Even chess experts perform worse when air quality is lower, suggesting a negative effect on cognition

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Here's something else chess players need to keep in check: air pollution.

That's the bottom line of a newly published study co-authored by an MIT researcher, showing that chess players perform objectively worse and make more suboptimal moves, as measured by a computerized analysis of their games, when there is more fine particulate matter in the air.

More specifically, given a modest increase in fine particulate matter, the probability that chess players will make an error increases by 2.1 percentage points, and the magnitude of those errors increases by 10.8%. In this setting, at least, cleaner air leads to clearer heads and sharper thinking.

"We find that when individuals are exposed to higher levels of air pollution, they make more more mistakes, and they make larger mistakes," says Juan Palacios, an economist in MIT's Sustainable Urbanization Lab, and co-author of a newly published paper detailing the study's findings.

The paper, "Indoor Air Quality and Strategic Decision-Making," appears today in advance online form in the journal *Management Science*. The authors are Steffen Künn, an associate professor in the School of Business and Economics at Maastricht University, the Netherlands; Palacios, who is head of research in the Sustainable Urbanization Lab, in MIT's Department of Urban Studies and Planning (DUSP); and Nico Pestel, an associate professor in the School of Business and Economics at Maastricht University.

The toughest foe yet?

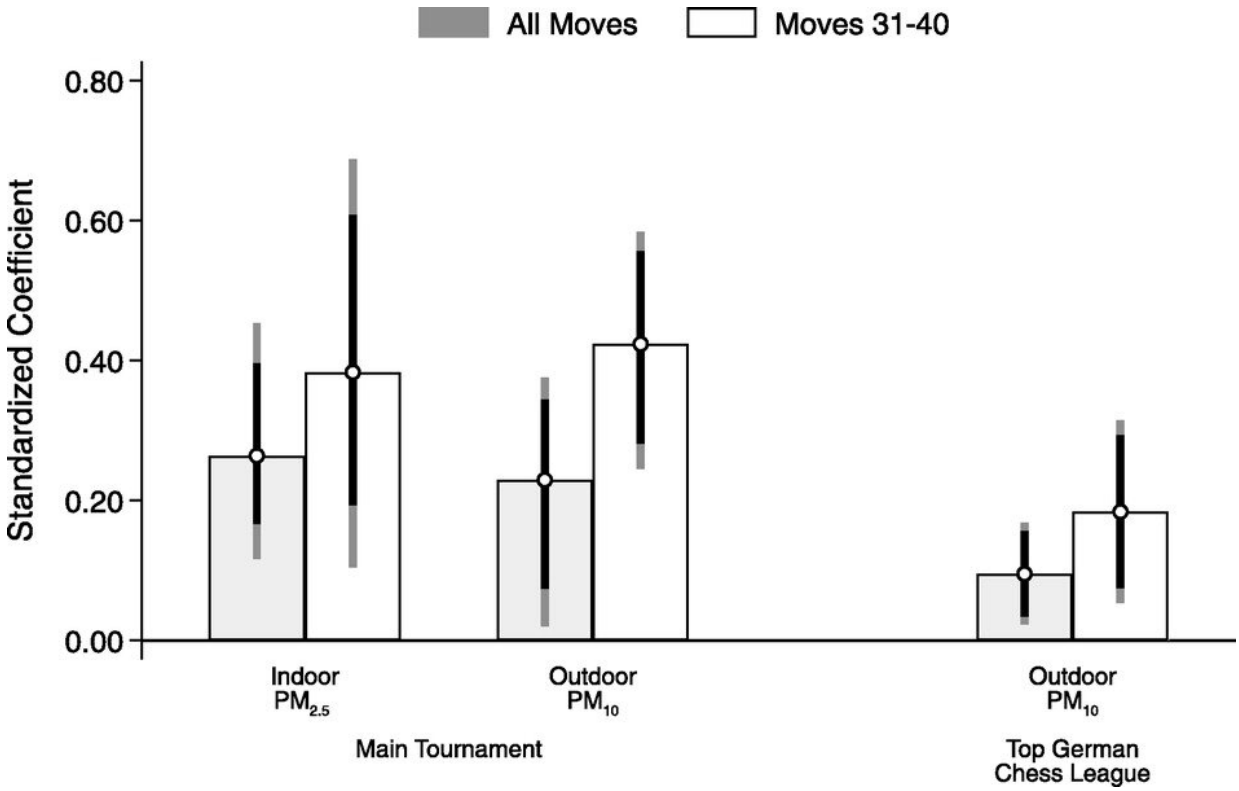
Fine particulate matter refers to tiny particles 2.5 microns or less in diameter, notated as $PM_{2.5}$. They are often associated with burning matter—whether through internal combustion engines in autos, coal-fired power plants, forest fires, indoor cooking through open fires, and more. The World Health Organization estimates that air pollution leads

to over 4 million premature deaths worldwide every year, due to cancer, cardiovascular problems, and other illnesses.

Scholars have produced many studies exploring the effects of air pollution on cognition. The current study adds to that literature by analyzing the subject in a particularly controlled setting. The researchers studied the performance of 121 chess players in three seven-round tournaments in Germany in 2017, 2018, and 2019, comprising more than 30,000 chess moves. The scholars used three web-connected sensors inside the tournament venue to measure carbon dioxide, $PM_{2.5}$ concentrations, and temperature, all of which can be affected by external conditions, even in an indoor setting. Because each tournament lasted eight weeks, it was possible to examine how air-quality changes related to changes in player performance.

In a replication exercise, the authors found the same impacts of air pollution on some of the strongest players in the history of chess using data from 20 years of games from the first division of the German chess league.

To evaluate the matter of performance of players, meanwhile, the scholars used software programs that assess each move made in each chess match, identify optimal decisions, and flag significant errors.



Comparison Impact Size of Air Pollution on Move Quality Across Samples for the Likelihood of Making a Meaningful Error. The figure shows the standardized estimated PM coefficients on the probability of making a meaningful error for each subsample separately. Gray bars represent the results using the full sample of moves, and white bars display the coefficients for the subsample of moves from the 31st to 40th move of the game, just before the time control takes place. We display the results for four different specifications. From left to right: (1) "Indoor $PM_{2.5}$" bars describe the PM estimates based on our indoor air-quality monitor, deployed at the tournament room in the main tournament; (2) "Outdoor PM_{10}" describes the results for the main tournament using the readings from the closest outdoor air-quality station; (3) the last pair of bars describe the estimates based on games in "the top German league" using readings from air-quality stations near tournament venues. The outcome variable "meaningful error" takes on the value of one if the move is marked as a meaningful error by the chess engine and zero otherwise. Dots describe point estimates. Black (gray) error bars show the 90% (95%) confidence intervals. Credit: *Management Science* (2023). DOI: 10.1287/mnsc.2022.4643

During the tournaments, $PM_{2.5}$ concentrations ranged from 14 to 70 micrograms per cubic meter of air, levels of exposure commonly found in cities in the U.S. and elsewhere. The researchers examined and ruled out alternate potential explanations for the dip in player performance, such as increased noise. They also found that carbon dioxide and temperature changes did not correspond to performance changes. Using the standardized ratings chess players earn, the scholars also accounted for the quality of opponents each player faced. Ultimately, the analysis using the plausibly random variation in pollution driven by changes in wind direction confirms that the findings are driven by the direct exposure to air particles.

"It's pure random exposure to air pollution that is driving these people's performance," Palacios says. "Against comparable opponents in the same tournament round, being exposed to different levels of air quality makes a difference for move quality and decision quality."

The researchers also found that when air pollution was worse, the chess players performed even more poorly when under time constraints. The tournament rules mandated that 40 moves had to be made within 110 minutes; for moves 31–40 in all the matches, an air pollution increase of 10 micrograms per cubic meter led to an increased probability of error of 3.2%, with the magnitude of those errors increasing by 17.3%.

"We find it interesting that those mistakes especially occur in the phase of the game where players are facing time pressure," Palacios says. "When these players do not have the ability to compensate [for] lower cognitive performance with greater deliberation, [that] is where we are observing the largest impacts."

'You can live miles away and be affected'

Palacios emphasizes that, as the study indicates, air pollution may affect

people in settings where they might not think it makes a difference.

"It's not like you have to live next to a power plant," Palacios says. "You can live miles away and be affected."

And while the focus of this particular study is tightly focused on chess players, the authors write in the paper that the findings have "strong implications for high-skilled office workers," who might also be faced with tricky cognitive tasks in conditions of variable air pollution. In this sense, Palacios says, "The idea is to provide accurate estimates to policymakers who are making difficult decisions about cleaning up the environment."

Indeed, Palacios observes, the fact that even chess players—who spend untold hours preparing themselves for all kinds of scenarios they may face in matches—can perform worse when air pollution rises suggests that a similar problem could affect people cognitively in many other settings.

"There are more and more papers showing that there is a cost with air pollution, and there is a cost for more and more people," Palacios says. "And this is just one example showing that even for these very [excellent] chess players, who think they can beat everything—well, it seems that with air pollution, they have an enemy who harms them."

More information: Steffen Künn et al, Indoor Air Quality and Strategic Decision Making, *Management Science* (2023). DOI: 10.1287/mnsc.2022.4643