Multi-level approaches to understanding and preventing obesity: analytical challenges and new directions

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Outline

• Motivation

• The multilevel approach
  – State-of-the-art analytical approaches
  – Challenges

• Role of systems approaches
Classic approach: Methodological individualism

- Individual-level inference
- Individual-level variables
- Individuals as units of analysis
- Group or population-level variables as proxies for unavailable individual-level data
- Populations as collections of individuals
Multiple levels of organization

Countries

Cities/Regions

Peer groups

Workplaces

Neighborhoods

Families

Individuals

Organ systems

Tissues

Cells

Molecules
Beyond individual-level factors

• Group-level attributes as themselves important to health outcomes

• Group-level attributes as modifiers of individual-level effects

• Outcome for one individual influences outcomes for others in the same group
Group-level effects

Figure 2  Distributions of systolic blood pressure in middle-aged men in two populations$^{2,3}$

Rose, 1985
Group-level variables as modifiers of individual-level effects
Group-level variables as modifiers of individual-level effects
Gene environment interaction

- Population-level features (e.g. availability of processed energy dense foods, transportation structures that detract from walking) as modifiers of gene effects on obesity

- Gene effects as context dependent
  - “...environmental variation depends on the genotypic distribution and genotypic variance depends on environmental variance”
    » Feldman and Lewontin 1975
Outcome for one individual influences outcomes for others within the same population

- Infectious diseases
- Behavioral characteristics
Social networks and obesity

Fowler and Christakis
NEJM 2007
Constructs relevant to health-related outcomes can be defined at different levels.

Understanding differences in individual-level outcomes may require information on the groups or contexts to which individuals belong.

Various features of populations or groups may be relevant.

Between and within group variability.

Factors amenable to intervention through policy change are often group-level factors.
The (now) standard approach to recovering the group or population dimension
Multilevel Models

\[ Y_{ij} = b_{0j} + b_{1j} X_{ij} + \varepsilon_{ij} \]

\( i = 1, \ldots, n_j \) individuals in \( j = 1, \ldots, J \) groups

**First level equation**

- Individual level model in each group

\( \varepsilon_{ij} \sim N(0, \sigma^2) \)

**Second level equation**

- Macro error
- Mean
- Variance of error

\( b_{0j} = \gamma_{00} + \gamma_{01} C_j + U_{0j} \)

\( U_{0j} \sim N(0, \tau_{00}) \)

\( b_{1j} = \gamma_{10} + \gamma_{11} C_j + U_{1j} \)

\( U_{1j} \sim N(0, \tau_{11}) \)

- Groups as sample of a “population of groups”
- Groups as “exchangeable”
- \( C_j = \text{group-level characteristic} \)

\[ \text{Cov} (U_{0j}, U_{1j}) = \tau_{01} \]
• Estimates “group” effects independent of individual characteristics

• Cross-level interactions: allows “individual-level effects” to be modified by context

• Decomposes between and within group variance and examines the contribution of group and individual-level factors to variability at both levels
Challenges in multilevel analysis

1. Design and measurement

2. Isolating context from composition (role of individual-level variables)

3. Time

4. Dynamic relationships
1. Design and measurement

• Specifying and operationalizing the relevant “contexts”

• Measuring “group-level” attributes
  – Ecometric assessments
    • E.g. GIS, surveys, systematic social observation

• Design requirements: multiple groups and multiple individuals within groups
2. Context and composition
Contextual factors

“True” relevant “group"

Individual-level factors

Mediators

Confounders

Omitted variables

Mismeasured variables

Available proxy

Contexts underspecified and interrelated

Individual-level confounders and mediators

Limitations of statistical adjustment
3. Time

- Lags
- Changing contexts
- Individuals moving from context to context
- Longitudinal studies that follow contexts AND individuals over time
4. Dynamic relationships
Structural features of neighborhoods → Neighborhood food availability → Dietary behaviors → obesity
Structural features of neighborhoods → Neighborhood food availability → Dietary behaviors → obesity

Family Income → Neighborhood food availability

?
Neighborhood food availability

Dietary behaviors

Family Income

Structural features of neighborhoods

Other neighborhood factors

obesity
Neighborhood food availability

Dietary behaviors

Family Income

Obesity

Other neighborhood factors

Structural features of neighborhoods

Neighborhood food availability

Society-wide food production factors

Society-wide food production factors
Patterning of health emerges from the functioning of a system:

- individuals interact with their environment

- individuals interact with each other

- individuals and environments adapt and change over time.
<table>
<thead>
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<th>Example neighborhood differences in physical activity</th>
</tr>
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<tbody>
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<td>I. Health is affected by features of neighborhood</td>
<td>Availability of places to be physically active and promotes physical activity</td>
</tr>
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<td>II. Persons are sorted into neighborhoods based on individual attributes</td>
<td>Persons of lower income and minorities live in neighborhoods with less resources</td>
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<td>-------------------------------------------------------------------------------</td>
<td>--------------------------------------------------------</td>
</tr>
<tr>
<td>III. Persons select neighborhoods based on preferences for certain attributes</td>
<td>Physically active persons choose to live in neighborhoods with more PA resources</td>
</tr>
<tr>
<td>IV. People change their behavior in response to the behavior of others around them</td>
<td>Seeing more people walk in the neighborhood stimulates individuals to walk</td>
</tr>
<tr>
<td>V. Neighborhoods change in response to the behavior of residents</td>
<td>The presence of more physically active residents increases the availability of recreational resources</td>
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The focus of regression approaches......

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Five features of dynamic systems

- Factors at multiple levels
- Interdependent/heterogeneous units
- Recursive relationships and feedback loops
- Non linear effects/Dynamic response \(\rightarrow\) effects at other locations and other times
- Unanticipated effects
Modeling/Simulation approaches

• Understanding of processes can lead to identification of more effective interventions

• Test interventions which are not feasible (yet) in the real world

• Evaluate effects of interventions under conditions different than those observed

• Systems approaches:
  – Systems dynamics modeling
  – Agent-based models
An example: Agent-based models

- Computer representations of systems: “agents” that interact in space and time

- “Agents” defined at multiple levels (persons, businesses, governments etc.)

- Agents change or take actions in response to:
  - their own attributes
  - interaction with other agents
  - the environment
  - prior experience

- Use simulation to observe how system dynamics emerge from agent interactions and adaptations

- Use summaries of simulations to draw conclusions regarding outcomes of modeled processes and how interventions on a given parameter may affect them
An hypothetical application to the study of the neighborhood patterning of health behaviors...
Define an ABM

• Agents: individuals and recreational facilities
  – Individuals have a certain physical activity level, leisure time, and income
  – Recreational facilities can be for fee or free

• Physical activity increase each time a person visits a recreational facility

• Individuals want to maximize their physical activity but their use of recreational resources is constrained by distance, personal income, and the fees charged

• Individuals’ decisions about using recreational facilities are also affected by decisions of other “agents” in their network

• Recreational facilities want to maximize the number of users and decide where to locate based on # users and presence of other facilities
An application to the study of physical activity.....

• Run model multiple times (simulations) to examine how changes in different conditions affect the spatial patterning of physical activity behaviors

• Thought experiments and interventions in virtual world...
  – Force recreational facilities to be equally distributed over space
  – Change fee structure of facilities
  – Make facilities in poor areas more attractive

• Quantify the impact of different “interventions” in the context of this system
Advantages

• Explicitly account for the interrelatedness of people and environments
  – relative importance of these reciprocal and dynamic relationships

• Force investigators to think about processes

• Thought experiments and evaluate the effects of hypothetical interventions in the context of SYSTEMS
  – Counterfactual comparison embedded in complexity
Caveats…

• Keeping it simple but relevant…
  – Fundamental processes vs. specific empirical problems?
  – Thought experiments vs. prediction

• Where is the data???
  – Justify modeled processes
  – Validate model results

• Transparency and communication

• WHEN DOES IT MAKE A DIFFERENCE???
Modeling/simulation approaches

• From describing associations to modeling the processes that generate them

• Investigation of effects
  – Under conditions different from those observed in real world
  – Accounting for feedback loops and adaptation of people and environments over time

• Conclusions contingent on validity of the model

• Process of building these models can highlight policy-relevant areas where we need mode data!

Auchincloss A. Diez Roux AV. A new tool for epidemiology? The usefulness of dynamic agent models in understanding place effects on health. AJE I 2008
• Everything is a “system”

• “Systems” can be investigated using a variety of approaches

• Methods can constrain our thinking
• Obesity as inherently a multi-level problem

• Long-term change likely requires multilevel approaches

• Complementary sources of evidence
  – Observational multilevel studies
  – Natural experiments/experiments
  – Systems/simulation approaches
  – Action based on best available evidence followed by rigorous evaluation
Challenges of experimental studies in studying multilevel effects

- Units
- Sample size
- Contagion processes
- Time Lags
- The intervention
- Testing an intervention vs. understanding a process
Why look at multilevel determinants of obesity?

• Insufficiency of purely individual-based explanations
• Contexts (physical and social) as predictors of health
• Contexts as modifiers of individual-level effects
• Public health and policy relevance of contexts
Recovering the "group" or population dimension

- Emergent group properties
- Group determinants of individual-level properties
- Relationships between individual-level variables may differ from group to group
- Within and between group variability
Obesity

Obesity in International Perspective


NHANES, Cutler et al. J Econ Perspectives 2003;17:93-118

Source: CDC BRFSS
• The methods we use have constrained our thinking.

• Will these new methods help?

• Can they be made realistic enough to be informative for public health?

• Processes vs. independent effects

• Think more creatively and broadly about the complex problems that we study.

• Broaden range of questions, address questions using a variety of approaches.