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MOVING BEYOND THE RESIDENTIAL NEIGHBOURHOOD FOR THE ASSESSMENT OF DAILY NOISE EXPOSURE: EXPERIMENTAL EVIDENCE WITH SPACE TIME ACTIVITY DATA

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ABSTRACT

Most studies assessing environmental noise in cities considered the residential neighbourhood as the only exposure environment, which may lead to biased estimates in noise-health relationship. In this study, conducted as part of the ANR SYMEXPO project, we go beyond the residential context and leverage real-time sensing technologies to measure individual noise exposure during space-time activities at a very fine resolution. 289 participants from MOBILISENSE study residing in the metropolitan area of Paris were followed with GPS receiver, accelerometer and a monitor for sound pressure for five days. Our hypothesis was that personal noise exposure can vary across space and time and for this reason residential noise (at the home location point or at the neighbourhood level) is not representative of the daily noise exposure. To test this hypothesis, we compared relationships between outdoor (home-based) residential noise level Lden (strategic noise map), one-kilometre residential neighbourhood noise level Lden (strategic noise map), sensor based daily noise level $L_{Aeq,24h}$ and activity and transport mode daily noise level $L_{Aeq,24h}$. Individual level variation of $L_{Aeq,24h}$ values was not found associated to the residential neighbourhood location. Sensor based measures considering all behaviours give more precise and relatively high exposure values compared to residential and home-based measures.

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1. INTRODUCTION

In many prior health studies, human exposure to noise was estimated using data collected or simulated at the residential location. For noise, the European standard method for counting the population exposed to environmental noise uses annual average maps of modelled road, air and rail traffic noise, calculated outside the most exposed facades of inhabitants [1]. However, the method used to calculate environmental exposures can have a significant influence on the associations estimated with health outcomes [2][3]. Trajectory based approaches have recently been developed, which provide a promising framework to improve the measurement of personal exposure [4]. In addition, the impact of individual mobility on noise exposure has recently been studied. In [5], it is shown that recreational places and transportation time account for a big share of noise exposure and related stress. In [6], it is shown that sensor-based measurements give more accurate and relatively higher exposure values than if individuals are considered at their place of residence.

In this study, we compared daily measured noise exposure with exposure calculated at the outdoor home place of residence, and at the residential neighbourhood. Measured noise exposure are calculated based on the cohort data from the MOBILISENSE study, in which 289 participants were followed with GPS receiver, accelerometer and a monitor for sound pressure for five days. A parallel mobility survey enabled to gather information on the space-time activities of the participants. This study is part of the ANR SYMEXPO project, which aims to include city-dwellers mobility in exposure assessment at both measurement and modelling approaches.

2. METHODS

2.1 Data collection

289 participants were recruited from May 2018 to March 2020 from preselected dwellings in the metropolitan area of Paris. Participants were adults participating in the MOBILISENSE study, which is described in more details in (Chaix et al., 2022). Participants were followed with multiple environmental sensors during the five days of data collection. Only the noise dimension is presented here. The noise data were collected at a one second resolution, through a SV 104A dosimeter (Svantek, Warszawa, Poland) fixed at the belt, with a microphone attached to the collar close to the ear. In addition, participants wore a BT-Q1000XT GPS receiver (Qstarz, Taipei, Taiwan) collecting location information every 5 seconds and a wGT3X+tri-axial accelerometer (ActiGraph, Pensacola, Florida, USA) on an elastic belt over all days.

The temporal evolution of positioning data, associated with a mobility survey, enabled to determine the space-time activity pattern of participants. Participants daily behaviours were divided into activities and transport mode. Seven categories of transport mode were defined: walking and jogging; soft mobility; car, motorcycle; public transport open (bus, tramway); public transport underground (subway; train); other. The activity type was classified into five categories: residence; work; food; commerce and services; leisure, cultural and social activity; changing mode. Time spent in different transport modes and activity type was measured.

In addition, multiple modeling estimates of noise exposure were calculated: outdoor residential noise level $L_{den,home}$, and residential neighbourhood noise level $L_{den,neigh}$. $L_{den,home}$ and $L_{den,neigh}$ values were calculated respectively at the home location of each participant and at the residential neighbourhood (arithmetical average over a 1 km buffer around the home location), by overlaying them with the 2017 regulatory noise map of the Paris metropolitan area [7], which adds the approximate average noise energy due to industrial noise, road, railway and air traffic. Finally, $L_{night,home}$ and $L_{night,neigh}$ indicators were similarly calculated, representing night time noise levels at the home location of each participant and at the residential neighbourhood, respectively.

2.2 Indicators calculation

As the purpose of the statistical analysis is to compare daily exposure from both measurement and modelling approaches, only the days with 24 hours of completed measurement data achieved by participants were kept in the analysis. Uncompleted days were filtered out. As a result only 232 participants are kept in the analysis, with an average of 2,46 days of measurement data per participant. For each participant, the following indicators are calculated:

- $L_{Aeq,24h}$, which represents to daily equivalent sound level over the 24h period;
- $T_{act/transp}$, which represents the proportion of the time spent in a given activity or transport over the 24h period, with Act/Transp taking the 5 and 7 listed values for Activity and Transport, respectively. Note that the sum of the twelve $T_{act/transp}$ values is 1;
- $L_{Aeq,24h,act/transp}$, which represents the contribution in the $L_{Aeq,24h}$ of a given activity or transport, with Act/Transp taking the 5 and 7 listed values for Activity and Transport, respectively. For instance, if an activity is performed for 12 hours with a L_{Aeq} of 60 dB(A), its $L_{Aeq,24h,act}$ is 57dB(A). Note that the sum of the twelve $L_{Aeq,24h,act/transp}$ is $L_{Aeq,24h}$;
- $NS_{act/transp}$, which represents the proportion in the $L_{Aeq,24h}$ of a given activity or transport, with Act/Transp taking the 5 and 7 listed values for Activity and Transport, respectively. For instance, if the $L_{Aeq,24h,act/transp}$ of a given activity is 57dB(A) and the $L_{Aeq,24h}$ is 60dB(A), then NS_{act} = 0,5. Note that the sum of the twelve $NS_{act/transp}$ values is 1.

In addition, similar calculations are performed with $L_{A50,act/transp}$ values, to analyse the sensitivity of the daily contribution to exposure of each transportation mode or activity due to the selected indicator. Indeed, sound levels distribution might greatly vary between transportation modes and activities, and this might impact the daily sound exposure dynamics. The selected L_{A50} based indicators are:

- $L_{Aeq50,24h}$, which represents to daily equivalent sound level over the 24h period, but calculated from the $L_{A50,act/transp}$ values (accounting for the duration in each activity or transport. Hence this is not a $L_{A50,24h}$ value, but more equivalent to a $L_{Aeq,24h}$ value but less sensitive to noise peaks within each activity or transport ;
- $L_{Aeq50,24h,act/transp}$, which represents the contribution in the $L_{Aeq50,24h}$ of a given activity or transport, with Act/Transp taking the 5 and 7 listed values for Activity and Transport, respectively. For instance, if an activity is performed for 12 hours with a L_{Aeq50} of 60 dB(A), its $L_{Aeq50,24h,act}$ is 57dB(A). Note that the sum of the twelve $L_{Aeq50,24h,act/transp}$ is $L_{Aeq50,24h}$;
- $NS_{50,act/transp}$, which represents the proportion in the $L_{Aeq50,24h}$ of a given activity or transport, with Act/Transp taking the 5 and 7 listed values for Activity and Transport, respectively. For instance, if the $L_{Aeq50,24h,act/transp}$ of a given activity is 57dB(A) and the $L_{Aeq50,24h}$ is 60dB(A), then NS_{act} = 0,5. Note that the sum of the twelve $NS_{act/transp}$ values is 1.

The interest in this second set of indicators is that, if an activity is associated with a strong $L_{Aeq,act/transp}$ but a low $L_{A50,act/transp}$ value (for instance if it has a low background noise but high noise peaks), its daily contribution will be high in $NS_{act/transp}$ but low in $NS_{50,act/transp}$.

3. RESULTS

3.1 Detail on exposure to sound levels within each activity or transport mode

The **Figure 1** represents the L_{A50} vs L_{Aeq} for each couple {participant, day} in which the activity or transport is performed (3085 individuals in total). The Figure 1 highlights the distinction in the couples of values {L_{A50},L_{Aeq}} between activity and transportation modes. In particular, “Residence” is associated with high L_{Aeq} but low L_{A50} values, which is confirmed by the poor correlation $r_{LAeq,LA50,residence}$ = 0.32, which contrasts for instance with $r_{LAeq,LA50,car,motorcycle}$ = 0.86 or $r_{LAeq,LA50,leisure}$= 0.88. Another relatively low correlation is the correlation between L_{Aeq} and L_{A50} in underground transport, with $r_{LAeq,LA50,publictransp.under}$ = 0.63. These low correlations can be explained by two different things:

- The very low correlation between L_{A50} and L_{Aeq} at residence comes from the very long period at night when sound levels avec very low, which results in very low L_{A50} values.
- The low correlation between L_{A50} and L_{Aeq} values within underground transportation modes come from noise peaks, to which L_{Aeq} is very sensitive.

As a consequence, the further analyses are shown for L_{Aeq} indicator, which is more standard. Further deeper analyses on the noise dynamics within each transport mode or activity will help understanding the daily sound levels exposure distribution.

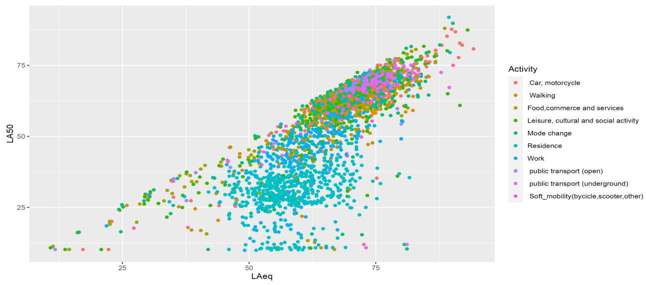

Figure 1. L_{A50} vs L_{Aeq} for each couple {participant, day} in which the activity or transport is performed (3085 individuals in total).

3.2 Assessment of daily exposure with measurements or modeling

The **Figure 2** represents the correlation matrix of the calculated exposure values $L_{den,home}$, $L_{den,neigh}$, $L_{night,home}$, $L_{night,neigh}$, and the measured $L_{Aeq,24h}$. These four calculated standard indicators for noise exposure assessment are poorly correlated to the measured $L_{Aeq,24h}$ ($r_{Lden,home, LAeq,24h}$ = 0.01, $r_{Lden,night,LAeq,24h}$ = 0.05, $r_{Lnight,home,LAeq,24h}$ = -0.06, $r_{Lnight,neigh, LAeq,24h}$ = 0.03), highlighting that sound level at the residence location does not capture the real exposure of participants. As it is the energetic sum of the twelve $L_{Aeq,act/transp}$, the $L_{Aeq,24h}$ value is correlated to these. Interestingly, the correlation matrix also shows some negative correlations, such as the correlation between $L_{Aeq,24h,car}$ and $L_{Aeq,24h,Tunder}$ or $L_{Aeq,24h,Topen}$. This is the result of the competition between transport modes: participants commuting by car do not take public transport modes. Indeed, since the $L_{Aeq,24h,act/transp}$ is a function of the $L_{Aeq,act/transp}$ and its duration, and given that the duration of a day is fixed, the time spent in an activity systematically reduces the time spent in other activities, and therefore their $L_{Aeq,24h,act/transp}$. Negative correlations are also observed between work and leisure daily sound level contributions.
The **Figure 3** details the contribution of each activity or transportation mode to the daily exposure to noise

($NS_{act/transp}$ values), as long of the proportion of the time spent in each activity or transportation mode ($T_{act/transp}$ values). The findings are:

- The high proportion of the time spent at home (67.8%) only corresponds to 24.4% of the daily sound level exposure, as sound levels at residence are low;
- The activities work and leisure correspond respectively to 14.8% and 14.4% of the daily sound level exposure (for only 4.3% of the time spent in leisure, cultural and social activities).
- 1.1% of the time spent in underground public transport correspond to 8.2% of the daily sound levels exposure.

These results suggest that the practices of mobility and activities have a strong impact on daily sound levels exposure, that are neglected by the standardized approach, that considers sound levels at the façade of the home location.

Further analyses are required to understand the meaning of these results for different social categories. For instance, a simple classification of participants per sector of activity (retired or not working; office job; industry; commerce, restaurant and social) shows that:

- Retired or not working spend 78% of their time at Residence, for 29.7% of their daily sound level exposure. This amount falls to 64.9% for the "Office job" class, for 22.2% of their daily sound level exposure.
- Results are more contrasted for underground public transport: not working or retired participants spend 0.5% of their time in underground public transport, for 3.4% of their daily sound level exposure, while participants working in Industry, construction or transport spend 1.7% of their time in underground public transport, for 12.7% of their daily sound level exposure.

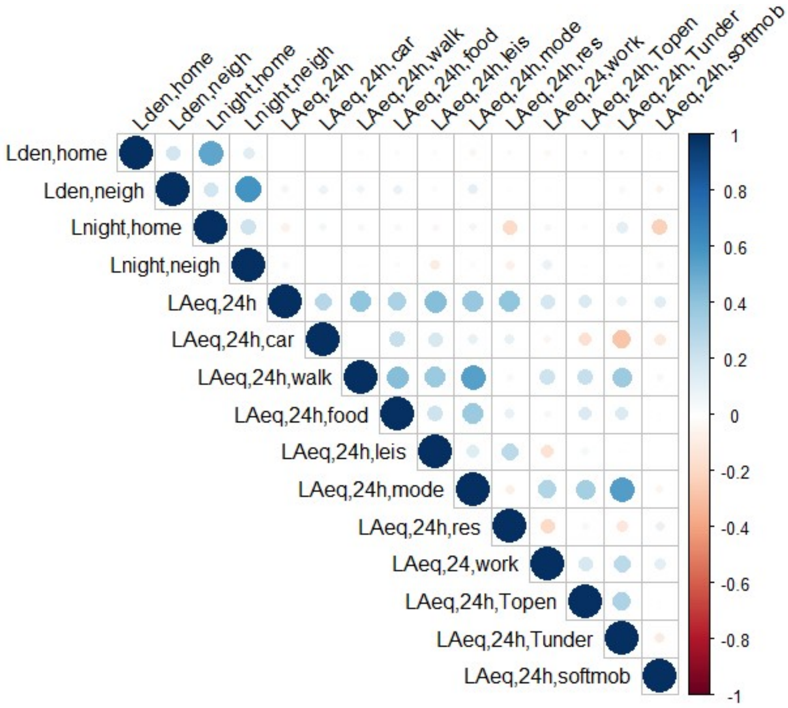

Figure 2. Correlation matrix between modeled and measured daily exposure.

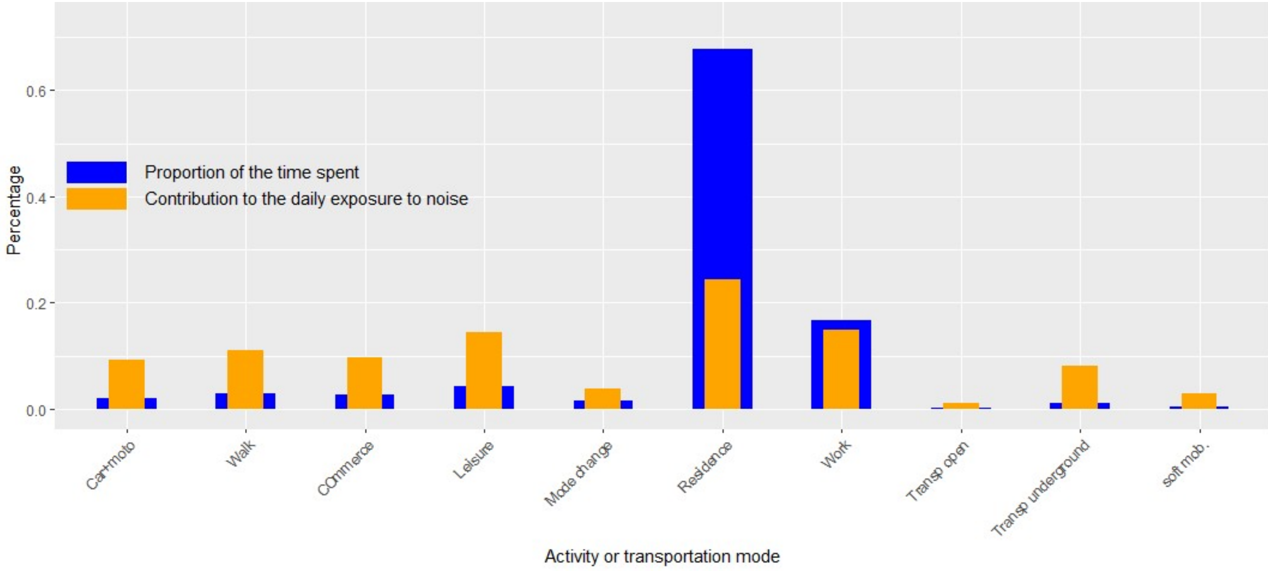

Figure 3. Proportion of the time spent in an activity / transportation mode ($T_{act/transp}$) as long as contribution of activity or transportation mode to the daily exposure to noise ($NS_{act/transp}$)

4. CONCLUSIONS

This paper investigates (i) the relevance of modeling approaches to capture the experience daily exposure to sound levels, (ii) the contribution of activities and transportation modes to the daily exposure to sound levels. Tis relies on a selected cohort data collection on 232 participants, which permitted to collect L_{Aeq} values for between 1 to 5 complete days, in concomitance with the activities and transportation modes performed. The results are the following:

- The standard approach that considers the sound levels at the façade of home locations fails to capture the measured 24h sound levels exposure;
- Sensor based measures highlight that (i) the residential sound levels explain a small amount of the daily sound levels exposure, (ii) the contribution of each activity and transportation mode to daily sound levels exposure is not necessarily linked to the time spent in the activity; this is particualry true to public transport underground, which amounts to a very little amount of time but to a not negectable coantribution of the daily sound nlevels exposure.

Further studies are required to better account for the potential environmental injustice that this finding may entail.

5. ACKNOWLEDGMENTS

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6. REFERENCES

[1] EU 2015/996. Establishing common noise assessment methods according to Directive 2002/49/EC of the European Parliament and of the Council.

[2] Chaix, B., Duncan, D., Vallée, J., Vernez-Moudon, A., Benmarhnia, T., & Kestens, Y. (2017). The “Residential” effect fallacy in neighborhood and health studies: Formal definition, empirical identification, and correction.

[3] Ma, J., Li, C., Kwan, M. P., Kou, L., & Chai, Y. (2020). Assessing personal noise exposure and its relationship with mental health in Beijing based on individuals’ space-time behavior. *Environment International*, *139*(April), 105737.

[4] Chaix, B., Kestens, Y., Perchoux, C., Karusisi, N., Merlo, J., & Labadi, K. (2012). An interactive mapping tool to assess individual mobility patterns in neighborhood studies. *American Journal of Preventive Medicine*, *43*(4), 440–450. https://doi.org/10.1016/j.amepre.2012.06.026.

[5] Tao, Y., Chai, Y., Kou, L., & Kwan, M. P. (2020). Understanding noise exposure, noise annoyance, and psychological stress: Incorporating individual mobility and the temporality of the exposure-effect relationship. *Applied Geography*, *125*(September), 0–6. https://doi.org/10.1016/j.apgeog.2020.102283

[6] Wang, J., Kou, L., Kwan, M. P., Shakespeare, R. M., Lee, K., & Park, Y. M. (2021). An integrated individual environmental exposure assessment system for real-time mobile sensing in environmental health studies. *Sensors*, *21*(12), 1–19. https://doi.org/10.3390/s21124039.

[7] Bruitparif. (2019). *Bruitparif - noise map*. https://www.bruitparif.fr/cartes-de-bruit/