Metrology of categorical data in psychometrics

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Variation in Primary Care Indicators

Potential causes of variation:
- Disease prevalence
- How physicians diagnose
- How data coders interpret diagnoses
- ....

Source: OECD analysis of data from Prince et al. (2013) and the United Nations.
Quality-assured measurement

Object: Health

Mini Mental State Examination

Person-centred care (PCC)
- Focus on health (not illness)
- People partners in care
- More symptoms
- Impact on Activities of Daily Living
- Subjective & perceptive
- ...

Cognitive ability?

0.8 units ± 0.2 units
Balance as Measurement Instrument - Sensitivity ($C$)

**Stimulus ($S$):** Mass of weight

**Response ($R$):** Mass of weight x Balance sensitivity

**Measurand 'restitution',** $S = C_{cal}^{-1} \cdot R$

**Calibration**

$R = C_{cal} \cdot S + "additional terms"$

Leslie.pendrill@ri.se 2017-12-13
Measuring Man:
- Status, function of person
- Test against specifications

Man as Measurement Instrument:
- Perception of product/service function, comfort etc
- Propose improvements in product

ISBN 978-1-84872-939-1 (Hardback)
Quality-assured categorical measurement

"Comfort"
Different scales of measurement

\[ x \geq y \text{ iff } \phi(x) \geq \phi(y) \]

(Strictly) monotone increasing transformation

Ordinal

Preference?

Hardness

Air quality

Grades of leather, lumber, wool, etc.

Intelligence tests, raw scores

\[ 1 + 2 + 3 \approx 6 \]

'Counted fractions'
### Logistic Ruling

![Logistic Ruling Graph](image)

\[
\log \left( \frac{P_{\text{success}}}{1 - P_{\text{success}}} \right) = z
\]

'Counted fractions'

---

**The Collected Works of John W. Tukey**

**Volume III**

**Philosophy and Principles of Data Analysis: 1949 - 1964**

Edited by Lyle V. Jones

*University of North Carolina, Chapel Hill*

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Comparing instruments rating of physical disability

W P Fisher Jr. 1999
Measurement system analysis

Quantitative

Measurand
(stimulus, $S$

e.g. task difficulty, $\delta$, $u_\delta$)

Restitution
$R \Rightarrow S$
e.g. $P_{success} \Rightarrow \delta$, $u_\delta$

Qualitative

Response indication, $R$
e.g. $P_{success}$

$log \left( \frac{P_{success}}{1 - P_{success}} \right) = \theta - \delta$
Difficulty $\delta$

Ability $\theta$

Rasch (1961)

- Correct ordinal data treatment
- Better resolution
- Separation of person and item measures

$\delta(\text{Difficulty})$

$\theta(\text{Ability})$

Measuring People

Man as Measurement Instrument

Environment

Object

Operator

Measurement method

$$\log \left( \frac{P_{\text{success}}}{1 - P_{\text{success}}} \right) = \theta - \delta$$

Prototypical Likert scale from a measurement perspective.
\[ \delta(\text{Difficulty}) \]

**Metrological references**

**Tasks**

**Difficulty**

**Mass**

**Physical disability**

Leslie.pendrill@ri.se 2017-12-13
NEUROMET

EMPIR 15HLT04: Innovative measurements for improved diagnosis and management of neurodegenerative diseases
June 2016 – June 2019

<table>
<thead>
<tr>
<th>Short Name</th>
<th>Organisation legal full name</th>
<th>Country</th>
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<tbody>
<tr>
<td>LGC</td>
<td>LGC Limited</td>
<td>United Kingdom</td>
</tr>
<tr>
<td>INRIM</td>
<td>Instituto Nazionale di Ricerca Metrologica</td>
<td>Italy</td>
</tr>
<tr>
<td>LNE</td>
<td>Laboratoire National d’Essais</td>
<td>France</td>
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<td>Physikalisch-Technische Bundesanstalt</td>
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<td>SP</td>
<td>SP Sveriges Tekniska Mobilverk</td>
<td>Sweden</td>
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<tr>
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<td>NeuroCure Clinical Research Medicine Charité</td>
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<td>CHRU Mpt</td>
<td>‘Laboratory of Biomedical Engineering’ Centre Hospitalier Universitaire de Montréal</td>
<td>Canada</td>
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<tr>
<td>UCL</td>
<td>National Amyloid Centre and Wolfson Drug Discovery, University College London</td>
<td>United Kingdom</td>
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<tr>
<td>UEA</td>
<td>School of Nursing at the University of East Anglia</td>
<td>United Kingdom</td>
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<table>
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<tr>
<th>WP No</th>
<th>Work Package Title</th>
<th>Active Partners (WP leader in bold)</th>
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<tbody>
<tr>
<td>WP1</td>
<td>Patient cohort sampling and stratification</td>
<td>PTB, Charité, SP, INRIM, CHRU Mpt, LGC, UEA</td>
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<tr>
<td>WP2</td>
<td>Minimally invasive methods for AD and PD diagnosis</td>
<td>LGC, LNE, CHRU Mpt, Charité, UCL, INRIM, UEA, SP</td>
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<td>WP3</td>
<td>Establishing traceability of AD and PD biomarker</td>
<td>UNE, LGC, CHRU Mpt, Charité, UCL, SP</td>
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<td>Patient-centred outcome measures</td>
<td>SP, Charité, LGC, PTB, LNE, INRIM, CHRU Mpt, UCL</td>
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<td>WP5</td>
<td>Creating impact</td>
<td>UCL, INRIM, UEA</td>
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<tr>
<td>WP6</td>
<td>Management and coordination</td>
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Acknowledgements
The European Metrology Programme for Innovation & Research (EMPIR, Horizon2020, Art. 185) is jointly funded by the EMPIR participating countries within EURAMET (www.euramet.org) and the European Union in this EMPIR 15 HLT04 NeuroMet project (coordinator: LGC (UK))

Leslie.pendrill@ri.se 2017-12-13
Quality-assured measurement

Object: Health

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0,8 units ± 0,2 units

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- …

Mini Mental State Examination

Leslie.pendrill@ri.se 2017-12-13
Using a Rasch scale to characterize the clinical features of patients with a clinical diagnosis of uncertain, probable, or possible Alzheimer disease at intake

Larry F. Hughes, Kyle Perkins, Benjamin D. Wright, and Heather Westrick

<table>
<thead>
<tr>
<th>SCALE DEFINED BY SCORES ON THE THREE TESTS</th>
<th>THE IMPLICATION FOR ALZHEIMERS?</th>
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</thead>
<tbody>
<tr>
<td>0  1  2  3  4  5  6  7  8  9  10  11  12  13  14  15</td>
<td>Hi ADL  Lo MMSE  Hi SBD</td>
</tr>
<tr>
<td>0  20  40  60  70  80  90  100</td>
<td>FOR ALZHEIMERS?</td>
</tr>
</tbody>
</table>

Uncertain: Possible: Probable
**Metrological references**

- **Task difficulty, $\delta$**
- **Delayed recall**
- **Orientation**
- **Naming objects**

**Mini Mental State Examination**
Svensk Revidering (MMSE-SR)

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MMSE Items expand

-6  -4  -2  0  2  4

Difficulty, $\delta$

Less difficult  More difficult

Naming objects

Delayed recall

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Svensk Revidering (MMSE-SR)
### Explaining cognitive ability

**Response = f(explanatory variables)**

<table>
<thead>
<tr>
<th>Explanatory variables, $X$</th>
<th>Response variables, $Z$</th>
<th>$A\beta$</th>
<th>tau</th>
<th>MRI</th>
<th>WMH</th>
<th>Age</th>
<th>Genes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cognitive ability, $\theta$</strong></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

\[ \theta = g[x_1, \ldots, x_n] \]

- **Negative effect**
- **Neutral**
- **Positive effect**

**Surrogates of Pathology:**
- CSF $A\beta$ - amyloid load
- CSF tau - neuronal injury
- MRI - neurodegeneration
- WMH - vascular disease
\[ \theta = g \left[ x_1, \ldots, x_n \right] \]

<table>
<thead>
<tr>
<th>Group</th>
<th>Correlation Analysis of Volumes with Cognitive Score</th>
<th>Reference</th>
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<tbody>
<tr>
<td>AD*</td>
<td>H** and A**: no significant correlation with MMSE</td>
<td>[31]</td>
</tr>
<tr>
<td>AD + HC*</td>
<td>A: correlation MMSE</td>
<td>[31]</td>
</tr>
<tr>
<td>AD + HC</td>
<td>H: correlation MMSE</td>
<td>[25]</td>
</tr>
<tr>
<td></td>
<td>A: no significant correlations</td>
<td></td>
</tr>
<tr>
<td>AD + HC</td>
<td>A: correlation MMSE</td>
<td></td>
</tr>
<tr>
<td>AD</td>
<td>A: no significant correlation with MMSE</td>
<td>[44]</td>
</tr>
<tr>
<td>AD</td>
<td>A: no significant correlations (MMSE, verbal memory). H: correlation (MMSE, verbal memory)</td>
<td>[30]</td>
</tr>
<tr>
<td>AD</td>
<td>H and A: correlation with MMSE and CDR</td>
<td>[26]</td>
</tr>
<tr>
<td>AD</td>
<td>H: no significant correlation (language, visuospatial, executive functions MMSE). A: correlation memory</td>
<td>[27]</td>
</tr>
</tbody>
</table>

No Rasch analysis!
Mini Mental State Examination

Under-estimate

Healthy

Mild cognitive impairment

Less able

More able

AD

MMSE

R amygdala

r = 0.62, P<0.001
r = 0.23, P=0.026
r = 0.19, P=0.031
r = 0.35, P=0.011
Cognitive assessment protocols
Multimodal statistical analysis applied to cognitive assessment protocols to improve outcomes (currently applied to literature data)

Variation in Primary Care Indicators

Potential causes of variation:

- Disease prevalence
- How physicians diagnose
- How data coders interpret diagnoses
- ….

Source: OECD analysis of data from Prince et al. (2013) and the United Nations.

Acknowledgments

This work has been performed as part of the 15HLT04 NeuroMet project which belongs to the European Metrology Programme for Innovation & Research (Horizon 2020), jointly funded by the EMRP participating countries within EURAMET (www.euramet.org) and the European Union.

Thanks are due, particularly, to:

• Members of the EMPIR NeuroMet consortium
• Stefan Cano, Modus Outcomes, Boston (USA) & Stotford UK
• William P. Fisher, Jr., Ph.D., Research Associate, BEAR Center, Graduate School of Education, University of California, Berkeley, CA (USA) & Principal, LivingCapitalMetrics Consulting
Acknowledgments

NeuroMET: www.lgcgroup.com/EMPIR-neuromet

This project has received funding from the EMPIR programme co-financed by the Participating States and from the European Union’s Horizon 2020 research and innovation programme.
EURAMET’s Research Programmes

- EURAMET's research programmes (EMRP and EMPIR) support the collaboration of European metrology institutes, industrial organisations and academia through Joint Research Projects (JRPCs). They are structured around European Grand Challenges in such areas as Health, Energy, the Environment and also aim to progress fundamental science.

- See [https://www.euramet.org/](https://www.euramet.org/) for more details.