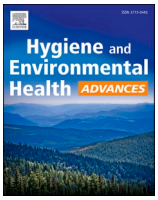
Hygiene and Environmental Health Advances 15 (2025) 100134

Contents lists available at ScienceDirect

Hygiene and Environmental Health Advances

journal homepage: www.elsevier.com/locate/heha



Do weekends matter in unraveling the impact of acute temperature exposure on the risk of daily mortality?

ARTICLE INFO

Keywords:
Weekends
Working day
Mortality
Temperature
Time-series

Dear Editor,

The "weekend effect" in healthcare refers to the phenomenon where patients admitted to hospitals on weekends tend to have worse outcomes compared to those admitted on working days, likely due to limited resources, more severe cases, and changes in staffing or shifts (Kostis et al., 2007; Roberts et al., 2015). Time-series analyses investigating temperature–mortality relationships in environmental epidemiology typically account for day-of-week variations (Gasparrini and Armstrong, 2010). However, the potential modifying effect of the weekend remains unexplored. This study aims to offer insights into the potential impact of weekend effect modification on temperature–mortality associations.

We used open-source data sets containing daily counts of all-cause mortality (International Classification of Diseases [ICD]−9 codes 0–799, ICD-10 codes A00-R99), cardiovascular mortality (ICD-9 codes 390–459, ICD-10 codes I00-I99), respiratory mortality (ICD-9 codes 460–519, ICD-10 codes J00-J99) for London (2001–2006), Valencia (2001–2007), Chicago (1987–2000), and Baltimore (1987–2000) (Tobias et al., 2024b). We estimated city-specific temperature–mortality associations using a time-stratified case-crossover design based on time-series data using a conditional quasi-Poisson regression model combined with distributed lag non-linear model (Tobias et al., 2024a). Seasonality, long-term trends, and the day of the week were adjusted via time-stratification. This was achieved using a three-way interaction between year, month, and day of the week to stratify the time-series. The association was modelled using a natural cubic spline with three internal knots placed at the 10th, 75th, and 90th percentiles of the temperature distribution for the same-day (lag 0) temperature exposure (Tobias et al., 2024a). We examined the temperature–mortality association separately for working days (Monday to Friday) and weekends (Saturday and Sunday) and subsequently compared the models across four cities. To assess the presence of effect modification by weekends, we fitted an all-days model both with and without an interaction term for weekends and compared these models using a likelihood ratio test. These choices are based on extensive previous work (Tobias et al., 2024a).

Fig. 1. illustrates the overall cumulative temperature–mortality associations for working days and weekends. The findings indicate that the temperature–mortality relationship for respiratory diseases is significantly modified by weekend effects in London (interaction $P = 0.02$) and Baltimore (interaction $P = 0.01$). Graphical visualization also reveals that the effect estimates at cold temperatures in London, and across the entire temperature range in Baltimore, are particularly influenced. However, this weekend effect appears to vary by study location (interaction $P = 0.18$ in Valencia; $P = 0.48$ in Chicago) and by the type of death (Supplementary Fig. 1 and Fig. 2).

Although the weekend effect has been extensively studied in the clinical studies, variations in human behavior patterns between weekends and working days, particularly in relation to outdoor activities, may modulate environmental exposures and thereby influence acute mortality risk. In particular, we speculate that on weekends in extreme heat or cold, easily increased exposure to respiratory diseases, driven by more frequent indoor social gatherings with family and friends in poorly ventilated spaces, changes in the types of air pollutants, leading to in a higher risk in heat and cold compared to all-cause and cardiovascular mortality (Aujesky et al., 2009).Moreover, environmental stressors such as air pollutants also differ between weekends and working days, which influence mortality risk in certain conditions, leading to varying susceptibility to ambient temperature across different days of the week (Jhun et al., 2014; Seguel et al., 2012; Shi et al., 2020; Sicard et al., 2020). A recent multi-country study found that suicide risk peaked on Mondays during working days, with weekend effects varying among countries (Lee et al., 2024). Although previous studies have frequently reported "U"- or "J"-shaped temperature–mortality relationships, our findings exhibited a predominantly J-shaped pattern, characterized by elevated risks at high temperatures but a less pronounced effect at lower temperatures (Gasparrini et al., 2015). This asymmetry may be attributed to our use of same-day (lag 0) temperature exposure, which captures acute effects of heat but may miss the delayed and cumulative impacts associated with cold-related mortality. Nevertheless, the results suggest that acute temperature extremes—particularly on weekends—may serve as a practical indicator for anticipating increases in healthcare demand.

This study has some limitations. First, we stratified the data by working days and weekends and considered only same-day temperature effects, which may have limited our ability to detect lagged responses, particularly for cardiovascular outcomes. Second, we did not adopt a

https://doi.org/10.1016/j.heha.2025.100134
Received 1 April 2025; Received in revised form 24 June 2025; Accepted 26 June 2025
Available online 3 July 2025

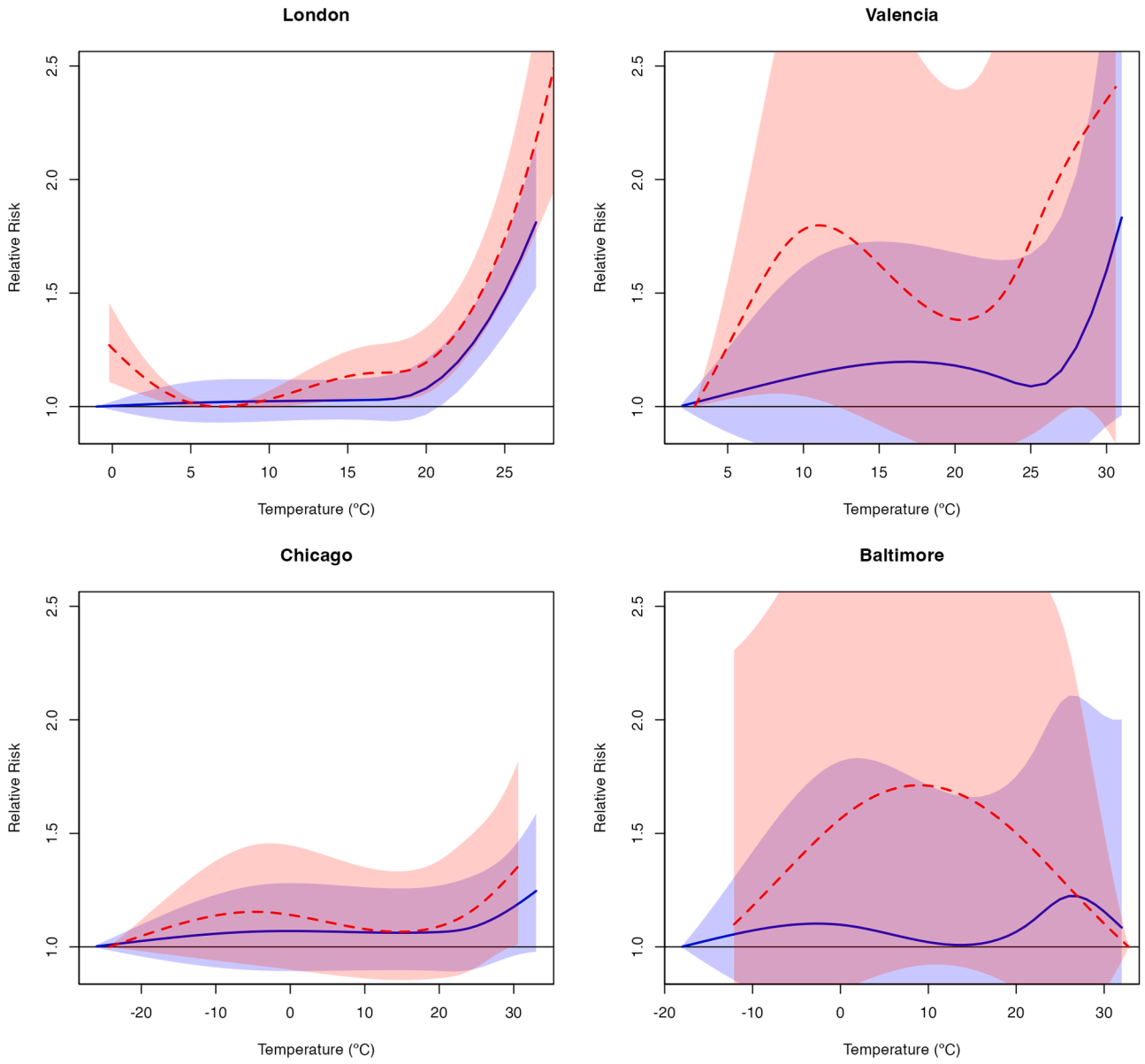


Fig. 1. Association between mean temperature and respiratory mortality on working days (solid blue line) and weekends (dashed red line) in London, Valencia, Chicago, and Baltimore. Solid lines represent estimated relative risks on working days, while dashed lines denote estimates for weekends. Shaded regions indicate 95 % confidence intervals. The interaction P-values for the weekend effect were 0.02, 0.18, 0.48, and 0.01 in London, Valencia, Chicago, and Baltimore, respectively.

two-stage design—commonly used in environmental epidemiology to increase statistical power and account for between-location heterogeneity—because the observation periods varied across cities (Sera and Gasparrini, 2022). This may have limited ability to detect nuanced, outcome-specific variations and reduced the generalizability of the findings. Future studies should incorporate lag structures and adopt two-stage designs across multi-country, multi-city datasets to more robustly characterize temperature–mortality associations, including potential modification by weekends.

Although further research is needed, our analysis highlights the importance of considering weekends in temperature studies as a potential effect modifier in temperature studies. From both clinical and prevention perspectives, accounting for variations in temperature-related mortality between working days and weekends could provide valuable insights for designing more targeted public health interventions.

Ethics approval and consent to participate

This study analyzed publicly available data. As such, the datasets were de-identified and fully anonymized in advance, and the analysis of publicly available data with no identifying information did not require ethical approval.

Consent for publication

Not applicable.

CRediT authorship contribution statement

Keita Wagatsuma: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Takahisa Ogawa:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Investigation,

Funding acquisition, Formal analysis, Data curation, Conceptualization. **Yi-Sheng Yang:** Writing – review & editing. **Kensuke Uraguchi:** Writing – review & editing. **Mami Hitachi:** Writing – review & editing. **Susana Silva:** Writing – review & editing. **Erik Pieter de Jong:** Writing – review & editing. **Ya-Yun Cheng:** Writing – review & editing. **Aurelio Tobias:** Writing – review & editing, Validation, Supervision. **Masahiro Hashizume:** Writing – review & editing, Validation, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

KW received funding from the Grants-in-Aid for Scientific Research (KAKENHI) by the Japan Society for the Promotion of Science (JSPS) (24K23680 and 25K20622). TO received funding from the KAKENHI by the JSPS (23K15682).

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.heha.2025.100134.

Data availability

Data and computing code are available upon reasonable request.

References

Aujesky, D., Jiménez, D., Mor, M.K., Geng, M., Fine, M.J., Ibrahim, S.A., 2009. Weekend versus weekday admission and mortality after acute pulmonary embolism. Circulation 119, 962–968. https://doi.org/10.1161/CIRCULATIONAHA.108.824292.

Gasparrini, A., Armstrong, B., 2010. Time series analysis on the health effects of temperature: advancements and limitations. Environ. Res. 110, 633–638. https://doi.org/10.1016/j.envres.2010.06.005.

Gasparrini, A., Guo, Y., Hashizume, M., Lavigne, E., Zanobetti, A., Schwartz, J., Tobias, A., Tong, S., Rocklöv, J., Forsberg, B., Leone, M., De Sario, M., Bell, M.L., Guo, Y.L.L., Wu, C.F., Kan, H., Yi, S.M., De Sousa Zanotti Stagliorio Coelho, M., Saldiva, P.H.N., Honda, Y., Kim, H., Armstrong, B., 2015. Mortality risk attributable to high and low ambient temperature: a multicountry observational study. Lancet 386, 369–375. https://doi.org/10.1016/S0140-6736(14)62114-0.

Jhun, I., Fann, N., Zanobetti, A., Hubbell, B., 2014. Effect modification of ozone-related mortality risks by temperature in 97 US cities. Environ. Int. 73, 128–134. https://doi.org/10.1016/j.envint.2014.07.009.

Kostis, W.J., Demissie, K., Marcella, S.W., Shao, Y.-H., Wilson, A.C., Moreyra, A.E., 2007. Weekend versus weekday admission and mortality from myocardial infarction. N. Engl. J. Med. 356, 1099–1109. https://doi.org/10.1056/nejmoa063355.

Lee, W., Kang, C., Park, C., Bell, M.L., Armstrong, B., Roye, D., Hashizume, M., Gasparrini, A., Tobias, A., Sera, F., Honda, Y., Urban, A., Kyselý, J., Íñiguez, C., Ryti, N., Guo, Y., Tong, S., de Sousa Zanotti Stagliorio Coelho, M., Lavigne, E., de'Donato, F., Guo, Y.L., Schwartz, J., Schneider, A., Breitner, S., Chung, Y., Kim, S., Ha, E., Kim, H., Kim, Y., 2024. Association of holidays and the day of the week with suicide risk: multicounty, two stage, time series study. BMJ 387, e077262. https://doi.org/10.1136/bmj-2024-077262.

Roberts, S.E., Thorne, K., Akbari, A., Samuel, D.G., Williams, J.G., 2015. Weekend emergency admissions and mortality in England and Wales. Lancet 385, 1829. https://doi.org/10.1016/S0140-6736(15)60580-3.

Seguel, R.J., Morales S, R.G.E., Leiva G, M.A., 2012. Ozone weekend effect in Santiago, Chile. Environ. Pollut. 162, 72–79. https://doi.org/10.1016/j.envpol.2011.10.019.

Sera, F., Gasparrini, A., 2022. Extended two-stage designs for environmental research. Environ Health 21, 41. https://doi.org/10.1186/s12940-022-00853-z.

Shi, W., Sun, Q., Du, P., Tang, S., Chen, C., Sun, Z., Wang, J., Li, T., Shi, X., 2020. Modification effects of temperature on the ozone-mortality relationship: a nationwide multicounty study in China. Environ. Sci. Technol. 54, 2859–2868. https://doi.org/10.1021/acs.est.9b05978.

Sicard, P., Paoletti, E., Agathokleous, E., Araminienė, V., Proietti, C., Coulibaly, F., De Marco, A., 2020. Ozone weekend effect in cities: deep insights for urban air pollution control. Environ. Res. 191, 110193. https://doi.org/10.1016/j.envres.2020.110193.

Tobias, A., Kim, Y., Madaniyazi, L., 2024a. Time-stratified case-crossover studies for aggregated data in environmental epidemiology: a tutorial. Int. J. Epidemiol. 53. https://doi.org/10.1093/ije/dyae020 dyae020.

Tobias, A., Ng, C.F.S., Kim, Y., Hashizume, M., Madaniyazi, L., 2024b. Compilation of open access time-series datasets for studying temperature-mortality association. Data Brief 55, 110694. https://doi.org/10.1016/j.dib.2024.110694.

Keita Wagatsuma[a,b,†,*], Takahisa Ogawa[c,d,†], Yi-Sheng Yang[e,f], Kensuke Uraguchi[g], Mami Hitachi[h], Susana Silva[i], Erik Pieter de Jong[j], Ya-Yun Cheng[k,l,m], Aurelio Tobias[n,o], Masahiro Hashizume[p]

[a] *Division of International Health (Public Health), Graduate School of Medical and Dental Sciences, Niigata University, Niigata, Japan*

[b] *Institute for Research Administration, Niigata University, Niigata, Japan*

[c] *Australian Institute of Health Innovation, Faculty of Medicine, Health and Human Sciences, Macquarie University, Sydney, Australia*

[d] *Department of Health Policy and Informatics, Graduate School of Medicine, Institute of Science Tokyo, Tokyo, Japan*

[e] *Department of Occupational Medicine, Fu Jen Catholic University Hospital, Taipei, Taiwan*

[f] *Institute of Environmental and Occupational Health Sciences, National Taiwan University College of Public Health, Taipei, Taiwan*

[g] *Department of Epidemiology, Graduate School of Medicine, Dentistry and Pharmaceutical Sciences, Okayama University, Okayama, Japan*

[h] *Department of Ecoepidemiology, Institute of Tropical Medicine, Nagasaki University, Nagasaki, Japan*

[i] *Department of Epidemiology, Instituto Nacional de Saúde Dr. Ricardo Jorge, Lisbon, Portugal*

[j] *Global Health Program, College of Public Health, National Taiwan University, Taipei, Taiwan*

[k] *School of Medicine, College of Medicine, National Sun Yat-sen University, Taiwan*

[l] *Center of Excellence for Metabolic Associated Fatty Liver Disease, National Sun Yat-sen University, Kaohsiung, Taiwan*

[m] *Aerosol Science Research Center, National Sun Yat-sen University, Kaohsiung, Taiwan*

[n] *Institute of Environmental Assessment and Water Research, Spanish Council for Scientific Research, Barcelona, Spain*

[o] *School of Tropical Medicine and Global Health, Nagasaki University, Nagasaki, Japan*

[p] *Department of Global Health Policy, Graduate School of Medicine, The University of Tokyo, Tokyo, Japan*

[*] Corresponding author at: Division of International Health (Public Health), Graduate School of Medical and Dental Sciences, Niigata University, 1-757 Asahimachi dori, Chuo-ku, Niigata City, Niigata 951-8510, Japan.
E-mail address: waga@med.niigata-u.ac.jp (K. Wagatsuma).

[†] These authors contributed equally to this work and share first authorship.