Digital phenotyping and machine learning in the next generation of digital health technologies: Utilising event logging, ecological momentary assessment & machine learning

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bio

• Researching in: artificial intelligence, digital interventions for mental health and wellbeing, assistive technologies
• UK Ofcom Advisory Committee on Older and Disabled People
• Winner European €100,000 IST Grand Prize
• 32nd British Human-Computer Interaction conference in 2018
• 31st European Cognitive Ergonomics conference in September 2019
Outline

• Assistive technology
• Growing importance of data
• Event logs
• Data analytics workflows
• Case study
  • Introduction
  • Results
  • Ecological momentary assessment
  • Machine learning
• Going mainstream with event logs
• Discussion and conclusions
Utilising event logging, ecological momentary assessment & machine learning

Assistive technology
Engagement with digital services

Older people

- The majority of those 65 or over (73%) were classified as Resistors or Abstainers

https://doi.org/10.1016/j.arr.2007.07.002
COGKNOW
Helping people with dementia navigate through their day

https://doi.org/10.1109/MCOM.2011.5681023
Utilising event logging, ecological momentary assessment & machine learning

Growing importance of data
Knowledge-based approaches
Handling uncertainty in activities of daily living

Fig. 1: Sensors within smart kitchen environment to assess the ADL of preparing a drink (a) picture of the semi-functioning kitchen, (b) cupboard with door sensor, (c) kettle with tilt switch and contact switch on tap, (d) contact sensors on sugar, tea and coffee jar and (e) contact sensor on coffee in ‘on’ state

https://doi.org/10.1108/17427371211262653
Knowledge-based approaches
Handling uncertainty in activities of daily living

(a) Making cold drink. (b) Making hot drink.

Ethics of assistive technology
Home surveillance of people living with dementia

Working together

What does this mean?

Utilising event logging, ecological momentary assessment & machine learning

Event logs
## Everyday technologies

### Event logging

<table>
<thead>
<tr>
<th>User ID</th>
<th>Date</th>
<th>Time Stamp</th>
<th>Event ID</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>16/02/2018</td>
<td>16:41:31</td>
<td>82993</td>
<td>Log-in</td>
</tr>
<tr>
<td>6</td>
<td>16/02/2018</td>
<td>16:47:02</td>
<td>82994</td>
<td>Home page</td>
</tr>
<tr>
<td>6</td>
<td>16/02/2018</td>
<td>16:48:05</td>
<td>82995</td>
<td>Search Query</td>
</tr>
<tr>
<td>6</td>
<td>16/02/2018</td>
<td>16:48:59</td>
<td>82996</td>
<td>Search Results</td>
</tr>
<tr>
<td>6</td>
<td>16/02/2018</td>
<td>16:49:31</td>
<td>82997</td>
<td>User Profile</td>
</tr>
</tbody>
</table>
Utilising event logging, ecological momentary assessment & machine learning

Data analytics workflows
Workflows

CRISP-DM Cross-industry standard process for data mining

Health Interaction Log Data Analysis (HILDA) Workflow

1. **Data Preparation**
   - Log data
   - Data cleaning (missing data, NULL & NA)
   - Is data clean & complete
     - Yes: Normalisation of Dates and Times
     - No: Iterate

2. **Data Prospecting**
   - Exploratory Data Analysis (histograms and distributions)
   - Relative time series analysis of events and feature usage

3. **Machine Learning**
   - **Unsupervised ML**
     - Feature extraction of rudimentary usage behaviours (frequency and variance of use, number of interactions etc.)
     - Iterate often as necessary
     - Cluster analysis
     - Data interpretation complemented by autoethnography & qualitative input from experts
   - **Supervised ML**
     - Feature extraction from initial user engagement data
     - Modelling to predict user type from initial user engagement data
     - Modal evaluation (accuracy, kappa...)

Iterate often as necessary
Workflow

- Log data
- Descriptive statistics and visualisation
- Select machine learning method
- For K-means clustering
  - Elbow method
  - Cluster labelling
- Predictive modelling

Utilising event logging, ecological momentary assessment & machine learning

Case study - Introduction
Case study in Ageing Well and e-Health

Reminiscence health app

Reminiscence is the sharing of memories of our personal life experiences
Reminiscence as an intervention can enrich the lives of people with dementia
InspireD is an app developed with input from the Reminiscence Network Northern Ireland and people with dementia and their caregivers

Overall Study

Outline

• Aim was to investigate the effects of individual specific reminiscence activity facilitated through the use of the InspireD app on people living with dementia and their caregivers, using a range of outcome measures
• Quasi-experimental study incorporating a paired sample of 28 dyads (person living with dementia and their caregiver), using repeated measures design was conducted with each participant serving as his or her own control
• Applied several scales at start, mid- and end-point of a 12-week use of the InspireD app in the homes of people living with dementia and their caregivers, with one-to-one interviews with participants carried out at the end of the 12 weeks
• Scales included mutuality*, quality of care-giving relationships and emotional wellbeing

InspireD App
System architecture & development process

Event logging study

Summary

- Digital technology is being increasingly used by older people yet there is a paucity of relevant usage interaction research* (aside from usual proprietary platforms)
- InspireD app designed to incorporate logging facility for key events by users across 45 specific activities, covering five different types of events:
  - Entry (Logging in),
  - Admin (Adding a photo, deleting an audio, etc.),
  - Reminiscing (Viewing a video, viewing a photo, etc.),
  - In the Moment (ITM) questions (Experience Sampling Method (ESM) (aka Ecological Momentary Assessment)) and
  - Exit (Logging out).
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Case study - Results
Results

Media

- Number of interactions by caregivers and people living with dementia in each of the multimedia features used to facilitate reminiscing
Results

Daily

- Number of event interactions by caregivers and people living with dementia per hour
Results

Type

• Number of personal and generic interactions by caregivers and people living with dementia
Results

Events

• Number of interactions by caregivers and people living with dementia (PWD) users in each of the classified events
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Case study - Ecological momentary assessment
Ecological momentary assessment

Concept

• Also called Experience Sampling Method
• Capture real-time data in an individual’s natural environment through repeated sampling, using:
  • Psychometric scales,
  • Open-ended questions, or
  • anything else used to assess an individual’s condition in that place and time.
• Provide a high degree of ecological validity as they study people as they go about day-to-day life.
• EMA requires participants to respond to questions ‘in the moment’, so it avoids recall bias which makes it a useful tool for people living with dementia where their memory is impaired.
Traditionally, EMA made use of paper diary techniques but nowadays can utilise devices such as smartphones or tablets to record digital data.

Recently, EMA was used to identify major areas of concern for caregivers of persons with Alzheimer’s disease, with the overall goal to provide support and information for caregivers in their home.

- Another study used ESM to examine the day-to-day burden of caregiving for dementia carers which could be used to tailor interventions to their individual need
Ecological momentary assessment
Items from the mutuality scale used to capture EMA data

A total of 5 different EMA questions from the mutuality scale were presented to people living with dementia and their carers.

<table>
<thead>
<tr>
<th>Number</th>
<th>Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>How attached are you {partners name}?</td>
</tr>
<tr>
<td>Q2</td>
<td>How much do the two of you laugh together?</td>
</tr>
<tr>
<td>Q3</td>
<td>How much do you confide in {partners name}?</td>
</tr>
<tr>
<td>Q4</td>
<td>How much do you enjoy sharing past experiences with {partners name}?</td>
</tr>
<tr>
<td>Q5</td>
<td>How much do you like to sit and talk with {partners name}?</td>
</tr>
</tbody>
</table>
Ecological momentary assessment

Logic for EMA questions presented to people living with dementia and their carers

START

User (carer or person with dementia) clicks on their photo to login to app

User performs action

Dismiss

Answer

Usage is between weeks 1 and 12 in the study

No question asked

Yes

User has completed active session

No question asked

No

Yes

Question has already been asked during active session

No question asked

No

Yes

One of outcome scale item questions randomly selected and presented to user

How attached are you (partners name)?

How much do the two of you laugh together?

How much do you confide in (partners name)?

How much do you enjoy sharing past experiences with (partners name)?

How much do you like to sit and talk with (partners name)?
Overall dismissal rate for questions asked during the trial period was 30.9%. Hence, almost 70% of questions were answered.

People living with dementia used the app more in the trial period than carers but despite this had a lower dismissal rate for questions (26.8%) compared to their carers (36.8%).

Dismissal rates were significantly different from the answer rates for each question.

<table>
<thead>
<tr>
<th>Question</th>
<th>Presented n(%)</th>
<th>Dismissed n(%)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>197 (26.09)</td>
<td>48 (20.60)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Q2</td>
<td>131 (17.35)</td>
<td>39 (16.74)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Q3</td>
<td>116 (15.36)</td>
<td>38 (16.74)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Q4</td>
<td>165 (21.85)</td>
<td>54 (23.18)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Q5</td>
<td>146 (19.34)</td>
<td>53 (22.75)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>
Ecological momentary assessment

Total number of questions presented across hours of day (left) and trial week (right) for each user

Potts, C., Bond, R., Ryan, A., Mulvenna, M.D., McCauley, C., Laird, L., Goode, D., (TBD) Evaluating the use of ecological momentary assessment within a digital health intervention for reminiscence: how do people living with dementia and their carers engage?, JMIR mHealth and uHealth, Accepted.
Ecological momentary assessment

Heatmap comparing dismissal rates for each media overall (all) and specific type (generic and personal). Plot coloured by p-value, significant values ($P >0.001$) are denoted with *
## Ecological momentary assessment

Future design recommendations for digital health apps incorporating EMA

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Proposed strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Questions asked</td>
<td>The actual EMA questions which are presented should be informed by user group co-design (e.g. user group made up of people living with dementia and their carers).</td>
</tr>
<tr>
<td>First question</td>
<td>EMA questions should only be presented after a period of 2-3 weeks to give users time to get comfortable using the app.</td>
</tr>
<tr>
<td>Frequency</td>
<td>No more than one question presented to users per day.</td>
</tr>
<tr>
<td>Hour of day</td>
<td>Questions presented at times when users were more likely to answer rather than dismiss questions i.e. after 8pm in the evening.</td>
</tr>
<tr>
<td>Current task</td>
<td>If user is trying to complete a task within the app such as uploading content to the app, then a question should not be presented.</td>
</tr>
</tbody>
</table>
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Case study – Machine learning
Potts, C., Bond, R., Ryan, A., Mulvenna, M.D., McCauley, C., Laird, L., Goode, D., (TBD) Evaluating the use of ecological momentary assessment within a digital health intervention for reminiscence: how do people living with dementia and their carers engage?, JMIR mHealth and uHealth, Accepted.
Feature selection

- numOfPWDInteractions,
- numOfCarerInteractions,
- numOfPWDUniqueDaysInteractions,
- meanUsageInterval,
- SDUsageInterval

Cluster 1: The hooked adopter
A very small number of users (3.6% or 1 user per 28 users) who fully adopted the system. They had 7.2 times more interactions than their carer. Whilst the PWD obsessively used the app, the carer showed a normal amount of usage, hence the PWD was independently dedicated.

Cluster 2: Typical user
The plurality of users (43%) fall into this cluster, hence making them the most typical user. This user has 1.7 times more interactions with the app than their carer. This indicates that this user has some dependence on the carer for app usage. This dyad uses the app 15% of days in a month.

Cluster 3: Disengaged irregular user
25% of users. These users had 25% less interactions with the app than the carer. Whilst the PWD had fewer interactions than the carer, the carer has fewer interactions than other carers in all other clusters.

Cluster 4: The well supported dependent user
29% of users - the second largest group of users. These users have 36% less interactions with the app than their carers. The carers are very enthusiastic and have more interactions than other carers in all other clusters but they seem to struggle to get PWD users to the same engagement level.
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Going mainstream with event logs
Northern Ireland Department of Health

• “HSCNI, have partnered up with ORCHA (the Organisation for the Review of Care and Health Applications) to provide this site for you all to solve just those problems.”

• “ORCHA carry out independent and impartial reviews of health and care related apps, and you’ll see that the resultant information is clearly presented for us throughout this website. We can be reassured that any apps shown on this site have undergone a rigorous review process, and can feel confident as we choose the best app for us.”

https://apps4healthcareni.orcha.co.uk/
https://apps4dementia.orcha.co.uk/about/
Unlock the power of digital health

Our partner, DRCHA, has reviewed thousands of apps to help you find those that are the best and the safest. Each app on this site has been evaluated against key criteria relating to Clinical Assurance, Data Privacy and User Experience. The results are all laid out so you can see what they found and feel confident in accessing high-quality digital health. DRCHA assesses more apps than anyone, which helps them to cover more conditions and be on top of new releases when they come out. Find the best apps to help support everything from pregnancy, stopping smoking, and mental wellbeing, to long-term conditions like diabetes.
Welcome to InspireD. This app helps people living with dementia to reminisce, through sound, image & video.
Inspired reminiscence app
Anonymous event logging architecture

- Inspired
- Name
- Email
- Lambda
- Amazon
- Google
- Firebase
- Event logs
- EMA
- BigQuery

Ulster University
Unlock the power of digital health

Our partner, ORCHA, has reviewed thousands of apps to help you find those that are the best and the safest. Each app on this site has been evaluated against key criteria relating to Clinical Assurance, Data Privacy and User Experience. The results are all laid out so you can see what they found and feel confident in accessing high-quality digital health. ORCHA assesses more apps than anyone, which helps them to cover more conditions and be on top of new releases when they come out. Find the best apps to help support everything from pregnancy, stopping smoking, and mental wellbeing, to long-term conditions like diabetes.
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Discussion and conclusions
Discussion

Interventions
- Social prescriptions
- Data-based -integrated telecare

Treatments
- Non-pharmacological
- Monitoring network

Challenges
- Obesity
- Age-related disease
- Depression
- Loneliness

Chatbots
- Cognitive behaviour therapy
- Therapeutic

Reminiscence apps
Discussion
Digital phenotyping and machine learning in the next generation of digital health technologies

- Obesity
- Age-related disease
- Depression
- Loneliness

Physical health
Mental health
Younger people
Older people
Conclusions

Summary

- Assistive technology
- Growing importance of data
- Event logs
- Data analytics workflows
- Case study
- Going mainstream with event logs
Conclusions

Public health

- Use of digital phenotyping data and analysis using artificial intelligence and machine learning is growing
- Many national public health organizations are exploring how to use digital technologies such as health apps and cloud-based services for the self-management of diseases
- Logging users’ interactions allows for greater insight into user needs and provides ideas for improving these digital interventions, for example through enhanced personalization
- However, the risks in using this data are manifold
Conclusions

Issues

- Ethics
- Bias
- Surveillance
Conclusions
Public health

• However, on balance it can be argued that public health (services) benefit since data can be automatically and hence cost-effectively collected
• Such data may facilitate new ways for digital epidemiological analyses and provide data to inform health policies
• Public health organisations can, should and do promote health apps
• Digital phenotyping analysis using machine learning and artificial intelligence will be taken up by these organisations
• Clear need for guidelines on the ethical application of these ‘democratized’ algorithms and techniques and on ownership of digital phenotype data
Thanks
Any questions?
Acknowledgements

The InspireD app for research study was co-created and designed with input from the Alzheimer’s Society, Reminiscence Network Northern Ireland (RNNI) and people living with dementia and their caregivers. Special thanks to Alex Turnbull, Software Engineer from Kainos Software Limited for invaluable assistance in technology selection decisions. The team (Prof A Ryan, Dr L Laird, Prof K Curran, Prof B Bunting, Prof M Mulvenna, Dr Finola Ferry, Dr R Bond) gratefully acknowledge the research funding provided by HSC R&D Grant COM/5016/14 in Northern Ireland.

The freely available commercially-developed InspireD app was co-created and designed with input from the Dementia NI, Dementia Empowering and Engaging Derry-Strabane (DEEDS). Special thanks to Scaffold Digital for developing the app. The team (Prof A Ryan, Prof M Mulvenna, Dr C McCauley, Dr L Laird, Dr D Goode, Dr R Bond, Ms C Potts) gratefully acknowledge the support provided by HSC R&D for commercial app development.

Publications (2017-2018)

Publications (2019-2020)


- Potts, C., Bond, R., Ryan, A., Mulvenna, M.D., McCauley, C., Laird, L., Goode, D., (TBD) Evaluating the use of ecological momentary assessment within a digital health intervention for reminiscence: how do people living with dementia and their carers engage?, JMIR mHealth and uHealth, Accepted.