Substitute teachers and replacement nurses may cause disease to spread faster (Update)

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Mathematical biologist Sam Scarpino aims to understand disease as an emergent process. His new study in *Nature Physics* pushes forward our understanding of how epidemics spread -- and has sobering implications for substitute teachers, replacement nurses, even members of a hockey team -- anyone who fills in for a sick colleague. Credit: Joshua Brown

Imagine a nurse who gets the flu while working at a hospital. He goes home to recover—and an uninfected replacement nurse comes in. This kind of substitution happens all the time in the real world—teachers, doctors, firefighters and others with essential societal roles get sick and a substitute comes in to fill their role.

A new study shows that this kind of health-protecting behavior—a "relational exchange"—can explosively accelerate the spread of some epidemics. This finding is in striking contrast to the standard "mass-action" disease models—like many used by the U.S. Centers for Disease Control and other health organizations—that don't account for this reality.

The study was published August 1 in the journal *Nature Physics*.

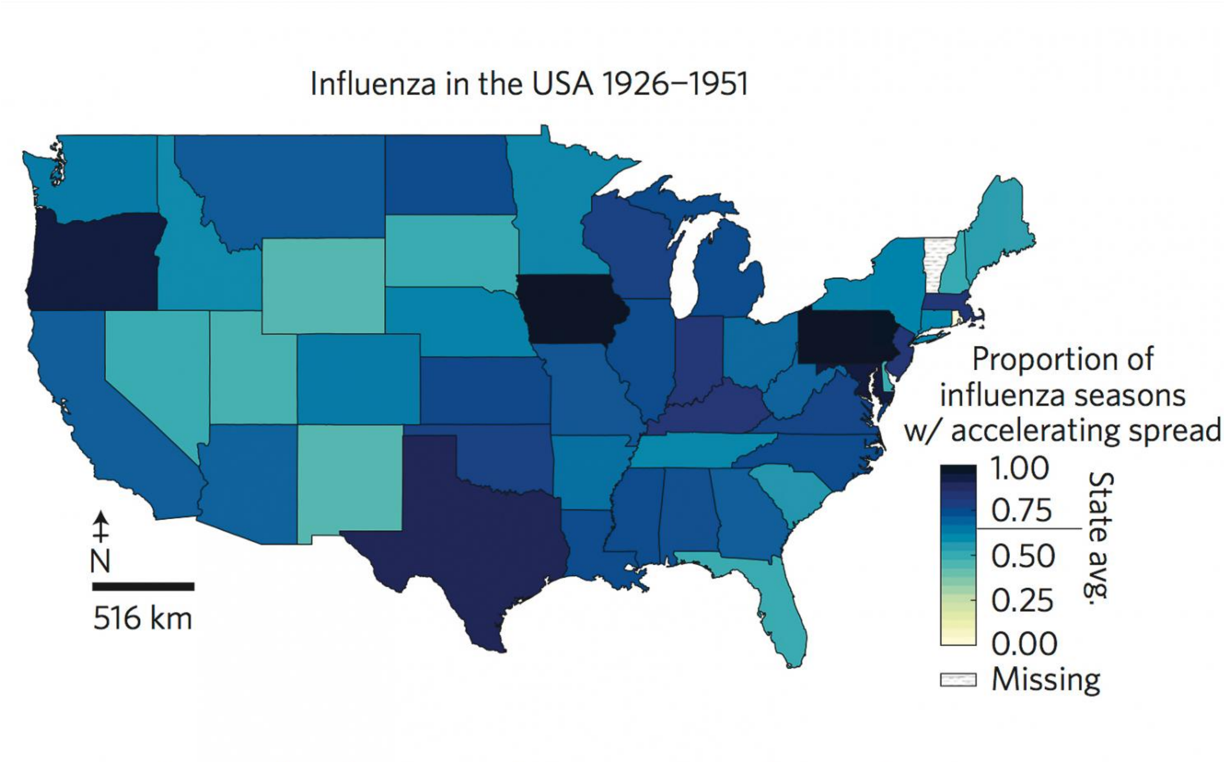
"One take-home of our study is that it may be very difficult to predict the size of a disease outbreak," says Sam Scarpino, a scientist at the University of Vermont who led the new research with two colleagues, "and that mass-action models can't really account for the kind of sudden speed up and slow down" in transmission that many real-world epidemics show—and that the scientists' new model produces.

Epidemic planning

"This doesn't mean nurses and doctors shouldn't go home when they're sick, " says Scarpino. Almost the opposite. Instead, the new findings suggest that as epidemics approach their peak, replacement workers are in a more dangerous situation than conventional disease models would suggest.

"If you're making strategic decisions about how many healthcare workers you need, how many people you might expect to show up in the hospital, or how many courses of antivirals or antibiotics you might need, then the pace and tempo of cases matters deeply," Scarpino says.

Being able to quickly replace sick workers not just at the beginning of an epidemic but at its peak is one key to limiting its spread. But if you can't predict that it's about to exponentially speed up "with a huge number of new cases coming in," Scarpino says, "that could easily overwhelm the health care system and hospitals."



A heatmap of the US states illustrating the proportion of influenza seasons between 1921 and 1951 showing evidence for "relational exchange." Over 70% of seasons across all states provide support for this powerful influence on the spread of flu, a new University of Vermont study shows. Credit: Courtesy Sam Scarpino. Published in *Nature Physics*.

Infected nodes

Disease modeling is becoming an increasingly important part of health-care and epidemic planning. The now-standard mass-action models assume that infected people interact with other people at random, like so many molecules bouncing in the air. This approach has been defended on these grounds: if it's not a perfect reflection of the real world then at least these models give forecasters a sense of the worst-case scenarios. But Scarpino and his colleagues disagree. Their approach represents this essential worker behavior in a dynamic network, where "infected nodes" get rewired when a replacement worker comes in. An emergent property of their model shows that there can be critical transitions where the epidemic accelerates faster than the supposed worst-case scenario of a mass-action model—and just as suddenly burns out.

And their model points to another worrisome dynamic. Imagine during a disease epidemic that the worker replacement rate is "high enough to keep an outbreak under control, but that after some time the rate is slightly reduced. This might occur, for example, after the initial fear wears off," the scientists write. Their model indicates that a slight reduction in the rate at which, say, sick teachers or doctors are replaced "can push the system over a discontinuous transition," such that a "microscopic change" in the rate of replacement can lead to a very large change in disease prevalence. Suddenly, the epidemic is now in a higher gear, and if public health officials then wish to "bring the system back to its previous state," they write, "the replacement rate must be increased well beyond its previous value for the system to return to the initial state."

Flu vs. dengue

The scientists were able to back-up their modeling results with data from actual epidemics. Scarpino and his two co-authors, Laurent Hebert-Dufrene at the Santa Fe Institute, and Antoine Allard at University of Barcelona in Spain, analyzed existing national data from seventeen flu outbreaks in the US, twenty-five years of state-level flu data, and nineteen years of dengue fever data from Puerto Rico. They found the predicted pattern—"accelerating exponential transmission near the outbreak peak"—in most of the outbreaks of influenza, but almost not at all in dengue.

"In this paper we use dengue fever as a kind of null model," explains Hebert-Dufrene. The scientist didn't expect to see the same accelerations in dengue from replacement behavior, "because in dengue, behavior is not as important," he says. "You can stay home, but the mosquitoes will find you."

The new study had its beginning during the recent Ebola outbreak in West Africa. During that time, Scarpino, a mathemetical biologist and expert on epidemiology who leads UVM's Emergent Epidemics Lab, observed how many health care and funeral workers would get sick and a healthy person would replace them—only to get sick themselves. He wondered how this kind of substitution affects the spread and speed of the virus and various other kinds of epidemics.

"Our study suggests that replacing sick workers quickly throughout an epidemic is important," Scarpino say, "and vaccines, if they're available, should be provided to substitute teachers and nurses and other critical replacement workers as far in advance as possible."

More information: Samuel V. Scarpino et al, The effect of a prudent adaptive behaviour on disease transmission, *Nature Physics* (2016). DOI: 10.1038/nphys3832

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