disabling conditions, including arthritis and other musculoskeletal conditions, cardiovascular disease, and diabetes (Brault et al., 2009; Fowler-Brown et al., 2013; Samper-Ternent and Al Snih, 2012; Wray et al., 2005). Chang, Alley, and Dowd report that between the periods 1988–1994 and 1999–2004, the relative odds of disability associated with obesity rose among Americans ages 60 and above (Alley and Chang, 2007; Chang et al., 2017). The authors found no increase in the relative odds between the periods 1999–2004 and 2005–2012. The earlier rise in the relative odds of obesity was hypothesized to be associated with increases in the time spent obese across cohorts due to rising earlier-life BMI and reductions in the obesity-mortality relationship (Alley and Chang, 2007; Chang et al., 2017). While we are unable to explicitly estimate the effect of time spent obese, our results do suggest that a high BMI earlier in life may independently contribute to disability risk over and above contemporaneous BMI.

Smoking influences disability by contributing to the risk of cardiovascular disease, musculoskeletal injury, and respiratory illness, among other conditions (Altarac, 2000; Claessen et al., 2010; Fowler-Brown et al., 2013; Husemoen, 2004; Lee et al., 2013; Lincoln et al., 2003; Murray and Lopez, 1997; Wray et al., 2005). While smoking rates have declined dramatically in recent decades, past smoking continues to influence disability risk. Among individuals under age 70 years, former smoking contributed nearly as much to incident disability as current smoking. Among those 70 years and older, for whom rates of current smoking were low, former smoking accounted for nearly all of smoking's effect on incident disability. This finding is attributable to the modest and non-significant positive association between current smoking and incident disability in this group. This may in turn be related to selective survival, in which underlying susceptibility to the harms of smoking may be lower among those who survive and continue to smoke into older age.

4.1. Study limitations and strengths

This study has limitations. Despite efforts to minimize it, some reverse causation may have remained in our models, likely resulting in underestimates of the risk factors' contributions to disability. The same concerns deterred our estimation of the contribution of sedentariness, beyond its effects on weight, in the main analysis: the pathway linking sedentariness and disability is bidirectional (Carlsson et al., 2006). In a supplementary analysis including sedentariness at study entry as a risk factor, sedentariness appeared to explain an additional 21–23 percentage points of incidence in the older group. However, reverse causation likely accounts for at least some of this apparent increase.

Use of self-reported height and weight may have led to underestimation of BMI, particularly among women and at older ages, potentially resulting in an underestimation of obesity's contribution to disability (Merrill and Richardson, 2009). Additionally, further work is needed to understand the main diseases and conditions that underlie the link between the risk factors and disability.

Concerted efforts to reduce obesity and smoking are needed in the policy and clinical arenas. Effective interventions to address these risk factors, particularly policies that target upstream social determinants, should be widely funded and accessible, especially for those at greatest risk. Clinicians should be familiar with these programs and ways to partner with or refer patients to them. This is of particular importance as the prevalence of obesity and disability rise (Flegal et al., 2016; Freedman et al., 2013; Martin and Schoeni, 2014; Ogden et al., 2016), and as electronic cigarette use among previous nonsmokers increases (McMillen et al., 2015). Amid an aging population, this shift may translate into growing numbers of people living with disability for longer periods of time, which has implications for health infrastructure and society more broadly.

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CRediT authorship contribution statement

Tarlise N. Townsend: Conceptualization, Methodology, Formal analysis, Writing - original draft. **Neil K. Mehta:** Conceptualization, Methodology, Writing - review & editing.

Declaration of competing interest

The authors have no conflicts of interest to disclose.

Appendix. Supplementary data

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