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Publication details, including instructions for authors and subscription information:

<http://www.tandfonline.com/loi/sgra20>

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Available online: 31 May 2007

To cite this article: Timo Hugg, Anu Valtonen & Auli Rantio-Lehtimäki (2007): Pollen concentrations inside private cars during the Poaceae and *Artemisia* spp. pollen season - a case study, Grana, 46:2, 110-117

To link to this article: <http://dx.doi.org/10.1080/00173130701374551>

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Pollen concentrations inside private cars during the Poaceae and *Artemisia* spp. pollen season – a case study

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Abstract

A growing number of studies are researching indoor air concentrations of pollen in buildings, but to our knowledge no studies have dealt with the precise concentration of pollen inside private cars. The aim of this study was to assess the risk of exposure to pollen in private cars throughout the Poaceae and *Artemisia* spp. pollen season.

The study was conducted in the town of Lappeenranta and along Highway 6 in south-east Finland between July 14 and August 17, 2003. The pollen concentrations were measured inside two moving and parked cars using rotorod-type samplers. Surface and ambient Burkard samples were also collected.

Both Poaceae and *Artemisia* spp. pollen were recorded only on one day and in low concentrations (< 10 pollen grains per cubic meter, pg/m³) inside moving and parked cars, whereas the concentrations of *Betula* spp. (0–15 vs. 0–12 pg/m³) and *Pinus* (0–41 vs. 0–80 pg/m³) ranged from low to moderate, respectively. The number of pollen grains on the inside surfaces of cars ranged from zero to 72 pg/cm² during the measurement periods.

The concentrations of Poaceae and *Artemisia* spp. pollen in the indoor air of the car during the flowering period were low, therefore, likely to cause reactions only in the most sensitive people. By contrast, even after the main flowering period the concentrations of *Betula* spp. pollen were on a level high enough to cause reactions in individuals with allergies.

Keywords: *Betula* spp., *Pinus*, pollen exposure, pollen grain, rotorod sampler

The prevalence of allergies has increased in Finland over recent decades (Haahtela et al., 1980; Rimpelä et al., 1995; Huurre et al., 2004). The current prevalence of allergenic rhinitis among the Finnish population is estimated as 15–25% (Remes et al., 1998; Huurre et al., 2004). Both the number of cars and the traffic volume has increased markedly in Finland (Heiniö et al., 2005) which has coincided with an increase in allergies. As a result, there are a growing number of road users with allergies. Roadsides constitute an increasingly important part of the living environment, while also acting as a potential source of pollen grains. Car travellers may be exposed in particular to the allergenic pollen of Poaceae and *Artemisia* spp., low-growing plants found in fluctuating quantities along the roads.

In Finland, the Poaceae comprises approximately 50 genera and 150 species but based on abundance

only a few species, primarily from the genera *Dactylis*, *Phleum*, *Festuca*, *Alopecurus* and *Agrostis*, are important allergens (Haahtela & Sorsa, 1999). Correspondingly, the *Artemisia* comprises seven species in Finland but only mugwort (*Artemisia vulgaris*) is common enough to cause allergic reactions which could be observed at the population level. The pollen season of Poaceae species usually starts in mid-June, peaking in July in South and Central Finland. During the peak period values of 100–200 pollen grains per m³ (pg/m³) as a daily average are generally measured at house roof level (Aerobiol Unit, 2006). Correspondingly, the pollen season of *Artemisia* spp. usually starts in mid-July, the peak period being reached at the end of July or the beginning of August. During the peak period values of 50–150 pg/m³ as a daily average are observed at house roof level (Aerobiol Unit, 2006).

The physical dimensions of *Artemisia* spp. pollen vary between $18\text{--}20 \times 20\text{--}23 \mu\text{m}$ and the longest axis of Poaceae pollen varies between $24\text{--}40 \mu\text{m}$ (and in cultivated grasses up to $65 \mu\text{m}$; Nilsson et al., 1977). Dispersal and penetration efficiency are relatively high due to the small size of the pollen grains. Together with *Betula* spp., Poaceae and *Artemisia* spp. are the major sources of allergenic pollen in Finland (D'Amato et al., 1998; Kilpeläinen et al., 2002; Vartiainen et al., 2002).

There have been some studies concerning bioaerosol penetration into the inside air of vehicles (Muilenberg et al., 1991; Holmquist & Vesterberg, 2001) but to our knowledge no studies have dealt with the precise concentration of allergologically important pollen grains inside private cars. Because people spend an increasingly larger part of their time in different vehicles, it is important to assess the pollen concentrations inside a vehicle. The aim of this study is to assess the risk of exposure to pollen grains in private cars throughout the Poaceae and *Artemisia* spp. pollen season. The effect of meteorological parameters on the pollen concentration was also estimated and the relationship between regional pollen data collected by Burkard sampler and local pollen data collected by rotorod-type sampler was determined.

Material and methods

Study areas

The study was conducted in the town of Lappeenranta ($61^{\circ}04' \text{N}$, $28^{\circ}11' \text{E}$) and along Highway 6 in south-east Finland between June 14

and August 17, 2003 (Figure 1). Lappeenranta is the centre of the South Karelia region, with 60 000 inhabitants. Highway 6 is characterised by heavy traffic. In particular, the transit traffic between Finland and Russia has increased over the last few years. Traffic volumes between the towns of Lappeenranta and Imatra vary between 9 000 and 15 000 cars per day (Savolainen, 2003).

The study areas between the Baltic Sea and the Eurasian continent have characteristics of both a maritime and a continental climate. The mean annual temperature in southern Finland is about 5.5°C and the mean rainfall is between 600 and 700 mm. The study areas belong to the temperate coniferous-mixed forest zone. The abundance of Poaceae and *Artemisia* spp. varied between and throughout the study sites.

Vehicles in use

Two different private cars were used in chronological sequence, a Nissan Sunny on route I (June 14 – July 14) during the best flowering period of Poaceae in Finland and an Opel Astra Caravan on routes II–IV (July 13 – August 17; Figure 1) during the best flowering period of *Artemisia* spp. in Finland. During the measurement period the window on the driver's side was either closed ($n=17$) or partly open ($n=21$), the volume and direction of ventilation were recorded and the speed of the vehicle was in accordance with the road traffic speed restrictions. The distances driven varied between the four two-week periods from 1 164 to 1 575 km.

Rotorod data collection and sample analyses

The pollen concentrations were measured inside a moving ($n=38$) and parked car ($n=6$) using rotorod-type samplers (Rantio-Lehtimäki et al., 1992). The samplers were equipped with a U-shaped metal rod (1.7 mm in diameter) and a power source (battery: Yuasa Corporation VdS No. G101094). Transparent Melinex tape coated with adhesive (Vaseline; <http://www.polleninfo.org/>) was fixed to the upper end of the rods. The rotation speed of each sampler was monitored with a digital tachometer (Ebro digital tachometer DT 2234, Ebro Electronic GmbH, Ingolstadt, Germany) to ensure proper performance. The average rotation speed of the arms was 2 369 rpm, varying between 2 273–2 537 rpm. Due to variation in the results between rods, the mean values of the two rods were calculated and used for the analyses.

The Rotorod sampler is thought to be appropriate for indoor/outdoor sampling, since the effects of wind speed and orientation have been shown to be

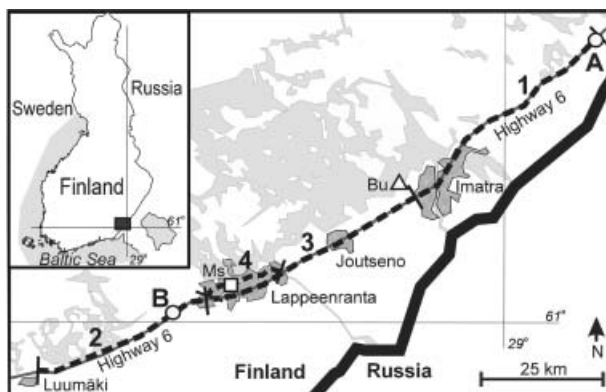


Figure 1. Map of the study area. Driving routes are presented as codes 1–4: 1 Imatra – Rautjärvi, 2 Lappeenranta – Luumäki, 3 Imatra – Lappeenranta, 4 Lappeenranta (passage through the town). The locations of parked car measurement sites are given as A (Untamo) and B (Nyrhilä). The location of the meteorological station in Lappeenranta is shown as an open square (Ms) and the location of the Burkard sampler (Bu) in Joutseno as an open triangle. Water areas are shaded in.

relatively small and the collection efficiency for particles of pollen size is good (Solomon et al., 1980; Frenz, 1999, 2000). Samplers were placed on the rear shelf of the car which, according to a previous study (Muilenberg et al., 1991), reflects the general particle distribution inside a car well enough. Owing to the sampling height and place used, the samplers can be concluded to collect particles in the main from local sources (Local pollen data; O'Rourke & Lebowitz, 1984). In order to minimise problems with oversampling (Sterling & Lewis, 1998), a sampling period was restricted to 20–30 min in the afternoon (15:00–17:00) simulating the period when commuter work traffic is heaviest. A summary of the measurement conditions is presented in Table I.

Using a similar method, the six samples were collected before, in the middle of, and after the study period, from a car parked on highway lay-bys, which was surrounded by vegetation composed of *Poaceae* and *Artemisia* spp. The window on the drivers' side was fully opened and the doors were opened and closed occasionally during the measurement period, simulating a pause in the resting place.

After each measurement period sampling tapes were detached and mounted on slides with Gelvatol (<http://www.geocities.com/>) under a cover glass. Prior to analysis, the samples were stored at room temperature in dust-proof preservation sheets for microscope slides. Pollen concentrations were determined by systematic sampling of microscopic fields and counted from the tapes under a 400× magnification using an optical microscope (Leitz Wetzlar, Germany). A single transect line from the middle of each sample was examined, comprising 21% of the

total collecting area. Rotorod pollen measurement data were converted to volumetric equivalents (pg/m³; Raynor, 1972).

Burkard data collection and sample analyses

As part of the Finnish pollen information network (Aerobiol Unit, 2006), daily regional pollen counts were made throughout the pollen season with a Burkard 7-day volumetric sampler (Burkard Manufacturing Co. Ltd., Rickmansworth, Hertfordshire, UK; Hirst, 1952). The sampler was located on the roof of a 19 m high building (in the town of Joutseno; 61°18' N, 28°41' E) at 119 m above sea level. Due to the sampling height used, the sampler can be thought to collect particles mostly from regional sources (Regional pollen data; O'Rourke & Lebowitz, 1984). The air suction volume of the sampler was 10 l/min, on average. Airborne particles were trapped on Melinex tape coated with adhesive (Vaseline) and attached to a clockwork device rotating at the rate of 2 mm per hour. Thus, the hourly particle content of the air could be calculated. Tape strips were cut into pieces, each 48 mm length corresponding to a single day's sampling. These were mounted on slides with Gelvatol under a cover glass.

Pollen concentrations were determined by random sampling of microscopic fields (60/day), comprising 2.3% of the total collecting area, and counted from the tapes by optical microscopy (400×, Leitz Wetzlar, Germany; Mäkinen, 1981). The sampling method, slide preparation and data interpretation were performed according to the standard methodology adopted by the Finnish pollen information

Table I. Summary of the conditions in private cars and the weather conditions during the sampling period¹.

The condition of measurement	Car I	Car II
Model (year)	Nissan Sunny 1.6 LX (1990)	Opel Astra Caravan 1.6 GL (1996)
Volume of ventilation	moderate (1–3/3; mean 2.2) ²	moderate (2/4) ²
Direction of ventilation	Front to back	Front to back
Fresh air filter	none	yes
Window (partly open)	10/19 (↑ 10 × 41 cm)	11/19 (↑ 5 × 47 cm)
Window (closed)	9/19	8/19
Speed limit (urban roads; km/h)	–	40–60
Speed limit (highway; km/h)	80–100	80–100
Number of rainy days	3	1
Number of totally cloudy days (coverage > 80 %)	5	3
Number of partly cloudy days (coverage 10–80 %)	5	12
Number of clear sky days (coverage < 10 %)	6	3
Monthly mean air temperature (°C; June) ³		12.2
Monthly mean air temperature (°C; July) ³		20.2
Monthly mean air temperature (°C; August) ³		15.1
Monthly mean precipitation (mm; June) ³		37
Monthly mean precipitation (mm; July) ³		74
Monthly mean precipitation (mm; August) ³		95

¹ The conditions of parked car measurements not included. ² Control range of ventilation was between 0–3 (Nissan) and 0–4 (Opel).

³ Measured at Lappeenranta airport meteorological station.

network following the principles of the European Aeroallergen Network (<http://www.polleninfo.org/>). Pollen concentrations were classified as low, moderate, or abundant (Viander & Koivikko, 1978; Rantio-Lehtimäki et al., 1991a). The distance between the Burkard sampler and rotorod-type samplers varied from 5 to 40 km (mean 22.5 km). Although the distance between samplers varied moderately, these are well in line with the previously estimated sampled area covered by a Hirst-type (Burkard) sampler (Comtois & Cagnon, 1988).

Surface samples

The sticky tape method was used in surface sampling (Holopainen et al., 2002). In the sticky tape method, two-sided tape (Scotch™, 12 mm × 10 m, 3M USA) is pressed against the collecting surface and ripped away. Pollen grains adhere to the surface of the tape. Pollen deposits on the dashboard and rear shelf (n=10) were studied from both cars in the middle of, and after the four-week measurement period. The inside surfaces of cars were cleaned with a vacuum cleaner and a wet towel before, and in the middle of (a wet towel only), the four-week measurement period. Thus the results of surface samples corresponded to dust accumulating during the two-week period. Using a slide preparation method similar to that in rotorod sampling, pollen grains were counted under the optical microscope (400×). Ten longitudinal traverses with 200 microscopic fields were examined, comprising 10.6% of the total sampling area. The dust sample measurement data were expressed as the number of pollen grains per square centimetre (pg/cm²).

Meteorological data

Weather conditions, including daily mean air temperature and mean wind speed, were recorded using information from the Lappeenranta Airport meteorological station (61°02' N, 28°10' E). Mean wind speed was expressed as a mean wind velocity recorded over a period of 10 min and measured at 15:00–15:10. The distance between the pollen samplers and the weather station varied from 5 km to 80 km (mean 42.5 km). In spite of the variable distance between the pollen samplers and the weather station, information based on the data from the meteorological station represents the general (daily mean) weather conditions in the region sufficiently well. Cloudiness was also estimated for the sample collection period and divided into four different classes: rain, totally cloudy, partly cloudy, and clear sky.

Statistical methods

Based on the use of similar methods and environmental conditions, the data from driving routes I–IV were pooled and analysed in chronological order as a single route. The Spearman statistical test (correlation coefficients) for non-parametric data was used to determine the relationship between indoor (rotorod) and outdoor (Burkard) concentrations of pollen and between pollen measurements and meteorological parameters. Wilcoxon 2-sample test for non-parametric data was used to paired comparison. The statistical analyses were performed using the SAS statistical package (SAS Institute, Cary, NC, USA). Average values are reported as arithmetic means.

Results

Both Poaceae (June 25) and *Artemisia* spp. pollen (July 24) were recorded only on one day and in low concentrations (<10 pg/m³) inside a moving car. The inside concentrations of *Betula* spp. (0–15 pg/m³) and *Pinus* (0–41 pg/m³) ranged from low to moderate even though their main flowering period was already over. During the measurement period, daily mean outdoor concentrations for Poaceae, *Artemisia* spp., *Betula* spp., and *Pinus* were 0–27, 0–5, 0–21, and 0–309 pg/m³ respectively. In the parked car samples, Poaceae (July 14) and *Artemisia* spp. (July 27) pollen were also recorded on one day only and in low concentrations. The concentrations of *Betula* spp. (0–12 pg/m³) and *Pinus* (0–80 pg/m³) ranged from low to moderate inside a parked car. Surprisingly, there were no statistically significant differences between the mean concentrations of *Betula* spp. and *Pinus* pollen inside a moving car when the windows were closed compared to the situation when one window was partly open. The mean concentrations of *Betula* spp. pollen were 2.2 (closed; SD 4.2) vs. 1.5 (open; SD 2.7) pg/m³ and of *Pinus* 6.7 (closed; SD 10.9) vs. 5.9 (open; SD 10.6) pg/m³ (Figure 2).

The pollen deposit on the surfaces was sporadic. The number of Poaceae and *Artemisia* spp. pollen grains ranged from 0–2 pg/cm² during the four two-week measurement periods. The number of *Betula* spp. pollen grains varied from 0–8 pg/cm² and those of *Pinus* 0–72 pg/cm² during the four two-week periods. Both *Betula* spp. and *Pinus* pollen were found on average in greater quantities from the dashboards than from the rear shelves of the cars, 2.4 (SD 3.3) vs. 1.2 (SD 1.8; *Betula* spp.) pg/cm² and 19.6 (SD 30.0) vs. 8.4 (SD 11.4; *Pinus*) pg/cm².

The mean outdoor wind velocity was higher during the moving car measurements (3.5 m/s;

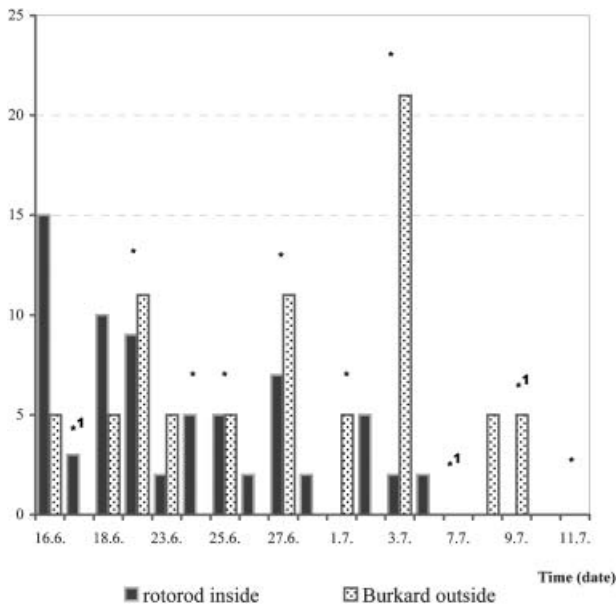


Figure 2. Concentrations of *Betula* spp. pollen grains (pg/m^3) inside a private car without a fresh air filter and outdoors during the measurement period in 2003. * The driver's side window was partly open during the measurement. ¹ Rain during measurement.

range 1–6 m/s) than during the parked car measurements (3.0 m/s; range 1–4 m/s). A positive relationship between rotorod and Burkard data and a negative relationship between pollen concentration and daily mean temperature were observed (Table II).

Discussion

Summary of the results

The concentrations of Poaceae and *Artemisia* spp. pollen in the indoor air of the car during the flowering period were unexpectedly low and are likely to cause reactions only in the most sensitive people. By contrast even after the main flowering period the concentrations of *Betula* spp. pollen were at levels high enough to cause reactions to individuals with allergies (Viander & Koivikko, 1978).

Validity of results

Due to the short sampling period (20–30 min) and the methodology, the limited number of measurements and lack of simultaneous measurements, the results should be interpreted with caution. Stationary sampling methodology used in the study does not directly reflect the amount of potentially inhaled particles and actual risk of exposure (Lee et al., 2006), although Riediker et al. (2000) observed a positive relationship between the personal and the stationary sampler. Pollen grains act as a carrier of allergenic material but pollen counts may include pollen grains devoid of allergens and thus may not represent a true allergen load (Schäppi et al., 1997). However, a positive relationship between the number of pollen grains and the allergen concentration has been previously observed (Spieksma et al., 1995; Schäppi et al., 1997).

Although environmental conditions and pollen concentrations can vary considerably between measurements near to the ground (rotorod) and at house roof level (Burkard) and although the distance between samplers was considerable, a good agreement between the rotorod and Burkard data was observed. The observation is line with the result of previous study (Frenz, 1999). Additionally, the good agreement between the current rotorod measurements (moving vs. parked cars) increases the reliability of the results. Interestingly, the results of rotorod measurements and surface sampling were also similar. However, the collecting efficiency of the sticky tape method for taking surface samples is not 100% (Holopainen et al., 2002). Due to the nature of the methodology employed and the relatively small sample size, the results of the sticky tape method should be interpreted with caution.

Low concentrations of Poaceae and *Artemisia* spp. pollen were not due to any fault in the sampler, but rather to the poor pollen production season of Poaceae and *Artemisia* species (Aerobiol Unit, 2004). Hence, the extension of the measurement period might not have produced any significant increase in the numbers of pollen grains. Furthermore, within the same measurement period

Table II. Spearman correlation coefficient between the rotorod and Burkard pollen counts and meteorological parameters (n=37–38; NR=due to lack of observation, not recorded).

Taxon	Correlation to Burkard value ¹	Correlations to meteorological factors		
		Daily mean temperature (°C)	Mean wind speed (m/s) ²	Cloudiness (0–3)
<i>Betula</i> spp.	0.48375** / NR	−0.53021***	0.00023	0.30873
<i>Pinus</i>	0.65707*** / 0.58790***	−0.41393**	0.00864	0.26970

¹ Daily mean Burkard value / Burkard value during the measurement periods (14:00–16:00). ² Mean wind speed recorded over a period of ten minutes (15:00–15:10). * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

other pollen types were observed which allowed reliable comparisons.

Comparison with previous knowledge

The results are in accordance with previous findings of decreasing numbers of pollen grains moving from outdoors to indoors (Muilenberg et al., 1991; Sterling & Lewis, 1998; Lee et al., 2006). Muilenberg et al. (1991) observed that vehicle speed within the range of 40–80 km/h, mostly corresponding to the speed of the current study, did not systematically influence bioaerosol penetration. Airborne pollen grains can enter the indoor air of the car through the air intake shaft, open windows and doors. Particles can also be carried in by drivers, passengers, pets and luggage.

It seems obvious that the fresh air filters efficiently prevent the penetration of whole pollen particles (diameter 20–60 µm; Gustavsson, 2001). However, fragments of pollen grains generated by processes where the grains are moistened, dry out and after that easily break down into smaller particles (Taylor et al., 2004), and certain fractions of smaller-sized allergenic particles (<1 µm in diameter; Rantio-Lehtimäki et al., 1994), might pass through the filtration system into the indoor air and cause allergic reactions during driving. Consistent with this, Holmquist and Vesterberg (2001) observed that birch and grass pollen antigens penetrated into the driving compartments of coaches equipped with fresh air filters, even at low to moderate, or moderate to abundant, outdoor pollen grain concentrations.

Due to the shortage of simultaneous measurements between the cars little can be said about the influence of a fresh air filter on the concentration of pollen grains. The results of pilot rotorod measurements (n=2) conducted simultaneously during the *Betula* spp. flowering season (22.5.) are in line with a previous study (Morrow Brown, 1991) and indicate that the fresh air filter effectively blocks the penetration of pollen. The *Betula* spp. concentrations were considerably higher in the indoor air of the car without a filter (37 pg/m³) compared to the car with a filter (5 pg/m³).

Irrespective of wind velocity and direction, the turbulence caused by a moving car probably disturbs and shakes off the pollen of wayside herbs and grass in parallel with the resuspension of the already settled pollen (Morrow Brown, 1991). In these circumstances, in a moving car with efficient ventilation, such as in the moving car measurements, pollen concentrations of Poaceae and *Artemisia* spp. species in particular were unexpectedly low. Whereas in a stationary car with an open window,

such as in the parked car measurements, the air exchange rate is considerably affected by the wind speed (Park et al., 1998). It is possible that the wind speed was not high enough to carry the relatively heavy pollen grains through the open window and doors to the sampler placed on the rear shelf, resulting in the observed low pollen concentration during the control measurements. Because *Betula* spp. and *Pinus* pollen were observed inside a car, it seems obvious that other mechanisms such as volume and the flying characters of pollen grains could explain the low indoor concentration of Poaceae and *Artemisia* spp.

Unlike in the previous study (Muilenberg et al., 1991), the concentrations of *Betula* spp. and *Pinus* pollen inside cars were on average although not statistically significantly higher when the windows were closed than when a window was partly open, and pollen grains were found in greater quantities from the dashboards than from the rear shelves. As the direction of the air flow in the ventilation system inside the car was from the front towards the back, it could be expected that pollen grains would be accumulated and found in greater quantities on the rear shelves compared to the dashboards, and in greater quantities when the window was open rather than closed. These unexpected results could be partly explained by the fast and efficient attachment of pollen on the indoor surfaces. Depending on the design and technology of the window and air intakes/outlet, the exterior and interior shapes and material of the car, vehicle speed, ventilation volume, turbulence and direction of the indoor air and the adhesion force of deposited pollen, different distribution figures are possible (Muilenberg et al., 1991; Richmond-Bryant et al., 2006). According to Muilenberg et al. (1991), it is possible that particle momentum in relation to vehicle speed restricted the penetration of bioaerosols, such as pollen size particles, which would have tended to follow the airflow past the open side windows. The results can also partly be a consequence of random variation related to a relatively small sample size.

The most abundant Poaceae species along the road verges of the study areas was *Festuca rubra* (Jantunen et al., 2004). From the allergology perspective, the more important species *Dactylis glomerata* and *Alopecurus pratensis* were also observed. Other Poaceae or *Artemisia* spp. covered only small percentages of the highway road verges. Since the soil in highway road verges was mostly too dry and poor in nutrients for the Poaceae and *Artemisia* spp., these unsuitable growing conditions can also decrease the production of pollen (Jantunen et al., 2004). A low concentration of *Artemisia* spp. pollen on urban roads (Route IV) where it were a

moderately abundant was a surprise, although the highest concentrations have been previously observed in the mornings (8:00–14:00; K  p  l  , 1981; Rantio-Lehtim  ki et al., 1991b), whereas the timing of the daily peak of Poaceae pollen were well in accordance with the measurement period adopted (K  p  l  , 1981; Rantio-Lehtim  ki et al., 1991b).

In keeping with the instructions for the public roads management in Finland, all verges are mown once or several times every summer (Finnish Road Administration, 2000). The majority of road verges were mown totally or partly before the beginning of July (Jantunen et al., 2004), i.e. at a time before the main flowering season of Poaceae and *Artemisia* spp.. Frequent mowing prevents and delays the flowering of all plants (Rantio-Lehtim  ki et al., 1992). Thus, the relatively low coverage of these plants along road verges, the inefficient spreading of the pollen grains of low growing species, the relatively calm wind conditions during the measurements, the early and repeated mowing of verges and the poor pollen production season may together explain the low concentrations of Poaceae and *Artemisia* spp. pollen inside a car. By contrast, enormous quantities of *Betula* spp. and *Pinus* pollen grains are produced and released during the pollination period (Taylor et al., 2004). The abundance of pollen after the pollination period could be explained by the resuspension of settled pollen in the relatively dry study conditions (Morrow Brown, 1991; Muilenberg et al., 1991). It is important to note that in dry outdoor and indoor conditions pollen grains can retain their structure for a long time as an allergenic particle (Yli-Panula & Ahlholm, 1998).

The positive relationship between the rotorod and Burkard data are in accordance with the previous study (Frenz, 1999), but the observed negative relationship between pollen concentration and daily mean temperature is the consequence of the phenology of the plants. After the pollination period the number of pollen grains decreases gradually to close to zero even if the temperature and other conditions becomes more favourable.

Conclusions

The study shows that the concentrations of Poaceae and *Artemisia* spp. pollen inside cars were low during the flowering period and are likely to cause reactions only in the most sensitive people.

The results also indicate that even after the main flowering period the concentrations of *Betula* spp. pollen can be preserved for a long time on a level causing reactions to individuals with allergies. The similarity of surface sample concentrations between

cars and the similarity between the measurements with an open and closed window indicate that the main penetration route of pollen inside the car could be through the doors, especially in cars equipped with fresh air filters. In the light of these results, it appears possible that the majority of pollen grains penetrate into the indoor air of the car at the moment of entering or the air intake in vehicles without efficient air filters.

Acknowledgements

We thank Professor Jouni Jaakkola and Dr. Kimmo Saarinen for their comments on the earlier draft and Dr. Juha Jantunen for technical assistance with illustration.

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