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Indoor time–microenvironment–activity patterns in seven regions of Europe

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Personal exposure to environmental substances is largely determined by time–microenvironment–activity patterns while moving across locations or microenvironments. Therefore, time–microenvironment–activity data are particularly useful in modeling exposure. We investigated determinants of workday time–microenvironment–activity patterns of the adult urban population in seven European cities. The EXPOLIS study assessed workday time–microenvironment–activity patterns among a total of 1427 subjects (age 19–60 years) in Helsinki (Finland), Athens (Greece), Basel (Switzerland), Grenoble (France), Milan (Italy), Prague (Czech Republic), and Oxford (UK). Subjects completed time–microenvironment–activity diaries during two working days. We present time spent indoors — at home, at work, and elsewhere, and time exposed to tobacco smoke indoors for all cities. The contribution of sociodemographic factors has been assessed using regression models. More than 90% of the variance in indoor time–microenvironment–activity patterns originated from differences between and within subjects rather than between cities. The most common factors that were associated with indoor time–microenvironment–activity patterns, with similar contributions in all cities, were the specific work status, employment status, whether the participants were living alone, and whether the participants had children at home. Gender and season were associated with indoor time–microenvironment–activity patterns as well but the effects were rather heterogeneous across the seven cities. Exposure to second-hand tobacco smoke differed substantially across these cities. The heterogeneity of these factors across cities may reflect city-specific characteristics but selection biases in the sampled local populations may also explain part of the findings. Determinants of time–microenvironment–activity patterns need to be taken into account in exposure assessment, epidemiological analyses, exposure simulations, as well as in the development of preventive strategies that focus on time–microenvironment–activity patterns that ultimately determine exposures.
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Introduction

Time–microenvironment–activity (TMA) studies have become an integral part of exposure assessment and risk management (Quackenboss et al., 1986; Adair and Spengler, 1989; Schwab et al., 1990; Jenkins et al., 1992; Nelson et al., 1994; Ackermann-Liebrich et al., 1995; Robinson and Blaire, 1995; Dorre, 1997; Echols et al., 2001; Klepeis et al., 2001; Rotko et al., 2001; McCurdy and Graham, 2003; Graham and McCurdy, 2004). They are particularly appropriate for personal exposure prediction as human activities impact the timing, location, and level of personal pollutant exposure, and therefore play a key role in explaining exposure variation (Rotko et al., 2001). There have been several studies in the US in the last 2 decades that link daily activity to personal pollutant exposure including TEAM (Wallace, 1987), THEES (Freeman et al., 1991), and NHEXAS (Freeman et al., 1999). Further, time spent in indoor environments has been identified as a major contributor to personal exposure (Quackenboss et al., 1986; Adair and Spengler, 1989; Jenkins et al., 1992; Leech et al., 2002). Two recent studies (McCurdy and Graham, 2003; Graham and McCurdy, 2004) developed a condensation of several factors thought to influence human activity decisions and tested them against TMA data from the Consolidated Human Activity Database (CHAD), which was developed by the US Environmental Protection Agency's National Exposure Research Laboratory (NERL). They concluded that age, gender, different weather variables, and day type (weekend, weekday, vacation etc.) have the most influence the way people spend their time. The study

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was, however, not able to test an additional set of attributes, that are expected to be important determinants of TMA patterns, namely lifestyle and life stage considerations (Chapin, 1974; Altergott and McCreedy, 1993).

The EXPOLIS study used a standardized protocol to assess TMA patterns among adults in seven cities across different regions in Europe (Jantunen et al., 1998). In the current paper, we use the EXPOLIS database to investigate individual determinants of time spent in indoor microenvironments (mE) and the extent to which they differ across cities. We describe the distribution of time spent indoors in three different locations (home, work, and other), and major sociodemographic sources of variability in time spent in these three environments. In addition, as environmental tobacco smoke is an important indoor exposure, and its regulation still differs across Europe, we also present time exposed to ETS in the workplace and other indoor locations. To identify some of the factors contributing to the ETS exposure we present sociodemographic determinants of exposure to ETS and highlight comparisons across Europe. Furthermore, we characterize the magnitude of relative variation in time spent in all four mentioned microenvironments between cities, subjects, and days.

Methods

The EXPOLIS Study

Air Pollution Exposure Distributions of Adult Urban Populations in Europe (EXPOLIS) used uniform questionnaires and time–activity diaries in conjunction with personal monitoring of pollutant concentrations in several countries in Europe. Within the framework of the EXPOLIS study, TMA data of 1447 subjects in seven cities (Helsinki, Athens, Basel, Grenoble, Milan, Prague, and Oxford) had been collected between 1996 and 2000. In total, 543 (47–200 per centre) subjects completed a diary during the period of personal exposure measurement (exposure sample), whereas 904 (7–272 per centre) participated in a less demanding diary-only study (diary sample). The EXPOLIS design and methodology has been described in detail elsewhere (Jantunen et al., 1998; Koistinnen et al., 1999; Hänninen et al., 2004).

Forty-Eight-Hour Time–Microenvironment–Activity Diary

The development of the EXPOLIS TMA diary was based on prior studies (Robinson, 1988; Schwab et al.,. 1990; Freeman et al., 1999; Robertson et al., 1999). The TMA diary was collected during working days only, for example, from Monday morning to Wednesday morning (from 0600 to 0600) or from Wednesday evening to Friday evening (from 1800 to 1800) for 48 h. Subjects were asked to record in the TMA diary every 15 min of the day in the appropriate microenvironment–activity category. Multiple entries were allowed for each 15 min-segment. We then calculated for each participant how much time he/she spent in each mE (each 15-min segment was divided evenly between all entries).

We distinguish two aspects of an individual's TMA pattern during the sampling period: (1) whether the person enters a specific microenvironment at least once and therefore becomes what we call a 'habitué' of the corresponding microenvironment (McCurdy and Graham, 2003; Graham and McCurdy, 2004), and (2) the total duration of time spent in specific microenvironments. To investigate TMA patterns across subgroups and cities, we present four criteria: (1) the percentage of people (habitués) entering in each microenvironment, (2) the duration of participation by these habitués, (3) the determinants for becoming a habitué (participation), and (4) the determinants for the duration of time spent in each microenvironment by the corresponding habitués.

Statistical Analysis

For each participant, the average time spent per 24 h in each microenvironment/activity was calculated based on the 48 h sampling period. If not noted differently, all subsequent calculations were based on those means. Only diaries that covered between 22.5 and 24 h per sampling day were included in the analyses, leading to a total sample of 1427 out of 1447. Time spent in the two microenvironments *other indoor* and *ETS indoors away from home* were log-transformed because of the skewed nature of their distribution.

For each city's study sample, the fraction of habitués (participants that entered the corresponding microenvironment at least once during the sampling period) has been calculated as well as the habitués' mean of time spent in the different microenvironments per day. We present coefficients of variation (CoV = s.d./mean) as a measure for assessing within-population variability in time spent in different microenvironments (Schwab et al., 1990) (Table 1).

To assess the impact of selected sociodemographic and environmental factors on time spent by habitués in indoor microenvironments, we constructed multiple linear regression models. The average daily time spent by habitués in the three microenvironments *home indoor*, *work indoor*, and *other indoor* (all other indoor locations besides home and workplace) were used as dependent variables, and the covariates *gender*, *age*, *educational level*, *work status*, *employment status*, *household size*, *having children at home*, and *season* were used as independent variables. All covariates were dichotomized except the employment status, which consisted of three categories (see Table 2) and the categorical variable for the city (numbered 1–7). We chose a multivariate approach to avoid confounded results. All models were adjusted for sampling status and city. The sampling status refers to the two groups of participants in EXPOLIS: the exposure sample and the diary sample. As shown in previous studies,

Table 1. Time spent in various indoor locations among people reporting time (habitués).

	n	Min	Median	Max	Mean[a]	SD	Coefficient of variation (%)	Habitués' fraction of the study population (%)
Home indoors								
Helsinki	430	3.81	13.15	24.00	13.73	3.01	22	100
Athens	98	4.19	15.30	24.00	15.44	4.08	26	100
Basel	320	0.94	13.02	22.48	13.53	3.34	25	100
Grenoble	100	3.88	14.13	23.63	14.67	4.14	28	100
Milan	298	8.13	13.09	22.50	13.48	2.60	19	100
Prague	81	7.63	13.23	23.50	13.92	3.50	25	100
Oxford	100	2.75	15.19	24.00	15.76	3.17	20	100
All cities	1427	0.94	13.31	24.00	13.95	3.29	24	100
Work indoors								
Helsinki	370	0.07	7.48	11.04	6.83	2.15	31	86
Athens	67	1.19	6.13	13.06	5.90	2.34	40	68
Basel	266	0.13	7.38	13.31	6.67	2.50	37	83
Grenoble	79	0.38	7.00	13.25	6.73	2.62	39	79
Milan	267	0.25	7.50	12.19	7.09	2.14	30	90
Prague	71	0.75	7.50	10.50	6.52	2.68	41	88
Oxford	77	1.00	6.25	17.25	5.90	2.81	48	77
All cities	1197	0.07	7.29	16.63	6.71	2.37	35	84
Other indoors								
Helsinki	349	0.04	1.00	10.70	1.53	1.58	104	81
Athens	69	0.06	1.44	7.75	1.76	1.50	85	70
Basel	293	0.04	1.50	10.69	1.84	1.57	85	92
Grenoble	74	0.13	1.19	16.88	2.22	2.94	132	74
Milan	272	0.06	1.23	10.56	1.58	1.32	83	91
Prague	56	0.08	1.16	8.58	1.69	1.81	107	69
Oxford	69	0.13	0.81	6.25	1.30	1.31	101	69
All cities	1181	0.04	1.25	16.88	1.67	1.64	99	83
ETS indoors away from home, non-smokers only								
Helsinki	62	0.06	0.50	9.04	1.19	1.83	154	19
Athens	35	0.13	1.25	10.25	2.16	2.56	118	43
Basel	114	0.04	0.56	7.38	1.08	1.37	127	48
Grenoble	32	0.13	0.56	9.75	2.02	2.95	146	32
Milan	123	0.06	1.00	11.63	2.01	2.53	126	60
Prague	13	0.13	0.81	4.75	1.09	1.18	108	20
Oxford	6	0.13	0.13	1.38	0.41	0.51	124	7
All cities	385	0.42	0.75	11.63	1.56	2.16	139	35

Time expressed in hours per day.
[a]Means for total population can be calculated by multiplying the means with the decimal habitués' fraction of the study population.

participants tend to adapt their behavior depending on the demands made on them. (Robinson, 1988; Boudet et al., 1997; Gruffermann, 1999). This so-called "Hawthorne effect" was also described in the EXPOLIS study (Boudet et al., 1997). In the second step, multiple logistic regression models were used to assess the impact of these same factors mentioned above on engagement (yes/no) in the three microenvironments *work indoor*, *other indoor*, and *ETS indoors away from home among non-smokers*. We present results from the logistic and linear regressions by microenvironment.

Likelihood ratio (LR) tests were employed to test for heterogeneity across cities in the effects of specific factors on TMA, using appropriately constructed interaction terms in the models. The LR test is a statistical test of the goodness-of-fit between two models. A relatively more complex model (including the interaction terms) is compared to a simpler but nested model (without interaction terms) to see if it fits the data set significantly better. The Null hypothesis is that there is no interaction between cities and the corresponding factor. We report the corresponding *P*-values of these LR tests. Both bi-directional (positive and negative signs of associations in the different cities) and unidirectional (either only positive or only negative sign of associations in all cities) effects of different factors were assessed. We frequently observed significant cross-city heterogeneity in results and therefore

Table 2. Results of the multivariate linear regressions of selected factors by city on time spent at home indoors.

Dependent variable: time spent at home indoors (h/day)	Helsinki	Athens	Basel	Grenoble	Milan	Prague	Oxford	
n	411	98	311	93	293	78	95	
Adjusted R^2	0.50	0.57	0.41	0.24	0.54	0.37	0.47	
F test	41.82	13.69	22.79	4.23	34.88	5.58	12.82	
Prob > F	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	
Intercept	17.85	18.43	15.81	19.58	17.20	21.01	20.58	
Independent covariates[d,e]	Coefficients (95% confidence interval)							Heterogeneity among cities[a]
Gender								
0: female, 1: male	−0.83 (−1.26,−0.39)	−2.54 (−3.77,−1.30)	−1.05 (−1.66,−0.43)	−0.74 (−2.45, 0.98)	−0.73 (−1.16,−0.29)	0.21 (−1.18, 1.61)	−0.99 (−2.04, 0.05)	0.036
Age								
0: <40 years, 1: >40 years	0.16 (−0.26, 0.59)	0.71 (−0.44, 1.87)	0.57 (−0.02, 1.17)	−0.85 (−2.87, 1.16)	0.38 (−0.05, 0.81)	0.20 (−1.18, 1.58)	−0.60 (−1.62, 0.43)	0.472
Working status								
0: Not working, 1: working	−4.87 (−5.66, −4.08)	−3.12 (−4.86, −1.38)	−3.09 (−4.12, −2.05)	−4.25 (−6.50, −2.01)	−4.41 (−5.50, −3.31)	−6.24 (−9.40, −3.07)	−5.64 (−7.17, −4.10)	0.151
Education[b,c]								
0: Lower, 1: higher than mandatory	−0.29 (−0.74, 0.15)	0.21 (−1.21, 1.64)	0.08 (−0.53, 0.70)	−0.63 (−3.42, 2.16)	0.25 (−0.17, 0.68)	−1.30 (−3.79, 1.19)		0.385
Living alone[b]								
0: no, 1: yes	−0.13 (−0.75, 0.49)	−0.52 (−2.92, 1.88)	−0.58 (−1.31, 0.16)	−0.26 (−2.58, 2.06)	−0.36 (−1.11, 0.39)	−2.05 (−4.00, −0.11)		0.127
Employment status (ref: (self-) employed)								
Housewife	0.47 (−1.03, 1.98)	2.41 (0.40, 4.43)	2.25 (0.91, 3.59)	N/A	1.92 (0.74, 3.10)	2.72 (−1.90, 7.33)	−0.91 (−2.94, 1.12)	0.586
Student, unemployed	1.86 (0.99, 2.74)	1.38 (−0.81, 3.58)	2.04 (1.00, 3.07)	0.96 (−1.37, 3.28)	1.56 (0.73, 2.39)	−0.24 (−2.93, 2.46)	−0.66 (−3.53, 2.22)	0.586
Children at home[b]								
0: no, 1: yes	0.45 (−0.03, 0.93)	0.23 (−0.97, 1.43)	1.31 (0.62, 1.99)	−0.74 (−2.69, 1.22)	0.44 (−0.01, 0.89)	−0.85 (−2.33, 0.62)		0.016
Season[c]								
0: Winter, 1: summer	−0.84 (−1.31, −0.37)	−2.10 (−3.24, −0.96)	−0.51 (−1.11, 0.08)	0.24 (−1.38, 1.86)	−0.42 (−0.85, 0.00)	−0.57 (−1.89, 0.75)	0.33 (−1.10, 1.75)	0.013

Times in hours per day.
[a] *P*-values of likelihood-ratio tests for the null hypothesis that there is no interaction between cities and the corresponding factor.
[b] Not tested in Oxford (all participants were parents, nobody lived alone, and information about education was missing in more than 60% of all cases)
[c] City-specific categories.
[d] 'N/A' indicates no observations in the corresponding subgroup.
[e] Models are adjusted for sampling status (coded: 'exposure' = 1 or 'diary only' = 0).

present results by city (except for the microenvironments other indoor and ETS exposure away from home).

We partitioned the total variance in time spent in specific microenvironments between cities, within cities (between subjects) and within subjects (between days) using nested ANOVA. The estimated variance components for city, individual, and day were transformed into percentages. Furthermore, we calculated the intraclass correlation statistic (ICC) according to the Spearman–Brown formula to assess the reliability of the 2-day mean (Shrout and Fleiss, 1979; McGraw and Wong, 1996; Baranowski and de Moor, 2000; Xue et al., 2004). An ICC expresses the between subject variability as a fraction of the variability between and within subjects. The lower the ratio, the less representative the 2-day mean, and more repeat measurements are required to derive a valid estimate of individual TMA. Assumptions have to be made regarding the between and within subject variance/covariance structure to calculate an ICC. We also calculated the number of sampling days required to achieve a desired level of reliability of 0.8 and 0.9 using the Spearman–Brown prophecy formula (Shrout and Fleiss, 1979; Xue et al., 2004). All participants with two valid sampling days were included in the analyses.

To assess potential structural patterns of missing diary data, which could have resulted in biases in the statistical analyses that were undertaken, two additional analyses were conducted: (1) comparison of the various time budgets of the study sample with complete 24 h diaries with the study population with incomplete diaries and (2) linear regression of the factors used in the statistical analyses on the missing time in the diaries. Significant differences were only found between cities. Participants in Helsinki and Oxford were slightly more likely to provide incomplete diaries. However, in order to keep adequate statistical power in our analyses, we decided to keep all diaries with more than 22.5 h coverage per day. We found most of the missing time to most likely be attributable to the two microenvironments *home indoor* and *other indoor*. Therefore, the observed cross-city heterogeneities in these two microenvironments could in part originate from this measurement error and should be interpreted with caution.

All statistical analyses were performed with Stata© Version 8.2 for PC except for the Analysis of Variance which was performed using SAS© Version 9.0 for PC.

Results

Table 1 presents the distribution of time spent in indoor locations (home, work, and other) by city. It only includes data of habitués.

Home indoor dominated time spent in indoor locations with 100% habitués in all seven cities and with averages ranging from 13.5 h/day in Milan to 15.8 h/day in Oxford, or 56% to 66% of a day. The coefficient of variation was low with values between 19% in Milan and 28% in Grenoble. Table 2 presents the effects of the factors in the multiple linear regression models on total time spent indoors at home. The most dominant, that is, in most cities significant, factors were *gender* and *work status*. The effect of *gender* is qualitatively the same in all seven cities with men spending less time at home indoors than women. The extent varies between the cities, leading to a significant interaction between city and gender (P-value LR test = 0.036). The effect of being male is strongest in Athens (slope of −2.54, $P<0.01$) and slightly reversed in Prague (0.21, $P>0.1$). Participants who worked away from home spent much less time at home indoors with an average difference of between −6.24 h/day ($P<0.01$) in Prague and −3.09 h/day ($P<0.01$) in Basel. Employed or self-employed participants spent significantly less time at home than housewives (except in Oxford), unemployed and students (except in Prague and Oxford). The effect of *age* only became significant in Basel and Milan with people older than 40 years spending 0.6 and 0.4 h/day more time at home, respectively. In Grenoble and Oxford *age*, influenced time spent indoors at home non-significantly in the opposite direction. People with children living in the same household tended to spend between 0.23 h/day (Athens, $P>0.1$) and 1.31 h/day (Basel, $P<0.01$) more at home indoors. However, in Grenoble and Prague this effect was inverted, causing a statistically significant heterogeneity among the cities (P-value LR test = 0.016). The participants spent between 0.42 h/day (Milan, $P<0.1$) and 2.1 h/day (Athens, $P<0.01$) less time indoors at home during the summer months, except in Grenoble and Oxford (statistically significant heterogeneity among the cities, P-value LR test = 0.013). The effect of *living alone* was non-significant (except in Prague) but unidirectional, with people who lived alone spending less time at home indoors. This effect ranged from −2.09 h/day in Prague ($P<0.01$) to −0.09 h/day in Helsinki ($P>0.1$). No statistically significant or consistent unidirectional effect of education level was noticeable.

Work Indoor

On average, 84% of participants worked indoors away from home at least once during the sampling period. We noticed a strong and unidirectional effect (logistic regression model, not shown) of *gender* and *level of education* on spending time at work indoor at least once during the sampling period. Men and more highly educated participants were more likely to work away from home, as were participants who were *living alone*. Participants with *children at home* were less likely to work indoors away from home. The median time per day at work indoors among the habitués ranged from 6.1 h/day in Athens to 7.5 h/day in Milan and Prague. Table 3 describes the coefficients of the multiple linear regressions for total time spent at work indoors among habitués. Men worked longer away from home than women in all cities except Helsinki and

Table 3. Results of the multivariate linear regressions of selected factors by city on time spent at the workplace among habitués only.

Dependent variable: time spent at work indoors (h/day)	Helsinki	Athens	Basel	Grenoble	Milan	Prague	Oxford	
n	353	67	261	72	262	69	73	
Adjusted R^2	0.04	0.09	0.22	0.07	0.21	0.07	0.11	
F test	2.95	1.84	9.12	1.70	8.66	1.68	2.70	
Prob > F	0.003	0.088	<0.001	0.115	<0.001	0.122	0.028	
Intercept	7.36	5.23	7.65	5.24	7.46	5.42	5.07	
Independent Covariates[d,e]	Coefficients (95% Confidence interval)							Heterogeneity among cities[a]
Gender								
0: female, 1: male	−0.60 (−1.04, −0.16)	0.96 (−0.19, 2.11)	0.67 (0.09, 1.24)	0.40 (−1.01, 1.81)	0.09 (−0.39, 0.57)	−1.64 (−2.95, −0.33)	1.98 (0.70, 3.26)	<0.001
Age								
0: <40 years, 1: >40 years	−0.26 (−0.70, 0.19)	−0.12 (−1.30, 1.05)	−0.77 (−1.34, −0.21)	0.68 (−0.91, 2.26)	0.09 (−0.40, 0.57)	0.74 (−0.59, 2.06)	0.21 (−1.06, 1.47)	0.213
Education[b,c]								
0: lower, 1: higher than mandatory	−0.10 (−0.57, 0.36)	0.03 (−1.40, 1.46)	−0.14 (−0.72, 0.45)	0.29 (−1.91, 2.49)	−0.29 (−0.78, 0.19)	0.79 (−1.69, 3.27)		0.616
Living alone[b]								
0: no, 1: yes	0.15 (−0.49, 0.80)	0.30 (−1.78, 2.37)	−0.39 (−1.07, 0.29)	−0.85 (−2.92, 1.22)	0.23 (−0.59, 1.06)	1.98 (0.15, 3.82)		0.122
Employment status (ref: (self-) employed)								
Housewife	N/A	N/A	−4.22 (−6.27, −2.17)	N/A	−5.52 (−7.47, −3.57)	N/A	−2.06 (−5.92, 1.79)	0.071
Student, unemployed	−2.22 (−3.43, −1.00)	−0.71 (−3.31, 1.88)	−2.90 (−3.97, −1.84)	−2.13 (−4.04, −0.22)	−3.13 (−4.11, −2.15)	0.68 (−2.27, 3.63)	N/A	0.071
Children at home[b]								
0: no, 1: yes	−0.08 (−0.57, 0.42)	−0.77 (−1.97, 0.43)	−1.16 (−1.81, −0.51)	−0.15 (−1.58, 1.28)	−0.34 (−0.86, 0.17)	0.59 (−0.85, 2.04)		0.136
Season[c]								
0: winter, 1: summer	0.43 (−0.06, 0.92)	1.51 (0.34, 2.68)	−0.30 (−0.86, 0.27)	0.14 (−1.13, 1.42)	0.16 (−0.32, 0.63)	0.27 (−1.03, 1.57)	−0.24 (−1.96, 1.49)	0.039

Times in hours per day.

[a] *P*-values of likelihood-ratio tests for the null hypothesis that there is no interaction between cities and the corresponding factor.

[b] Not tested in Oxford (all participants were parents, nobody lived alone, and information about education was missing in more than 60% of all cases).

[c] City-specific categories.

[d] 'N/A' indicates no observations in the corresponding subgroup.

[e] Models are adjusted for sampling status (coded: 'exposure' = 1 or 'diary only' = 0).

Prague. Moreover, we found participants with children at home spent less time at work (except in Prague) and participants generally spent more time at work indoors in the summer than in winter (except in Basel and Oxford). These two effects, however, were only significant in Basel as well as in Helsinki and Athens, respectively. In an extended analysis (data not shown) we also found the workplace location to be an important discriminating factor, with participants who work in industrial areas spending more time at their indoor workplaces. *Living alone* significantly affected time at work only in Prague (1.98, $P<0.05$). A*ge* and *education* were not significant predictors.

Indoor At Other Places Than Home Or Work

An average of 83% of all participants spent at least some time in indoor locations besides home or workplaces during the sampling period. Results from the logistic regression of spending any time in other indoor locations (data not shown) indicate that men were generally less likely to spend any time in other indoor locations. This effect is very stable and especially strong in Helsinki and Oxford. The participants' *age* had no apparent influence. Work and employment status both seemed to be influential, however, without any common pattern across cities. More highly educated participants were more likely to spend time in other indoor locations. In all seven cities, participants with *children at home,* were less likely to go to other indoor places. *Living alone* exhibited a similar influence with exceptions for Grenoble and Prague. In addition, people were overall less likely to stay in other indoor places in the summer months. However, this effect is bi-directional (ORs below and above 1 in the different cities). Participants in Helsinki were significantly less likely and participants in Prague significantly more likely to spend time in other indoor locations. People working away from home also tended to be less likely to go to other indoor places except in Athens and Oxford. No apparent effect by the employment status could be observed. As can be seen from Table 1, the mean values for total time spent in other indoor locations by habitués are between 1.3 h/day in Oxford and 2.2 h/day in Grenoble, but the CoVs are quite high: 83% to 132%. The factors that we found to be associated with total time spent indoors away from home by habitués (Table 4) were similar in all cities with one exception: working subjects in Prague and Oxford spent more time in other indoor environments. The multivariate linear regression model (Table 4) is based on pooled data from all cities. In short, we found significant positive associations for men, more highly educated participants, participants living alone, unemployed participants and students. Participants with children at home commonly spent shorter periods of time in other indoor locations. Working away from home also led to significantly less time in other indoor locations in Helsinki, Basel, and Milan. Also, time spent in this microenvironment was significantly shorter in summer.

Table 4. Results of the multivariate linear regression on the natural logarithm of time spent per day indoors in other places than home or work among habitués only

	Dependent variable: time spent in other indoor places [ln(hrs/d)]
N	1103
R^2	0.08
F test	5.43
Prob > F	<0.001
Constant	0.34 (−0.01, 0.69)
Independent covariates[c]	*Coefficients (95% confidence interval)*
Gender	
0: female, 1: male	0.14 (0.02, 0.26)
Age	
0: <40 years, 1: >40 years	−0.08 (−0.20, 0.04)
Education[a,b]	
0: Lower 1: higher than mandatory	0.21 (0.08, 0.33)
Living alone[b]	
0: no, 1: yes	0.35 (0.18, 0.52)
Employment status	
1: Housewife	0.03 (−0.29, 0.34)
Reference: (self-) employed	
2: Student, unemployed	0.23 (0.02, 0.44)
Children at home[b]	
0: no, 1: yes	−0.13 (−0.26, 0.00)
Season[a]	
0: Winter, 1: summer	−0.12 (−0.24, 0.00)
Working status	
0: Not working, 1: working	
In Helsinki	−0.53 (−0.86, −0.20)
In Athens	−0.13 (−0.70, 0.44)
In Basel	−0.49 (−0.83, −0.15)
In Grenoble	0.07 (−0.46, 0.59)
In Milan	−0.49 (−0.92, −0.05)
In Prague	0.44 (−0.40, 1.27)
In Oxford	0.44 (−0.50, 1.39)

Times in hours per day.
[a]City-specific categories.
[b]Not tested in Oxford (all participants were parents, nobody lived alone, and information about education was missing in more than 60% of all cases).
[c]Model is adjusted for city (coded: 1 to 7) and sampling status (coded: 'exposure' = 1 or 'diary only' = 0).

Non-Smokers Exposed To ETS Indoors Away From Home

The fraction of non-smokers exposed to ETS indoors away from home (at work or other places) varied significantly among the cities with values between 6% in Oxford and 60% in Milan (Table 1). Table 5 shows the results from the logistic regression and indicates associations between ETS exposure and *gender*, *age*, *work status*, *education*, and *having children at home*. No significant heterogeneity among the seven cities was detected (LR test). We therefore present one model based on all cities. Male non-smokers were significantly more likely to report any indoor ETS exposure than female non-smokers. Non-smokers who worked on the sampling days were more likely to get exposed to ETS away from home (except in Helsinki and Oxford where we found no difference, data not shown). Participants older than 40 years, participants living with children in the same household, and more highly educated participants were generally less likely to be exposed to ETS. No significant or unidirectional effects were observed for *season*, *whether someone lived alone*, or for *unemployed participants* and *students*. The median time per day of the habitués ranges from 0.13 h/day in Oxford to 1.25 h/day in Athens. Some additional analyses (data not shown) revealed that non-smokers who were only exposed to ETS in the workplace (12% of all non-smokers) were exposed for an average of 1.9 h/day. On the other hand, non-smokers who were only exposed to ETS in other indoor locations (16% of all non-smokers) were exposed on average for less than 0.9 h/day. If exposed to ETS at work and other indoor locations (7% of all non-smokers), the average exposure time was 2.5 h/day.

Table 5. Results of the multivariate logistic regression of selected factors on the occurrence of ETS exposure indoors away from home among non-smokers.

	Dependent variable: occurrence of ETS exposure indoors away from home (yes/no)
n	1028
Pseudo R^2	0.15
LR χ^2 (df)	197.16 (16)
Prob $> \chi^2$	<0.001
Independent Covariates[c]	Odds Ratios (95% Confidence Interval)
Gender	
0: female, 1: male	1.52 (1.13, 2.03)
Age	
0: <40 years, 1: >40 years	0.76 (0.56, 1.01)
Education[a,b]	
0: Lower 1: higher than mandatory	0.62 (0.45, 0.85)
Living alone[b]	
0: no, 1: yes	0.98 (0.65, 1.49)
Employment status	
1: Housewife	0.42 (0.19, 0.93)
Reference: (self-) employed	
2: Student, unemployed	0.95 (0.56, 1.60)
Children at home[b]	
0: no, 1: yes	0.66 (0.48, 0.91)
Season[a]	
0: Winter, 1: summer	0.91 (0.68, 1.21)
Working status	
0: Not working, 1: working	1.68 (0.98, 2.88)

[a]City-specific categories.
[b]Not tested in Oxford (all participants were parents, nobody lived alone, and information about education was missing in more than 60% of all cases).
[c]Model is adjusted for city (coded: 1 through 7) and sampling status (coded: 'exposure' = 1 or 'diary only' = 0).

Relative Variability Between Cities, Subjects, and Days

The results of the nested ANOVA in Table 6 indicates that most of the total variance in time spent in various indoor microenvironments stems from differences among participants, with the exception of other indoor. For this microenvironment, substantial differences were observed between the two sampling days (approximately 71% of total variance). Time spent exposed to ETS away from home and time spent at work show the lowest relative day-to-day variability. This leads to an estimated reliability of the 2-day mean of 0.85 and 0.84, respectively. The estimated reliability for *other indoor* was the lowest (0.45). The number of sampling days needed to reach a reliability of 0.8 for the multi-day-mean is 2 for the mE *work indoor* and *ETS indoor away from home*, 3 for the mE *home indoor*, and 10 for the mE *other indoor*.

Table 6. Variance (in % of total) explained by city, subject, and day (sampling day within subject) for the daily time spent in the indoor environments (using both sampling days) and the estimated reliability of the 2-day mean. All participants (habitués and non-habitués) are included

	Home indoor ($n = 1356$)	Work indoor ($n = 1356$)	Other indoor ($n = 1356$)	ETS indoors away from home among non-smokers ($n = 1114$)
Between cities	3.8%	3.2%	1.0%	7.2%
Between subjects	55.9%	69.6%	28.2%	67.4%
Between days (within subjects)	40.3%	27.2%	70.8%%	25.4%
Estimated reliability of 2-day mean[a]	0.75	0.84	0.45	0.86
Number of days needed to reach reliability of 0.80/0.90[b]	3/7	2/4	10/22	2/3

[a]Estimated using the Spearman–Brown formula and the appropriate ICC index (derived from between and within subject variance), desirably above 0.8 (Shrout and Fleiss, 1979).
[b]Estimated using the Spearman–Brown prophecy formula (Shrout and Fleiss, 1979).

Discussion

Models to predict personal exposure rely on the characterization of activity patterns of the population at risk as human activities impact the timing, location, and level of personal pollutant exposure. This is especially important for evaluation of public policies and urban planning that may change behavior of individuals, resulting in a concurrent shift in the patterns of exposure experienced by the population. This paper addresses several key aspects in the use of time activity information in exposure simulation studies by evaluating sources of variability in European cities and whether data from one city can be generalized to other locations in Europe. The current study indicates both opportunities and limitations of generalizing results. We characterized variability of time spent by the adult urban European population in four different indoor environments on an average workday (mean of two consecutive workdays) in seven European cities. Data were gathered in a uniform way in seven different regions of Europe, allowing us to capitalize on a large data set, and to assess heterogeneity across geographical regions. In this analysis, we confirmed that sociodemographic and environmental factors are associated with workday TMA patterns in seven European cities. We showed substantial heterogeneity in TMA across subgroups by *gender*, *education*, *work status*, *employment status*, *living alone*, *having children at home*, and *season*. Additionally, we observed that the variability in workday TMA patterns was largely driven by the differences between days and subjects rather than between cities. However, the specific relevance of the above mentioned factors, that are associated with TMA patterns, varied substantially among the cities.

Previous US-based studies have reported *age* and *gender* as primary attributes which influence TMA patterns in the general population (Schwab et al., 1989, 1990; Johnson et al., 1995; Echols et al., 1999; McCurdy and Graham, 2003; Graham and McCurdy, 2004). In addition, total time spent indoors also depends on meteorological conditions and day-type (McCurdy and Graham, 2003; Graham and McCurdy, 2004). As shown in our study, sociodemographic parameters (besides *age* and *gender*) explain a further fraction of the variability when only focusing on workdays.

The most common factors found to be associated with indoor TMA patterns in this study are *gender*, *work status*, *employment status*, *living alone*, *children at home*, and *season*. Out of these, *work status*, *employment status*, *living alone*, and *children at home* often exhibited the same qualitative effect in all seven cities. Only in Grenoble did we find reversed effects of the two factors *living alone* and *children at home* on time spent indoors at work and at home compared to the other cities. As discussed below, city-specific selection biases may be a source of this observed heterogeneity.

The relevance of *gender* was rather heterogeneous across the surveyed cities. In this study, the role of women in the workforce differs across Europe and can primarily be divided into two groups with opposing effects: (1) Helsinki and Prague, where working women spent more time at work than their male counterparts and (2) Athens, Basel, Grenoble, Milan, and Oxford, where the situation was reversed. Recent comparisons between 13 European countries found men to generally work longer than women (Eurostat, 2003). However, this gender-related difference is not equally large in all countries. In Finland, the difference is particularly small (Eurostat, 2004; ExpoFacts, 2005). Some of the differences between women and men found in this study might also represent a particularity of urban populations that is less present in rural areas. The findings that women spend more time than men home indoors and less time in other indoor places are in line with surveys in other European countries (Eurostat, 2004). The authors caution against generalizing gender-related effects in TMA patterns from one city to another.

Unlike in previous studies, *age* did not contribute to TMA patterns in our study as significantly as often described elsewhere. However, the range of age in our study population was much more restricted than in other studies where differences in TMA patterns were mostly detected between childhood, working age, and older ages (McCurdy and Graham, 2003; Graham and McCurdy, 2004). For example, McCurdy used the ages 16–54 years as one single age group and Graham found the two age categories 21–44 and 45–65 years to be ‘‘indistinguishable’’ (in regards to time spent outdoors). It has been shown in the past that transition status, rather than age itself, tends to account for most of the variation in patterns of time use among young adults (Szalai, 1972). Nevertheless, trends of spending more time at home and less time in other indoor places besides home and work with increasing age can still be observed and are in accordance with recent surveys in Europe (Eurostat, 2004).

The general occupational situation often affected TMA patterns in addition to the specific work situation on the sampling days. Apparently, participants who were employed spent time differently, even on their days off, compared to unemployed, housewives, and students. Persons who are employed have more of their time predetermined and generally reduce their time spent at home and in other places than home, workplace, or transit (Eurostat, 2004).

Having children at home and living alone are two further factors that influence TMA patterns and, thus, exposures determined by TMA. Raising children leads to more time being spent at home and less at work and in other indoor places. In detail, it is mostly the women that adapt their schedules to their children by spending more time at home and less time at work and other indoor places (Eurostat, 2004). This was already shown in early time use studies and has recently been confirmed in many European countries (Szalai, 1975; Eurostat, 2005).

A higher than mandatory level of education was only associated with less ETS exposure and generally spending more time in other indoor places than home or work. Else, TMA patterns were not associated with educational status.

Season affected TMA pattern differently among the cities. Weather and climatic conditions are, however, known to affect time–activity decisions of humans primarily in regards to total time spent indoors or outdoors (Ott, 1989; Johnson et al., 1995; Echols et al., 1999; McCurdy and Graham, 2003; Graham and McCurdy, 2004). Geographical differences in this effect have not been found previously. In EXPOLIS, weather information was not available for all cities, and therefore season was used as a surrogate for the general climatic situation. We suspect that this simplification caused the heterogeneity in the effect of season as in some cities, similar weather conditions can arise in all seasons. Also, while the weather certainly influences the total time spent outdoors, we expect the split between indoor microenvironments to be less affected, particularly during working days.

In the search for ETS exposure mitigation strategies among non-smokers, it is important to identify the microenvironments that contribute the most to total exposures. We focused on indoor locations away from home, as these may be better suited for regulation. Our results highlight the need to strengthen workplace smoking regulation as it reflects the key determinant for ETS exposure away from the home. Differences in ETS exposure across Europe are substantial. Occurrence of ETS exposure was more likely in other indoor locations than work. On average, however, these events were much shorter. Although concentrations of tobacco smoke in each microenvironment require evaluation, exposure to ETS in the workplace clearly remains a priority for exposure reduction strategies. Non-smokers who worked away from home were more likely to get exposed to ETS indoors away from home in all cities except Helsinki and Oxford. This is most likely the result of strict regulations for protection of non-smokers at workplaces in Finland since the 1980s. Additionally, all Oxford participants were parents, a group that reported less ETS exposure in all cities (c.f. the effect of *children at home* and the fraction of participants getting exposed to ETS indoors away from home in Oxford).

Besides the variability in the study population's time spent in the various indoor environments, which was caused by sociodemographic factors, we also found substantial day-to-day variability in individual time–activity. Common for all microenvironments is a small relative contribution of the between cities variance to the total variability (compared to between subjects and days). Approximately 95% of variance stems from differences within the cities and within the individuals (between sampling days) in all analyzed microenvironments, with the exception of *indoor ETS exposure* and *work indoors*. These two time–microenvironment–activities differ the least between workdays. The relative variability (fraction of total variability) between individuals in time spent in the home and other indoor locations is not as great as for work indoors and indoor ETS exposure. Time spent in other indoor locations is most unstable within individuals (between sampling days) and usually competes directly with time spent at home indoors. It is important to note that although the differences between cities contribute only little to the total variability they are nevertheless significant. The observed variability between days has implications for the estimates of individual's TMA patterns when they are based on the average of only two sampling days. To reliably estimate a subject's specific daily TMA pattern, the intraclass correlation coefficient is preferably above 0.8 (Shrout and Fleiss, 1979). In our study, this goal is only achieved for the two most stable microenvironments *work indoors* and *indoor ETS exposure*. Therefore, studies with a focus on average exposure of individuals in the microenvironment *other indoor* need longer-term observation periods, as suggested previously (Echols et al., 1999), in order to capture the variability adequately. This holds true even when only focusing on regular workdays. We also suspect the microenvironment *other indoor* to be highly variable in regard to the different submicroenvironments it conglomerates. However, EXPOLIS provides stable estimates for the total population and the main subgroups thath can be used in exposure simulation studies. Tables of TMA pattern distributions by city and various subgroups are available in a comprehensive report (Schweizer et al., 2004).

There are a few methodological aspects to be considered in the interpretation and use of the results. In general, R^2 is rather low in all models (usually <0.2). Thus, there are many characteristics that contribute to TMA patterns and that were not accounted for or only partially captured in our data. Despite the low significance of the models in some cases (cities), we still expect the used regression methods to adequately estimate basic trends in the associations between sociodemographic factors and time spent in the indoor microenvironments given the available data. The general accuracy of the gathered data must at least partially be tempered by two aspects: (1) participants not correctly reporting TMA data and (2) participants not reporting TMA data at all for some time during the sampling period. However, the precision of our study design is relatively high compared to many recall and retrospective studies (often: only seven microenvironments in 60 min steps, EXPOLIS: 11 microenvironments in 15 min steps). Because of the absolute nature of this measurement error, the error increased with shorter durations. Thus, our models for longer-lasting microenvironments (e.g. home indoor) could be more accurate than for shorter lasting microenvironments (e.g. other indoor). After carefully examining the TMA diaries, we expect the missing time to be attributable to time spent home indoor, the longest lasting microenvironment, and therefore the overall impact may be limited.

Most of the heterogeneity among the seven cities was caused by differing effects in Grenoble and/or Prague. We suspect selection bias to be at least partly accountable for this (Boudet et al., 1997; Oglesby et al., 2000; Rotko et al., 2000). The study samples are not equally representative of the general population of adults. Samples in Helsinki and Basel were closest to a random population sample, but participation in demanding studies such as EXPOLIS are generally prone to selection bias (Rotko et al., 2000). The city sample size was often less than 200, thus the various subgroups within the cities are small and may not necessarily reflect the corresponding subgroups at large. As an example, the factor *having children at home* had significantly heterogeneous effects on TMA patterns among the cities. In Grenoble, in contrast to the other cities, participants with children at home spent more time at work and less time at home than participants in childless households. Compared to other cities, participants with children at home in Grenoble are older and more than twice as likely to be male. Thus, the effect of having children at home in Grenoble is mainly driven by the effect of being male and older than 40 years. The age effect itself is relatively strong in Grenoble compared to the other cities. Nevertheless, we assume that some of the mentioned differences between the cities are results of city-specific situations (e.g. differing ETS regulations) and may therefore prohibit generalization of the corresponding results from one city to another. But there are also opportunities for extrapolating some observed effects from one city to another, such as the effects of work and employment status.

In conclusion, the present investigation suggests that person-to-person and day-to-day fluctuations were major sources of variance in workday indoor TMA. Furthermore, differences in the socioeconomic and demographic statuses also led to differing workday indoor TMA patterns of the study participants. These determinants of TMA patterns need to be taken into account in exposure assessment, epidemiological analyses, exposure simulations, as well as policies and the shaping of preventive strategies to focus on those with TMA patterns that ultimately determine exposures. Our data may give some guidance for the design of future exposure studies in highlighting areas where additional information may be gathered in questionnaires, or by microenvironment sampling. Associations between environmental exposures and health effects may vary across the subgroups given their potentially different exposures. Determinants of TMA patterns may be useful, therefore, in epidemiological studies in the absence of direct measurements of TMA patterns or exposures. Furthermore, mitigation strategies may be targeted towards subgroups with similar patterns of time–activities that affect personal exposures.

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