Understanding how big data analyses can inform theories of rehabilitation

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Disclosure

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Aphasia rehabilitation - where do things stand?

Treatment works at the individual patient level and for specific impairments -
• Semantic feature analysis (SFA) (Boyle, 2004; Boyle & Coehlo, 1995; Coelho et al., 2000; Hashimoto & Frome, 2011; Kiran & Bassetto, 2008),
• Phonological component analysis (Leonard et al., 2008; van Hees et al., 2013; Wambaugh, 2003),
• Phonomotor therapy (Kendall et al., 2015),
• Verb network strengthening treatment (VNeST) (Edmonds et al., 2014a),
• Treatment of underlying forms (TUF) (Dickey & Thompson, 2007; Thompson et al., 2010a; Thompson et al., 2010b; Thompson & Shapiro, 2005),
• Orthographic impairment approaches (Beeson & Egnor, 2006; Kiran, 2005; Orjada & Beeson, 2005),
• Constraint induced language therapy (Breier et al., 2011; Maher et al., 2006; Pulvermuller et al., 2001),
• Melodic intonation therapy (MIT) (Hough, 2010; Morrow-Odom & Swann, 2013; Norton et al., 2009; van der Meulen et al., 2012), and
• Multimodal aphasia therapy (Boo & Rose, 2011; Rose & Douglas, 2008; Rose et al., 2013).

Moreover, many of these impairment-based approaches have been found to facilitate changes in functional communication skills (Berthier et al., 2009; Edmonds et al., 2014a; Hough, 2010; Kendall et al., 2015; Martins et al., 2013; Milman et al., 2014; Pulvermuller et al., 2001; van der Meulen et al., 2014; Wilssens et al., 2015).
What we don’t yet know is-

When a patient walks into the clinic, can we accurately prescribe the right therapy and dosage for the patient and make some predictions about how much improvement he/she will show?
Patient factors

- Age
- Lesion location
- Lesion size/volume
- Months post stroke
- Education
- Severity of impairment

Treatment factors

- Amount/Intensity of therapy
- Optimal dosage
- Type of treatment
- Therapy setting (home, clinic)

Therapy Outcomes
### Patient factors
- Age
- Lesion location
- Lesion size/volume
- Months post stroke
- Education
- Severity of impairment

### Treatment factors
- Amount/Intensity of therapy
- Optimal dosage
- Type of treatment
- Therapy setting (home, clinic)

### Therapy Outcomes
What can big data tell us?

Can large scale data be used to answer questions about the effectiveness of aphasia rehabilitation

Three questions:

1. How does therapy at home compare to therapy in the clinic?
2. How does severity of impairment influence outcomes?
3. What is the optimal dosage of treatment?
20,000 individuals with post-stroke aphasia who used Constant Therapy program (2013-2016)
Retrospective analysis
Clinician signs up for constant therapy and enrolls patients

Patients are assigned specific therapy tasks

Clinician analyzes data on usage and performance

Patient completes CT program
Constant Therapy’s 70+ tasks are grouped by functional skill area and arranged by order of difficulty within that domain.
Question #1: How does therapy at home compare to therapy in the clinic?
1. How does therapy at home compare to therapy in the clinic?

- 3652 patients
- Clinic patients - 1575 patients (Clinic-only users who only received therapy under the care of a clinician)
- Home therapy patients - 2077 patients (Home-only users with no clinician guidance)
How does therapy at home compare to therapy in the clinic?

- Effectiveness of therapy was represented by the number of calendar days patients spent between:
  - Struggling at a task (<60% accuracy) to
  - Mastering a task (>90% accuracy)

- Each therapy task was analyzed independently
- 46 out of 244 therapies have at least 20 Clinic-only and 20 Home-only users
- Patients who finished tasks in less than a day or who took more than 60 days to finish the task are not included
QUESTION 1

(F(1,7133) = 246.61, p < .001) where clinic users took a higher number of calendar days to reach 90% accuracy than home users.

(F(1,7190) = 85.70, p < .001) where clinic users had a greater median number of days between sessions than home users.

(F(1,7190) = 71.97, p < .001) where overall clinic users took fewer days of therapy to reach 90% accuracy than home users.

(F(1,7190) = 13.31, p < .001) where clinic users completed more items per therapy day than home users.
**QUESTION 1**

<table>
<thead>
<tr>
<th>2017</th>
<th>August</th>
<th>CLINIC PATIENT</th>
<th>HOME PATIENT</th>
</tr>
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<tr>
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<td>TUESDAY</td>
<td>WEDNESDAY</td>
<td>THURSDAY</td>
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<td>Notes:</td>
<td>04</td>
<td>05</td>
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- **Main findings**
- For patients who improve from 60-90%, both groups require a similar number of therapy sessions to achieve mastery.
- Patients practicing only at home can master tasks in a shorter time than patients practicing only in the clinic.
Main findings

For patients who improve from 60-90%, both groups require a similar number of therapy sessions to achieve mastery.

Patients practicing only at home can master tasks in a shorter time than patients practicing only in the clinic.
Question #1: How does therapy at home compare to therapy in the clinic?

Question #2: How does severity of impairment influence treatment outcomes?

Question #3: How does severity and dosage (amount of practice) influence treatment outcomes?
Question #1: How does therapy at home compare to therapy in the clinic?

Question #2: How does severity of impairment influence treatment outcomes?

Question #3: What is the optimal dosage for optimal treatment outcomes?
In patients with acute aphasia, one randomized control trial showed that patients with mild aphasia improved more than patients with severe aphasia.


Pedersen and colleagues showed that initial aphasia severity predicted language impairment in the chronic stage and was associated with poorer outcomes in the long term.


One large-scale study examined overall stroke outcomes (not specifically language) and found that greater severity predicted a poorer outcome after rehabilitation.

- However, another study showed that at even severe patients with aphasia benefited from very early language therapy.

- In a meta-analysis, Robey showed that acute patients with severe aphasia show substantial gains after treatment but chronic patients with moderate and severe aphasia also show substantial gains after rehabilitation.

- In chronic aphasia, Persad and colleagues reviewed outcomes from rehabilitation centers that provide intensive comprehensive aphasia treatment and found both mild and severe chronic patients with aphasia to benefit from such treatment
Calculation of Severity of impairment

11,888 patients

244 unique therapy tasks

Each Therapy

starting_accuracy
- 0.0 to 0.4
- 0.4 to 0.5
- 0.5 to 0.6
- 0.6 to 0.7
- 0.7 to 0.8
- 0.8 to 0.9

More severe
Less severe
Patient factors
- Age
- Lesion location
- Lesion size/volume
- Months post stroke
- Education
- Severity of impairment

Treatment factors
- Amount/Intensity of therapy
- Optimal dosage
- Type of treatment
- Therapy setting (home, clinic)

Therapy Outcomes
Severe patients older (60.7 years) than less severe patients (59 years), though mean age = 60 years, Main effect of group: (F (1749)= 3.6, p <.001)

Severe patients slightly more chronic (2.3 years) than less severe patients (1.8 years), though all patients mostly chronic, Main effect of group: (F (1749)= 7.7, p <.00001)
Based on an initial baseline assessment, a given task is assigned as long as its performance is less than 90% accuracy and below average latency.

For each subject fitting the cohort selected, the accuracy and latency of the first and last 10 items are compared to determine improvement.

To account for familiarity effects, the first 3 items patients did were ignored.

2-tailed Paired T-Tests were used to identify significant improvements in accuracy and latency. Due to the logarithmic distribution of the latency, log(latency) were compared to normalize the distribution.
1. More severe patients show more gains (F (5, 6942)= 477.1, p < .00001) than less severe patients.

2. The same effect is seen across different domains:
   Main effect of domain: (F (12, 6942)= 30.09, p < .00001)
   Main effect of severity: (F (5, 1694)= 336, p < .0001)
   Significant interaction: (F (60, 1694)= 2.4, p < .0001)
Question # 3: How does severity and amount of treatment influence treatment outcomes?

<table>
<thead>
<tr>
<th>Patient factors</th>
<th>Treatment factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>Amount/Intensity of therapy</td>
</tr>
<tr>
<td>Lesion location</td>
<td>Optimal dosage</td>
</tr>
<tr>
<td>Lesion size/volume</td>
<td>Type of treatment</td>
</tr>
<tr>
<td>Months post stroke</td>
<td>Therapy setting (home, clinic)</td>
</tr>
<tr>
<td>Education</td>
<td></td>
</tr>
<tr>
<td>Severity of impairment</td>
<td></td>
</tr>
</tbody>
</table>

Therapy Outcomes
Question # 2: How does severity and amount of treatment influence treatment outcomes?

Calculation of Amount of Therapy

- Each item practiced = Trial = Teaching episode (Warren et al., 2007)
- Amount of therapy = Cumulative trials (completed task count) (independent of time/sessions)
- Intervention intensity = dose (number of trials), dose frequency (number of trials per day per week), intervention duration (in months) (Warren et al., 2007)

<table>
<thead>
<tr>
<th>Completed Tasks</th>
<th>Fewer items</th>
<th>More items</th>
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<tbody>
<tr>
<td>13-23</td>
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<td>501-1000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1001-99999</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
1. With more practice, improvements are between 20-50 points for more severe patients, slightly less for less severe patients, \((F, (25, 6904) = 24.5 \ p < .0001)\)

2. More severe patients can achieve high levels of accuracy (80% or higher) with increased practice; \((F, (25, 1724) = 26.5, \ p < .0001)\)
1. When therapy is standardized and individualized, both less severe and more severe patients improve.

2. Patients with lower initial scores showed more improvements (20-50 points gains) than patients with higher initial scores.

3. These improvements hold at the level of an individual task as well as across different language and cognitive domains.

4. Severe patients can achieve success on trained tasks, they need a lot of practice.
Why are these results important?

Initial severity an important predictor of recovery; patients with milder aphasia show greater recovery than severe patients (Laska et al., 2001; Pedersen et al., 2004; Plowman et al., 2011) “All in all, the patient with the most impaired speech function may have the greatest potential recovery during rehabilitation.” Laska et al., 2001

• While it is logical to assume that more intensive treatment results in greater outcomes:
-- It has been demonstrated in chronic (Bhogal et al., 2003a; Bhogal, Teasell, & Speechley, 2003b; Cherney et al., 2008) and in acute patients with aphasia (Godecke et al., 2014),
-- Other studies have questioned this premise (Bakheit et al., 2007; Dignam et al., 2015).

• These results suggest that severe patients can achieve success on trained tasks, they need a lot of practice
Question #1: How does therapy at home compare to therapy in the clinic?

Question #2: How does severity of impairment influence treatment outcomes?

Question #3: What is the optimal dosage for optimal treatment outcomes?
Participants

- 2216 individuals with aphasia or stroke with reported deficits in language domains were included in the study
- Participants consented that their data be analyzed for research purposes
- Average age: 64 years
- 1313 patients in the acute stage (<6 months)
- 903 users in the chronic stage (>6 months)
- Participants used CT as much or as little as they desired
Progress through a skill area is represented by a numerical domain score indicating their demonstrated ability level in that skill area.

As a user demonstrates recovery by succeeding in exercises they previously struggled with, they are presented with more difficult exercises and their domain score increases.

**SAMPLE DOMAIN: Auditory Memory**

**HEALTHY ADULTS (MTURK)**

**STROKE PERFORMANCE**
SAMPLE DOMAIN: Auditory Memory

HEALTHY ADULTS (MTURK)

Domain Score Formula: \( \frac{\text{Highest Task Recently Passed}}{\text{Total Tasks in the Domain}} \)

If this is the Highest Task Passed
Domain Score: \( \frac{6}{17} = 35\% \) mastered
### Analysis

<table>
<thead>
<tr>
<th>Domain Name</th>
<th>Domains</th>
<th># data points</th>
<th># Patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analytical</td>
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<td>15750</td>
<td>1795</td>
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<tr>
<td>Arithmetic</td>
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<td>961</td>
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<tr>
<td>Attention</td>
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<td>1663</td>
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<td>Auditory Comprehension</td>
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<tr>
<td>Auditory Memory</td>
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<td>17160</td>
<td>1863</td>
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<tr>
<td>Naming</td>
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<td>15407</td>
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<td>Phonological Processing</td>
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<td>12115</td>
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<tr>
<td>Production</td>
<td>8</td>
<td>8415</td>
<td>1224</td>
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<tr>
<td>Quantitative</td>
<td>9</td>
<td>11648</td>
<td>1368</td>
</tr>
<tr>
<td>Reading</td>
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<td>18094</td>
<td>1909</td>
</tr>
<tr>
<td>Sentence Planning</td>
<td>11</td>
<td>12481</td>
<td>1728</td>
</tr>
<tr>
<td>Visual Memory</td>
<td>12</td>
<td>15333</td>
<td>1691</td>
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<tr>
<td>Visuospatial</td>
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<td>16693</td>
<td>1800</td>
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<tr>
<td>Writing</td>
<td>14</td>
<td>12153</td>
<td>1442</td>
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</table>

Varying # of patients and data points in each domain
Analysis approach

- Users were divided into one of seven groups based on how many average days per week they used CT over a 3-month period (i.e., from 0 times/week to 6 times/week).
- 50% of participants used CT 2 or more days per week.
- Compared the change in domain score over time to their baseline score.
- For each domain, analyze the relation between the rate of improvement and the dosage of therapy per week.
- A linear mixed model was generated for change from baseline domain score with fixed factors of average app usage & domain area and fixed effects of age, time since injury, & weeks used.
- The derived coefficients were compared across usage groups using paired Wald tests, revealing significant differences in the coefficients.
Results: Covariate effects of age and condition since
After 3 months, participants who practiced less than 1x per week showed significantly slower progress through domains compared to those who practiced greater than 3x/week.
While all groups, on average showed improvement over time, participants who used CT greater than 3x/week showed higher rates of improvement than those that used the app 0-1x/week (p<0.001) across 11/14 domains.

Rate of improvement significant 5x/6x times a week better than 1x/2x for most domains (Domains Analytical, Visuospatial, visual memory, sentence planning, reading, production, attention, arithmetic) (p<.05).

For auditory comprehension, 4x times/week better than 1x, 2x, or 3x.

Gains noted even after controlling for different age and time post-stroke.
Discussion

- According to the ASHA NOMS 2011 report, 78.1% of patients with stroke receive 2 or less sessions per week in the outpatient setting.

- This lower treatment dosage in the clinic is likely multifactorial including clinician time/schedule constraints, insurance reimbursement, and client fatigue (Harnish et al., 2014).

- After 3 months, participants who practiced less than 1x per week showed significantly slower progress through various skill domains compared to those who practiced greater than 3x/week (best outcomes 5x/6x per week) which reinforces the idea that increased treatment dosage results in better outcomes.

- Adds to increasing evidence of providing intensive, sustained therapy for stroke patients with aphasia, even in the chronic phase (Baumgartner et al., 2013; Carpenter & Cherney, 2016; Dignam et al., 2016).

- Next steps:
  - Identify whether different levels of severity influence the gains made with practice 4x times/week.
In the future

- Lab/clinic
  - Neuro-profile
  - Lang/Cog profile
  - Social/functional profile
  - Predict prognosis and recovery trajectory

- Intensive aphasia therapy & individual therapy
- Individual therapy & social groups
- Social groups & vocational training
Next Steps: Population analysis to predict recovery trajectory

Improvements shown by Constant Therapy users in Reading for 0 months

Many Constant Therapy users who had difficulty deciding if two written words belong to the same category were able to master this task and continue on to other exercises.

Move the slider bar to see more details!
Next Steps: Population analysis to predict recovery trajectory

Improvements shown by Constant Therapy users in Reading for 1 month

After 1 month(s) of Constant Therapy, 51% of users who initially had difficulty deciding if two written words belong to the same category where able to master this task and continue on to other exercises.

The top 12% of users continued on and mastered being able to decide if a description of a feature matches a given picture.
Next Steps: Population analysis to predict recovery trajectory

Improvements shown by Constant Therapy users in Reading for 3 months

After 3 month(s) of Constant Therapy, 64% of users who initially had difficulty deciding if two written words belong to the same category were able to master this task and continue on to other exercises.

The top 10% of users continued on and mastered being able to fill in the blank to complete a passive (direct object-verb-subject) sentence.
Next Steps: Population analysis to predict recovery trajectory

Improvements shown by Constant Therapy users in Reading for 5 months

After 5 month(s) of Constant Therapy, 68% of users who initially had difficulty deciding if two written words belong to the same category were able to master this task and continue on to other exercises.

The top 10% of users continued on and mastered being able to organize and sequence steps to everyday tasks.
Closing the loop between the clinician and patient
# Constant Therapy

## MY PATIENTS

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<th>Total Patients</th>
<th>Total Exercises Done</th>
<th>Total Home Exercises Done</th>
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<tbody>
<tr>
<td>13</td>
<td>19,822</td>
<td>18,567</td>
</tr>
<tr>
<td>1 DISCHARGED LAST WEEK</td>
<td>▲ 1,613 FROM LAST WEEK</td>
<td>▲ 1,451 FROM LAST WEEK</td>
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<table>
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<th>Home Exercises</th>
<th>Clinic Exercises</th>
<th>Average Activity</th>
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<tr>
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<td>144</td>
<td>4.9 days / wk</td>
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<tr>
<td>On track</td>
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<tr>
<td>On track</td>
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<td>102</td>
<td>1.8 days / wk</td>
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<tr>
<td>On track</td>
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<td>230</td>
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<td>1.6 days / wk</td>
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Closing the loop between the clinician and patient
Acknowledgements:

- CONSTANT THERAPY
  - Mahendra Advani
  - Veera Anantha

- BOSTON UNIVERSITY
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