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Public Health and Safe Communities Require Open Societies*

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Abstract

This study explores how social organization impacts public health and functional ability in aging populations with declining intrinsic capacity. Using a dynamical network model based on Kuramoto oscillators, four societal structures (segregated, totalitarian, military, and open) were analyzed for their ability to sustain synchronization and collective coordination. Results show that open societies, characterized by decentralized and bidirectional feedback mechanisms, outperform other models in maintaining functional ability under lower intrinsic capacities. The findings highlight the importance of structural conditions in promoting healthy aging and suggest that open societies are better equipped to support resilience and dignity in aging populations.

Keyphrases

Public health, safe communities, open societies, dynamic network models, resilient social structures, healthy aging populations.

Contents

Introduction

Public health is often described as "the science and the art of preventing disease, prolonging life, and promoting physical health" (Winslow 1920, p. 30). Yet from its earliest formulations, it was never conceived as a purely medical undertaking. In its seminal definition, cited above, Winslow (1920, *ibid.*) emphasized that public health is realized "through organized community efforts," extending beyond clinical care to include environmental sanitation, health education, and "the development of the social machinery" that secures for every individual a standard of "living adequate for the maintenance of health."

This conception implies that health is shaped not only by individual choice or medical intervention, but by the ways in which societies organize the conditions of everyday life. Individual behaviors matter, yet they are always situated within social arrangements that enable or constrain what individuals are able to do.

Accordingly, the aims of public health cannot be separated from the aims of the society and from safe communities within which it operates. When social priorities undergo a shift, so too, must the orientation of public health practice. At the moment of societal change, public health is therefore compelled to appeal to reason, to reconsider the balance between individual freedom and social obligation, and to reflect on the forms of social organization required to sustain human well-being. This implicitly raises a more fundamental question: How societies must organize themselves in order to enable individuals to sustain healthy lives over time?

This question becomes particularly salient in the context of population aging (Prince et al. 2015; Demiray et al. 2017). As life expectancy continues to increase, health can no longer be understood as a binary choice between health and illness, but rather as a condition that must be promoted over time. The World Health Organization (2015) defines *healthy aging* "as the process of developing and maintaining the functional ability that enables well-being in older age" (World Health Organization 2015, p. 28), where *functional ability* depends on "the intrinsic capacity of the individual, relevant environmental characteristics and the interactions between the individual and these characteristics" (World Health Organization 2015, p. 28). Here, *intrinsic capacity* "is the composite of all the physical and mental capacities of an individual" (World Health Organization 2015, p. 28), *cf.* also Cesari et al. (2018).

Importantly, the WHO's definition of functional ability is not value-neutral. Functional ability is described as enabling individuals "to be and to do what they have reason to value" (World Health Organization 2015, p. 28). Taken seriously, this formulation does more than just describing simply some outcome: it presupposes that individuals are capable of forming judgements about what they value, and that social conditions exist under which such judgements can be meaningfully acted upon.

Within this framework, if health unfolds across prolonged phases of

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declining intrinsic capacity, the ability of societies to organize their environments and social relations becomes a key determinant of whether individuals can continue to live independently and participate in social life with dignity. Healthy aging emerges not merely as the outcome of individual medical status, but through public health efforts and societal challenges that fundamentally depend on social structure and modes of organization. The framework thus specifies the aims of healthy aging, while leaving open the question of the societal conditions under which these aims can be the maintained over time.

Karl Popper's (2013) concept of the "*open society*" provides a normative framework that renders explicit the social conditions under which individual functional ability can be meaningfully realized. By distinguishing open from closed societies according to the degree to which individuals are recognized as agents capable of rational judgment and personal decision-making (K. R. Popper 2013, pp. 165, 482), Popper's framework offers a way of conceptualizing social organization that is directly relevant to the aims of public health under conditions of aging. Grounded in a commitment to human dignity, the open society treats individuals as "ends in themselves," in the sense of Kant's *categorical imperative* (Kant 2002, AA 4:462), thereby clarifying how functional abilities can be actively exercised in practice rather than merely acknowledged in principle.

At the same time, taking these social conditions seriously does not imply that societies can be treated as fully predictable or centrally controllable systems (K. Popper 1957). As Popper repeatedly emphasized, social systems differ fundamentally from natural systems in that individuals continuously adapt their behavior in response to new information (K. R. Popper 2013, Vol. I, Ch. 10). Accordingly, the formalization of social structure adopted here is not intended to generate predictions or policy prescriptions, but to serve as an analytical tool for comparing how different forms of social organization give rise to distinct dynamical properties under otherwise comparable public health conditions.

Building on this perspective, the present study examines how different forms of social organization shape the maintenance of functional ability under conditions of declining intrinsic capacity. To address this question, individuals are conceptualized as adaptive dynamical units, while social structure is represented as a network of interactions through which coordination, support, and regulation, such as caregiving and caretaking, e.g., are mediated.

A key assumption of this approach is that individual functional ability is not static, but temporally structured. Everyday functioning unfolds through recurrent cycles of activity and rest, such as circadian sleep-wake rhythms, that constrain when and how individuals are able to respond to social affordances, to interact with each other, and to participate in social activities. Empirical studies of daily activity patterns illustrate that even in naturalistic settings, individual behavior exhibits rhythmic structure rather than random fluctuation (Borbély et al. 2017).

For illustration, we discuss the study by Borbély et al. (2017). Alexander A. Borbély is a Hungarian-Swiss pharmacologist and sleep-researcher who was continuously wearing a wrist accelerometer for more than three decades. Figure 1 shows his actigram time series for two months, first from November 13 – December 13, 2000 with 15-min time resolution; second for September 8 – October 8, 2008 with 2-min time resolution after semi-automatic segmentation into sleep (blue areas) and waking periods (white areas) (Martin et al. 2018; Yordanova et al. 2019).

This temporal organization provides a natural entry point for dynamical modeling. More generally, functional ability unfolds as a time-dependent, within-individual process that cannot be adequately captured by static descriptions. Nonstationarity in human systems is a pervasive problem along the time dimension of actogram time series (Boker and Martin 2018). Everyday individual activity is characterized by a pronounced rhythmic temporal structure under naturalistic conditions, shown in Fig. 1. At the social level, coordination can thus be conceptualized as the coupling of intrinsic temporal processes, motivating a dynamical representation of social organization in terms of coupled oscillatory units.

Within this framework, social organization is formalized using a stochastic phase-coupled Kuramoto oscillator model (Kuramoto 1975; Rodrigues et al. 2016; Gil 2016; Graben 2016), in which each individual possesses an intrinsic temporal structure reflecting basic cycles of activity and rest. Social organization is encoded in the pattern and strength of coupling between individuals as a mathematical graph structure. Collective coordination emerging from these interactions is quantified through a global *order parameter*, providing an operational analogue of population-level functional ability.

This formulation makes it possible to compare different social network structures, such as *segregated*, *totalitarian*, *military* and *open societies* as stereotypical network models. Rather than predicting outcomes or prescribing interventions, the model serves to clarify how the organization of social connections influences the robustness, stability, and coordination of individual functioning as intrinsic capacity, the *control parameter* of our simulation model, declines.

Methods

In order to describe the synchronization of individual circadian rhythmic activity in several forms of societies, we use stochastic phase-coupled oscillator models that are well-known as *Kuramoto oscillator models* in the dynamic systems literature (Kuramoto 1975; Rodrigues et al. 2016; Gil 2016; Graben 2016).

Let $n \in \mathbb{N}$ be the number of oscillators (*individuals*) in a human population (Gil 2016; Graben 2016). Then, the dynamics of the k-th oscillator is described by its instantaneous phase $\varphi_k(t) \in \mathbb{R}$ through the Kuramoto differential equations

$$\dot{\varphi}_k(t) \quad = \quad \Omega + \sum_{j=1}^{n} a_{kj} \sin(\varphi_j(t) - \varphi_k(t)) + \frac{1}{c}\eta(t) \,, \tag{1}$$

where $\Omega > 0$ is the external driving frequency given as $\Omega = 2\pi/T$ with $T = 24\,$h, modeling the day-night cycle. The second term in Eq. (1) accounts for the social interactions between individuals k and j ($j \neq k$). The society is described by a (normalized) graph adjacency matrix $\boldsymbol{A} = (a_{kj})_{1 \le k,j \le n}$ such that its Frobenius norm is given as $\|\boldsymbol{A}\| = 1$. The pairwise interaction of Kuramoto oscillators is due to the sine-nonlinearity in Eq. (1) , leading to the entrainment of oscillators with deviant phases. Finally, the third term $\eta_k(t)$ in Eq. (1) presents a stochastic perturbation according to an $\mathcal{N}(0,1)$ Gaussian white noise process. Its *control parameter* c describes the *intrinsic capacity* of the society members, measuring the resilience against phase perturbations.

In our simulation experiments, we study four different kinds of social network topologies, that are sketched in Fig. 2 for a small population of $n = 6$ individuals.

Figure 2(a) depicts a *segregated society* of strictly isolated individuals, indicated by the (non-normalizable) adjacency matrix $\boldsymbol{A} = 0$. In Fig. 2 (b) we show a social network where one distinguished individual directly rules over all the others members. This is our simplified caricature of a *totalitarian society*, governed by a Duke (or a "*Führer*"). The social network plotted in Fig. 2 (c) is characteristic for a military "command-obedience" chain (Gil 2016), to which we therefore refer as a *military society*. Finally, Fig. 2 (d) displays what might be called *open society*, or democratic society in the motivating study by Gil (2016). In this case, the society's graph is completely connected, i.e., every node is bidirectionally connected to every other node (excluding self-connections, though).

The Kuramoto system Eq. (1) is implemented in MATLAB® using SDETools.[1] After numerically solving Eq. (1) , the phases $\varphi_k(t)$ are first transformed into their associated elongations, $y_k(t)$, through

$$y_k(t) = \sin \varphi_k(t) \,. \tag{2}$$

Finally, a simple segmentation approach (Martin et al. 2018; Yordanova et al. 2019) distinguishes sleep and wake phases through a *static encoding* of the time series $y_k(t)$ in a symbolic dynamics (Graben 2001),

$$s_k(t) = \begin{cases} 0 & : \quad y_k(t) < 0 \\ 1 & : \quad y_k(t) \geq 0 \,. \end{cases} \tag{3}$$

Therefore, positive values of $y_k(t)$ are interpreted as "awake" and negative ones as "asleep".

In the next step, we have to compute a suitable *order parameter* for the circadian Kuramoto model that we could interpret as a measure of *functional ability* here. To this end, we determine the *word statistics* of the binary symbolic dynamics as the cylinder set measures of the symbols "0" and "1" across the population (Graben 2001). These cylinder measures, $N_0(t)$ as the count of the numbers of zeros, and $N_1(t)$ as the count of the numbers of ones, yield the normalized difference

$$m(t) = \frac{|N_1(t) - N_0(t)|}{n} \,. \tag{4}$$

Then, the temporal average over the duration of the simulation, D,

$$M = \frac{1}{D} \sum_t m(t) \tag{5}$$

is known as *magnetization* in statistical mechanics providing the desired *order parameter* of *functional ability*.

Results

For each of the four stereotypical social network structures, we simulate the synchronization dynamics over a duration of $D = 10$ days with a step-size of $\Delta t = 1$ h and intrinsic capacities $c \in \{1, 2, 5, 10\}$ as selected control parameter values. The resulting symbolic dynamics for an abundance of $n = 100$ individuals are plotted in Figures 3 – 6. In each panel, the symbolically segmented time series, $s_k(t)$, are visualized as image plots, encoding "0" by black pixels, and "1" by white ones. Thus, highly synchronized circadian activity, on the one hand, is shown as white vertical stripes for day-light activity and black vertical stripes for sleep. On the other hand, lack of synchronization among individuals appears as largely meandering stripes.

Figure 3 displays the symbolized circadian rhythmic activity for the segregated society (cf. Fig. 2 (a)). In Fig. 3 (a) we present the result for the largest intrinsic capacity, $c = 10$, in Fig. 3 (b) for a smaller value, $c = 5$, in Fig. 3 (c) for a low value, $c = 2$, and finally in Fig. 3 (d) for the lowest value, $c = 1$. If intrinsic capacity, c, is high, the individuals are able to follow the social affordances in a "meaningful" way, yielding high synchronization. If c is rather low, by contrast, they are unable to synchronize and exhibit strong phase variability.

Next, Fig. 4 shows the symbolic dynamics for the totalitarian society (cf. Fig. 2 (b)). In Fig. 4 (a) we deliver the result for the largest intrinsic capacity, $c = 10$, in Fig. 4 (b) for a smaller value, $c = 5$, in Fig. 4 (c) for a low value, $c = 2$, and ultimately in Fig. 4 (d) for the lowest value, $c = 1$.

After the third simulation, Fig. 5 depicts the results for the military society (cf. Fig. 2 (c)). In Fig. 5 (a) the results for the largest intrinsic capacity, $c = 10$, are presented. In Fig. 5 (b) for a smaller value, $c = 5$, in Fig. 5 (c) for a low value, $c = 2$, and in Fig. 5 (d) for the lowest value, $c = 1$.

Finally, Fig. 6 plots the results for the open society (cf. Fig. 2 (d)). In Fig. 6 (a) we give the result for the largest intrinsic capacity, $c = 10$, in Fig. 6 (b) for a smaller value, $c = 5$, in Fig. 6 (c) for a low value, $c = 2$, and eventually in Fig. 6 (d) for the lowest value, $c = 1$.

Comparing Figures 3 – 6 against each other, reveals that homogeneous societies possessing rather large values of intrinsic capacity are able to resists stochastic perturbations similarly well. However, for smaller values of intrinsic capacity, the social network topology plays a decisive role. Only the open society shown in Fig. 6 exhibits some resilience against rhythmic perturbations for $c = 2$. Yet, for the lowest value of intrinsic capacity, $c = 1$, differences between social structure are fading out.

Finally, we run last simulations for population sizes $n = 1000$ in all four types of social networks. The independent variable: intrinsic capacity, is varied within an interval $c \in [0.1, 20]$ with increment $\Delta c = 0.1$. Figure 7 plots the functional dependency of the order parameter: functional ability, M, against the control parameter: intrinsic capacity, c.

As Fig. 7 reveals, there are little differences between the first three network topologies of the segregated, the totalitarian, and the military society. Only the open society outperforms the other three models with respect to functional ability which is maintained for a considerable range of smaller values of intrinsic capacity.

Discussion

This study has proposed a dynamical network framework to investigate how different forms of social organization maintain functional ability under conditions of declining intrinsic capacity. Individuals were modeled as rhythmically active units embedded in distinct social network structures, with social organization represented through graphical connectivity patterns of coupling between individuals. The aim of this framework was not to reconstruct the full complexity of social reality, but rather to isolate and analyze the fundamental dynamical role of social structure in sustaining collective coordination.

In the model, this structural effect was encoded in the coupling matrix: Different social network topologies implement distinct pathways of mutual influence, feedback, entrainment and error correction, thereby determining whether a population can sustain stable synchronization under stochastic perturbations. Synchronization was treated as an observable dynamical phenomenon, such that structural strengths and vulnerabilities of different forms of social organization can be compared.

Our simulation results indicate that the degree of synchronization

[1] *Stochastic Differential Equations Toolbox* by Andrew D. Horchler, `https://github.com/horchler/SDETools`

is highly sensitive to social network topology. Specifically, open society networks are able to achieve collective synchronization earlier and more robustly, resulting in significantly higher population-level functional ability than segregated societies, totalitarian societies, or military societies. As a proof-of-concept, we have shown that, under the long-term decline of intrinsic capacity, associated with population aging, the presence of decentralization and bidirectional feedback mechanisms in open societies may play a decisive role in maintaining resilient collective coordination and sustained functional ability.

These findings can be situated within broader discussions of healthy aging and public health. Sixty years ago, the health education leader Dorothy Nyswander, reflecting on her professional career, evaluated both her own work and the field at large using the standard of an "open society." (Nyswander 1967) She explained an open society as one that respects individual rights and dignity, accommodates diversity and dissent, promotes social justice, and enhances individual control and self-determination.

As Popper also emphasized, society is not a natural system, and no individual or group possesses sufficient knowledge to predetermine the course of social development (K. Popper (1957, Ch. 22), K. R. Popper (2013, Vol. I, Ch. 7)). Treating health protection as a goal to be achieved through technocratic central control neglects the individual's capacity to adapt to new information.

Recognizing individuals as *persons* (Kant 2002, AA 4:438) entails acknowledging their right to act freely by preserving their inherent dignity (Kant 2002, AA 4:434). This dignity extends beyond mere survival to include the right to shape one's own life. No single moral goal should override this principle. Excessive restrictions on individual behavior based on any one value-system constitute a form of *a priori* reasoning, which excludes the legitimacy of individual choice. This type of reasoning can be traced back to Kant's a priori framework, and Popper's theory of the open society seeks to resist social engineering that imposes absolute values.

An open society is not an abstract moralistic phrase, but a set of concrete structural conditions. It is the very aspect that the dynamical model presented in our study seeks to illustrate that rather than adjudicating value conflicts, an open society can demonstrate why, under conditions of declining intrinsic capacity, like aging population, certain social structures are more favorable in sustaining synchronization and functional ability.

Future research should incorporate more complex social network structures to extend the current framework. *Small-world networks* (Watts and Strogatz 1998), characterized by strong local clustering and sparse long-range connections, will theoretically enable coordination across groups while maintaining community-level support. This feature is particularly relevant in aging societies, because older individuals often rely on stable local relationship networks, while society as a whole requires effective crosslink for resource allocation and risk sharing. Moreover, *scale-free networks* (Albert and Barabási 2000) rely on highly connected hubs and hierarchical structure dependence on upper-level coordination mechanisms. And also our caricature of a totalitarian network model might be further improved, using a hierarchical tree-structure model, that Luboeinski et al. (2023) have dubbed the *Kronecker-Leskovec network*. Comparative analysis of these structures could further explore whether social complexity and redundancy play a role in risk distribution and support for vulnerable populations in aging societies.

Another important limitation of the present model is the assumption of homogeneous intrinsic capacity across individuals. In reality, populations exhibit significant heterogeneity in health status, access to resources, and vulnerability. Extending the framework to inhomogeneous societies, would aid in analyzing how social organization buffers or amplifies health inequalities in the context of aging.

Conclusion

These findings clarify the structural conditions required to sustain public health goals in the context of healthy aging. In this sense, open societies can buffer the long-term effects of declining intrinsic capacity of the aging society through its composite, decentralized social structures.

Citation

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Contributions

Kiersten Xiangqi Zhu (KXZ) and Peter beim Graben (PbG) have conceived the organization of the study. PbG has implemented the numerics and run the simulations. Both authors have written the manuscript together.

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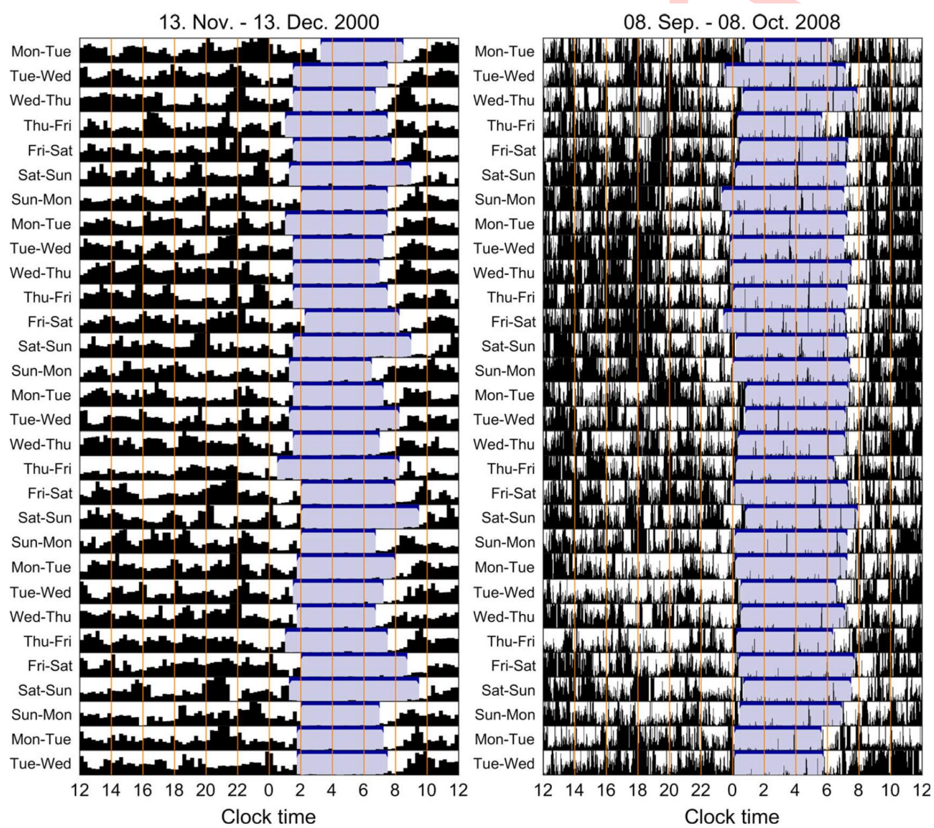
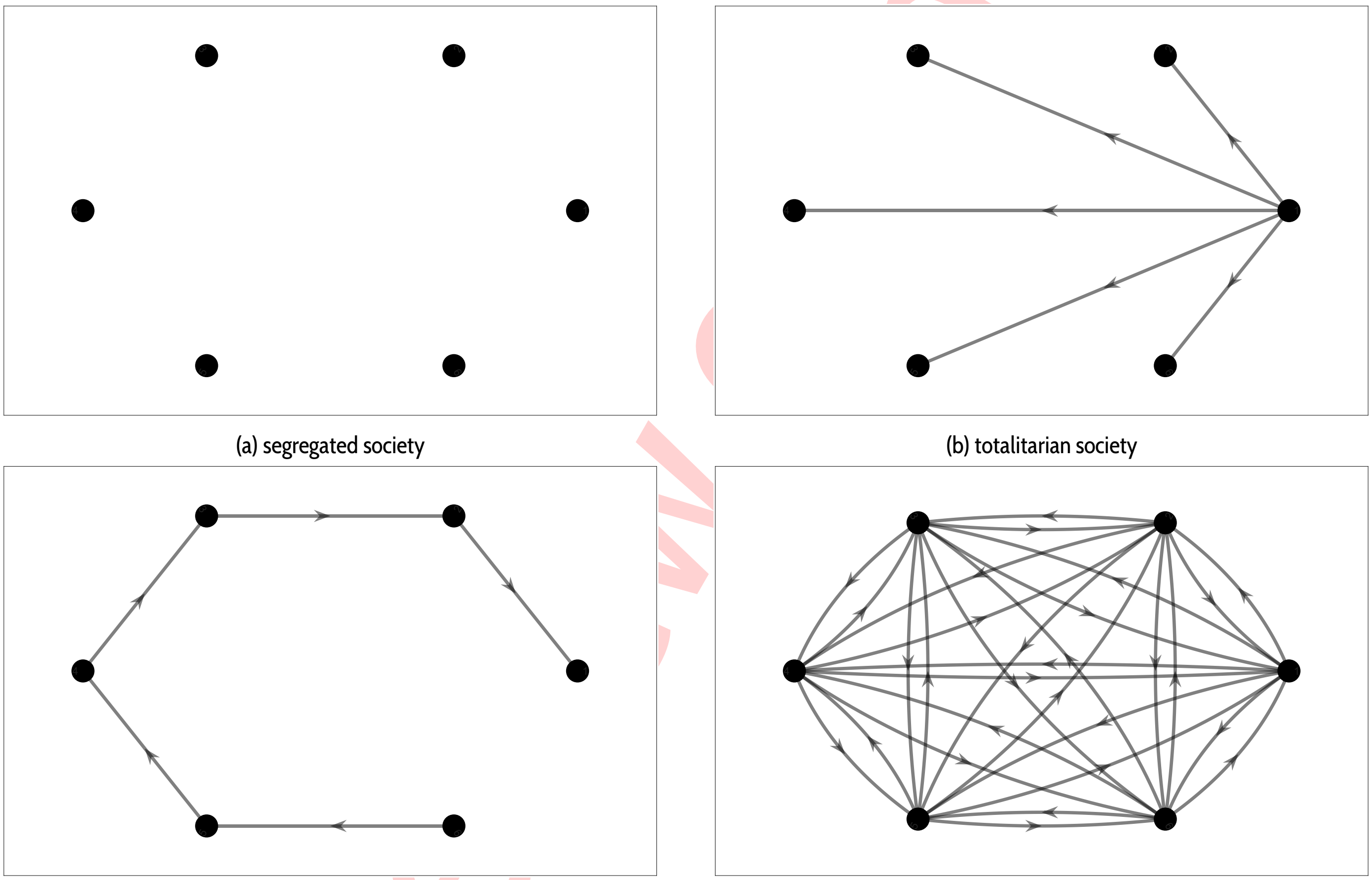
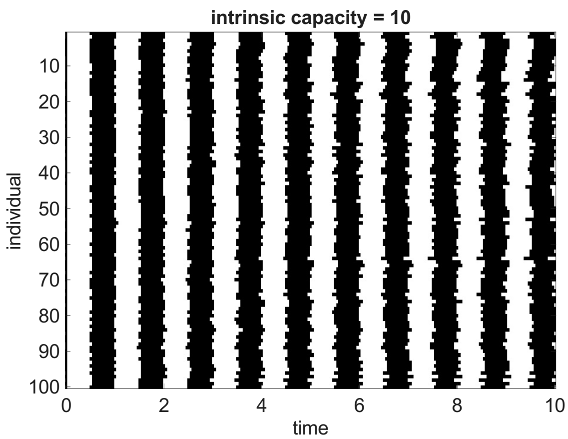


Figure 1: Accelerometer actograms of Alexander A. Borbély illustrating the semiautomatic definition of sleep (blue areas) and waking periods (white areas) (Borbély et al. 2017, p. 190, Fig. 1). Left: November 13 – December 13, 2000 with 15-min time resolution; right: September 8 – October 8, 2008 with 2-min time resolution. Reprinted with permission from the European Sleep Research Society.

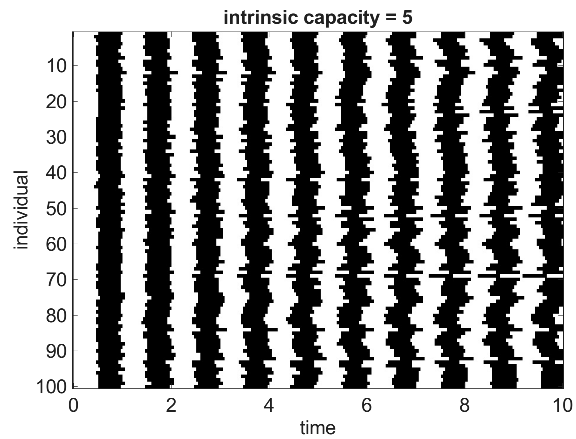


(a) segregated society
(b) totalitarian society
(c) military society
(d) open society

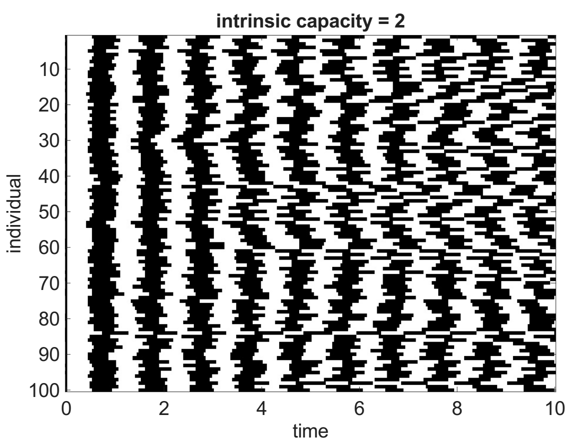
Figure 2: Schematic social network topologies. Number of individuals $n = 6$ for illustration.



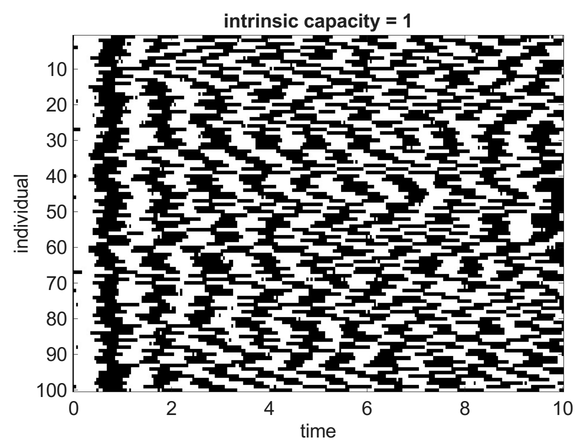
(a) $c = 10$



(b) $c = 5$

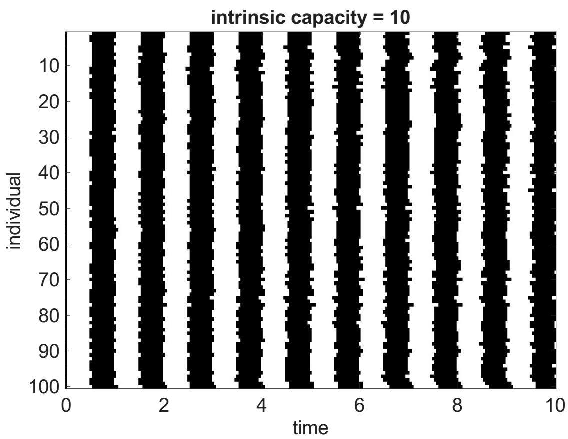


(c) $c = 2$

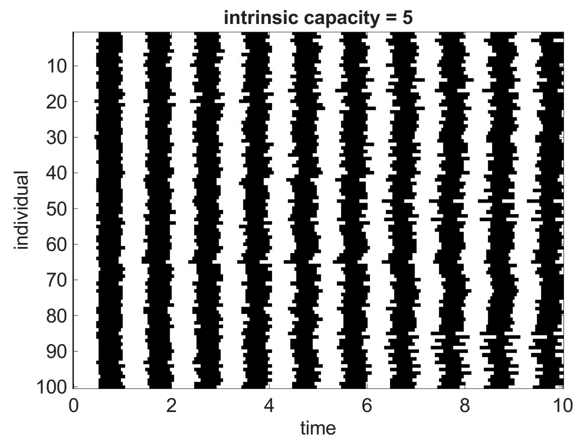


(d) $c = 1$

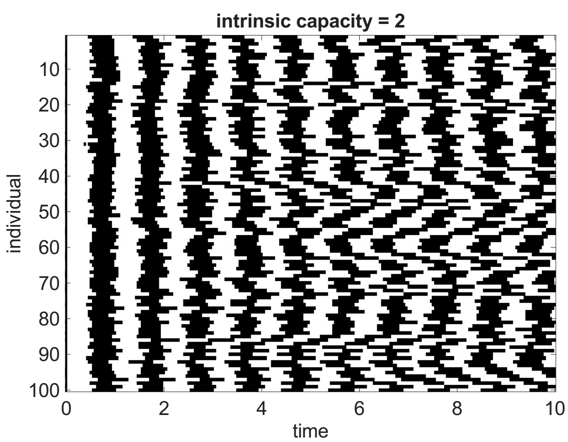
Figure 3: Simulation results for a segregated society of $n = 100$ individuals.



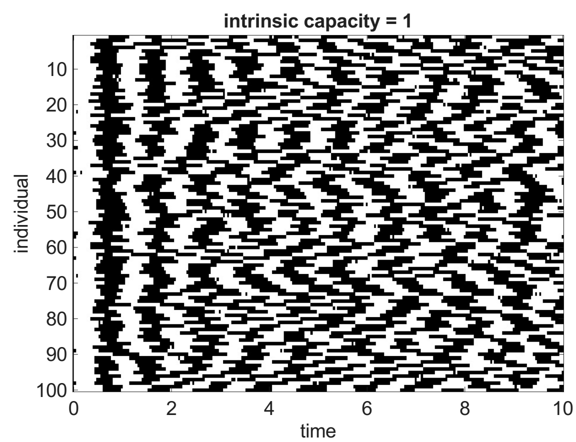
(a) $c = 10$



(b) $c = 5$

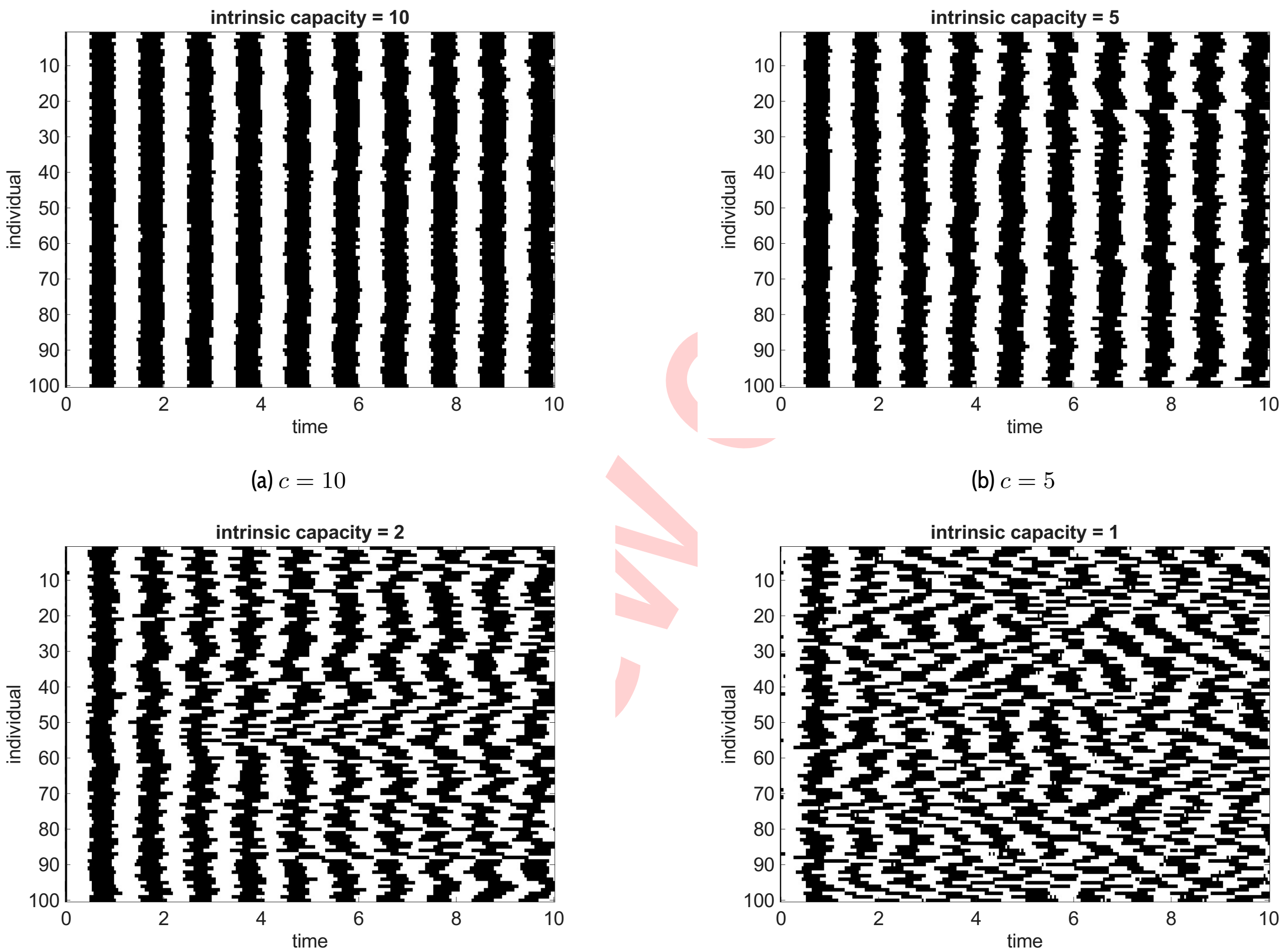


(c) $c = 2$



(d) $c = 1$

Figure 4: Simulation results for a totalitarian society of $n = 100$ individuals.



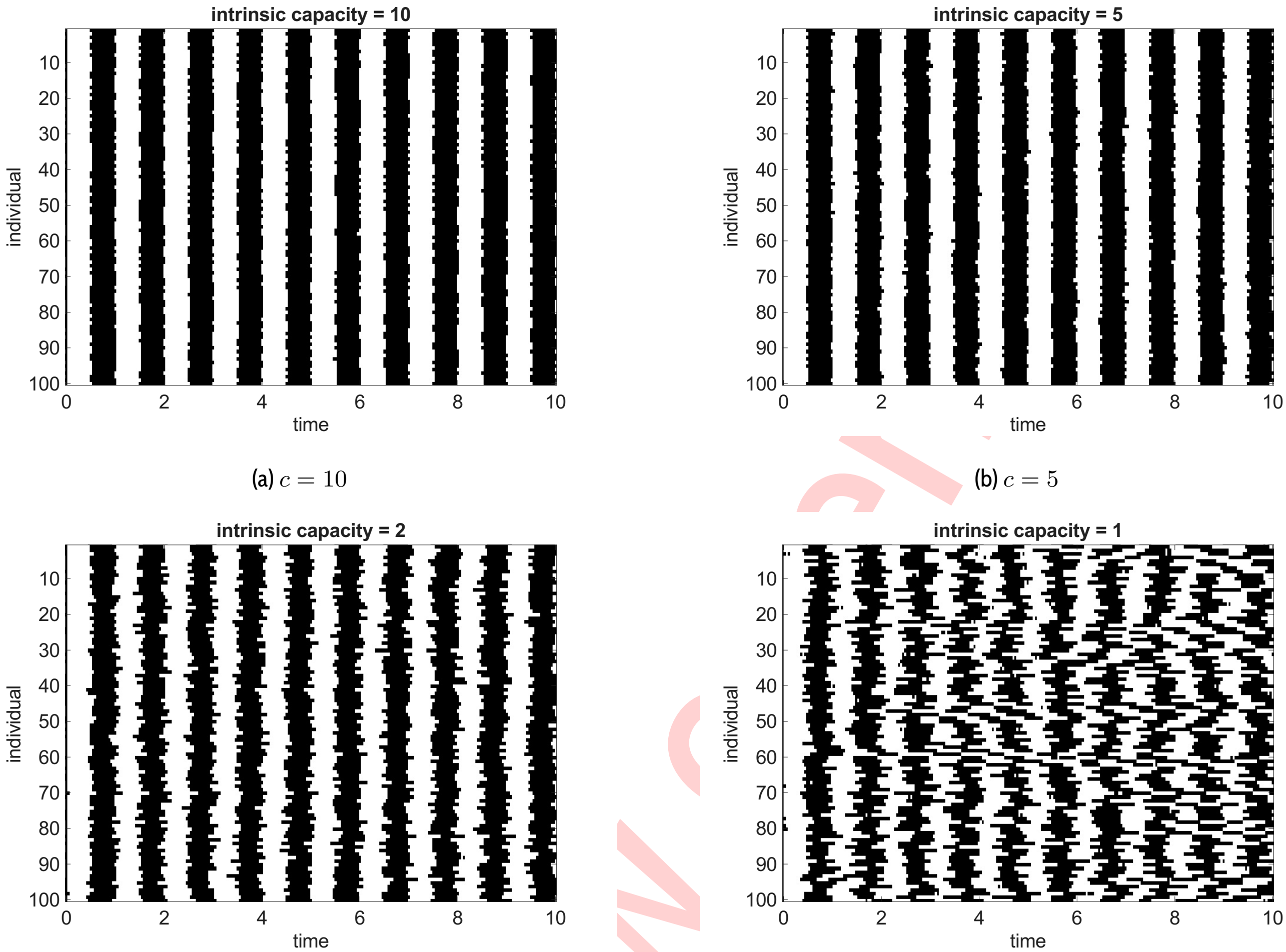
(a) $c = 10$

(b) $c = 5$

(c) $c = 2$

(d) $c = 1$

Figure 5: Simulation results for a military society of $n = 100$ individuals.



(a) $c = 10$ (b) $c = 5$

(c) $c = 2$ (d) $c = 1$

Figure 6: Simulation results for a open society of $n = 100$ individuals.

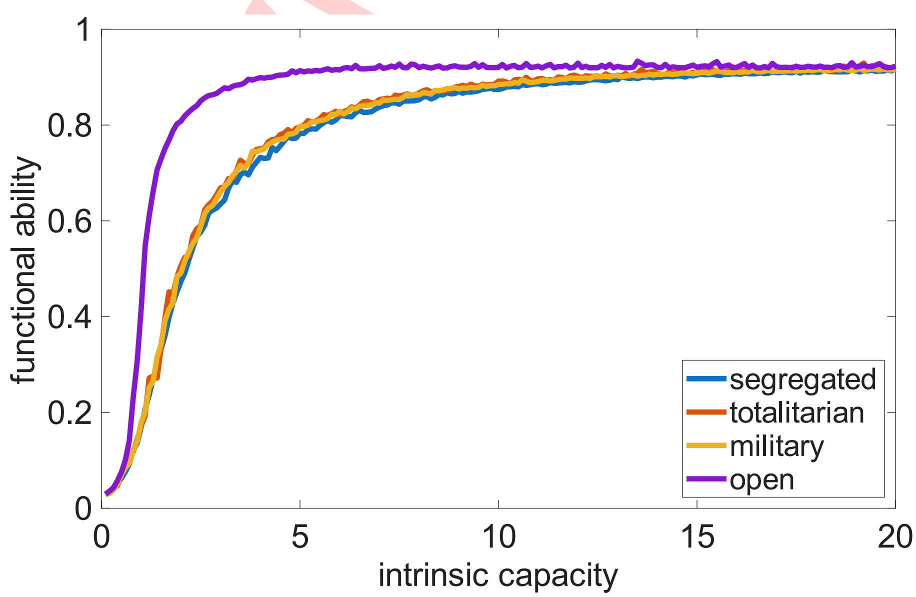


Figure 7: Healthy aging dynamics. Functional ability M against intrinsic capacity c for four stereotypic social network structures of $n = 1000$ individuals. Blue: segregated society, red: totalitarian society, yellow: military society, violet: open society.