Towards a New Generation of Prognostic Tools for Falls Incorporating Sensor-Based Activity Features

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Acknowledgements

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Acknowledgements
Prognostic tools for falls are needed as strategic components for fall prevention
# Prognostic tools: a bit of history

## Traditional tools (1st generation)
- Often based on subjective evaluations
- No use of statistics, no probabilistic meaning

## 2nd generation tools
- (e.g. PPA)

## Sensor-based tools (3rd generation)
- Proof of concept

## Validation of traditional tools

## Time line

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1986</td>
<td>Get-Up and Go Test</td>
</tr>
<tr>
<td>1986</td>
<td>POMA</td>
</tr>
<tr>
<td>1991</td>
<td>TUG</td>
</tr>
<tr>
<td>2003</td>
<td>Lord’s PPA</td>
</tr>
<tr>
<td>2008</td>
<td>Lamb’s screening tree</td>
</tr>
<tr>
<td>2010</td>
<td>Deandrea’s review on fall risk factors</td>
</tr>
<tr>
<td>2013</td>
<td>Howcroft’s review on sensor-based tools</td>
</tr>
</tbody>
</table>

## Advancements
- **1986**: Get-Up and Go Test
- **1991**: TUG
- **2003**: Lord’s PPA
- **2008**: Lamb’s screening tree
- **2010**: Deandrea’s review on fall risk factors
- **2013**: Howcroft’s review on sensor-based tools

## Key Concepts
- Consciousness in statistics - development and validation
- Advent and diffusion of high-throughput technology: -inertial sensors
- Advances in statistical learning for high-dimensional problems
**Issue 1: Heterogeneity**

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### Clinical Investigations

**Discriminative Ability and Predictive Validity of the Timed Up and Go Test in Identifying Older People Who Fall: Systematic Review and Meta-Analysis**

Daniel Schoene MSc\(^1\), Sandy M.-S. Wu MBBS\(^3\), A. Stefanie Mikolaizak BScPT (Hons)\(^1\), Jasmine C. Menant PhD\(^1,2\), Stuart T. Smith PhD\(^1,2\), Kim Delbaere PhD\(^1,2\) and Stephen R. Lord DSc\(^1,2\)*

Article first published online: 25 JAN 2013

DOI: 10.1111/jgs.12106

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### Results

Fifty-three studies with 12,832 participants met the inclusion criteria. The pooled mean difference between fallers and non-fallers depended on the functional status of the cohort investigated: 0.63 seconds (95% confidence (CI) = 0.14–1.12 seconds) for high-functioning to 3.59 seconds (95% CI = 2.18–4.99 seconds) for those in institutional settings. The majority of studies did not retain TUG scores in multivariate analysis. Derived cut-points varied greatly between studies, and with the exception of a few small studies, diagnostic accuracy was poor to moderate.

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### Conclusion

The findings suggest that the TUG is not useful for discriminating fallers from non-fallers in healthy, high-functioning older people but is of more value in less-healthy, lower-functioning older people. Overall, the predictive ability and diagnostic accuracy of the TUG are at best moderate. No cut-point can be recommended. Quick, multifactorial fall risk screens should be considered to provide additional information for identifying older people at risk of falls.
Issue 2: Low prognostic value

1. Clinical risk factors

and/or

2. Sensor-based activity features
CLINICAL RISK FACTORS
Clinical knowledge

Clinical risk factors for falls have been well identified

Risk Factors for Falls in Community-dwelling Older People: A Systematic Review and Meta-analysis

Deandrea, Silvia; Lucenteforte, Ersilia; Bravi, Francesca; Foschi, Roberto; La Vecchia, Carlo; Negri, Eva

Epidemiology: September 2010 - Volume 21 - Issue 5 - pp 658-668
doi: 10.1097/EDE.0b013e3181e89905
Injury: Review Article

Risk factors for falls in older people in nursing homes and hospitals. A systematic review and meta-analysis

Silvia Deandrea, Francesca Bravi, Federica Turati, Ersilia Lucenteforte, Carlo La Vecchia, Eva Negri

Received: August 7, 2012; Received in revised form: December 5, 2012; Accepted: December 7, 2012; Published Online: January 07, 2013
A Web-based Fall Risk Assessment Tool

A Web-based Fall Risk Assessment Tool

Approach:
1. convert ORs in probabilities
2. compute the total risk through an LPAD program

FRAT-UP

• Assessment tool for evaluating the fall risk within a year
• Aimed to general practitioners and health organizations (per-subject evaluation vs. population wide)
• So far focused on community-dwelling older people
• Based on 26 risk factors available in the literature
• Exploits available clinical information about the subject
• Freely available as a web-based application at the url ffrat.farseeingresearch.eu
User interface

- Allows the use of statistical prevalence of the risk factor
- Support for dichotomic, scalar and synergy risk factors

Health profile of the subject:

- Does the subject use sedatives?
- Diabetes blood glucose 126?
- Fear of falling (Cevalpande)?
- Does the subject suffer rheumatic disease?
- Does the subject suffer Parkinson?
- Does the subject suffer any pain?
- Does the subject use antihypertensives?
- Does the subject use antiepileptics?
- Is the subject female?
- Does the subject live alone?
- Does the subject use a walking aid?
- Dizziness or unsteadiness last year?
- Urinary incontinence last year?
- History of previous strokes?
- History of previous falls?

- Physical activity level:
- Visual stereognosis:
- Number of ADL disabilities (0-6):
- Hearing impairment?:
- Revised Walking Subscore:
- Visual acuity (3 meter):
- Subject’s number of IADL:
- MMSE score:
- How does the subject feel:
- CESD:
- Number of drugs used by the subject:
- Contrast sensitivity:
- Age: 75

Run the assessment!  Generate a report (pdf)
The InCHIANTI study

http://www.inchiantistudy.net/

Its goal is to translate epidemiological research into geriatric clinical tools that make possible more precise diagnosis and more effective treatment in older persons with mobility problems.
The InCHIANTI study

- **Home Interview**
  - MMSE
  - Social Network
  - CESd
  - OMS
  - Quality of sleep
  - Therapy
  - Incontinence
  - Questionnaire on falls
  - Physical activity
  - Questionnaire on foot
  - Food Questionnaire EPIC

- **Blood test**
  - Instrumental Exam
  - Blood test standard
  - Biological bank
  - EKG
  - 12 Canal
  - pQCT leg 4% 16% 33% 66%
  - ENG leg
  - Motor nerve conduction velocity
  - BIA
  - (Body Impedimetric Assessment)
  - Color doppler scan
    - neck vessels, index of Winsor

- **Medical Examination**
  - Family history
  - Remote pathological assessment
  - Desease assessment
  - Trail Making Test
  - Questionnaires on pain
    - Spine
    - Knee
    - Hip
  - Clinical examination

- **Tests of Performance**
  - Perdue Pegboard
  - Short Physical Performance Battery (SPPB)
  - Tests of walking
    - 4mt usual pace and fast pace
    - 7mt test with different conditions
  - Tests of endurance
    - 400 mt
    - 60mt with increased body weight
  - ROM leg
  - Power Rig leg
  - Muscle Strenght arm and leg

**InCHIANTI Study time-table**

- **Baseline**
  - n=1453
  - 1998

- **Follow-up 1**
  - n=1167
  - 2000

- **Follow-up 2**
  - n=1067
  - 2002

- **Follow-up 3**
  - n=900
  - 2004

- **Follow-up 4**
  - 2006

- **2008**

- **2010**

- **2013**
Validation on the InChianti DB (N=977)

AUC = 0.642 (95% CI 0.614-0.669)

Validation on other DBs

- ActiFE
- InCHIANTI
- ELSA

**Table: AUC (95% CI)**

<table>
<thead>
<tr>
<th>Model Description</th>
<th>ActiFE</th>
<th>ELSA</th>
<th>InCHIANTI</th>
</tr>
</thead>
<tbody>
<tr>
<td>FRAT-up</td>
<td>0.565 (0.533-0.594)</td>
<td>0.706 (0.688-0.724)</td>
<td>0.637 (0.593-0.678)</td>
</tr>
<tr>
<td>Models fitted on ActiFE (HA)</td>
<td>0.570 (0.527-0.600)</td>
<td>0.686 (0.674-0.697)</td>
<td>0.625 (0.608-0.634)</td>
</tr>
<tr>
<td>Models fitted on ELSA (HE)</td>
<td>0.573 (0.567-0.579)</td>
<td>0.724 (0.693-0.748)</td>
<td>0.614 (0.600-0.627)</td>
</tr>
<tr>
<td>Models fitted on InCHIANTI (HI)</td>
<td>0.569 (0.560-0.578)</td>
<td>0.700 (0.692-0.712)</td>
<td>0.635 (0.580-0.694)</td>
</tr>
<tr>
<td>Models trained on non-harmonized datasets (and tested on same dataset)</td>
<td>0.581 (0.547-0.628)</td>
<td>0.716 (0.695-0.742)</td>
<td>0.629 (0.580-0.680)</td>
</tr>
</tbody>
</table>

*Palumbo et al. 2015, in preparation*
Prognostic tools: FRAT-UP

Clinical risk factors: can we do better?

Data-driven approach
- Extraction of ~1000 variables from the InChianti DB
- Multiple imputation
- Poisson LASSO regression for variable selection and parameter estimation
- 10-fold cross-validation

Palumbo et al., PLOS One, submitted
Clinical risk factors: can we do better?

<table>
<thead>
<tr>
<th></th>
<th>Single falls</th>
<th></th>
<th>Multiple falls</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AUC (95% C.I.)</td>
<td>p value Risk indicator vs FRAT-up / Risk indicator vs Lasso</td>
<td>AUC (95% C.I.)</td>
<td>p value Risk indicator vs FRAT-up / Risk indicator vs Lasso</td>
</tr>
<tr>
<td>Number of previous falls</td>
<td>0.574 (0.551-0.597)</td>
<td>** / **</td>
<td>0.640 (0.603-0.678)</td>
<td>** / **</td>
</tr>
<tr>
<td>Gait speed</td>
<td>0.594 (0.566-0.622)</td>
<td>** / **</td>
<td>0.653 (0.615-0.692)</td>
<td>** / *</td>
</tr>
<tr>
<td>SPPB</td>
<td>0.590 (0.563-0.618)</td>
<td>** / **</td>
<td>0.645 (0.604-0.686)</td>
<td>** / **</td>
</tr>
<tr>
<td>FRAT-up</td>
<td>0.638 (0.610-0.666)</td>
<td>− / 0.92</td>
<td>0.713 (0.675-0.752)</td>
<td>− / 0.62</td>
</tr>
<tr>
<td>Lasso</td>
<td>0.639 (0.611-0.667)</td>
<td>0.92 / −</td>
<td>0.708 (0.669-0.747)</td>
<td>0.62 / −</td>
</tr>
</tbody>
</table>

*Palumbo et al., PLOS One, submitted*
SENSOR-BASED ACTIVITY FEATURES
## State of the art

<table>
<thead>
<tr>
<th>Authors</th>
<th>Journal</th>
<th>N</th>
<th>N of fallers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paterson et al.</td>
<td>Gait Posture 2011</td>
<td>97</td>
<td>54</td>
</tr>
<tr>
<td>Schwesig et al.</td>
<td>Clin Rehabil 2013</td>
<td>171</td>
<td>40 (17 cases)</td>
</tr>
<tr>
<td>Doi et al.</td>
<td>J Neuroeng Rehabil 2013</td>
<td>73</td>
<td>16</td>
</tr>
<tr>
<td>Weiss et al.</td>
<td>Neurorehabil Neural Repair 2013</td>
<td>71</td>
<td>12</td>
</tr>
<tr>
<td>Weiss et al.</td>
<td>Plos One 2014</td>
<td>67</td>
<td>14</td>
</tr>
<tr>
<td>Schwenk et al.</td>
<td>Gerontology 2014</td>
<td>77</td>
<td>28</td>
</tr>
<tr>
<td>Rispens et al.</td>
<td>JMIR Res Protoc 2015</td>
<td>202</td>
<td>70</td>
</tr>
</tbody>
</table>

Only studies with falls assessed prospectively are included
State of the art: main limitations

- Very few studies have made use of information about falls collected prospectively.
- Datasets are relatively small.
- Lack of validation of previous results impedes the assessment of the robustness of the results obtained so far.
The added value of a measurement

Model 1: Fall prediction with median values

Added value of accelerometry

- 6-month history of falls
- local divergence exponent AP
- intensity VT
- number of strides
- geriatric depression scale
- smoothness ML
- sample entropy VT
- intensity VT x number of strides
- smoothness ML x number of strides

ROC for logistic prediction model

- AUC 0.82*

Gait features computed from long-term recordings of PA

(van Schooten et al., J. Gerontol 2015)
Instrumented functional tests on the InChianti population

- TUG: 95 x 95
- Repeated chair standing: 120 x 120
- Quiet standing: 67 x 67
- 400 m walk: 133 x 133

*e.g. Coni et al., IEEE-EMBS, 2015*
Preliminary results

- 257 subjects aged 65+
- 25 of them (9.7%) fell during the 6-m follow-up
- Lasso, LDA, QDA on sensor-based data only: AUC $\sim 0.58$ (sd=0.15)
- Features more often selected:
  - duration of Sit-to-Walk (TUG)
  - RMS of the acceleration during chair rising (vertical and antero-posterior components, 5RCS)
  - total time for 5RCS
  - coefficient of variation of the cadence during straight course (400m)
Preliminary results

• Factor analysis on data from TUG
  – global performance
  – smoothness of sit to walk transition (StW)
  – lateral weight shift control during the turn to sit transition (TtS)
  – lateral weight shift control during StW
  – forward weight shifting control during StW
  – smoothness of TtS

• Smoothness of StW associated with falls at 6 months (p=0.01, AUC=0.74)

Colpo et al., Proc. GSA, 2015
Prognostic tools: we can do better

![Graph showing AUC values for various risk scores and measures related to CVD, Type 2 diabetes, Breast cancer, Colorectal cancer, and Falls.](image-url)

- **AUC**: Area Under the Curve
- **CVD**: Cardiovascular Disease
- **Type 2 diabetes**
- **Breast cancer**
- **Colorectal cancer**
- **Falls**

Risk scores and measures include:
- Framingham Risk Score
- Global Cardiovascular Risk
- Reynolds Risk Score
- ACC/AHA Risk Prediction Score Log
- ASCVD Score
- ONC Risk Score
- AUSC Score
- ARIC Score
- Aurora-Care Score
- Framingham Offspring Study Score
- San Antonio Risk Score
- QldScore
- MDC Score
- Gail Score
- Tyrer and Waters Score
- BAC score
- Prentice Score
- Tyers Score
- Impulsiv Score
- Friesen Score
- TUG
- FRAT-UP
- Instrumented TUG
Conclusions

• Even after exploring over a large number of clinical features, it is not likely to improve substantially the predictive accuracy that is obtainable from well-acknowledged risk factors.

• Movement sensors technology allows measuring activity features in a reliable way, unobtrusively, and at low cost. Possibly, future sensor-based prognostic tools will enable subjects to self-assess their fall risk and mobility status.

• Preliminary evidence shows that sensor-based features may add prognostic value to classical clinical risk factors but more work is needed!
Future applications

Integration with diagnostic tests

1. FRAT-up as a first-level assessment of the risk per-subject

2. If appropriate, second level assessment: "Timed Up-and-GO" test with a commercial smartphone
   - Diagnostic test executed in a controlled environment
   - Farseeing app developed on purpose

3. Third level assessment: activity day life monitoring with commercial smartphone
   - One week observation
   - Farseeing app developed on purpose

Prototype available at:
http://ffrat.farseeingresearch.eu/bruxelles/
A risk to avoid
Save the date!

2nd EU Falls Festival
Bologna, 23rd and 24th February 2016

The theme of the EUFF2016 will be “Implementation of Innovation into Policy and Practice”.

To register your interest:
eufallsfestival@manchester.ac.uk