INTRODUCTION

Firearm violence remains an inequitable and significant social burden in the U.S. Annually, firearm violence costs approximately 30,000 lives each year and nearly $165 billion.¹ Despite an ongoing emphasis on curbing the gun violence epidemic, firearm violence mortality rates have remained relatively stable throughout the 21st century.¹ Further, discrete geographic areas and demographic segments endure a disproportionate burden from firearm violence.¹,³ Firearm homicides in particular have risen in recent years, and these trends have been exacerbated during the coronavirus disease 2019 (COVID-19) pandemic.⁴

Driven by an array of macrostructural forces and policies that are particularly salient in both the current zeitgeist and empirical literature, including structural racism,⁵,⁶ health/healthcare disparities,⁷,⁸ and liberal firearm access/ownership policies,⁷,⁹ the longstanding and disproportionate impacts of firearm violence suggest that novel approaches may be needed to understand the underlying causal mechanisms that shape these outcomes and represent potential targets of corresponding preventive efforts. As evidence of the underlying dynamic complexity that characterizes many of these mechanisms continues to emerge, research and prevention based on complex systems—grounded research and prevention that can holistically embody the endemic and novel forces that shape firearm violence and guide high-leverage preventive solutions. Here, the potential of complex systems and syndemic perspectives is demonstrated, with a focus on firearm homicides; however, the potential of these ideas is more broadly applicable.

RETHINKING CAUSALITY IN FIREARM VIOLENCE: COMPLEX SYSTEMS AND SYNDEMIC PERSPECTIVES

Endeavors to understand causality in firearm violence research has almost universally fallen within the same paradigm that continues to dominate the social sciences. In the pursuit of discrete risk factors, this paradigm is grounded in 2 key assumptions. First, complex phenomena are best understood by deconstructing them into their component parts to be investigated in isolation. Aggregating these component-based insights can then lead to an understanding of the whole (reductionism). Second, cause—effect relationships are characterized by proportionality and superpositionality (linearity). Therefore, firearm violence research is characterized by methodologies that emphasize variable isolation and analytical techniques that rely on quantitative statistical methods that explain aggregate indicators via probability theory and macroscopic laws of averages.¹⁰

Undoubtedly, the current paradigm in firearm violence research has been critical in explicating numerous causal mechanisms across levels of influence, including distal forces. For example, key ecologic forces that shape gun violence—such as neighborhood characteristics (e.g., socioeconomic disadvantage, residential instability),¹¹ social network connectiveness,¹² and social trust—have been connected to a diverse array of downstream consequences that reinforce geographic and demographic inequities (e.g., through their detrimental impacts on children).¹³ However, as this body of literature on firearm violence continues to expand, researchers have started bringing to light a growing list of shortcomings in understanding the causal nature of these events and deficiencies in actions to prevent them.¹⁴ For example, although the current paradigm is grounded in linearity, research has revealed the tendency of firearm violence to shape, and be shaped by, inequities...
in a reciprocal manner, thereby forming feedback loops.\textsuperscript{15} Additionally, existing studies that investigate the causality of firearm homicides have shown unclear and often contradictory findings when examining risk factors for firearm violence across multiple levels of analysis, such as the influence of specific individual- or community/neighborhood-level risks on gun violence.\textsuperscript{11,15} Such findings have been found when investigating domains spanning across individual-level antecedents and racial/ethnic factors to firearm ownership rates and healthcare access.\textsuperscript{7,9,16} Similar shortcomings have been observed regarding emerging risks associated with firearm violence during the COVID-19 pandemic.\textsuperscript{17} Therefore, the key underlying mechanisms that shape firearm violence have been described as undertheorized.\textsuperscript{9} Furthermore, instances of success in prevention initiatives are overshadowed by the aforementioned population-level persistence of, and recent trends in, firearm violence rates.

Together, these shortcomings may be interpreted as an opportunity to fill an epistemologic and paradigmatic niche in gun violence research and prevention by integrating a new theoretical lens. This lens would no longer be oriented on risk factors but rather would focus on holistically capturing the multifactorial and interactive causal nature of firearm violence over time.\textsuperscript{10} Furthermore, this novel perspective should be able to conceptualize how macro-level forces interact with downstream forces to shape firearm violence.\textsuperscript{10} In other words, understanding should be focused on those dynamically complex causal mechanisms that generate and perpetuate the disproportionate distribution of these outcomes over time. However, because this perspective directly contrasts with the assumptions that underpin the dominant paradigm, adopting this dynamic complexity lens will necessitate the adoption of alternate theoretical and methodologic approaches. Thus, complex systems approaches constitute a novel paradigm in firearm violence research and prevention that is oriented toward phenomena that are best explained through a dynamic complexity lens. This paradigm aligns with a growing list of researchers who have characterized the causal nature of firearm violence as complex.\textsuperscript{9,16} However, integrating complex systems approaches takes these calls several steps further by emphasizing a paradigmatic shift that holistically embodies those properties of dynamic complexity that have been observed in studies on firearm violence. These properties include, but are not limited to, nonlinearities\textsuperscript{16,18} and interactions\textsuperscript{2,9,16} among dynamics,\textsuperscript{16,17} spatiotemporally distal,\textsuperscript{3,9,16,19} and heterogeneous\textsuperscript{3,9,16,18,20} causal factors that exhibit adaptation and self-organization\textsuperscript{7,9} and generate the emergence\textsuperscript{20} of population-level patterns of firearm violence.

**PUTTING THE PIECES TOGETHER: RECONCEPTUALIZING FIREARM VIOLENCE THROUGH THE SYNDEMIC LENS**

Complex systems approaches—and their corresponding theoretical assumptions in particular—may provide new-found insights into the nexus of dynamically complex longstanding (i.e., endemic) and emerging (i.e., novel) forces, or vulnerabilities, that shape the disproportionate burden of firearm violence within geographies and demographics.\textsuperscript{10} However, this paradigmatic shift may be daunting for many, especially given the infrequent exposure to these approaches in most academic programs and the limited number of professional training opportunities to acquire proficiency in theory and methodology. Furthermore, the assumptions that define complex systems approaches are innately more difficult than those within the dominant paradigm that more easily coalesce with mental models. Together, these (and other) barriers may hinder the integration of complex systems approaches into firearm violence research and prevention.

Fortunately, syndemic theory represents an accessible—yet powerful—way of engaging in complex systems—grounded firearm violence research and prevention. *Syndemics* are defined as the clustering, owing to contextual and social factors, of multiple and adversely interacting disease states (i.e., afflictions) within populations. The co-occurrence of these interacting afflictions leads to increased burden and vulnerability in these populations that then reinforces those macro-level factors, thus creating a reinforcing loop that perpetuates disparities.\textsuperscript{21} Altogether, viewing firearm violence through this lens may provide the theoretical foundation for complex systems-oriented research and prevention that can:

1. conceptualize the emergence of interacting firearm violence and associated afflictions as the product of macrostructural and historical policies and forces that have unfolded and continue to unfold over time.
2. anticipate how these afflictions may influence endemic and novel vulnerabilities and shape disparities in firearm violence in a nonlinear manner.
3. identify innovative and holistic multilevel prevention efforts.\textsuperscript{21}

**Firearm Violence as an Endemic Syndemic: Macrostructural Drivers and Downstream Impacts**

Longstanding vulnerabilities that are maintained through enduring dynamically complex causal mechanisms and shape the persistent clustering of firearm violence within specific geographies and demographics may constitute an endemic firearm violence syndemic. A
conceptual, feedback loop–focused framework of this syndemic is presented in Figure 1, where the following 3 dynamically complex causal mechanisms shape endemic vulnerabilities across multiple levels of influence are explored: (1) structural racism/discrimination, (2) health/health care, and (3) firearm access/ownership. This characterization is intended as an evidence-grounded primer in conceptualizing firearm violence as syndemic, rather than as an inclusive framework that embodies the full array of plausible causal mechanisms. The nested layers in the hierarchy are labeled on the left side of the figure, and the spatiotemporal scale of the dynamic processes that unfold within and across these layers is indicated by the arrow on the right side of the figure. The unidirectional arrows indicate the downstream influence of key causal forces across the levels of the hierarchy, and the bidirectional arrows indicate the interacting and interrelated causal nature of these forces both within and across levels.

In this conceptual framework, endemic vulnerabilities are shaped by the aforementioned macrostructural and historical forces and policies that induce downstream firearm violence and related afflictions: structural racism and discrimination, inequitable health/healthcare policies, and liberal firearm access/ownership policies. These macrostructural forces in turn induce environmental and social policies and forces, such as neighborhood disinvestment and socioeconomic inequality, inadequate healthcare access/quality, and community access to firearms. Multi-layered policies and forces then play out at the individual level by shaping exposures and resources related to firearm violence risk among perpetrators and victims, including household economic deprivation and vulnerability (e.g., unemployment), inadequate resources for firearm injury treatment and recovery (e.g., lack of long-term mental and physical care for gunshot wound survivors), and the likelihood of a firearm being present during violence that manifest as firearm violence clusters within those populations and geographies in which these afflictions co-
occur. These forces are also interacting and interrelated within levels; for example, at the Environmental and Social Forces and Policies level, neighborhood disinvestmment and socioeconomic inequality can exacerbate issues with inadequate healthcare access/quality and can impact community access to firearms. Finally, mutual and reinforcing firearm violence afflications may perpetuate extant firearm violence clusters through their influence on upstream and other macrostructural forces and policies (as indicated by red unidirectional arrows). For example, higher levels of firearm violence have been shown to deteriorate the economic health of communities through upstream mechanisms by reducing the growth of businesses and slowing home value appreciation, thereby perpetuating and accelerating socioeconomic inequality in those communities with firearm violence syndemicity.

Firearm Violence as a Novel Syndemic: Emerging Macrostructural Drivers and Downstream Impacts

Novel vulnerabilities emerge over time and may be triggered by events such as national emergencies and epidemics (e.g., the crack cocaine epidemic). These events result in major societal disruptions that increase firearm violence and disparities through their exacerbatory impacts on endemic dynamically complex causal mechanisms. For example, the COVID-19 pandemic has rapidly triggered a series of changes in macrostructural forces and policies that may have worsened endemic firearm violence vulnerabilities and induced novel vulnerabilities. Thus, the aforementioned endemic firearm violence syndemic may be continually shaped, reinforced, and even exacerbated by such emerging phenomena and corresponding policy responses, therefore constituting a novel firearm violence syndemic that is demonstrative of the dynamic nature of firearm violence syndemicity.

In Figure 2, emerging macrostructural drivers that correspond to the reciprocal, dynamically complex causal mechanisms from Figure 1 (structural racism/discrimination, health care, and firearm access/ownership) are presented to show how they may exacerbate the endemic firearm violence syndemic and introduce novel syndemicity. First, policies such as stay-at-home/shelter-in-place orders that have shifted work organization toward remote work have been less applicable to low-income and racial/ethnic minority workers, who tend to work in essential occupations. Second, COVID-19 healthcare policies implemented in response to the pandemic have been shown to exacerbate existing inequities in healthcare access/quality. Third, economic policies during the COVID-19 pandemic have determined firearm retailers to be essential businesses, thereby ensuring continued community-level firearm access, and other COVID-19 policies (e.g., stay-at-home orders) have been associated with increases in firearm violence. Finally, those interacting afflications caused or exacerbated by novel policies and forces triggered by the COVID-19 pandemic may reinforce inequitable structural and historical policies and forces.

Leveraging Syndemic Theory to Transform Firearm Violence Prevention

Viewing firearm violence disparities through a syndemic lens can provide holistic, complex systems—informedit insights about syndemogenesis—the development and exacerbation of syndemic interactions. This knowledge can then lead to holistic, syndemic-informed preventive solutions that simultaneously address macro-level forces that lead to the clustering of afflications, as well as co-occurring and interacting afflications at the individual level. For example, syndemic-informed prevention targeting the dynamically complex causal mechanism centered on firearm access/ownership from Figures 1 and 2 may simultaneously reform federal firearm laws and enhance street-level enforcement of corresponding laws to ensure legal firearm ownership. Further, syndemic perspectives can be integrated into existing evidence-based firearm violence prevention programs, such as those focused on street outreach (e.g., Cure Violence), greening (e.g., Clean & Green), and hospital-based interventions, by emphasizing macro-level forces and policies that are not currently addressed. More broadly, syndemic-informed prevention may generate countersyndemics, which represent high-leverage intervention opportunities where the targeted change to one vulnerability or affliction can nonlinearly protect against firearm violence and other mutually reinforcing afflictions. An example of a potential countersyndemic may be targeting healthcare access and quality, such as through macro-level healthcare reform, which could then simultaneously address multiple syndemic afflications—namely, the prevalence of mental/behavioral antecedents of violence (e.g., by improving access/availability of mental health resources) and insufficient resources for gunshot wound treatment/recovery (e.g., by improving access to trauma centers).

MOVING FORWARD: INTEGRATING COMPLEX SYSTEMS APPROACHES AND SYNDEMIC THEORY INTO GUN VIOLENCE RESEARCH AND PREVENTION

Engaging in novel, syndemic-grounded gun violence research and prevention is possible through methodologies already commonly used in the field, such as cross-sectional and longitudinal designs and geospatial
modeling, and analytical techniques, such as linear modeling. However, an array of methodologic and analytical approaches, collectively referred to as computational modeling and simulation techniques, are specifically tailored for engaging in complex systems science. Within the firearm violence literature, computational modeling and simulation techniques, such as system dynamics modeling, agent-based modeling, and network analysis, have been used in this and related domains. Further, these techniques have been successfully used in syndemic-grounded research and thus could be extended to explore firearm violence syndemicity and identify syndemic-informed preventive solutions.

As a final note, the integration of complex systems and syndemic approaches advocated for in this manuscript should not be understood as a replacement for current empirical work. Instead, they should be viewed as alternative approaches that, when combined, can be complementary and, in fact, can be synergistic. In particular, the development and validation of computational modeling and simulation techniques typically rely on inference drawn from an array of studies grounded in the current risk factor paradigm. In this way, these models meaningfully integrate known science by putting the pieces together into holistic, complex systems–grounded empirical frameworks, thereby harnessing the strengths of both.

CONCLUSIONS

The persistent and inequitable clustering of firearm violence within specific communities and populations and the inherent limitations of the dominant research paradigm indicate the need to consider novel approaches to research and prevention. Complex systems approaches may facilitate an understanding of the dynamically complex causal mechanisms that generate and perpetuate the disproportionate distribution of firearm violence. Syndemic theory may represent a powerful, complex systems–grounded theoretical framework for holistically conceptualizing how firearm violence and associated reinforcing afflictions nonlinearly emerge from endemic

Figure 2. Conceptual framework of novel firearm homicide syndemic.
and novel vulnerabilities that are shaped by structural and historical policies and forces. These theoretical insights may then inform high-leverage, syndemic-informed prevention strategies.

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