

# Population-level violence as a whole

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## **Abstract**

Violence is preventable and the United Nations' Sustainable Development Goals set out violence prevention as a global priority – calling for countries to halve their violent death rates by 2030. Despite action since, there has been limited progress in reducing violence globally.

In this essay, we argue that current violence prevention efforts are being heavily shaped by reductionism – the now-dominant research paradigm across the sciences. We make the case that this reductionist philosophy has prematurely misguided violence research away from studying populations as a whole. We further argue that the mainstream statistical methods in violence research are reinforcing this reductionist bias by oversimplifying 'cause' and 'effect' relationships. After revisiting foundational principles in sociology and public health, and drawing on advances in social epidemiology and complexity science, we suggest that violence – at any level – is better understood as an emergent property of a complex system.

We call on the field of violence research to return to a holist lens to maximise gains in explanatory theory and better position the evidence to directly inform effective intervention strategies for reducing violence at scale.

## **Main text**

Interpersonal violence took over 458,000 lives worldwide in 2021 alone.<sup>1</sup> It is therefore not surprising that the 2030 Sustainable Development Goals (SDGs) placed violence centre stage, calling for global action to half homicide rates by 2030 (SDG 16.1).<sup>2</sup> “Immediate action and radical changes” are needed if we are to curb population-level violence on a global scale.<sup>2</sup> Current violence prevention efforts, however, have fallen short.

In this analytic essay, we argue that the current shortcomings in violence prevention efforts can be traced back to the evidence used to inform them. The dominant research paradigm used to generate knowledge on the causes of population-level violence is misguided in two critical ways. First, although the study of population-level violence originated from disciplines concerned with the population as a whole, violence research has come to be dominated by the reductionist philosophy that population-level violence is best understood by individuals, their causes, and the link between individuals and populations.<sup>3-5</sup> Second, the ability to identify causes of population-level violence is being heavily shaped by the mainstream statistical methods – such as regression techniques – which assume that independent causal effects are identifiable and cause-effect relationships are unidirectional.<sup>6</sup> By going back to basics and asking what population-level violence is, and what causes it, we make a case for the pragmatic importance and possible autonomy of higher-level population properties that – although may depend on and emerge from individuals – are not fully explained by, and irreducible to, these individuals. We then draw on lessons learned from other disciplines to suggest that population-level violence is better characterised as an emergent property of a complex system;<sup>7</sup> and call for future research on population-level violence to return to disciplinary roots of holism to maximise gains in causal explanations and intervention efforts.<sup>8</sup>

### **Definition of population-level violence**

Interpersonal violence is an individual’s intentional use of force against another individual, which either results in or has a high likelihood of resulting in injury or death.<sup>9</sup> While some forms of violence (e.g., structural violence) might occur at different levels, interpersonal violence occurs at the individual-level via individual cases of violent perpetration and/or violent victimisation; it logically follows that any summary measure of group-level violence,

including population-level violence, is simply the aggregate of these individual cases of violence. This is because population counts are the sum of individual cases of violence, and the population rate is the proportion (a special type of ratio) of population counts (numerator) over the population size (denominator).<sup>10</sup>

In a naïve sense, that is, from a mathematical perspective, population-level violence is simply the aggregation of individual cases of violence. It is important to distinguish between population-level violence and its causes. Just because population-level violence is defined as the sum of individual cases of violence does not mean it is caused by the sum of individual causes of cases of violence.

### **Causes of population-level violence**

There is evidence to suggest that the sum of individual causes of cases of violence alone cannot capture the complete picture. Rather, violence is caused by levels beyond the individual. Seminal socioecological models of human behaviour postulate that causes span from more proximal influences (e.g., familial and household dysfunction) to wider influences at the institutional and societal level (e.g., cultural norms, social inequality, and social disorganisation),<sup>11,12</sup> while multilevel modelling has provided empirical evidence of the significance of multiple influences – which originate from different levels and yet can each help to explain violence.<sup>13</sup>

These multiple levels of possible causes brings the “levels of explanation problem” (micro-macro problem), which lies at the heart of the ecological and atomistic fallacies.<sup>5</sup> Distilled down, the problem can be summarised as: what causes an outcome at one level might not cause the same analogical outcome at another level of analysis. For instance, the percentage of a country’s population living in poverty might cause population-level violence, but this does not necessarily mean that being poor causes an individual to be violent. Differences between individual and population causes reflect how exposures are distributed. For example, a national economic recession that equally affects everyone living in that country may cause an increase in population rates of violence, but it is unable to explain differences in individual cases of violence as the economic recession is ubiquitous: every individual experiences the same exposure.<sup>14</sup>

Although the levels of explanation problem is pervasive across research disciplines and topics, it was Geoffrey Rose that placed it centre stage for public health research and prevention strategies. Rose showed that the causes of individual cases are not the same as the causes of population incidence.<sup>15</sup> While the former seeks to explain within-population variation in violence to understand why some individuals are more likely to perpetrate (or be a victim of) violence than others, the latter seeks to explain between-population variation in violence, asking questions like: i) why is Brazil more than 30-fold more violent than Japan?<sup>16</sup> and ii) why did the United States recently experience a unprecedented rise in lethal violence?<sup>17</sup> Answers to these questions may be critical to understanding the causes of population-level violence yet reveal little about what causes an individual to engage in violence.<sup>14</sup>

## **A brief history of the study of population-level violence**

### ***The population as a whole***

The idea that populations deserve studying in their own right—as *the* unit of analysis—has a long history before Geoffrey Rose. In the 19<sup>th</sup> century, the observation that populations are predictable and can behave like a collective individual, where some behaviours are universal to all individuals within the group so that the group takes on its own form of behaviour, gave birth to a new wave of sciences, including sociology and epidemiology.<sup>19</sup> These sciences sought to study populations, propped up by the methodological holist belief that a population is not just a sum of its individuals (Box 1). Instead, causality operates at the population-level (as well as the individual-level) and population properties, such as population-level violence, cannot be fully understood, predicted, or reduced to its individuals and their properties.<sup>5,20</sup> The influence of these ideas extended beyond science at the time, as seen in Figure 1, French artist Delacroix paints a distinct collective persona of the crowd during the 1830 July Revolution, which could not have been predicted by the crowd's individuals.

### ***The reduction to individuals***

However, the search for population-level causes of violence has proven elusive. While epidemiological and sociological studies continue to document a growing list of population-level correlates (e.g., social determinants of health), there has been limited success in establishing population-level causes.<sup>21</sup> In contrast, the search for individual-level causes of

violence has been more fruitful. For example, poverty has been repeatedly shown to increase the risk of individual violent behaviour, even when controlling for confounding.<sup>22</sup>

This asymmetry in causal evidence has shifted research toward individualism.<sup>3-5</sup> There have been attempts to bridge the gap between macro and micro-level explanations by developing frameworks that link population-level phenomena to individual behaviors.<sup>3,4</sup> These theoretical frameworks, foundational to the subfields of analytical sociology and criminology, have helped integrate different levels of analyses and clarify how population-level causes may work through individual-level mechanisms.<sup>4</sup> Figure 2 (panel a) shows the original framework of the classic Coleman's boat, depicting the relationships between multiple levels of analyses. Although there have been small variations to Coleman's boat since,<sup>5</sup> the underlying principle has remained the same: population-level causes can only operate via individuals and individual-level mechanisms (*pathways 1 to 3*, Figure 2, panel a).

This move towards methodological individualism is not specific to violence.<sup>23</sup> The idea that population-level phenomena are best explained by individuals is now the dominant research paradigm in the sciences, including those that historically evolved to study populations as wholes (e.g., epidemiology).<sup>24</sup> The rise in methodological individualism is often attributed to the successes of germ theory in epidemiology.<sup>25</sup> Germ theory demonstrated that disease epidemics can be fully explained by specific organisms that are transmitted via individual behaviour. This is because each contagious disease depends on individuals being infected with one specific organism, and each disease only results from being infected by that specific organism. This singular dependency of the organism (i.e., cause) to the contagious disease (e.g., effect), satisfies the two conditions of *supervenience* and *realisation* – concepts that originate from the philosophy of the mind (Box 1). As a result, germ theory was able to showcase the explanatory power of reductionism for disease causation and revolutionise public health interventions, including the advent of vaccines. It is then not surprising that other sciences have been influenced to place individuals at the heart of causal explanations.<sup>24</sup>

### ***When supervenience is not enough***

Supervenience is a concept that originates from the philosophy of mind (see Box 1). It describes a relationship where a higher-level property, such as cognition or population-level violence, depends on lower-level properties, such brain states or individuals.<sup>20</sup> The reduction of population-level phenomena to individual-level explanations has seemed particularly

appropriate for violence research because population-level violence clearly *supervenes* on the number of violent individuals. There can be no change in population-level violence without some change in the number of individual cases of violence. Individuals are the perpetrators, victims, or agents, of any act of violence, which researchers are able to directly interrogate by measuring and studying people's intentions, beliefs, and desires.<sup>20</sup> The same cannot be said for populations.

Centuries of debate in the philosophy of mind has shown that supervenience is a necessary condition for reductionism; however, it is not sufficient.<sup>20</sup> Dependency does not equate to causality – much like correlation does not imply causation. Unlike contagious diseases that have the 'germ' as a common explanatory basis, population-level violence is a complex phenomenon that can be realised by a very different subset of individuals via very different individual-level mechanisms. For example, in one country with extreme inequality, poor individuals may resort to violence for material gain. In a second country with the same rate of violence, generations of racial discrimination may lead members of the marginalised group to engage in retaliatory violence. In a third country with the same rate of violence, a natural disaster, such as flooding, may result in individuals committing acts of domestic violence due to heightened stress and strain. Each scenario creates the same numeric outcome at the population-level but via distinct individual-level mechanisms.

Population-level violence is *multiply realised*. Multiple realisability alone is not necessarily incompatible with reductionism, especially if there are only a few different individual-level explanations or if those explanations share some common feature. However, the usefulness of reductionism comes into question when the same population-level of violence can arise from an endless combination of *wildly disjunctive* individual-level properties so that the individual-level explanations become too numerous, heterogenous, and context dependent to be able to offer a generalisable understanding of population-level violence (Box 1).<sup>20</sup> Even if every population's violence can be ultimately and fully reduced to a different set of individuals (and their causes and mechanisms), such explanations have limited predictive power and are thus poorly placed to identify common leverage points for population-level intervention.

**Box 1.** Relevant concepts from the philosophy of the mind and science.

**Methodological holism.** The belief that causality operates directly at the population-level and therefore that population-level phenomena, such as violence, cannot be fully reduced to individuals and individual-level mechanisms. Original thinkers include the sociologists Adolphe Quetelet and Emile Durkheim.

**Methodological individualism.** The belief that causality only operates at the individual-level and therefore population phenomena, such as violence, can only be ultimately explained by individuals and individual-level mechanisms. Methodological individualism is anchored by a reductionist perspective, and original thinkers include the philosopher Karl Popper, and the sociologists Max Weber and Carl Menger.

**Reductionism.** The idea that complex phenomena (e.g., population-level violence) can be fully explained by reducing them to their simplest parts (e.g., individuals). Reductionism has become the dominant research paradigm across the sciences due to great successes in explaining quantum physics and infectious diseases.

**Supervenience.** Describes a relationship where higher-level properties (e.g., population-level violence) depend on lower ones (e.g., individuals). Thus, there can be no change in the higher-level property without some change in the lower-level property. While supervenience is a necessary condition for reduction, it is not sufficient.

**Multiple realisation.** Describes a relationship between lower and higher-level properties, whereby the same higher-level property (e.g., same rate of population-level violence) arises from numerous different lower-level (e.g., individuals) mechanisms.

**Wild disjunction.** Describes the scenario when an overly broad and heterogenous set of lower-level properties (e.g., individuals) are used to try to explain a higher-level property (e.g., population-level violence). Jerry Fodor argued that a true scientific law cannot have wildly disjunctive components.

**Emergence.** When a high-level property arises that is not additive and not predicted or fully reducible to lower-level properties. Instead, the emergent property only exists at that higher-level.

### **Emergence**

Another challenge to the traditional reductionist paradigm is that some population properties are seemingly irreducible to individuals. For instance, population rates of violence are remarkably stable over time, even as individuals join and leave the population.<sup>19</sup> This casts doubt on whether individuals can be the explanatory basis; if individuals were only using free will, rates would fluctuate erratically, yet they remain remarkably stable from one year to the next.<sup>19</sup> They would also change as individuals move in and out of a given population. Yet, the predictability of populations over time is so well-established that many quasi-experimental

study designs, including interrupted time series analyses, leverage the fact that prior population rates are *the* strongest predictor of future population rates to control for confounding by design.<sup>26</sup>

The idea that there are some population properties that cannot be predicted by their constituent parts mirrors the philosopher George Henry Lewes's (1875) need to differentiate between effects that are resultant and those that are emergent.<sup>20</sup> An emergent effect is one that is not additive, not predicted by its knowledge of constituent parts, and not fully reducible to its parts (Figure 1). Instead, an emergent property belongs to the whole. In the case of population-level violence, the whole is the population and its emergent properties are those that arise from a large network of individuals continuously interacting over time.<sup>8,20</sup>

Examples of causal emergence go beyond human populations. For example, ants individually have minimal intelligence and, in their near-blindness, limited chances of survival. A collection of one hundred ants also will walk around in circles until they die of exhaustion. Yet, put half a million ants together, and colony behaviour emerges, which is collectively organised, intelligent, and can create complex structures that are critical for the survival of the colony. Similar properties emerge when moving from white blood cells to an immune system or from vocabulary (tokens) to large language models, such as ChatGPT.<sup>27</sup> Human populations are just one of many examples in our complex world of when new, unexpected properties emerge that belong to the collective whole.

### **An emergent property of a complex system**

A complex systems approach offers a different lens.<sup>6,7</sup> Rather than hunting population causes or reducing explanations to individuals, a systems approach recognises that violence – at any-level – emerges from the functioning of a complex system (Box 2). This complex system of a human population includes heterogeneous agents at multiple levels (e.g., individuals, communities, populations), interactions between agents (within and across levels), bi-directionality (e.g., feedback loops), and nonlinearity (e.g., leverage points).<sup>28</sup> Hence, a complex systems approach is able to overcome some of the limitations of reductionism whilst building on the cumulated knowledge in violence research.

The analytical sociology and criminology frameworks that bridge the micro-macro gap are a useful starting point from a complex systems standpoint, such as Coleman's boat (Figure 2,

panel a). We show in Figure 2 how these existing frameworks can be iteratively developed to capture the complexity needed to reflect how a population ('the system') functions over time. We also draw on empirical findings to support each addition of complexity below.

The first addition of complexity is recognising that causality can operate at the macro-level (*pathway 4*, Figure 2, panel b). Although population-level properties might have originally arisen from individuals and their interactions, the dynamic complexity of human populations means that some emergent properties can no longer be meaningfully traced back to the individuals and take on causal power in their own right.<sup>29</sup> For example, studies have found that people living in neighbourhoods that were historically racially segregated via redlining are more at risk of violence, irrespective of the person's race or ethnicity.<sup>30</sup> This demonstrates that the legacy of structural racism in the US, a population-level property, continues to shape rates of violence in these communities (*pathway 4*, Figure 2, panel b). More recent analyses of multi-cohort studies have pointed to the independent influence of social change on criminal behaviour, which can be, in part, explained by changes in the collective efficacy of communities, bolstering mechanisms of social control and alleviating social disorganisation.<sup>31</sup> Regardless of how these factors shape population rates of violence, controlling for many possible individual-level risk factors and mechanisms has not yet proved sufficient to knock out these higher-level statistical relationships.<sup>31</sup>

The second addition of complexity is embedding bidirectional relationships to account for reciprocity, feedback loops, and adaptation over time (*pathways 1b-4b*, Figure 2, panel c; Box 2). At the individual-level, a well-documented reciprocal relationship is that poverty increases the risk of violent perpetration, and violent perpetration increases the risk of poverty (*pathways 2a-2b*, Figure 2, panel c).<sup>22</sup> Across levels of analysis, it has been shown that some properties have a bidirectional relationship, where there is the 'objective' population-level measure, such as social inequality or institutional trustworthiness, and the 'subjective' perception of social inequality or institutional trust by the individual. The former exerts influence that flows from the population-level measure to the individual-level risk factor poverty (*pathway 1a*, Figure 2, panel c), while the latter starts at the individual-level and flows to the population-level measure as it is the individual's perception (*pathway 1b*, Figure 2, panel c).

There are also clear examples of positive and negative feedback mechanisms in system responses to violence interventions (*pathways 4a-b*, Figure 2, panel c). Positive feedback mechanisms can explain the presence of leverage points, where small changes result in large amplified (and sometimes delayed) effects. For instance, the public health intervention of urban

greening and installing public lighting changes the environment, constraining opportunities for violence and improving perceptions of public safety, which, in turn, promotes the presence of people on the streets and further constrains opportunities for violence.<sup>32</sup> Conversely, there is also evidence of negative feedback mechanisms. Since the 1970s, the US has implemented ‘tough on crime policies’, leading to mass incarceration. Instead of successfully reducing population rates of crime and violence, the complex system has seemingly resisted the intended effects of these policies and has had the unintended impact of disrupting family life and fragmenting communities, thus reinforcing the cycle of violence and intergenerational transmission of offending.<sup>33</sup>

A third, related addition of complexity is the interconnectedness of the whole system. A systems approach expands and places emphasis on the interdependencies and interactions among all individuals and across all levels of analysis (*pathways 5-6*, Figure 2, panel d). A growing number of studies underline the interconnectedness of violence between individuals, from classical works on the cycle of violence<sup>34</sup> to more recent studies showing that violence has contagion-like features, spreading through networks through social interactions.<sup>35</sup> Violence prevention efforts have also highlighted these interdependencies via interference.<sup>36</sup> Hotspot policing is a commonly cited example of interference, where intensifying policing in one area creates spillover effects, such as displacing or diffusing crime in nearby areas. Real-life violence prevention efforts have thus demonstrated the importance of considering the interconnectedness of the system when intervention planning.

## **Box 2.** Relevant concepts from complex systems approaches.

**Complex systems.** A large network of interconnected agents with no central control, only simple rules, and yet as a coherent whole show complex collective behaviour, sophisticated information processing, and adaptation via learning or evolution. These collective behaviours are nonlinear, dynamic, and often unpredictable and irreducible to the agents alone.

**Agents.** Autonomous entities in a system that interact with each other and higher levels of the system according to specific rules. Agents can be individuals, ants, or cells, depending on the system in question, and are the fundamental basis for any agent-based models.

**Feedback loops.** Circular chains where the results of a cause and effect return as a future input to influence the system. Feedback mechanisms can with be positive (reinforcing), amplifying change, or negative (balancing), minimising change by stabilising the system. Policy resistance is an example a stabilising response of a complex system.

**Adaptation.** The process by which a system and/or its agents change behaviour in response to learning from feedback mechanisms. For example, adaptative systems can learn to evolve for survival or learn to improve its performance.

**Leverage points.** Critical places within the system where a small change leads to an amplified effect, thus large overall change in the system. Leverage points are instructive for informing effective interventions and identifying what causes matter most.

## **Methodological myopia: the hidden influence of traditional statistics**

Traditional statistical methods in the social sciences, including regression techniques, have also contributed to the current shortcomings in violence research. Common statistical models excel when there is variation in the variables of interest. With more data points, comes more power. Collecting big data on violence at the individual-level is much more attainable than collecting big data at the population-level. If the research question is “why is Brazil more than 30-fold more violent than Japan?”, then analyses are limited to two data points.<sup>16</sup> If, on the other hand, the research question is “why did the United States recently experience a unprecedented rise in lethal violence?”,<sup>17</sup> then analyses are restricted to the data that has been historically and consistently collected over time. These challenges in obtaining sufficient population-level data

have nudged violence research towards analyses that focus on individual, rather than population, differences.<sup>14</sup>

Regression and related models also require a researcher to select a ‘cause’ and ‘effect,’ and in their simplest – and most used – form, they assume a simple unidirectional cause-effect relationship. As the dose of the cause is amplified, there is a proportional increase in the effect. There have been important advances in regression modelling, which allow researchers to incorporate multiple levels of analysis within the same model (i.e., multilevel modelling).<sup>13</sup> Analytical coding software has also facilitated the use of more generalised applications of regression models to capture more complex non-linear relationships between variables, such as penalised GLMs and GAMs. Nevertheless, regression techniques are still predicated on two fundamental assumptions: i) there is a unidirectional cause-effect relationship; and ii) causal effects are mathematically identifiable (i.e., they can be isolated).

These assumptions are likely contributing to the lack of success in identifying population causes because if populations do function as a dynamic, interactive multilevel system, then population-level violence is the end result of a multiplicity of processes across different levels. Violence as an emergent property of a complex system cannot be captured by simple linear, logistic, or polynomial relationships. In addition, teasing apart one causal effect from another may be mathematically impossible and nonsensical. When explaining changes in population violence over time, for example, researchers have repeatedly attempted to attribute explanations to changes either to age, period, or cohort effects. However, age-period-cohort effects are perfectly co-linear; making it mathematically impossible to identify their effects in a single regression model.<sup>37</sup> Similarly, it may not make sense to statistically control for one variable, such as poverty rates, in an effort to artificially isolate the causal effect of another, such as income inequality. In reality, these characteristics are intrinsically entwined, interacting to shape population properties. The traditional analytical techniques that are commonplace in violence research may thus be poorly placed to uncover the causes and mechanisms that give rise to population-level violence.

### **Toward a holistic research agenda**

Progress in violence prevention depends on asking – and prioritising – questions most relevant to populations.<sup>15</sup> To avoid answering the wrong questions (Type III error) researchers must not to conflate individual causes of violence with population causes, even when data and analytic

challenges make individual-level analyses more appealing.<sup>14</sup> Research questions should instead be grounded in conceptual and theoretical relevance, with explicit recognition that population causes may be ubiquitous across individuals and that such interventions may yield only modest benefits for any one person. These paradoxes underscore the importance of designing the “right” research questions to generate the “right” answers for population-level violence prevention efforts going forward.<sup>14</sup>

While traditional statistical methods have contributed to Type III errors in the field, promising analytic tools are emerging, which are better suited to answer population-level questions. Systems modelling approaches, including social network analysis, agent-based models, and system dynamics modelling, can be used to operationalise violence as an emergent property of a complex system. By simulating dynamic interactions among within and across levels of analysis, these approaches move beyond simple cause-effect frameworks. These methods have been used to explain unintended consequences of interventions and policy resistance,<sup>33</sup> and identify leverage points for reducing urban violence<sup>38</sup> – embracing a consequentialist perspective of asking ‘what matters most’.<sup>39</sup>

Other advances include the application of machine learning and Bayesian methods to violence research. For example, Least Absolute Shrinkage and Selection Operator (LASSO) regression addresses multicollinearity by penalizing coefficients and has been incorporated into Structured Life Course Modelling Approaches (SLCMA) to formally test competing life-course hypotheses. This approach has clarified that the effects of poverty on violence primarily reflect cumulative exposure rather than a critical development period.<sup>22</sup> Bayesian statistics, on the other hand, can help to overcome data challenges in population-level analyses. By formally incorporating prior knowledge, Bayesian methods, such as Bayesian hierarchical modelling, can achieve efficient model estimation with smaller datasets and more sparse data than previously required by frequentist frameworks.<sup>40</sup> Together, these methodological advances broaden the toolkit, enabling the field to pursue conceptually grounded questions that capture complexity and are better positioned to directly inform population-level prevention strategies.

## **Conclusions**

The limited success in the hunt for population-level causes of violence has misguided efforts away from holism, and reductionism has now become the dominant paradigm in violence research. The ontological truth about whether population-level violence can be fully explained

and reduced to individuals and individual-level mechanisms will likely remain a lively debate for centuries. We have suggested some reasons why the position of reductionism may not be appropriate for understanding population-level violence. Regardless of the ultimate truth, we argue that a holist philosophy is most practically relevant for understanding and preventing population-level violence – like air pressure in weather forecasting rather than individual air molecules. We advocate for studying population-level violence *as a whole*, as this approach offers the greatest gains for explanatory theory and intervention, which is perhaps why the holist disciplines of sociology, epidemiology, and public health emerged in the first place. By re-framing violence an emergent property of a system, building complexity into the existing theoretical frameworks, and coupling the ‘right’ theoretical questions with the ‘right’ methodological tools, the field will be better equipped to inform population-level interventions. Through this holistic lens that crosscuts levels of analysis, the hope is that violence research can evidence those intervention strategies that are capable of radically reducing population rates of violence on a global scale.

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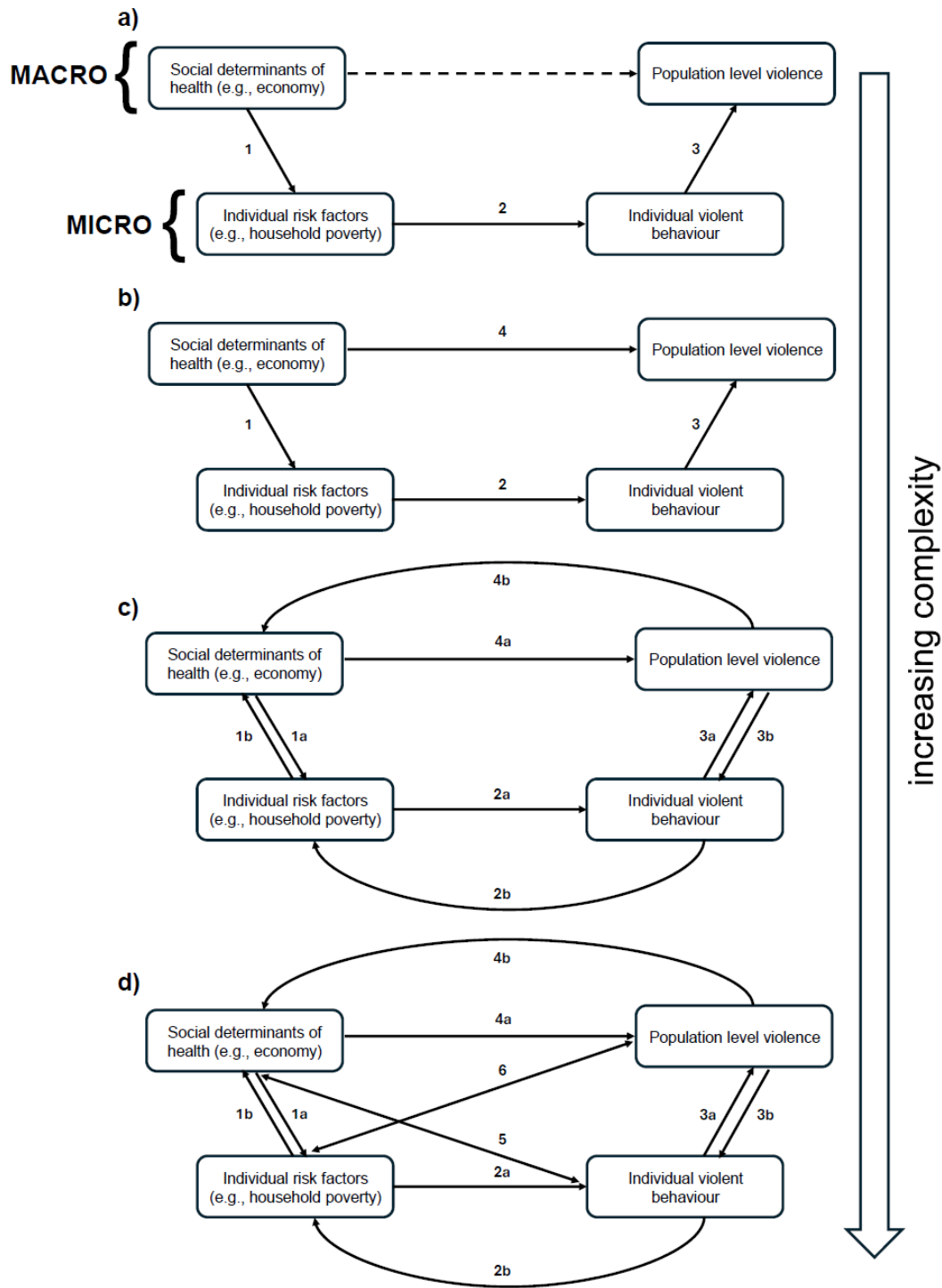
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## Figure



**Figure 1.** Liberty Leading the People, oil on canvas by Eugène Delacroix, 1830, on display in the Louvre Museum, Paris.

*The image is a faithful photographic reproduction of a two-dimensional, public domain work of art obtained from [Wikipedia](https://en.wikipedia.org/wiki/Liberty_Leading_the_People). Permission to re-use is covered by the public domain (common licensing) in the United States because it was published (or registered with the U.S. Copyright Office) before January 1, 1930.*



**Figure 2.** Iteratively building complexity to reflect the functioning of a complex system, starting with a simple macro- to micro-level framework. *Panel a* is adapted from Coleman (1990) and reflects Coleman’s original micro–macro “boat” framework. *Panel b* extends this framework by incorporating causal influences that operate directly at the macro level. *Panel c* introduces the complexity of bidirectional relationships within and across levels of analysis, including positive and negative feedback loops. *Panel d* further adds diagonal bidirectional relationships (e.g., social determinants of health directly constraining individual violent behavior, and vice versa). For illustrative purposes, we include only two levels to represent the population (macro, higher level) and individuals (micro, lower level). However, the frameworks should also be used to build in other important (‘meso’) levels, including families, neighbourhoods, and communities.