Dynamic Systems Modeling of Ecological Momentary Assessment Data among Problem Drinkers in Treatment

J. Morgenstern & A. Kuerbis
Columbia University

&
H.T. Banks, K.L. Sutton, K.L. Rehm
North Carolina State University
www.ncsu.edu/crsc
www.ncsu.edu/cqsb

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Overview of Talk

Background on alcohol use disorders & status treatment science

New approach to understanding how treatments work

Aims & methods of modeling project

Preliminary modeling results

Lessons learned (so far) for behavioral scientists
Prevalent & Costly Societal Problem

• 6% prevalence of Alcohol Dependence (AD)
• Another 10% are Problem Drinkers (PD)
• Estimated annual cost to society $184 billion
• 2nd leading cause of disability among 24-44 year olds (after depression)
Status of Treatment Research Efforts

Discovery of Several Modestly Effective Treatments Over Last Two Decades

• Behavioral interventions
• Medications
• Combination of medications & behavioral interventions

New Directions in Treatment Research

• Genetics (phenotypes)
• Neuroscience
• Mechanisms of behavior change (MOBC)
Challenges of Studying Mechanism of Behavior Change (MOBC) in Alcoholism

- Heterogeneous disorder
- Heterogeneous course
- Self-change is potent factor in remission (spontaneous remission)
- Maintenance of problem drinking and change appear
  - multi-determined (social, psychological, biological)
  - reciprocal influences across domains (complex, non-linear models)
  - time variable course (time scale??)
Problem Drinkers Entering Brief Motivational Treatment

-12 weeks

9 weeks intensive observation

0

12 weeks

Job Warnings

Enters treatment

Homeostasis

No change

Fluctuating course

Rapid Resolution
Ecological Momentary Assessment (EMA)

- Repeated sampling of behavior in near real time using technology
- Minimize recall bias
- Measurement in-vivo may be more accurate
- Temporal sequencing and within-person assessment of change
Methodological Challenges in the Analysis of EMA Data:

Intensive Longitudinal Data (ILD) requires new methodological approaches as well

- Complexity & variability of individual trajectories
  - Difficult to capture with polynomials
  - Is population based average representative of individual trajectories?
- Limitation of fixed time-graded effects in linear methods
  - Representation of time goes beyond fixed interval (time as covariate)
  - Within-subjects changes in association with variables over time
- Dynamic modeling offers an alternative approach with substantially greater flexibility to model change
Project Goals

Use mathematical models to understand dynamic cognitive processes underlying behavior change in problem drinkers from EMA data

- Develop mathematical models to describe interacting mechanisms within an individual

- Calibrate/validate models via parameter estimation from EMA data (Project MOTION)

- Use quantitative information from these efforts to design future response (data) collection protocol

- Use models as tools to better understand current and design future improved treatment strategies
Secondary Analysis of Project MOTION Data

Project MOTION Aims

1. Test hypothesized mechanisms of action on Motivational Interviewing (MI) among problem drinkers seeking moderation

2. Gain a better understanding of when and how drink reduction occurs during initiation of change efforts
# Two Design Components: (1) RCT Component Analysis of MI

## Main Effects

<table>
<thead>
<tr>
<th>Treatment Conditions</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full MI (A &amp; B)</td>
<td>FMI &gt; HMI &gt; CTL</td>
</tr>
<tr>
<td>Half MI (A)</td>
<td>Drink Reduction (End Treatment)</td>
</tr>
<tr>
<td>Self-Change Control</td>
<td></td>
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</tbody>
</table>
Hypothesized MOBC of Motivational Interviewing

Increase in Control (Top-Down)
- Commitment to reduce drinking
- Confidence in ability to cope with tempting situations

Decrease in Drive Factors (Stimulus-Driven)
- Negative affective arousal
- Cravings to drink
Two Design Components: (2) Intensive (Daily) Repeated Measures of Mediators & Outcome

Daily Data Collection of Mediators and Outcomes Across Eight Weeks (56 Days)

C → D → Drk

-1 Randomization  1  2  3  4  5  6  7  8
Reciprocal Feedback Among Control, Drive, and Drinking

Control System
- Motivation
- Self-efficacy

Internal States (Drive)
- Negative Moods
- Desire to Drink

Drinking
Ecological Momentary Assessment (Daily computerized call)

- Daily activities (11)
  - Pleasant, stressful, drinking-related events
- Current mood (11)
  - Adjectives sample circumplex mood model
- Perceived stress (4)
- Desire to drink (3)
- Commitment to reduce drinking (2)
- Confidence to not drink heavily (1)
- Alcohol use (standard drinks)
  - Prior evening since last call, current day
- Prior day’s drinking judged as excessive (1)
Interpretation of MOTION data to build dynamic model

- Too much detail renders model intractable and ultimately uninformative
- Too little detail may not accurately represent key elements of modeled system
- Combine similar responses in IVR data, mindful of not losing distinct aspects of cognitive processes
- Timescale: triweekly appears to be informative, yet not too detailed
Early Iterative Efforts at Model Building

• Repeated attempts to build models that related events, mood, stress, drive, control, and drinking across all participants
  – Various statistical data reduction techniques
  – 3-D visualizations of daily (raw) data over time
  – Conceptual redefinition of constructs

• Some preliminary findings
  – Difficult to find relationships between daily stress, mood, & drinking
  – Substantial individual variability in trajectories
Interpretation of MOTION data to build dynamic model

• Variability among patients; groups of individuals with similar relationships → cohorts

• For each patient, examined the dynamics in variables with dynamics in alcohol → if there seemed to be a relationship, that variable was considered important for the mathematical model

• Once variables selected to be important for drinking behavior, screened for relationships in the dynamics of these variables

• For initial efforts, focus on one individual who appears to be a `typical responder'
Example: Categorical model for Patient 6029 (responder)

Confidence & commitment no heavy drinking next day

Limit L(t) → Drinks A(t) → Guilt G(t)

Commitment Q(t) → Drinks A(t) → Guilt G(t)

Desire D(t) → Guilt G(t)

Prior day's drinking excessive

Commitment no drinking next day
Initial Model

\[
\begin{align*}
\frac{d}{dt} A(t) &= -a_{1,2} \chi_{(G>0)} \left( \int_{-\tau_1}^{0} G(t+s) \kappa_1(s) ds \right)^2 + a_{1,3} \chi_{(D>0)} D(t) \\
&\quad -a_{1,4} (Q(t) + \chi_{(Q>0)} Q^2(t)) - a_{1,5} L(t) \\
\frac{d}{dt} G(t) &= a_{2,1} \left( \int_{-\tau_2}^{0} A(t+s) \kappa_2(s) ds - (1 + \chi_W(t)) A_G^* \right) \\
\frac{d}{dt} D(t) &= -a_{3,4} Q(t) - a_{3,5} L(t) - a_{3,2} \left[ \exp \left( \frac{1}{G_{D1}^{**}} \int_{-\tau_3}^{0} G(t+s) \kappa_3(s) ds \right) - G_{D2}^* \right] \\
\frac{d}{dt} Q(t) &= -a_{4,1} \left( 1 + \chi_W(t) \chi_{(D>0)} \right) D(t) \\
&\quad -a_{4,1} \left[ \exp \left( A_{Q1}^* \min(0, (A(t-\tau_4) - A_{Q1}^*)) \right) - (1 - \chi_W(t)) A_{Q2}^* \right] \\
\frac{d}{dt} L(t) &= a_{5,2} G(t) - a_{5,3} D(t) - a_{5,1} \left[ \exp \left( \frac{1}{A_{L1}^*} \min(A_{L1}^*, (A(t-\tau_5) - A_{L1}^*)) \right) - A_{L2}^* \right] .
\end{align*}
\]
6029 Weekly Drinking Pattern before and during Treatment
Tri-Weekly Drinking Pattern during Treatment
Final Reduced Model for 6029

\[ \frac{d}{dt} A(t) = a_{13} h(t), \]
\[ \frac{d}{dt} G(t) = a_{21} \left[ \int_{-1}^{0} A(t + s) ds - (1 + c_1 \chi_{W(t)}) A^{*} \right]. \]
Lesson Learned about Modeling for Behavioral Scientists

• Modeling individual-level behavioral dynamics is novel & challenging
• Modeling provides powerful tool for behavioral scientists to represent complex interrelationships among variables:
  – Feed forward and feedback loops
  – Non-linear, time-delay, threshold effects
  – Person-centered versus variable centered approaches
• Ideal discovery method to build behavior change mechanism models
Lessons learned from 6029

• Recognizable response pattern from clinical literature
  – Drinking and internal dynamics change prior to treatment
  – “turning point” or decision-making process
• Is 6029 a “prototype” of responder?
  – If so, a quite different treatment might be useful
• New conceptual directions on mechanisms
  – Norm violation (guilt) not part of applied explanations, but important in conceptual models of self-regulation
  – Weekday/weekend dynamic was not predicted in model, but may represent a cognitive control mechanism that has been speculated as important to controlling cravings