

# Objectively Assessed Secondhand Smoke Exposure and Mental Health in Adults

## *Cross-sectional and Prospective Evidence From the Scottish Health Survey*

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**Context:** Secondhand smoke (SHS) exposure has been related to various somatic health outcomes, although very little is known about the association between SHS exposure and mental health.

**Objective:** To assess the associations between mental health and SHS exposure, which was objectively measured using the salivary cotinine level as a circulating biochemical marker.

**Design, Setting, and Participants:** In a cross-sectional and longitudinal study, a representative sample of 5560 nonsmoking adults (mean [SD] age, 49.8 [15.4] years; 45.5% men) and 2595 smokers (mean [SD] age, 44.8 [14.8] years; 50.2% men) without history of mental illness was drawn from the 1998 and 2003 Scottish Health Survey. A priori, study participants with cotinine values of 15.00 µg/L or higher (to convert to nanomoles per liter, multiply by 5.675) were assumed to be smokers and recategorized as such in all analyses.

**Main Outcome Measures:** A score greater than 3 on the 12-item General Health Questionnaire was used as an indicator of psychological distress. Incident psychi-

atric hospital admissions over 6 years of follow-up were also recorded.

**Results:** Psychological distress was apparent in 14.5% of the sample. In logistic regression analyses of the cross-sectional data, after adjustments for a range of covariates, high SHS exposure among nonsmokers (cotinine level >0.70 and <15.00 µg/L) was associated with higher odds of psychological distress (odds ratio=1.49; 95% confidence interval, 1.13-1.97) in comparison with participants with cotinine levels below the limit of detection ( $\leq$ 0.05 µg/L). In prospective analyses, risk of a psychiatric hospital admission was related to high SHS exposure (multivariate adjusted hazard ratio=2.84; 95% confidence interval, 1.07-7.59) and active smoking (multivariate adjusted hazard ratio=3.74; 95% confidence interval, 1.55-8.98).

**Conclusions:** Exposure to SHS is associated with psychological distress and risk of future psychiatric illness in healthy adults. These concordant findings using 2 different research designs emphasize the importance of reducing SHS exposure at a population level not only for physical health but also for mental health.

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**A** GROWING BODY OF LITERATURE has demonstrated the harmful physical health effects of secondhand smoke (SHS) exposure.<sup>1-5</sup> Given the highly prevalent exposure to SHS—in the United States, an estimated 60% of American nonsmokers had biological evidence of exposure to SHS<sup>2</sup>—even a low level of risk may have a major public health impact. Although smoke-free legislation currently exists in a number of countries such as the United States and Britain, such policies have not been introduced on a worldwide scale and it is therefore crucial to accumulate knowledge about the disease burden associated with SHS. In addition, SHS exposure at home is growing in relative importance as restrictions on smoking in workplaces and public places spread.<sup>6</sup>

The existing evidence of the health consequences of SHS has largely relied on crude, self-report measures such as exposure in the workplace or via a family member.<sup>1</sup> Recent studies using valid objective biochemical markers of SHS have reported associations with various health outcomes, including markers of inflammation, glucose control, and cardiovascular disease risk.<sup>7-11</sup> There is, however, very limited information on the association between objectively assessed SHS exposure and mental health in humans.

There are good reasons to anticipate an influence of objectively assessed SHS exposure on mental health. A strong link exists between active smoking and mood disorders,<sup>12</sup> and animal data also indicate that tobacco can induce negative mood.<sup>13</sup> In rats, nicotine intake during adolescence

leads to a depressionlike state manifested in decreased sensitivity to natural reward and enhanced sensitivity to stress and anxiety-eliciting situations later in life.<sup>13</sup> In humans, SHS exposure assessed using salivary cotinine levels was cross-sectionally associated with depressive symptoms in never smokers.<sup>14</sup> Also, in a group of Swiss never-smoking adults, self-reported SHS exposure was inversely associated with health-related quality of life, including physical functioning, extent of disability, bodily pain, and social functioning domains.<sup>15</sup> The association between SHS and mental function is biologically plausible because nicotine is known to affect psychophysiological pathways that are relevant to mental health such as the dopaminergic system,<sup>16</sup> adrenocortical function,<sup>17</sup> and activation of neuroimmunological pathways that have been linked to depression.<sup>18</sup>

Using cross-sectional data, it is not possible to determine the direction of the association between SHS and mental health. That is, while SHS exposure might predict mental illness, it is equally likely that persons with mental illness seek or find themselves in social or working environments with ambient tobacco smoke. It is therefore very important to investigate these associations prospectively; however, to our knowledge, no such study exists. The aim of this study was to examine cross-sectional and longitudinal associations between objectively assessed SHS exposure and mental health in a large representative sample of adults from the Scottish Health Survey.

## METHODS

### STUDY DESIGN AND PARTICIPANTS

The Scottish Health Survey is a periodic survey (typically administered every 3-5 years) that draws a nationally representative sample of the general population living in households.<sup>19</sup> Sampling was made using a multistage stratified probability approach with postcode sectors selected at the first stage and household addresses selected at the second stage. Stratification was based on geographical areas and not on individual characteristics of the population. For the present analyses, we used data from the 1998 and 2003 surveys, where the response rates were 77% and 67%, respectively. The initial sample consisted of 9500 adults older than 18 years who had provided a salivary cotinine sample; after the exclusion of participants with a history of psychiatric hospital admissions ( $n=158$ ) as recorded at study baseline and participants with missing data on other covariates ( $n=1187$ ), the complete analytical sample consisted of 8155 participants (4321 women). Excluded participants were older ( $P<.001$ ), displayed higher cotinine values ( $P=.02$ ) and greater levels of psychological distress ( $P<.001$ ), and had a higher prevalence of long-standing illness ( $P<.001$ ). Participants gave full informed consent to participate in the study, and ethical approval was obtained from the London Research Ethics Council. Trained interviewers visited households, and interviewing was conducted using computer-assisted personal interviewing.

### MENTAL HEALTH AND PSYCHIATRIC ADMISSION

In the cross-sectional survey, mental health was assessed using the 12-item version of the General Health Questionnaire, which is a measure of psychological distress devised for population studies.<sup>20</sup> The questionnaire inquires about general level of happi-

ness, experience of depressive and anxiety symptoms, and sleep disturbance over the last 4 weeks. Interpretation of the responses is based on a 4-point response scale scored using a bimodal method (symptom present: not at all=0, same as usual=0, more than usual=1, and much more than usual=1). The 12-item General Health Questionnaire is a highly validated instrument and has been strongly associated with various psychological disorders such as depression and anxiety.<sup>20</sup> The surveys were prospectively linked to a patient-based database of hospital admissions up to December 31, 2007 (Information Services Division Scotland, Edinburgh, Scotland). We obtained admission dates for psychiatric episodes (from 1980 onward) and a diagnosis based on the *International Statistical Classification of Diseases, 10th Revision* as described elsewhere.<sup>21</sup>

### ASSESSMENT OF DIRECT SMOKE AND SHS EXPOSURE

Data on self-reported smoking were collected using standard methods (current smoker, ex-smoker, or never smoker). Exposure to SHS was assessed using the salivary cotinine level, which is a reliable and valid circulating biochemical marker of nicotine exposure.<sup>22</sup> A dental roll saturated with the participant's saliva was placed in a tube and later analyzed using a Hewlett Packard hp5890 gas chromatograph (Hewlett Packard, Palo Alto, California) with a rapid liquid chromatography technique. The technique had a coefficient of variation of less than 7%. All valid cotinine values were obtained from saliva samples with sufficient volume to undertake the assay and with no evidence of contamination. In keeping with other analyses,<sup>7,23</sup> participants reporting nonsmoking status but with salivary cotinine levels of 15.00  $\mu\text{g/L}$  or higher (to convert to nanomoles per liter, multiply by 5.675) were recategorized as smokers ( $n=310$ ).

### DEMOGRAPHIC CHARACTERISTICS

Interviewers measured height and weight for the calculation of body mass index (BMI; calculated as weight in kilograms divided by height in meters squared). Inquiries were also made regarding demographic and health-related issues such as physical activity, alcohol intake, presence of long-standing illness, and social status. Socioeconomic status was assessed using the Registrar General Classification (professional/intermediate, skilled nonmanual, skilled manual, part-skilled/unskilled), a standard approach in the United Kingdom.<sup>24</sup>

### STATISTICAL ANALYSIS

Exposure to nicotine was categorized into 5 groups: low SHS exposure (reference group; salivary cotinine level below the detectable limit,  $\leq 0.05 \mu\text{g/L}$ ); low to moderate SHS exposure (salivary cotinine level 0.06-0.30  $\mu\text{g/L}$ ); moderate SHS exposure (salivary cotinine level 0.31-0.70  $\mu\text{g/L}$ ); high SHS exposure (salivary cotinine level 0.71-14.99  $\mu\text{g/L}$ ); and current smoker (based on self-report or salivary cotinine level  $\geq 15.00 \mu\text{g/L}$ ). This categorization of SHS exposure was based on previous evidence for health effects at this level of exposure.<sup>7,10</sup> The nonsmoking group consisted of both never smokers and ex-smokers. Given the skewed distribution of the 12-item General Health Questionnaire score, we used a cutoff score of higher than 3 to denote psychological distress, which has been previously validated.<sup>20</sup>

We used logistic regression analyses to compute odds ratios (ORs) with accompanying 95% confidence intervals (CIs) for the association between cotinine categories and psychological distress. We fitted several models that included basic adjustment for age and a fully adjusted model adding in sex, physical activity cat-

**Table 1. Baseline Characteristics in Relation to Nicotine Exposure (Salivary Cotinine Level) in 8155 Study Participants**

Variable	Nonsmokers by Salivary Cotinine Level				Smokers, With Salivary Cotinine Level ≥15.00 µg/L (n=2595)	P Value for Overall Trend	P Value for Trend in Nonsmokers
	≤0.05 µg/L (n=823)	0.06-0.30 µg/L (n=1663)	0.31-0.70 µg/L (n=1253)	0.71-14.99 µg/L (n=1821)			
Age, mean (SD), y	52.7 (14.9)	50.1 (15.0)	49.5 (15.5)	48.4 (15.8)	44.8 (14.8)	<.001	<.001
Male, %	39.1	41.8	45.5	51.7	50.2	<.001	<.001
Social status IV or V, %	15.5	15.7	19.1	22.7	28.8	<.001	<.001
No physical activity, %	22.5	20.7	20.1	25.8	24.9	.01	.01
Unsafe alcohol intake, % <sup>a</sup>	13.4	13.4	19.4	23.6	28.6	<.001	<.001
Chronic illness, % <sup>b</sup>	44.2	40.7	40.1	44.5	43.4	.03	.03
BMI, mean (SD)	27.2 (4.9)	27.2 (4.8)	27.6 (4.9)	28.1 (5.1)	26.3 (4.9)	<.001	<.001

Abbreviation: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared).

SI conversion factor: To convert salivary cotinine level to nanomoles per liter, multiply by 5.675.

<sup>a</sup>Unsafe alcohol intake refers to more than 14 units/wk in women and more than 21 units/wk in men.

<sup>b</sup>Self-reported chronic illness includes heart disease, hypertension, diabetes, cancer, neuromuscular conditions, endocrine or metabolic conditions, epilepsy, bronchitis, asthma, other respiratory disorders, and illnesses related to the stomach, digestive system, and bowel.

egory (activity for ≥30 minutes at a frequency of 0, <1, 1-2, 3-4, or ≥5 times per week), alcohol intake (nondrinker, moderate, or above safe limit), BMI, social status, and long-standing illness. In the fully adjusted model, all covariables were entered simultaneously. We fitted a sex × cotinine level category interaction term into the logistic regression models to assess effect modification. Having first ascertained that the proportional hazards assumption had not been violated, with hospital admission for a psychiatric admission as the outcome of interest we used Cox proportional hazards models to compute hazard ratios with accompanying 95% CIs for the association with cotinine levels. In these analyses, the reference group contained participants with salivary cotinine values of 0.70 µg/L or lower. Months were the time scale; for participants with no record of an event, the data were censored at December 31, 2007. Adjustments were made similar to those just described, with baseline psychological distress included as an additional covariate. All analyses were conducted using SPSS version 14 statistical software (SPSS Inc, Chicago, Illinois).

## RESULTS

In the present sample, 31.8% of the participants were classified as current smokers and psychological distress was apparent in 14.5% of the entire sample. Based on purely self-reported information, the medians for salivary cotinine levels were 0.4 µg/L in never smokers, 0.5 µg/L in ex-smokers, 272.5 µg/L in moderate smokers (<20 cigarettes per day), and 380.8 µg/L in heavy smokers (≥20 cigarettes per day). Among nonsmokers (including never smokers and ex-smokers), higher cotinine values were found in younger adults and were associated with lower social status, higher BMI, presence of chronic illness, lower physical activity, and higher alcohol intake (**Table 1**). Smokers tended to be younger than nonsmokers, have a lower BMI, belong to lower social status groups, and have higher alcohol intake.

In **Table 2**, we show the cross-sectional relationship between cotinine level and psychological distress as assessed using the 12-item General Health Questionnaire. In age-adjusted analyses, adults with a higher cotinine level had an elevated risk of psychological distress, and this association was incremental across the

cotinine categories. This strong gradient essentially persisted after adjustment for a wide range of possible confounders. In multivariate models, other factors associated with psychological distress included physical activity (for ≥30 minutes of physical activity ≥5 times per week vs none: OR=0.48; 95% CI, 0.40-0.58), alcohol intake (for moderate vs none: OR=0.78; 95% CI, 0.66-0.91), and long-standing illness (OR=2.71; 95% CI, 2.36-3.11). Because there was an interaction between sex and cotinine category ( $P < .001$ ), we also present analyses separately for men and women. In both sexes, a positive cotinine level–psychological distress relationship was apparent; however, effects were stronger for men than for women, where statistical significance at conventional levels was not apparent. When we repeated analyses among never smokers (n=3515), the results remained largely unchanged, demonstrating an elevated risk of distress in participants with high cotinine levels (>0.70 and <15.00 µg/L) (age-adjusted OR=1.93; 95% CI, 1.35-2.75).

In prospective analyses, we examined the association between cotinine level and risk of psychiatric hospital admissions. There were 41 new admissions over an average follow-up of 5.9 years (range, 2 months to 8.3 years), consisting of events related to depressive episodes (n=14), psychoactive substance abuse (n=13), schizophrenia (n=3), nonspecific delirium (n=4), diseases related to the nervous system (n=3), and suspected mental and behavioral disorder (n=4). In comparison with low SHS exposure (cotinine level ≤0.70 µg/L), there was an increased risk for a psychiatric admission in participants with high SHS exposure (hazard ratio=2.84; 95% CI, 1.07-7.59) and current smokers (hazard ratio=3.74; 95% CI, 1.55-8.98) after adjustment for age, sex, social status, BMI, chronic illness, psychological distress at baseline, physical activity, and alcohol intake. A cumulative survival plot of nicotine exposure on psychiatric events is displayed in the **Figure**. To address the issue of reverse causation, we removed 6 psychiatric admissions that occurred in the first year. In these analyses, the results were essentially unaltered (data not shown).

**Table 2. Association Between Nicotine Exposure and Risk of Psychological Distress at Baseline<sup>a</sup>**

Exposure Group by Salivary Cotinine Level, µg/L	Cases/Total Participants, No.	Age-Adjusted OR (95% CI)	Fully Adjusted OR (95% CI) <sup>b</sup>
Full cohort <sup>c</sup>			
Nonsmoker			
≤0.05	75/823	1 [Reference]	1 [Reference]
0.06-0.30	183/1663	1.23 (0.92-1.63)	1.23 (0.92-1.64)
0.31-0.70	146/1253	1.30 (0.97-1.75)	1.30 (0.96-1.75)
0.71-14.99	257/1821	1.62 (1.23-2.13)	1.49 (1.13-1.97)
Smoker, ≥15.00	520/2595	2.45 (1.89-3.17)	2.15 (1.64-2.80)
<i>P</i> value for overall trend		<.001	<.001
<i>P</i> value for trend in nonsmokers		.002	.12
Women			
Nonsmoker			
≤0.05	55/502	1 [Reference]	1 [Reference]
0.06-0.30	131/969	1.25 (0.89-1.74)	1.26 (0.88-1.74)
0.31-0.70	99/684	1.35 (0.95-1.92)	1.37 (0.93-1.91)
0.71-14.99	132/876	1.41 (1.00-1.97)	1.27 (0.84-1.67)
Smoker, ≥15.00	304/1290	2.39 (1.75-3.26)	2.16 (1.57-2.98)
<i>P</i> value for overall trend		<.001	<.001
<i>P</i> value for trend in nonsmokers		.25	.50
Men			
Nonsmoker			
≤0.05	20/321	1 [Reference]	1 [Reference]
0.06-0.30	52/694	1.23 (0.72-2.09)	1.25 (0.73-2.15)
0.31-0.70	47/569	1.37 (0.80-2.36)	1.34 (0.77-2.33)
0.71-14.99	125/945	2.34 (1.43-3.82)	2.13 (1.29-3.52)
Smoker, ≥15.00	216/1305	3.08 (1.91-4.97)	2.55 (1.56-4.17)
<i>P</i> value for overall trend		<.001	<.001
<i>P</i> value for trend in nonsmokers		<.001	.003

Abbreviations: CI, confidence interval; OR, odds ratio.

SI conversion factor: To convert salivary cotinine level to nanomoles per liter, multiply by 5.675.

<sup>a</sup>Psychological distress is defined by a 12-item General Health Questionnaire score higher than 3.

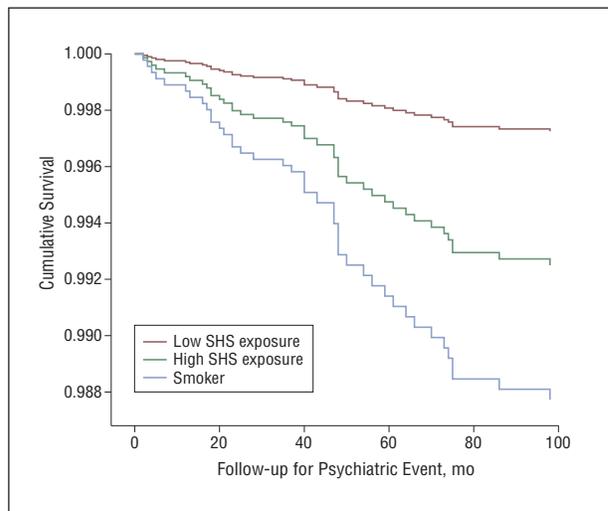
<sup>b</sup>The fully adjusted model adjusts for age, social status, body mass index, chronic illness, physical activity, and alcohol intake.

<sup>c</sup>The ORs in the full cohort are additionally adjusted for sex.

## COMMENT

The aim of this study was to examine cross-sectional and prospective associations of objectively assessed SHS exposure with mental health. Cross-sectionally, we found a robust dose-response association between nicotine exposure and psychological distress, which was apparent at low levels of SHS exposure and became stronger in current smokers. Importantly, this association was replicated in prospective analyses that demonstrated an association between SHS exposure, smoking, and risk of psychiatric episodes. These results were obtained using an objective biomarker of nicotine exposure, which demonstrated high validity when compared with self-reported smoking habit. The fact that the results of the age-adjusted and fully adjusted models were similar suggests that the associations were not accounted for by measured covariates. Although CIs were relatively large in some analyses, the effect sizes were substantial.

To our knowledge, only 1 previous study has examined the association between objectively measured SHS exposure and mental health.<sup>14</sup> It showed a cross-sectional association between SHS exposure and depressive symptoms in 2026 never-smoking men and women, which confirms our findings. However, the prospective nature of our study adds considerably to the current evidence base. A strong association between active smoking and depression is known to exist,<sup>12</sup> although the na-



**Figure.** Cumulative survival plot of nicotine exposure and risk of all incident psychiatric admissions (survival refers to the avoidance of a hospital admission for psychiatric illness). Low secondhand smoke (SHS) exposure, the reference group (n=3739), was defined as having a salivary cotinine level of 0.70 µg/L or lower; high SHS (n=1821), a salivary cotinine level of 0.71 to 14.99 µg/L; and active smokers (n=2595), self-report or a salivary cotinine level of 15.00 µg/L or higher. To convert salivary cotinine level to nanomoles per liter, multiply by 5.675.

ture of this association is difficult to interpret. In a cohort of Swedish participants, heavy smoking was associated with increased risk of suicide over 26 years of follow-

up, but the excess risk of suicide among smokers was almost entirely explained by an increased prevalence of heavy alcohol consumption and low mental well-being among the smokers.<sup>25</sup> In our analyses, the association between nicotine exposure and risk of psychiatric events persisted despite adjustment for psychological distress at baseline, which was in itself strongly associated with psychiatric admissions (hazard ratio=2.95; 95% CI, 1.52-5.73). Animal data have indicated that tobacco can induce negative mood,<sup>13</sup> suggesting that tobacco exposure may be a direct cause of psychiatric illness. In a small cohort of adolescents, smoking was associated with a higher risk of depressive episodes over 5 years of follow-up, which was partly explained by dysfunction of the hypothalamic-pituitary-adrenal axis.<sup>26</sup> Other biological mechanisms might include low-grade inflammation, which is elevated with SHS exposure<sup>7</sup> and associated with mood disorders such as depression.<sup>18</sup> In addition, the dopaminergic system may play a role. Smokers who are genetically predisposed to low resting intrasynaptic dopamine levels have heightened smoking-induced dopamine release,<sup>16</sup> which has been associated with greater depression and anxiety.<sup>27</sup> Thus, this genetic predisposition may also operate in relation to SHS exposure. Taken together, therefore, our data are consistent with other emerging evidence to suggest a causal role of nicotine exposure in mental health. One further possibility is that elevated cotinine levels in nonsmokers might reflect use of cannabis, which has also been associated with risk of psychosis.<sup>28</sup> Nevertheless, this is speculative because baseline data on cannabis use were not available in our study, preventing us from examining this issue.

The strengths of the study include the sampling of a large, representative, general population-based group, the objective measurement of SHS exposure, the well-characterized study members (facilitating insights into the role of potential confounding factors), and the prospective element of the study design. The limitations of the study should also be recognized. We did not have sufficient suicide deaths to facilitate a meaningful analysis. Given that much psychiatric illness is managed in primary care or in outpatient clinics, in our prospective analyses we only captured cases severe enough to warrant hospital admission. Thus, the presence of prevalent but unidentified psychiatric illness that did not lead to an inpatient stay may have introduced biases into our analyses. However, we attempted to address this issue in our cross-sectional analyses by examining associations with subclinical levels of psychological distress. The data were collected before the introduction of smoke-free legislation in Scotland; thus, it is not possible that this intervention affected our results. The smoking ban appears to have had a considerable effect on the health of the Scottish population,<sup>29</sup> although we were unable to estimate the effects of this intervention in these analyses because follow-up data on cotinine levels were not available. Owing to the lack of follow-up data on cotinine levels, we were also unable to account for the effects of changes in smoking behavior that are known to fluctuate over time. Further studies will be required to investigate the possible biological pathways through which SHS exposure influences mental health.

In summary, we found a robust dose-response association between objectively assessed nicotine exposure and psychological distress, which was apparent at low levels of SHS exposure and was strongest in current smokers. This association was replicated in prospective analyses that demonstrated an association between SHS exposure, active smoking, and risk of psychiatric episodes over 6 years of follow-up. To our knowledge, this is the first study to demonstrate a prospective association between objectively assessed SHS exposure and mental health in a representative sample of a general population.

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