MACC

Monitoring Atmospheric Composition and Climate

Deliverable D_O-INT_3.7

Review of personal exposure data in the EU

Lead Beneficiary

University of West Scotland

SEVENTH FRAMEWORK
PROGRAMME

Introduction

O-INT_3 aims to improve individual-level exposure estimation for epidemiological studies and health impact assessment. To this end, personal exposure models are being developed and validated using data from a bespoke air pollution monitoring campaign in London (see O-INT_3.8), a general approach that has already seen some attention in previous studies (ADAMS et al. 2001a, Gulliver & Briggs, 2005, KAUR & NIEWENHUIJSEN 2009). The comparison between traditional exposure metrics (e.g. outdoor fixed-site ambient monitoring) and personal exposure modeling will form the basis of discussion with users as part of O-INT.

The purpose of this report is to review previous personal exposure studies that have been undertaken in a range of microenvironments (e.g. indoor, outdoor and transport) as part of the basis for informing and designing personal monitoring work to be undertaken in MACC. Here we limit the scope of the review to particulate air pollution as it is the main pollutant of concern (BELL et al. 2004, LARRIEU et al. 2007), and to studies done in Europe as they provide contextual data for the extent of regional ensemble modeling done in MACC.

Although personal air pollution monitoring acts as the most direct way of assessing personal exposures, the number of exposure studies that have done personal measurements of particulate air pollution is relatively small. This is partly due to the general time consuming nature of personal monitoring and compounded for particles due to the more expensive and complex nature of the technology required compared to gases (e.g. NO_2, CO etc.). The total number of studies reporting on personal exposures monitoring to particulates in Europe is about 30. These studies can broadly be grouped as 1) daily (or 48-hour), integrated exposure measures covering routine patterns of personal activity (e.g. home-work-shops-home etc.) and 2) personal exposures in specific microenvironments (e.g. transport, indoor, occupational). Very few studies have related personal exposure to particles with ventilation or dose and are excluded from this review.

Personal exposures studies using continuous monitoring over one to two days

Studies covering continuous exposures over one or more days often use diaries to record the time spent undertaking different activities (in different locations). Table 1 shows a summary of those studies. Many of these focus on ETS (Environmental Tobacco Smoke), but only the non-ETS influenced samples are shown (apart from KOISTINEN et al. 2001), as they are more relevant to our monitoring and modeling aims in MACC.

Many of these studies have included comparisons between personal, indoor and outdoor monitoring. The outdoor monitoring usually refers to air pollution monitors placed outside the façade of the home. Detailed comparison between studies is not always possible, or indeed wise, due to the differences in study designs and monitoring equipment used. Some comments can however be made by way of summarizing the general messages coming from these studies.

Table 1 shows average concentration of particulate air pollution by fraction for personal, indoor, and outdoor concentrations, where available. Also shown are the correlations (as either Pearson's, Spearman's, or r^2) between personal, outdoor and indoor concentrations, except in the case of the study by BRAUER et al. (2002) where ratios between personal and microenvironmental exposures are shown. In most studies, similar levels of exposures are reported between average personal exposures and indoor and outdoor concentrations but in two cases (JANSSEN et al, 1998; JANSSEN et al. 2005) personal exposures are much higher than other microenvironmental exposures. VIOLANTE et al. (2006) shows extremely high average personal exposure (about four fold to most other results). The reason for which is a focus only on policemen and traffic wardens, which spend a more than average time in high pollution level transport environments.

In most cases it is not possible to extend this comparison to separating the personal exposure related only to the periods spent outdoors and periods spent indoors. Most studies are collecting PM filter samples for the whole period of time (GAUVIN et al. 2002; HARRISON et al. 2002; JANSSEN et al. 1998; JANSSEN et al. 2005; LAI et al. 2004;

PHILLIPS et al. 1998a; PHILLIPS et al. 1998b; PHILLIPS et al. 1999; VIOLANTE et al. 2006). Studies conducted as part of the EXPOLIS study used a set up with two filters for each participant. One filter was used during leisure times and the other one was used for workdays only (KOISTINEN et al. 2001; KOUSA et al.2002).

Correlations between personal, outdoor and indoor exposures provide comparative information. Apart from the study by KOUSA et al. (2002), higher correlations are seen between personal and indoor concentrations than between personal-outdoor, and indoor-outdoor concentrations.

Table 1. Personal exposure studies collecting sample over periods of about 1-2 days

Study	**Pollutant**	**City**	**Total no. of samples**	**Time**	**Mean Personal conc. $\mu g/m^3$**	**Mean home Indoor conc. $\mu g/m^3$**	**Mean home outdoor conc. $\mu g/m^3$**	**FSM**	**Personal versus indoor**	**Personal versus outdoor**	**Indoor versus outdoor**
Brauer, M. et al. (2000)	PM2.5	Banska Bystrica, Slowakia	49	24h			22 (Summer) 32 (Winter)		Ratios: 1.0 – 3.9	Ratios: 1.6 – 4.2	
	PM10						35 (Summer) 45 (Winter)		Ratios: 1.1 – 2.9	Ratios: 2.1 – 4.1	
Gauvin, S. et al. (2002)	PM2.5	Paris, France	30	48h	29.4			20			
		Grenoble, Switzerland	15		18.2			19.7			
		Toulouse, France	23		19.8			17			
Harrison, R. et al. (2002)	PM10	Birmingham UK	110	10 x 8h	54.9						
Janssen, N. A. H. et al. (1998)	PM10	Amsterdam, Netherlands	37	ca. 5 x 8h	62	35	42		0.71_a	*0.34_a*	*0.5_a*
Janssen, N. A. H. et al. (2005)	PM2.5	Amsterdam, Netherlands	225	24h	13.0 (Median)	3.6 (Median)	1.7 (Median)		0.84_b	0.76_b	0.79_b
		Helsinki, Finland	238	24h	7.0 (Median)	6.4 (Median)	7.8 (Median)		0.90_b	0.74_b	0.80_b
Koistinen, K. J. et al. (2001)	PM2.5	Helsinki, Finland	135	48h	9.9 (AM)	8.2 (AM)	9.5 (AM)		0.53_c (including ETS)	0.17_c (including ETS)	NA
Kousa, A. et al. (2002)	PM2.5	Helsinki, Finland	48 – 138	48h					0.35_a	0.47_a	0.65_a
		Prague, Czech Republic	9 – 29	48h					0.1_a	0.08_a	0.34_a
		Basel, Switzerland	21 – 29	48h					0.37_a	0.22_a	0.54_a
		Athens, Greece	7 – 22	48h					0.2_a	0.4_a	0.82_a
Lai, H. et al. (2004)	PM2.5,	Oxford, UK	27	48 h	17.4 (AM) 10.7 (GM)	17.3 (AM) 11.3 (GM)	9.1 (AM) 6.2 (GM)		0.60_a	-0.41_a	0.11_a
Phillips et al. (1998a)	PM3.5	Paris, France	7	24h	42 (AM), 37 (GM)						
Phillips et al. (1998b)	PM3.5	Lisbon, Portugal	20	24h	34 (AM), 31 (GM)						
Phillips et al. (1999)	PM3.5	Basel, Switzerland	25	24h	38 (AM), 29 (GM)						
Violante, F. S. et al. (2006)	PM10	Bologna, Italy	371	3 - 6h shifts, 4 weeks	182.8			43.5		0.19_c	

AM (Arithmetic Mean), GM (Geometric Mean); correlations: (a) Pearson's, (b) Spearman's, (c) coefficient of variation – r^2

Concentrations were always seen to be high than between personal and outdoor concentrations, probably reflecting the longer amounts of time spent indoors by the study participants. The main remark to make against the results shown in Table 1 is that except in a few cases the correlations are generally at best good and often only moderate. This shows that microenvironmental exposures are generally not good markers for personal exposures.

The study by BRAUER et al. (2000) showed personal exposures to be always higher than indoor and outdoor exposures, with the difference as much as a factor of about 3 for indoors and a factor of 4 for outdoors. In other studies, personal exposures have been seen to be generally higher than indoor concentrations and sometimes higher that outdoor concentrations (GAUVIN 2002; JANSSEN et al. 2005; JANSSEN et al. 1998; KOISTINEN et al. 2001).

Personal Monitoring in Transport Microenvironments

Transport is of particular interest as for many people it will represent their peak exposure in their daily routine. Most of the studies looking at specific microenvironments have been done in transport and comparisons have generally been made in levels of concentrations between different transport modes (e.g. walking, in-car, bus etc.) and between transport modes and fixed-site, ambient monitoring. Table 2 summaries personal exposure studies in transport microenvironments. These studies represent journey-time exposures and thus have exposure periods lasting typically no more than 1 hour, and often only a few minutes. The studies collecting minute-to-minute data (or even second-to-second) have shown highly varying and rapidly changing pollution levels over short distances and short time spans. For the purposes of this report results from the different studies are summarized as the average exposures found for different modes of transport, as shown in Table 2.

As Table 2 shows, the studies vary by the fraction of particulates measured (i.e. PM_{10}, $PM_{2.5}$ etc.), combination of modes of transport studied, types of route and geographical setting (e.g. roadside, background), and season. What is not shown are other major factors that potentially influence results such as different levels of 'background' (i.e. regional and far-travelled air pollution), meteorological conditions, and the types of monitoring equipment used (e.g. optical, gravimetric etc.).

Furthermore, there are a range of additional factors which can influence results from these studies such as, for cycling and walking, proximity to other people, passing smokers in the street, position on the pavement/road, and for motorised vehicles factors include the number of passenger, fuel type, vehicle upholstery, use of air conditioning/vents, and whether windows were open or closed. Direct comparison of results between many of these studies is almost always impossible, and notwithstanding attempts to replicate study designs in different areas is still problematic due to not being able to control for certain environmental factors (e.g. background air pollution, street characteristics, meteorology etc.).

Putting these factors aside, looking at specific mode-to-mode comparisons will often dramatically reduce the number of available studies. Taking studies that have compared $PM_{2.5}$ exposures from walking and in-car, for example, which represent the main modes of transport in many areas, reduces the total number from 30 studies down to six. As Figure 1 shows, very different messages can be drawn based on which studies are cited. Two studies (BRIGGS et al., 2008 and MORABIA et al., 2009) have seen much higher average levels of $PM_{2.5}$ while walking than in-car, in contrast to other studies (GULLIVER et al., 2004; KAUR et al., 2005; MACNABOLA et al., 2009)which have seen in-car exposures higher than walking. It is clear from looking closely at these study designs that, in addition to some of the factors cited above, the walking and in-car routes were not always the same, with the walking route passing through some areas of 'background' air pollution.

There are some stand-out results and broad conclusions that can be drawn from the studies shown in Table 2, as follows. In the few cases where subways (i.e. tube/underground) have been studied (ADAMS et al., 2001; PFEIFER et al., 1999; SITZMAN et al., 1999) levels of air pollution found in subways are between several and many orders of magnitude above levels found in other modes of transport. ADAMS et al. (2001) reported 5-fold to 8-fold levels of concentrations in $PM_{2.5}$ concentrations between subways and bus, car, and bicycle. Similarly, PFEIFER et al. (1999)

Figure 1. Studies comparing walking and in-car $PM_{2.5}$ exposures

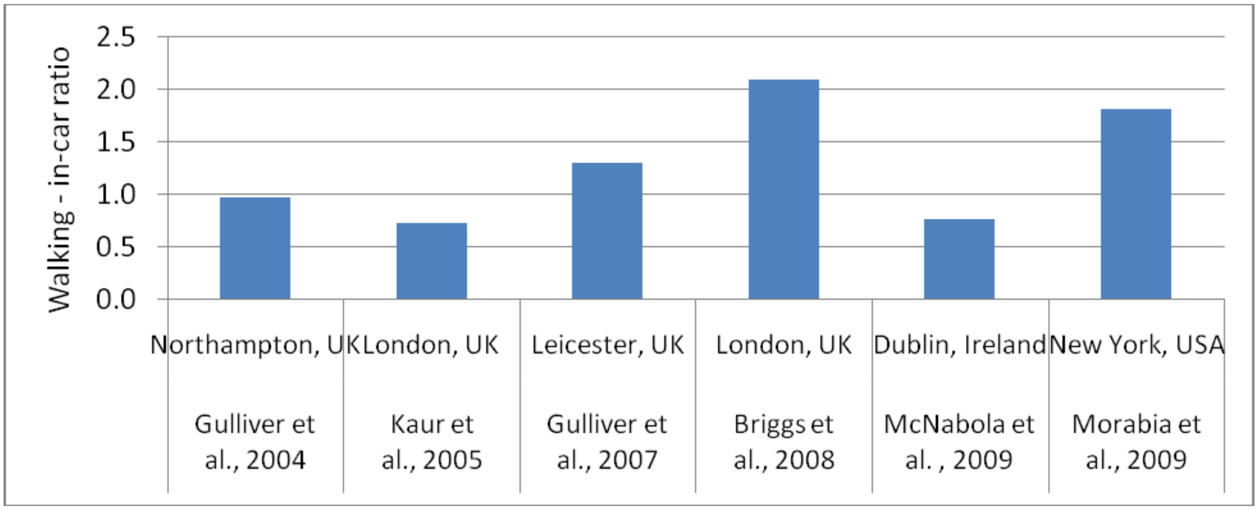

Table 2: Publications on personal Monitoring in Transport Microenvironments.

Publication	**city of data**	**Total no. of samples**	**Pollutant**	**Mode**	**Time**	**Average concentration in µg/m³**	**Standard Deviation [other statistical results]**	**Comments**
Adams, H. S. et al. (2001b)	London, UK	Study A: 345	PM2.5	Study A: Bicycle	twice during 3 weeks (winter & summer)	34.5 (GM Summer) 23.5 (GM Winter)	1.7, (GSD Summer); 1.8 (GSD Winter)	3 Fixed routes (3 – 4 miles each), inter-mode comparison.
				Bus		39.0 (GM Summer) 38.9 (GM Winter)	1.8 (GSD Summer) 2.1 (GSD Winter)	
				Car		37.7 (GM Summer) 33.7 (GM Winter)	1.5 (GSD Summer) 2.4 (GSD Winter)	
				Subway		247.2 (GM Summer) 157.3 (GM Winter)	1.3 (GSD Summer) 3.3 (GSD Winter)	
		Study B: 120	PM2.5	Study B: Bicycle	B: 31 days (summer)	34.2	1.9 (GSD)	Real commuter routes
Bevan, M. A. J. et al. (1991)	Southampton, UK	16	PM3.5	Bicycle	35min each route	130	[Median 110, Range 230]	
Briggs, D. J. et al. (2008)	London, UK	46	PM10-2.5	Walking	routes each; car average: 3.7; walking average: 12.8; on 7 working days	27.56	13.16, [CV 47.8]	

Publication	city of data	Total no. of samples	Pollutant	Mode	Time	Average concentration in µg/m³	Standard Deviation [other statistical results]	Comments
				Car		5.87	3.09 [CV 52.6]	
			PM2.5 - PM1	Walking		6.59	3.12 [CV 47.3]	
				Car		3.01	1.10 [CV 36.5]	
			PM1	Walking		3.37	3.40 [CV 100.9]	
				Car		1.82	1.10 [CV 60.4]	
Gee, I. L. & Raper, D. W. (1999)	Manchester, UK	Buses: 34	PM4	Bus (2 routes)	3h periods (7 - 10am)	338	300	
		bicycle: 8		Bycycle	3h periods (7 - 10am)	54	34	
Gulliver, J. & Briggs, D. (2004)	Northampton, UK	74	PM10	Walking	total monitring of 38h mainly during mornings (8am) and evenings (3pm)	38.18	25.17 [Range 93.98]	
				Car		43.16	22.71 [Range 91.04]	
			PM2.5	Walking		15.06	16.15 [Range 70.49]	
				Car		15.54	15.92 [Range 73.99]	
Gulliver, J. & Briggs, D. J. (2007)	Leicester, UK	66 (33 each mode) (19 on route1, 16 route 2)	PM10 - PM2.5	Walking	on 10 different days	22.1	9.8 [Median 18.6, Range: 30.9]	
				Car		15.1	5.1 [Median 14.5, Range 19.8]	
			PM2.5 - PM1	Walking		10.9	5.7 [Median11.1, Range 16.5]	
				Car		8.3	4.0 [Median 7.2, Range 13.4]	
			PM1	Walking		4.8	5.1 [Median 3.3, Range 21.1]	
				Car		2.9	1.54 [Median3.0, Range 5.9]	
Pfeifer, G. D. et al. (1999)	London, UK	taxi driver: 10, underground: 4	PM2.5	Taxi	taxi driver: 7days within 2 weeks, 16h each, subway: 2 days of about 8 hours each	33.36	[Range 20.73]	Study was not directly aimed on taxi and subway (comparison taxi driver and office workers)
				Subway		246	[Range 52.49]	

Publication	city of data	Total no. of samples	Pollutant	Mode	Time	Average concentration in µg/m³	Standard Deviation [other statistical results]	Comments
Kaur, S. et al. (2005a)	London, UK	155 (one busy road)	PM2.5	Walking	during 12 days (2x morning and 2x afternoon), each sample min 20min	37.7 (AM) 33.8 (GM)	16.4 (ASD) 1.7 (GSD) [Range 82.3; 5. Percentile 35.1; 95. Percentile 40.3]	
Kaur, S. et al. (2005b)	London, UK	197 (walking 56, cycling 48, bus 42, car 29, taxi 22)	PM2.5	Walking	3 times a day (morning, lunch, afternoon) (2 routes) min. 18min each tour	27.5 (AM), 23.8 (GM)	1.8 (GSD) [Range 59.1, 5. Percentile: 23.7; 95. Percentile: 31.3]	
				Cycling		33.5 (AM) 30.6 (GM)	1.5 (GSD) [Range 67.8, 5. Percentile: 29.3; 95. Percentile: 37.7]	
				Bus		34.5 (AM) 31.8 (GM)	1.6 (GSD) [Range 58.6, 5. Percentile:30.8; 95. Percentile : 38.2]	
				Car		38.0 (AM) 34.9 (GM)	1.6 (GSD) [Range 43.3, 5. Percentile: 32.6; 95. Percentile 43.3]	
				Taxi		41.5 (AM) 39.0 (GM)	1.4 (GSD) [Range 53.9, 5. Percentile 35.1; 95. Percentile 48.0]	
McNabola, A. et al. (2009a)	Dublin, Ireland	20	PM2.5	Car	About 25min per journey	103.64		
McNabola, A. et al. (2009b)	Dublin, Ireland	200	PM2.5	Walking	3km route, peak traffic hours.	63.45	38.17	aim: peak traffic exposure
				Bicycle		88.14	61.54	
				Car		82.73	44.84	
				Bus		128.16	68.08	
Praml, G. & Schierl, R. (2000)	Munich, Germany	201 (Circular buses: 85; Radial Buses: 52; Trams: 54)	PM10	Bus	201 journeys of approx. 4h duration each	Circular buses: 164.95; Radial buses: 110.08	Circular buses: [Range: 512] radial buses: [Range 175]	
				Tram		183.41	[Range: 501]	
Sitzmann, B. et al. (1999)	London, UK	Bicycle: 4, Subway: 2	PM5	Bicycle	1 week, approx 1.5h per day	a) 88.54 b) 16.28 c) 16.49 d) 14.00	a) 6.52 b) 4.72 c) 4.07 d) 2.34	Further samples were taken and analysed for particle counts.
				Subway		a) 708.60 b) 892.84	a) 43.15 b) 55.18	

AM (Arithmetic Mean), ASD (Arithmetic Standard Deviation), ETS (Environmental tobacco Smoke), GM (Geometric Mean), GSD (Geometric Standard Deviation) found subway concentrations of $PM_{2.5}$ to be 7-fold higher than those found in taxis. In the study by SITZMANN et al. (1999), subway concentrations of PM_5 were a staggering 10 to 40 times higher, depending on the week when the monitoring took place, than those found for bicycle, albeit based on a fairly limited sample size. Subways clearly need more investigation to confirm the extremely high concentrations found in these studies.

Several studies in Table 2, namely ADAMS et al. 2001b, KAUR et al. 2005b, and MCNABOLA et al. (2009b) compare $PM_{2.5}$ exposures across multiple transport modes at the same time. Average concentrations of $PM_{2.5}$ are broadly similar between the different modes of transport in each case, except in the study by MCNABOLA et al. (2009) which found elevated exposures in buses. It is noteworthy that the focus of MCNABOLA et al. (2009b) on peak traffic exposure which is seen by $PM_{2.5}$ levels about twice as high as for the two other studies.

Most of the remaining studies compare two modes. It is important to note that the studies by SITZMANN et al. (1999) (bicycle and subway), GEE & RAPER (1999) (bicycle and bus), PFEIFER et al. (1999) (taxi and subway) and PRAML & SCHIERL (2000) (tram and bus), did not undertake simultaneous monitoring between modes, nor did they cover the same route. Results are therefore specific to each setting and do not represent the ideal basis for comparison. Three UK studies however simultaneously monitored walking and in-car exposure on the same route: BRIGGS et al. (2008), GULLIVER & BRIGGS (2004) and GULLIVER & BRIGGS (2007). They perhaps provide a better basis for drawing conclusions on levels of concentrations between the modes of transport studied.

Finally, some studies collected highly specialized data within one transport microenvironment. MCNABOLA (2009) looked at differences of in-car exposure for varying distances to the car in front. The study by KAUR et al. (2005a) assesses exposure differences for different walking positions on the pavement (close to road or away from road). BEVAN et al. (1991) look at differences for cycling exposure in different wind conditions. The part B of the study by ADAMS et al. (2001) collects exposure from cycling commuters in order to compare them with the monitoring along fixed routes (part A).

In addition, some of these studies have made comparisons between exposures found in different modes of transport and levels found in by local fixed-site air pollution monitoring stations (FSM). The following refers to only studies where walking and in-car exposures have been compared with FSMs. Gulliver et al. (2007), for example, showed that average PM_{10} exposures while walking were about 14.4 $\mu g/m^3$ (67%) higher than at the fixed site, while in-car exposures were 2.9 $\mu g/m^3$ (13%) higher. Generally, these results are similar to those reported in other studies. In a study in Northampton, using the same monitoring devices, for example, Gulliver and Briggs (2004) found that PM_{10} concentrations were 11.6 $\mu g/m^3$ higher while walking and 16.6 $\mu g/m^3$ higher in-car than at a nearby FSM. Kaur et al. (2005b) similarly found that a background FSM underestimated pedestrians' exposure to PM2.5 by about 2–3 times and that average pedestrian exposures were 15 $\mu g/m^3$ higher than recorded at a roadside monitoring site on Marylebone Road, London. In a study of particulate air pollution in Prague, BRANIS (2006) found average PM_{10} concentrations in the street over a repeated 600m journey to be 64.9 $\mu g/m^3$ and 86.0 for morning and evening sampling periods, respectively, compared with concentrations of 42.7 $\mu g/m^3$ and 44.3 $\mu g/m^3$ at the nearest ambient FSM for the same periods.

It is worth emphasising, however, that part of the disparity between concentrations found during walking and those at roadside FSMs will be due to vertical and horizontal differences in distance between the personal monitor and FSM inlets. Even where a roadside monitor is located within the same space occupied by walkers there will generally still be a 1.5–2m difference in the vertical height of the personal monitor and FSM inlets.

Summary

The main findings from this review are summarized as follows:

- Results of most existing personal monitoring studies are very difficult to compare or transfer to other personal exposure situations.

- Many daily (i.e. integrated) studies have looked only at ETS situations, with some differentiation between ETS and non-ETS across the studies.

- The 'integrated' studies tend to be characterized by one or two days of sampling per subject and do not therefore capture day-to-day and seasonal variations in activity patterns for individuals.

- Studies in transport microenvironments tend to capture data at high temporal resolution due to the shorter monitoring times.

- Exposures in subways are much higher than in other transport modes but only a few studies have reported on this comparison.

- Very few studies have looked at individual-level ventilation and dose by different modes of transport.

- Personal exposures in transport microenvironments have been seen to be generally between 1.5 and 3 times higher than recorded at nearby roadside fixed-site monitors suggesting that models are required to convert monitored and (modeled) outdoor concentrations into personal, journey-time exposures.

Many of the daily, integrated exposure monitoring studies have coarse temporal resolution and have not been able to separate the contributions to average or total exposures from all the different microenvironments. Studies looking at transport alone have captured higher resolution data and this type of monitoring ideally needs to be extended to looking at the range of microenvironments covered in daily routines (e.g. home indoors, home outdoors, journeys, work, leisure etc.). An approach which captures high resolution data across daily routines with repetition between different days and seasons will add value to the existing body of personal exposure studies. This data will be collected in MACC in order to calibrate and validate the personal exposure modeling. Special attention will also be given to different transport microenvironments as for many they represent the peak exposure period. The above review will be used at the end of the study as a basis for comparison with the new MACC exposure monitoring data.

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