



REPLY TO JOLY:

Inferring causation from comprehensive analysis of observation

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In our paper, “How jet lag impairs Major League Baseball performance,” we describe performance reductions in teams as a function of travel across time zones and attribute these effects to jet lag (1). The letter by Joly (2) raises the issue of correlation versus causation, implying that we cannot conclude that jet lag causes these effects. In cases where laboratory studies or prospective controlled intervention trials are not possible or are difficult, retrospective studies in natural settings can be valuable. Nonetheless, to effectively decipher potential causation from these studies, one needs to apply a robust statistical model that comprehensively accounts for potential confounding variables (i.e., potential causative factors). In fact, it is well established that regression models like ours can be used for causal inference in such scenarios (3, 4).

In our case, these potential confounding variables include whether the game is played at home or away, park effects, and travel amount and direction. To ensure robust effects, we examined a sizeable dataset encompassing over 20 y of data and over 45,000 games. Indeed, we believe we went further in terms of the volume of analyzed data and consideration of confounding

variables than any report to date examining the effects of jet lag on athletic performance. For the most significant effect we observed—home runs allowed—this effect is reproducible, evident in both home and away teams. Finally, these effects are consistent with an extensive literature on human circadian clocks (5), with the observation that eastward travel was generally more detrimental than westward travel (6, 7). The fact that we accounted for all of these variables over so many years and that the major effect we observed is reproducible, and that the effects we observed are consistent with an extensive literature on human circadian clocks, provides high confidence that the effects of jet lag do indeed cause the effects on performance that we observed.

It should be noted that even in experimental studies under highly controlled conditions, a standard of $P < 0.05$ is often used, indicating that there is always some uncertainty in the validity of results from even the most well-controlled studies that make claims about “proof.” As Joly notes about our results, “. . . I am of course not disputing that jet lag is the most likely cause for the effects recorded” (2). We could not agree more.

- 1 Song A, Severini T, Allada R (2017) How jet lag impairs Major League Baseball performance. *Proc Natl Acad Sci USA* 114:1407–1412.
- 2 Joly E (2017) Baseball and jet lag: Correlation does not imply causation. *Proc Natl Acad Sci USA* 114:E3168.
- 3 Cox DR, Wermuth N (2004) Causality: A statistical view. *Int Stat Rev* 72:285–305.
- 4 Gelman A, Hill J (2007) *Data Analysis Using Regression and Multilevel/Hierarchical Models* (Cambridge Univ Press, Cambridge, UK).
- 5 Czeisler CA, et al. (1999) Stability, precision, and near-24-hour period of the human circadian pacemaker. *Science* 284:2177–2181.
- 6 Takahashi T, et al. (1999) Re-entrainment of circadian rhythm of plasma melatonin on an 8-h eastward flight. *Psychiatry Clin Neurosci* 53:257–260.
- 7 Sack RL (2010) Clinical practice. Jet lag. *N Engl J Med* 362:440–447.

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The authors declare no conflict of interest.

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