



# **Ecological Momentary Assessment in Mental Health Research**

**A practical introduction, with  
examples in R**



# Ecological Momentary Assessment in Mental Health Research

A Practical Introduction, With Examples in R

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# Preface

Given known limitations of retrospective self-report questionnaires, such as recall bias and poor generalisability of assessment results to real-life situations, mental health researchers increasingly adopt alternative assessment tools. One of the promising alternatives is Ecological Momentary Assessment (EMA), in which emotions and behaviours are repeatedly sampled in everyday life, through wearable electronic devices. By providing detailed data on within-person processes, EMA may be the key in the development of personalised health interventions.

EMA studies are challenging. Researchers, who are new to the field, face a dazzling array of options related to the electronic wearables, outcomes selection, study design considerations, ethical and regulatory constraints, data management, statistical analysis, and study reporting. Although standards are emerging, clear guidelines for EMA research do not - at present - exist.

This research manual provides a practical introduction to EMA-research. It was written for the Amsterdam School of Public Health (APH), to aid beginning researchers looking for practical advice in conducting EMA studies. It provides an overview of EMA instruments, outcomes, methods and analytical techniques, guidelines for EMA-studies, and a catalogue of EMA research in the APH consortium.

The manual comprises six parts:

- Part I introduces EMA and R. Chapter 1 defines EMA, and discusses the opportunities and challenges of EMA research. Chapter 2 introduces R, which, as the manual aims to show, is an indispensable tool for the EMA researcher.
- Part II focuses on EMA study design (chapter 3), EMA instruments (chapter 4) and EMA data management (Chapter 5).
- Part III introduces four EMA data analysis techniques: Feature Extraction (chapter 6), Mixed Modelling (chapter 7), Timeseries Analysis (chapter 8), and Network Analysis (chapter 9).
- Part IV details the momentary assessment of three key mental health variables: Mood (chapter 10), Activity (chapter 11), and Context (chapter 12).
- In part V, the application of the preceding material is illustrated in three case studies: The critical Slowing Down study (CSD; chapter 13), an EMA study of suicidal ideation (the CASPAR study; chapter 15), and a study into a new GPS-based measure of activity (the Home Range Estimation-study; chapter 16).
- Part VI provides three catalogues of EMA resources. Chapter 16 lists EMA research groups, chapter 17 lists EMA instruments, and chapter 18 summarises R extinctions (packages) that are useful in EMA data analysis.

The manual was written in Bookdown (Xie, 2016, 2018). Sources are freely available at ‘github’, via [https://github.com/jruwaard/aph\\_ema\\_handbook](https://github.com/jruwaard/aph_ema_handbook). Please post your comments and suggestions there, or via e-mail, through [aph.ema@ggzingeest.nl](mailto:aph.ema@ggzingeest.nl).



# **Part I**

# **Introduction**



# Chapter 1

## What is EMA?

Ecological Momentary Assessment (EMA) has many aliases. It is known as ‘experience sampling’ (Larson and Csikszentmihalyi, 1983), ‘ambulatory assessment’ (Ebner-Priemer and Trull, 2009) or ‘Ambulatory self-reporting’ (Conner and Barrett, 2012), ‘real-time data capturing’, the ‘continuous unified electronic diary method’ (Ellis-Davies et al., 2012), and as the ‘intensive-longitudinal study design’ (Bolger and Laurenceau, 2013). The different terms stress different aspects of EMA research. All terms, however, refer to research methods that involve the repeated sampling of people’s current thoughts, emotions, behaviour, physiological states, and context, in their natural environment, typically (but not necessary) via electronic wearable devices (Shiffman et al., 2008).

EMA has been around for many years. Already in the 1980’s, early pioneers used electronic devices to elicit responses from study participants to tap into (mental) health processes in everyday life (see, e.g., Csikszentmihalyi and Larson, 2014). Recent years, however, have witnessed a large increase in EMA research. Rapid technological developments, a marked interest in the individual, and a wide recognition of the need to study health-related processes in real-life situations have all contributed to this.

With the increased adoption of EMA comes a growing need for methodological guidelines. EMA studies have unique characteristics that require specialised research skills, related to study design statistical analysis. In many cases, these skills are not part of the standard curriculum of academic departments. This book was written to fill this gap.

### 1.0.1 Self-report versus Observational EMA

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#### 1.0.1.1 Self-report EMA

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### 1.0.1.2 Observational EMA

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### 1.0.2 Time-contingent and signal-contingent sampling

EMA sampling may focus on a single time-point (signal-contingent sampling), an event (event-contingent sampling), or a combination of both (Conner and Lehman, 2012).

In *signal-contingent sampling*, participants respond to questions when they are prompted to do so by a signal. Signal-contingent sampling can follow a fixed or a random scheme. In a fixed scheme, participants are prompted at fixed time-points, for example at 9:30, 12:30, and 16:30. In a random scheme, prompts are sent at random time points, typically in pre-set intervals, for example, participants could be prompted to complete two assessments per day, one at a random time point between 10:00 and 14:00, and one at a random time point between 14:00 and 16:00. Using pre-set intervals ensures that participants do not receive several prompts within a limited time-frame (Piasecki et al., 2007). In addition, it ensures that participants are not bothered by prompts at inappropriate times (e.g., most participants do not appreciate prompts after 22:00 and before 7:30).

In *event-contingent sampling*, study participants complete an assessment whenever a specific event occurs, such as a panic attack or alcohol consumption. One option is to simply instruct the participants to do so. In that case, it is important to be clear, in the instructions, to provide a clear definition of the target event, and to stress the importance to rate each event. In some cases, it may be possible to trigger event-based prompts automatically, for example by linking a self-report EMA questionnaire to an automatically detected change in activity level (Smyth and Stone, 2003).

## 1.1 Why EMA?

EMA aims to “minimize recall bias, maximize ecological validity, and allow study of microprocesses that influence behavior in real-world contexts.” (Shiffman et al., 2008).

### 1.1.1 Focus on the Individual

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[The Ergodicity hypothesis] Donec sed lectus at sem ultrices commodo. Proin a viverra metus, nec scelerisque odio. Morbi viverra tristique libero vel fringilla. Sed at varius erat, id consequat nibh. Ut eget leo blandit orci posuere tincidunt ac sed erat. Aenean metus metus, eleifend ut facilisis a, fringilla ut neque. Nunc hendrerit cursus eleifend.

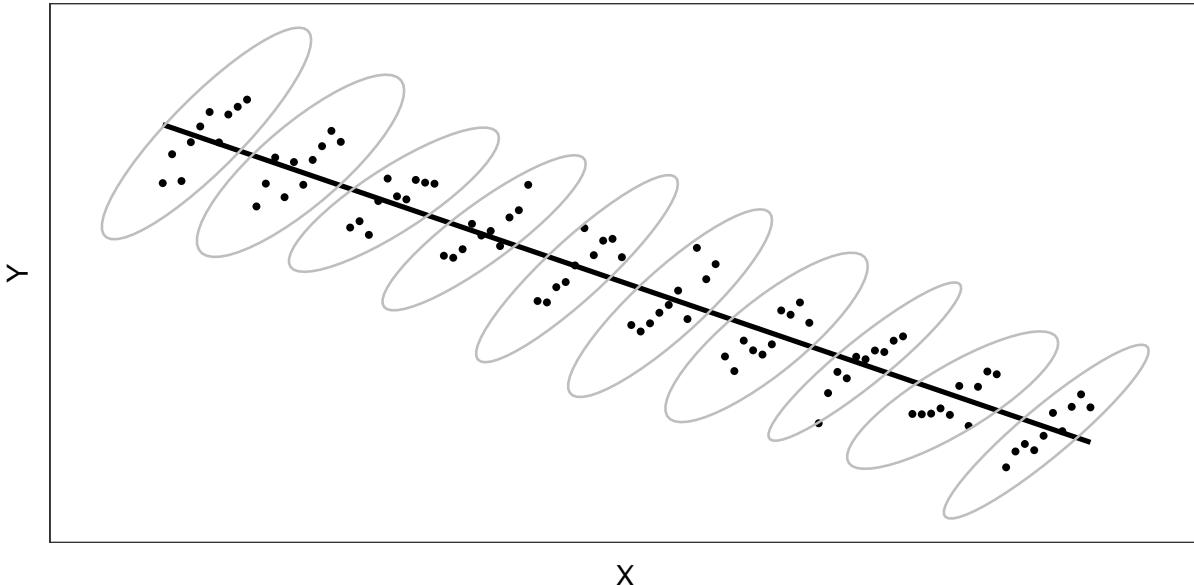


Figure 1.1: An extreme case of how individual effects may be different from group effects: the effect of x on y is positive for individuals (marked by ellipses), but negative for the group (as illustrated by the negative regression line).

### 1.1.2 Focus on mental health dynamics

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[State versus trait] Donec sed lectus at sem ultrices commodo. Proin a viverra metus, nec scelerisque odio. Morbi viverra tristique libero vel fringilla. Sed at varius erat, id consequat nibh. Ut eget leo blandit orci posuere tincidunt ac sed erat. Aenean metus metus, eleifend ut facilisis a, fringilla ut neque. Nunc hendrerit cursus eleifend.

[ Latent variables versus Symptom clusters] Lorem ipsum dolor sit amet, consectetur adipiscing elit. Aliquam vehicula augue metus, in tincidunt urna luctus sit amet. Sed ultrices, erat at laoreet semper, sem tellus hendrerit mi, eget pulvinar massa nisl ac dolor. Nunc ac tellus nec tortor interdum porta. Vestibulum hendrerit tempus condimentum. Donec a mollis sem. Aenean lectus nunc, bibendum ut orci vel, tristique pellentesque arcu.

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### 1.1.3 Focus on Real Life

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### 1.1.4 Focus on the Context

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## 1.2 Clinical Applications

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### 1.3 Further Reading

Table 1.1: Reviews of EMA studies targeting specific Mental Health Conditions

Disorder	Reference to Review
Anxiety	Walz et al. (2014)
Depression / Mood disorders	aan het Rot et al. (2012), Ebner-Priemer et al. (2009), Telford et al. (2012), Wenze and Miller (2010), Wichers et al. (2011)
Eating disorders	Engel et al. (2016), Haedt-Matt and Keel (2011)
Psychosis	Oorschot et al. (2012)
Substance abuse	Shiffman (2009)
Well-being	Cornet and Holden (2018)



# Chapter 2

## R & RStudio

In this chapter, you will learn how to install and use two programs that are indispensable for the management and analysis of EMA data: R and RStudio.

### 2.1 What are R and RStudio?

R is a programming language and software environment for statistical computing and data visualisation. RStudio is a powerful user interface to R. It has many useful features that greatly simplify R-work. We strongly advise you to adopt the R/RStudio-combo.

### 2.2 Why R?

R, some may have told you, is for data scientists, methodologists, and scientific programmers only. It has a steep learning curve. If you are trained in SPSS, it will take time to become as productive in R as in SPSS. Why then, should you invest in R?

- Unlike SPSS, R is free. It does not eat up your budget. Why pay for something that you can get for free?
- R is cutting-edge. Methodological innovations first appear in R. Network analyses, for example (see Chapter 9), can be run in R, but not (yet) in SPSS. For some analyses, you need this alternative.
- Mastering R improves your connection to the statisticians in your team. They probably prefer R over SPSS. It is more efficient and less error-prone to all speak the same language.
- R is great for data-management. Clinical research, and especially EMA research, requires hundreds of operations on multiple raw data files. R excels at that. SPSS, frankly, does not. If you care about reproducible research (which you should), R can be a great help in putting it into practice.
- R can be used at different levels. If you want to be a basic user, that's fine. However, if you want to dive deeper, you will find that you can easily do so. You can study source code to understand a particular technique better. You can code new functions. R allows you to grow.
- R's user base is expanding every year. Chances are high that R will be the standard in your next workplace. R will look great on your CV.

You don't have to be a programmer or methodologist to use R. Yes, it takes time to master its full potential, but you should be able to run basic analyses in it within a week. This chapter will get you started.

## 2.3 Installing R & RStudio

Both R and RStudio are available, at no costs, for all major operating systems.

- Download R from the Comprehensive R Archive Network (CRAN), at <https://cran.r-project.org/bin/>
- Download RStudio from <http://rstudio.org>

Install R first, and RStudio second. If you install the programs in this order, RStudio will automatically find R on your computer.

If you installed R or RStudio previously, please update. This book assumes you will be working with version 3.4.2 (or higher) of R, and version 1.1.414 (or higher) of RStudio.

## 2.4 Interacting with R through the RStudio console

If you open RStudio, you will be presented with the interface shown in Figure 2.1. Rstudio's main window is divided in four panes (subwindows), which further contain several tabbed windows.



Figure 2.1: The RStudio Interface

Commands are sent to R starts in the bottom-left pane, named “Console”. To test this, move your cursor to the bottom line, immediately after the prompt sign (“>”). Next, type the statement below (note that ‘#’ denotes a comment line; R ignores it, so there is no immediate need to type that). To execute, press ‘Enter’.

R will execute the command and return the answer back to the console.

```
# Code snippet 2.1: R is a calculator.
1 + 1
```

Results of calculations can be saved into variables, by making use of the assignment operator (“`<-`”). If you type the name of a variable, R returns its value.

```
# Code snippet 2.2: Using <- to declare and set a variable.
N <- 50 + 50
N
#> [1] 100
```

To appreciate why R is such a popular tool for statistical computing, consider the following command, which, in one line, 1) uses the variable `N`, just created, to 2) generate 100 random numbers from the normal distribution, and 3) plot a histogram of these numbers.

```
# Code snippet 2.3: Plotting the histogram of a sample from the normal
# distribution.
hist(rnorm(N))
```

The plot appears in the bottom-right pane, as in Figure 2.1.

## 2.5 Writing R-scripts

Working in the console is a great way to interactively explore R and data, but what if you want to save a particularly useful chain of statements? For this, you can use a script file.

To create a script file, use the RStudio menu: `File > New File > R Script`. This will open a new tab in the top-left pane of RStudio, where you can edit the script.

- In the script window, type all statements that you have been entering in the console in the previous section.
- Next, select all lines in the script.
- Press `Ctrl+Enter` to run the script.

All commands in the script are executed. The commands are echoed in the console pane, and results are shown immediately, as was the case before, when you typed the commands in the console yourself.

Scripts can also be run line by line. Move the cursor to the line you want to run, and press “`Ctrl+Enter`”. The line is copied to the console and executed, and the cursor in the script will move to the next line, allowing you to walk through the script, step by step.

## 2.6 Importing your data

Something that confuses new Rstudio users, who are more familiar with SPSS, is that it is not obvious how to import data into RStudio. In SPSS, the data are in plain sight. In R, you first have to import the data.

### 2.6.1 Using RStudio menu’s to import data

One way to load data into R is to use RStudio’s data import wizard. Follow the steps below to see how this works with data stored in a comma-separated-values (csv) format, a common data format to which many programs, including SPSS and Excell, can export data to.

- Download the example csv data file at <https://tinyurl.com/ybfafxxk> (or create a csv-version of one of your own data files).
- In RStudio’s menu, choose `File > Import Dataset > From Text (base)`.

- In the window that appears, click on **Browse** to locate the csv- file on your computer, and click **Import** in the next window (see Figure 2.2).

RStudio shows the data, in tabular view, in the top-left window, ready for analysis. You will also find a new entry in the **Environment**-tab in the top-right pane. When you click the small arrow, at the left of the name, you will see a brief summary of the contents of the data.

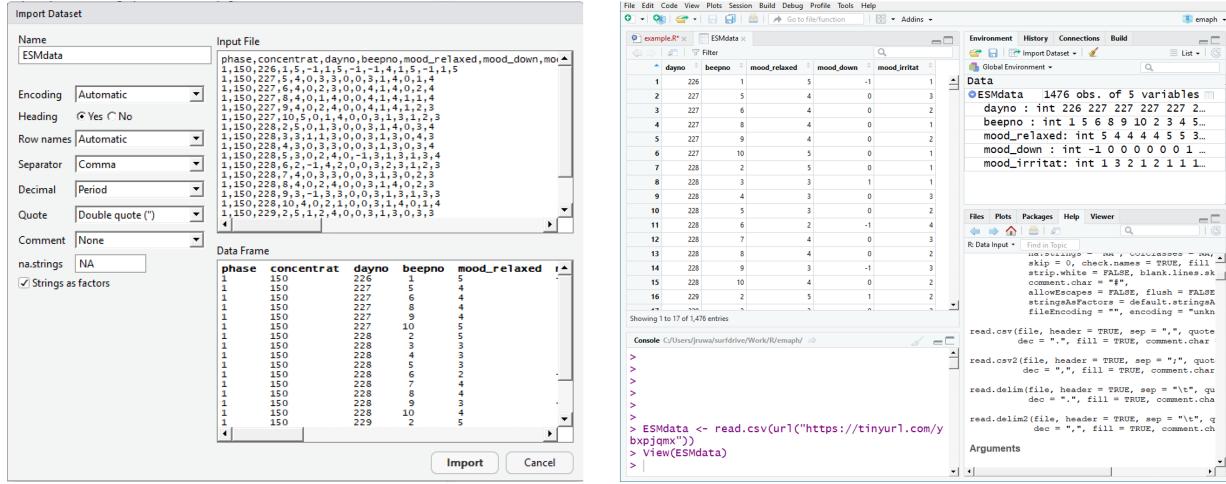


Figure 2.2: RStudio's CSV import wizard.

## 2.6.2 Using functions to import data

While RStudio's Data import wizard is useful, you will probably use it less over time. Most likely, you will convert to using the more efficient R commands to import data. For example, it takes only a single line to download and import the example data.

```
# Code snippet 2.4: importing csv-data from the internet.
ESMdata <- read.csv(url("https://tinyurl.com/ybfafxxk"), row.names = NULL)
```

## 2.6.3 Accessing your data

Since the data is now in the environment (under the name `ESMdata`), you can use it in other R commands. For example, to produce a more detailed summary of the first four columns of `ESMdata`, you type:

```
# Code snippet 2.5: summarising data.
summary(ESMdata)
   dayno      beepno    mood_relaxed    mood_down    mood_irritat
Min.   : 1   Min.   : 1.00   Min.   :1.00   Min.   :-3.000   Min.   :1.00
1st Qu.: 61  1st Qu.: 3.00   1st Qu.:4.00   1st Qu.: 0.000   1st Qu.:1.00
Median :252  Median : 5.00   Median :4.00   Median : 0.000   Median :2.00
Mean   :199  Mean   : 5.24   Mean   :4.17   Mean   : 0.178   Mean   :2.24
3rd Qu.:303  3rd Qu.: 8.00   3rd Qu.:5.00   3rd Qu.: 0.000   3rd Qu.:3.00
Max.   :366  Max.   :10.00   Max.   :7.00   Max.   : 3.000   Max.   :7.00
   NA's    :2   NA's    :2   NA's    :3
```

To inspect the first 6 lines of data, type,

```
# Code snippet 2.6: Show first 6 lines of a data frame.
head(ESMdata)
```

```
#>   dayno beepno mood_relaxed mood_down mood_irritat
#> 1    226      1        5       -1        1
#> 2    227      5        4        0        3
#> 3    227      6        4        0        2
#> 4    227      8        4        0        1
#> 5    227      9        4        0        2
#> 6    227     10        5        0        1
```

To view all rows of data in a spreadsheet (as in Figure 2.2, type:

```
# Code snippet 2.7: Show data as spreadsheet.
View(ESMdata)
```

To work with a specific variable in the dataset, use '\$'. For instance, to print the first 20 numbers in the `mood_relaxed` variable, type:

```
# Code snippet 2.8: accessing a single variable in a data frame.
head(ESMdata$mood_relaxed, n = 20)
```

This allows you to apply functions to specific variables. For example, to calculate the mean of scores in `mood_relaxed`, type:

```
# Code snippet 2.19: Calculating the mean of a variable.
mean(ESMdata$mood_relaxed)
#> [1] 4.17
```

There are many ways in which you can summarise and manipulate your data. At this point, the important milestone is that you imported and accessed data in R.

## 2.7 Extending R with Packages

R's attractiveness lies in the ease with which it can be extended with new functionality. Through so-called packages, which can be freely downloaded from the internet, specialised functions can be added to your workspace.

### 2.7.1 Installing R-packages from CRAN

Packages can be found at the CRAN website. To browse through the impressive list of available packages, see [https://cran.r-project.org/web/packages/available\\_packages\\_by\\_name.html](https://cran.r-project.org/web/packages/available_packages_by_name.html)

If you find a package you like, you can install it via the RStudio menu system, choosing `Tools > packages`. But you can also use the console, via the `install.package` function.

A popular package, `tidyverse`, is used extensively in the examples of this manual. Package `tidyverse` comprises a set of popular packages from the creators of RStudio, that greatly simplify working with R. So, while you are at it, install this package now.

```
# Code snippet 2.10: installing a package from CRAN.
install.package(tidyverse)
```

The `tidyverse` contains a package called 'haven', which allows you to read and write SPSS datafiles (.sav files). This is very convenient. You don't have to convert all your SPSS data to csv files. See `?read_spss` to learn how to import an SPSS-file (or use the data import wizard, by choosing 'File > Import Dataset > From SPSS', in RStudio's top-right pane).

## 2.7.2 Installing R-packages from GitHub

Not all packages are at CRAN. Many ‘unofficial’ packages are shared at a site called ‘GitHub’. This book’s companion R package ‘emaph’, for example, which contains specialised EMA functions datasets, is on GitHub. You need package emaph to run many examples in the book, so let’s install this package now.

GitHub packages can be installed via the `install_github` function, which is defined in a package called ‘devtools’. So, to install ‘emaph’, enter the following in the console:

```
# Code snippet 2.11: Install the GitHub 'emaph' package.
install.packages("devtools")
devtools::install_github("jruwaard/emaph")
```

## 2.7.3 Using packages

To use packages, you have to tell R to load them. You do this with the `library` function. For example, to use package ‘tidyverse’ and ‘emaph’, type:

```
# Code snippet 2.12: Loading packages.
library(tidyverse)
library(emaph)
```

Once loaded, you can use the functions and datasets of the packages. Packge ‘emaph’ provides dataset ‘csd’, which contains the data from the ‘critical slowing down’-study (Kossakowski et al., 2017; Wichers et al., 2016), in which a patient recorded his mood, for 239 days (see also Chapter 13).

To plot the irritation levels of this patient in the first six days, using the `ggplot` function from package ‘ggplot2’ (which is in ‘tidyverse’), type:

```
# Code snippet 2.13: Using ggplot to plot EMA time series.
ggplot(data = subset(csd, dayno <= 6),
       mapping = aes(x = beepno, y = mood_irritat)) +
  geom_point() + geom_step() +
  scale_x_continuous(breaks = 1:10) +
  facet_wrap(~ dayno, nrow = 2)
```

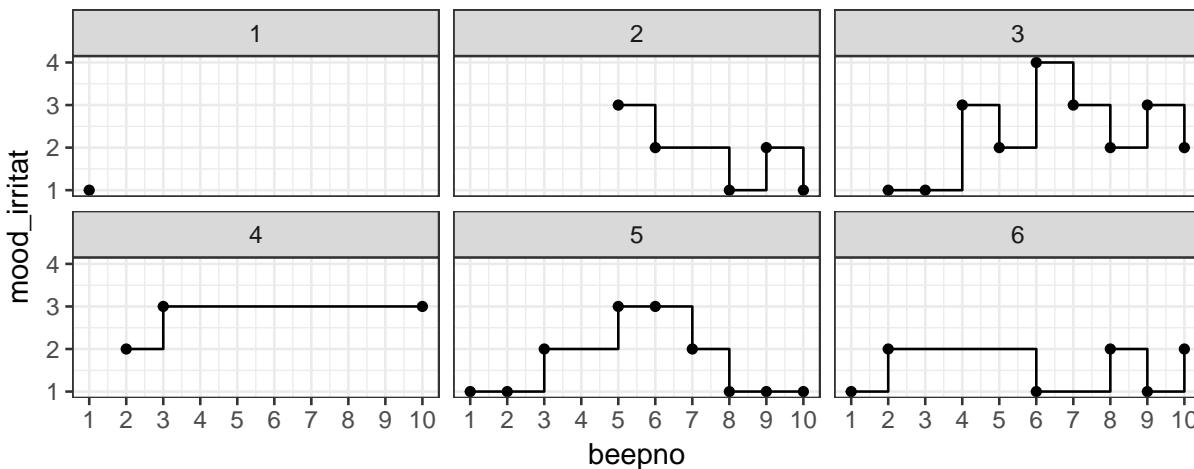


Figure 2.3: Irritation levels of a single patient, in the first six days of an EMA study.

## 2.8 Getting help

R has no point-and-click menu's that you can browse through to select a statistical procedure. This is a problem for many new users. What if you want, for example, to generate random numbers from a distribution with a mean of 2 and standard deviation of 4? How to tell this to R?

### 2.8.1 Using ‘?’ to consult the documentation

The good thing is that you already known the name of the function to use, since we used it in the previous section: it is ‘`rnorm`’. To check the documentation of this function, type `?rnorm` in the console.

```
# Code snippet 2.14: Using '?' to find the documentation of a function.
?rnorm
```

This opens the documentation of the `rnorm` function in the ‘Help’-tab, in the bottom right pane, from which you learn that that the `rnorm` function accepts `mean` and `sd` (standard deviation) as additional parameters, which are 0 and 1 default, respectively (which explains why `norm(100)` worked in the previous examples). So, to generate the required numbers, you type:

```
# Code snippet 2.15: Plotting the histogram of a custom random sample
hist(rnorm(1000, mean = 2, sd = 4))
```

All functions in R are documented, and this documentation is shown in RStudio’s Help pane when you prepend `?` to the name of the function in the console.

### 2.8.2 Using RStudio’s global documentation index search

What if you do not know the name of a function? Suppose you want to run a t-test for independent groups. Does R have a function for that?

At the top-right of the ‘Help’ pane, RStudio has a search input field, which allows you to search through all documentation that is installed on your computer. The search field auto-completes your input. If you type a ‘t’ in this field, you will be presented with a list of functions starting with a ‘t’. In this list, you find a likely candidate: a function called `t.test`. From the documentation of this function (`?t.test`), you learn that, indeed, this is the function you were looking for.

```
# Code snippet 2.16: Running a t-test, on two simulated samples.

# generate two samples (N = 100 per group) from the normal distribution
A <- rnorm(100); B <- rnorm(100)

# the t-test should be non-significant
t.test(A, B)
#>
#> Welch Two Sample t-test
#>
#> data: A and B
#> t = -0.3, df = 200, p-value = 0.8
#> alternative hypothesis: true difference in means is not equal to 0
#> 95 percent confidence interval:
#> -0.332 0.244
#> sample estimates:
#> mean of x mean of y
#> 0.0708 0.1149
```

### 2.8.3 Learning from examples

This book contains many R code snippets. By studying these examples, you will become more familiar with R. Some examples will introduce R language constructs and functions that are unknown to you. Learn from these examples, by using ? on each element that you do not understand.

### 2.8.4 Google

With Google, you will find many answers to your R questions. Googling for “t-test R”, for example, results in a rich set of online resources. Good resources are:

- RSeek (see <http://rseek.org/>)
- Stackoverflow: (see <https://stackoverflow.com/questions/tagged/r>)
- SearchR (see: <http://search.r-project.org/>)

### 2.8.5 Read books

This book does not provide a comprehensive tutorial. There is no need for that, since excellent resources are readily available. A selection is presented below.

- Many mental health researchers own a copy of Andy Field’s popular book “Discovering Statistics Using IBM SPSS Statistics” (Field, 2013). For those, Field’s R-version of this book, “Discovering Statistics Using R” (Field et al., 2012) provides a familiar companion in making the transition to R. See <https://www.discoveringstatistics.com/>
- Free manuals can be found at the official CRAN site. The manuals are dry, but complete and authoritative, since the authors are members of the R core development team. See <https://cran.r-project.org/manuals.html> (or type `help.start()` in the console).
- While at CRAN, be sure to browse the ‘contributed documentation’-section. On this page, you will find many freely available manuals contributed by the R community. See <https://cran.r-project.org/other-docs.html>

### 2.8.6 Online Courses

- DataCamp, an online data science education platform, offers several high-quality interactive courses in R. See <http://www.datacamp.com>
- The Try-R course at the CodeSchool website provides an alternative to DataCamp. See: <http://tryr.codeschool.com/>
- The Quick-R website provides a solid, concise, and rich introduction to R. See <https://www.statmethods.net/>

### 2.8.7 Learn R, in R

Package ‘swirl’ comprises a set of interactive courses that teach many aspects of the R language. See <http://swirlstats.com>

```
# Code snippet 2.18: starting the interactive swirl-course in R.
install.packages("swirl")
library("swirl")
swirl()
```

## **Part II**

# **EMA Methods**



# **Chapter 3**

## **Study Design**

As with all scientific research, EMA studies start with mindful consideration of the study design. Issues that need to be considered are, for example, the research question(s), the hypotheses, the population of interest, and the nature of the comparison groups (Shiffman et al., 2008).

This chapter highlights key design aspects of EMA studies. Ample information on general study design issues can be found elsewhere (see for example, the APH quality handbook, Amsterdam Public Health, 2018).

### **3.1 What is the research question?**

Given the plethora of new research options that emerged from the rapid development in EMA technologies, it can be tempting to dive straight into explorative data collection, without giving much consideration to the theoretical background of the study. That, however, would be one pitfall of EMA research to avoid. Data mining is no substitute for theory. Asking participants to contribute data without a rationale is unethical. As in all scientific activities, defining the research question should be a first step.

Ask yourself what EMA could bring to your topic of interest. How is it different from traditional assessment methods? What questions does it allow you to address that you could not answer without it? For this, you could use any of the EMA advantages discussed in Chapter 1. Are you interested in real-life behaviour, in individual differences between participants, in potential causal pathways between health-related variables? What relationships do you expect to find, and why? A solid theoretical background, and clearly formulated explicit research questions and hypotheses will help to make the right choices when you have to decide on the other aspects of the study design.

### **3.2 Who are the prospect participants?**

Given the experimental nature of EMA, studies are often piloted in healthy or sub-clinical populations. This is a recommended first step to test the experimental procedures and to avoid unnecessary burden of vulnerable patient populations. You should be aware, though, that results obtained in non-patient populations do not necessarily generalise to patient populations. EMA mood ratings, for example, might be much more variable in patients compared to non-patients. Pilot studies should therefore also be conducted in the target population.

### 3.3 How are theoretical experimental variables operationalised?

With the study hypotheses in place, experimental constructs can be operationalised into well-defined quantifiable measures.

Precies def wat meten betrouwbaarheid, validiteit, ruwe dat. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Aliquam vehicula augue metus, in tincidunt urna luctus sit amet. Sed ultrices, erat at laoreet semper, sem tellus hendrerit mi, eget pulvinar massa nisl ac dolor. Nunc ac tellus nec tortor interdum porta. Vestibulum hendrerit tempus condimentum. Donec a mollis sem. Aenean lectus nunc, bibendum ut orci vel, tristique pellentesque arcu. Vestibulum id laoreet neque. Phasellus at ex velit. Vestibulum scelerisque nulla ut massa tempor, ac dapibus dui viverra.

What is the data acquisition interface? (Stone and Shiffman, 2002). Opletten wat je koopt aan technologie. Onderbouw keuze. Zie hoofdstuk X. Gevalideerd vs nieuw.

- Technical Reliability of data platform
- Track record of data platform suppliers
- User-friendliness of data device for study participants.
- User-friendliness of data platform for researcher (availability of an administrative back-office).
- Location of data storage
- Costs

For an overview of existing EMA data platforms, see 17.

### 3.4 Constructing the Sample Plan

An important next step is to define the EMA data sample plan. Questions that need to be answered are:

- How many days will data collection last?
- On each day, how often are participants assessed?
- How and when are participants invited for assessment?

The questions above should be answered as detailed as possible to best serve the research question and the statistical power (see below). In practice, however, it is often necessary to balance between research interests, respondent burden, and practical considerations, such as hardware limitations.

When determining the appropriate sample plan, researchers are advised to start with mapping the expected fluctuation or patterns, based on available knowledge. For example, when an event is rare, it can be sufficient to ask participants to initiate EMA whenever the event occurs, or prompt them with an end-of-day diary. Adding more prompts in this scenario would not lead to more reliable data (Piasecki et al., 2007).

Increasing the assessment frequency and study duration will allow for a more detailed assessment of the outcome of interest. It is tempting to collect often and for a long period of time. However, this may also increase respondent burden, which may affect compliance and accuracy. Measurement reactivity could occur, where the EMA-induced enhanced focus on the outcome of interest causes participants to increase or decrease on this outcome (Hufford et al., 2002; van Ballegooijen et al., 2016).

Issues related to hardware should also be considered. Electronic wearables have limited battery life and memory storage space. Actigraph watches memory space limitations may require participants to visit the research site. GPS-monitoring apps may have a negative impact on the battery life of the smartphone of the participants. These practical issues may result in data loss, through problems with study adherence or even study drop-out.

Once all decisions related to the sampling plan are made, the procedure should be thoroughly tested. As a first step, it can be insightful to simulate the sample plan, as is done below, using the ‘sample\_plan’ of package ‘emaph’:

```
# code snippet 3.1: simulating a signal-contingent sample plan
plan <- sample_plan(n_participants = 5,
                     n_days = 2,
                     times = c("09:00-11:00", "12:30", "17:00-19:00"),
                     plot = TRUE)
```

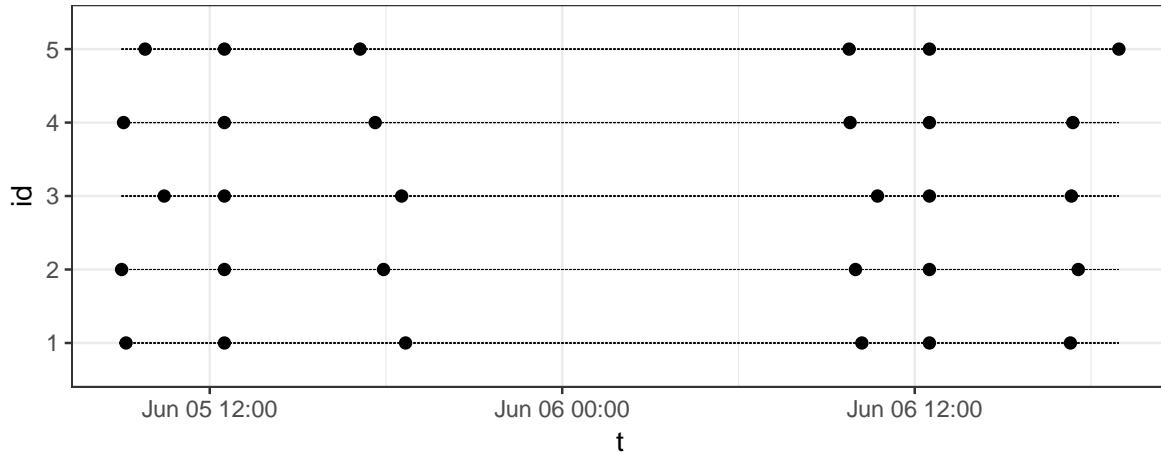


Figure 3.1: Simulated EMA sampling plan

## 3.5 Power Analysis

The power of a statistical test is the probability that it will detect an effect when this effect, in reality, exists. It is a function of the strength of the effect size, sample size, the significance level (alpha), and the statistical model. Determining the power of the experiment is an important step in the design of any study - EMA studies included. Both underpowered and overpowered studies are a waste of time and resources.

Conducting a power analysis can be easy or very difficult, depending on the complexity of the experimental design and the adopted statistical technique. For simple tests, such as the t-test and ANOVA, straightforward analytical solutions exist, which are implemented in readily available tools. In R, one of those tools is package ‘pwr’.

For example, to use ‘pwr’ to calculate the power of a t.test to detect a moderate effect size ( $d = 0.5$ ), with  $n = 30$  per group, and a (two-sided) significance level alpha of .05, type:

```
# code snippet 3.2: Power analysis of a t-test
# (analytical approach)

library(pwr)
pwr.t.test(d = 0.5,
            n = 30,
            sig.level = 0.05,
            type = "two.sample",
            alternative = "two.sided")

#>      Two-sample t test power calculation
#>
#>      n = 30
#>      d = 0.5
```

```
#>     sig.level = 0.05
#>     power = 0.478
#>     alternative = two.sided
#>
#> NOTE: n is number in *each* group
```

The power is 48% - not even close to the generally adopted standard of 80%. More participants are needed to detect the hypothesised effect.

EMA study designs are often characterised by repeated measures, complex multi-level structures and the application of advanced statistical techniques. You may find that available power calculators are too limited to properly take key aspects of your design into account. If this happens, simulation techniques may help. If power is the probability that a test will detect an effect it exists, it can be determined by noting the proportion of times a statistical test reaches significance, if it is run, many times, on simulated data, in which the hypothesized effect is present. To illustrate how this works, we will calculate the power of the t-test again, through simulation:

```
# code snippet 3.2: Power analysis of a t-test
# (simulation approach)

m1 = 0    # mean in group 1
m2 = 0.5 # mean in group 2
sd = 1    # sd (in both groups)
n = 30    # sample size, per group

# conduct the experiment many times
nsim <- 10000
p <- numeric(nsim)
for (i in 1:nsim) {

  data <- data.frame(
    outcome <- c(
      rnorm(n, m1, sd), # group 1 data
      rnorm(n, m2, sd)  # group 2 data
    ),
    group <- c(
      rep(1, n), # group 1 indicator
      rep(2, n)) # group 2 indicator
  )

  # save significance of test
  p[i] <- t.test(outcome ~ group, data)$p.value
}

# power
sum(p < 0.05) / nsim
#> [1] 0.476
```

As can be seen, the simulation results are very close to the output of ‘pwr.t.test’.

There was no immediate need to run this simulation. We already knew that the power was 48%. The example illustrates, however, that simulation is a valid option when power calculators are too limited (or too difficult to understand...). Simulating the right data, of course, can be challenging as well, but you will find that R has packages that simplify data simulation. For example, ‘mvrnorm’ in package MASS (Venables and Ripley, 2002) can be used to generate correlated data, and package ‘simstudy’ (Goldfeld, 2018) can be used to generate complex (longitudinal) data.

## 3.6 Ethical Considerations

When collecting digital data, you should be mindful of the rules and regulations that apply to data collection, storage and sharing. From May 2018 onward, the European Committee has enforced the General Data Protection Regulation (GDPR) (in Dutch, Algemene Verordening Gegevensbescherming (AVG)). The regulation aims to protect the data and privacy of EU citizens.

### 3.6.1 Privacy Protection

Aliquam vehicula augue metus, in tincidunt urna luctus sit amet. Sed ultrices, erat at laoreet semper, sem tellus hendrerit mi, eget pulvinar massa nisl ac dolor. Nunc ac tellus nec tortor interdum porta. Vestibulum hendrerit tempus condimentum. Donec a mollis sem. Aenean lectus nunc, bibendum ut orci vel, tristique pellentesque arcu. Vestibulum id laoreet neque. Phasellus at ex velit. Vestibulum scelerisque nulla ut massa tempor, ac dapibus dui viverra.

[EMA data sharing is complicated. Indirect identifiability should perhaps be the default assumption. GPS data cannot be fully anonymised.] Vivamus enim turpis, pulvinar volutpat purus nec, lobortis imperdiet diam. Nunc hendrerit cursus eleifend. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Vivamus enim turpis, pulvinar volutpat purus nec, lobortis imperdiet diam.

### 3.6.2 Medical device

All clinical studies that involve human participants need to be evaluated by a Medical Research and Ethics Committee (MERC; Dutch: ‘METC’). Recently, the committees have also been tasked to determine whether a medical device is used and to evaluate the safety and quality of the device. Researchers are therefore required to add a section in the research protocol, explaining why the software/device is or is not a medical device. This paragraph gives a brief overview of this process.

The official definition of a medical device (Medical Device Act, or ‘Wet Medische Hulpmiddelen’) is as follows:

“Any instrument, apparatus or appliance, any software or material or any other article that is used alone or in combination, including any accessory and the software required for its proper operation, that is intended by the manufacturer to be used specifically for diagnostic or therapeutic purposes, and is intended by the manufacturer to be used for human beings for the purpose of:  
- diagnosis, prevention, monitoring, treatment or alleviation of disease - diagnosis, monitoring, treatment, alleviation of or compensation for an injury or handicap - investigation, replacement or modification of the anatomy or of a physiological process - control of conception, and which does not achieve its principal intended action in or on the human body by pharmacological, immunological or metabolic means, but which may be assisted in its function by such means.”  
(CCMO, 2018)

In short, software can be classified as a medical device if it collects patient-specific data and is specifically intended for one of the above-mentioned objectives. Or in other words, if a health care professional takes this information into account when determining the course of treatment. The law does not differentiate between passive and active EMA.

In practice, the definition of medical devices leaves a lot of room for confusion. Researchers often struggle with the question whether their assessment tools should be considered a medical device or not. For this purpose, flowcharts exist that help to determine whether an app or product should be classified as a medical device (see, e.g., Ekker and van Rest, 2013, and <http://cetool.nl/general/scanAid>). Figure 3.2 shows such a flow-chart.

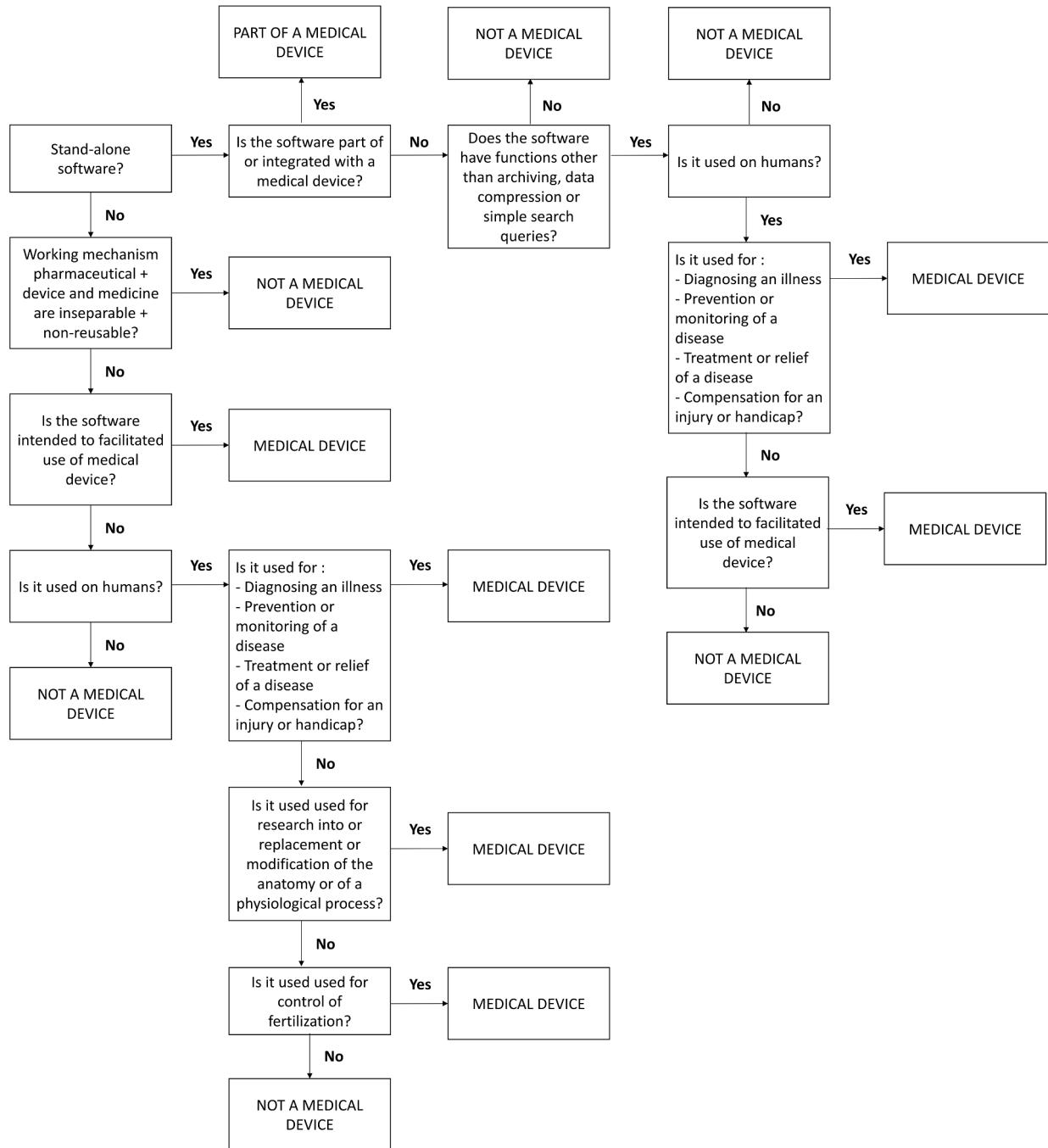


Figure 3.2: Flow-chart medical device.

### 3.6.3 Data Processing Agreements

When data processing is (partly) outsourced to a third party, a Data Processing Agreement (DPA) should be drafted, that specifies the agreements between the ‘controller’ and ‘processor’. In this context, a controller is the person or organisation that determines the why and how of data collection (for example you as a researcher). The processor processes the data on behalf of the controller, for example by storing the data in a

cloud. Aspects of data processing that need to be addressed in the agreement are for example: > Context, duration and termination of agreement > Processing data > Secure data storage > Sharing or exporting data > Confidentiality > Data leaks > Liability > Data storage period

### 3.6.3.1 Informed consent

Part of the General Data Protection Regulation is that individuals should provide consent before their data can be collected and processed. The European Union has formulated a number of conditions that need to be met for a consent to be valid:

“it must be freely given; it must be informed; it must be given for a specific purpose; all the reasons for the processing must be clearly stated; it is explicit and given via a positive act (for example an electronic tick-box that the individual has to explicitly check online or a signature on a form); it uses clear and plain language and is clearly visible; it is possible to withdraw consent and that fact is explained (for example an unsubscribe link at the end of an electronic newsletter email)”.

The CCMO offers a template that can be used to construct an informed consent form for your specific study [see <http://www.ccmo.nl/en/consent>].



# Chapter 4

## EMA instruments

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Aliquam vehicula augue metus, in tincidunt urna luctus sit amet. Sed ultrices, erat at laoreet semper, sem tellus hendrerit mi, eget pulvinar massa nisl ac dolor. Nunc ac tellus nec tortor interdum porta. Vestibulum hendrerit tempus condimentum. Donec a mollis sem. Aenean lectus nunc, bibendum ut orci vel, tristique pellentesque arcu. Vestibulum id laoreet neque. Phasellus at ex velit. Vestibulum scelerisque nulla ut massa tempor, ac dapibus dui viverra.

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### 4.1 Section

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# Chapter 5

## Data management

Modern EMA research generates a lot of data. Repeated self-reports, GPS-data, accelerometer data, background demographic data and traditional questionnaire data quickly add up to hundreds of megabytes of raw data. This raises the importance of proper data management. Without a proper data management plan, the EMA researcher quickly drowns in the data feed.

### 5.1 Using RStudio-projects to manage EMA data

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“File | New Project...”

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### 5.2 Project directory structure

```
1 project
2   |--data
3   |   |--source
4   |   |   |--keyfile.csv
5   |   |   |--GPS
6   |   |   |   |--subject1.json
```

```

7   |   |   |   °--subject2.json
8   |   |   |--accelerometer
9   |   |   |   |--subject1.bin
10  |   |   |   °--subject2.bin
11  |   |   °--surveys
12  |   |   |   |--demographics.sav
13  |   |   |   °--survey.sav
14  |   °--pruned
15  |   |   |--GPS.Rda
16  |   |   |--accelerometer.Rda
17  |   |   °--surveys.Rda
18 |--scripts
19   |   |--import
20   |   |   |--import_GPS.R
21   |   |   |--import_accelerometers.R
22   |   |   °--import_surveys.R
23   |   °--analysis
24   |   |   |--explore.R
25   |   |   °--test.R
26 |--output
27   |   °--images
28   |   |   |--figure_1.png
29   |   |   °--figure_2.png
30 °--README

```

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### 5.3 The keyfile

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Table 5.1: Sample Study Keyfile

ID	Status	SurveyID	Watch ID	App ID
P001	QM01221	192.A102.83A	APC009	
P002	QM01228	192.A102.83B	APC010	

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Store personal data in another location. Aliquam vehicula augue metus, in tincidunt urna luctus sit amet. Sed ultrices, erat at laoreet semper, sem tellus hendrerit mi, eget pulvinar massa nisl ac dolor. Nunc ac tellus nec tortor interdum porta. Vestibulum hendrerit tempus condimentum. Donec a mollis sem. Aenean lectus nunc, bibendum ut orci vel, tristique pellentesque arcu. Vestibulum id laoreet neque. Phasellus at ex velit. Vestibulum scelerisque nulla ut massa tempor, ac dapibus dui viverra.

## 5.4 Source data

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## 5.5 Import & Prune

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## 5.6 Visual Exploration

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## 5.7 Analysis

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## **Part III**

# **Analytic Approaches**



# Chapter 6

## Feature Extraction and Selection

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### 6.1 Feature extraction

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```
# Figure 6a: Features of a timeseries
d <- data.frame(i = 1:100)

d$x <- rnorm(nrow(d), 0, 2)
d$mean <- mean(d$x)
d$variance <- var(d$x)
d$autocorrelation <- cor(d$x, lag(d$x), use = "complete.obs")
d$rolling_mean <- zoo::rollapply(d$x, 10, fill = NA, mean)
d$rolling_variance <- zoo::rollapply(d$x, 10, fill = NA, var)
d$rolling_autocorrelation <- zoo::rollapply(d$x, 10, fill = NA,
                                              function(x) {
                                                cor(x, lag(x), use = "complete.obs")
                                              })

d <- gather(d, aspect, value, -i)
d$aspect = factor(
  d$aspect,
```

```
levels = c(  
  "x", "mean", "variance", "autocorrelation",  
  "rolling_mean", "rolling_variance", "rolling_autocorrelation"))  
  
ggplot(data = d,  
        aes(x = i,  
            y = value)) +  
  geom_point(alpha = .3, size = .8) +  
  geom_line() +  
  facet_wrap(~ aspect, scales = "free", ncol = 2) +  
  theme(axis.title.x=element_blank(),  
        axis.text.x=element_blank(),  
        axis.ticks.x=element_blank())
```

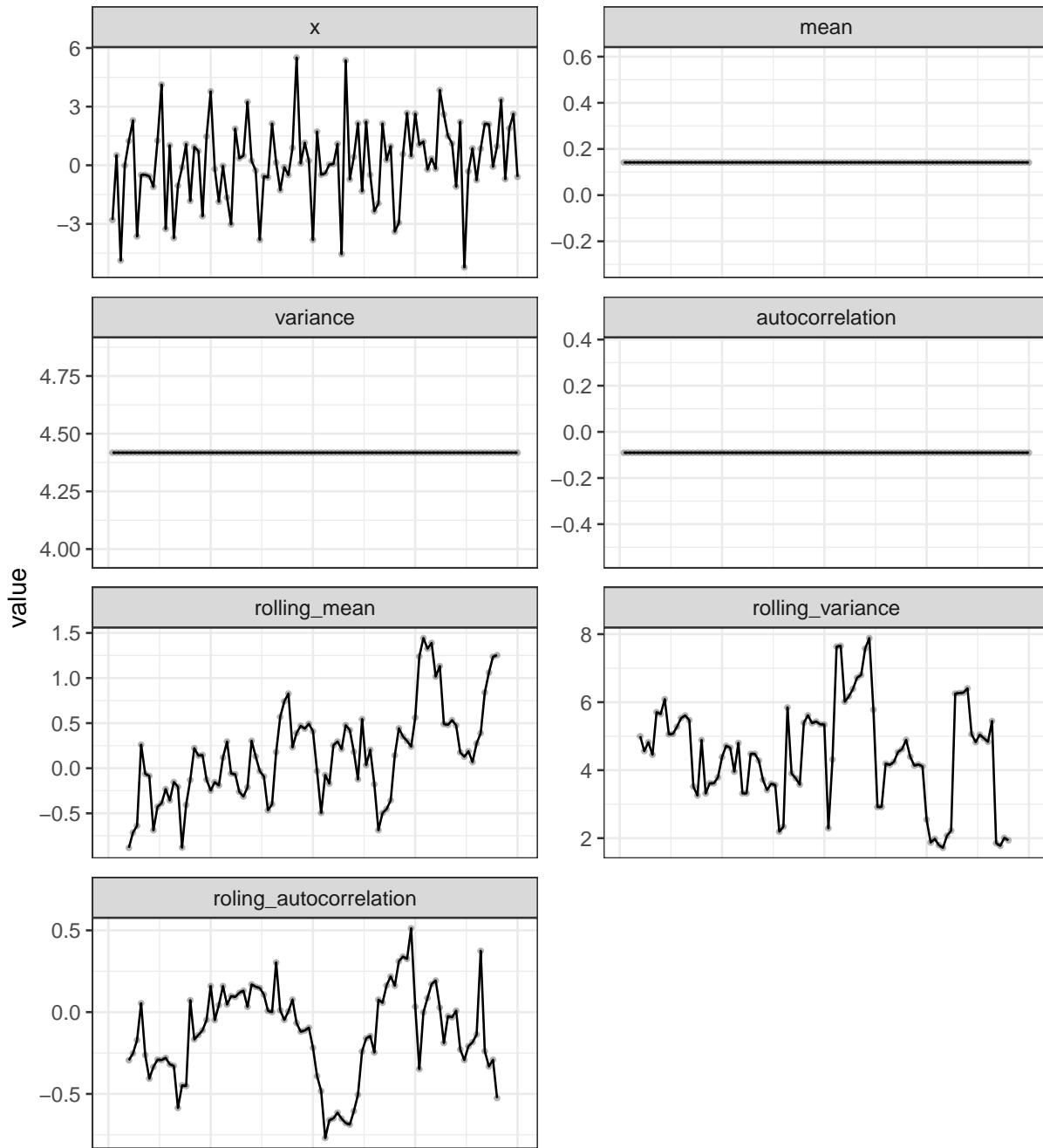


Figure 6.1: features of a series.

### 6.1.1 Variance

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### 6.1.2 Autocorrelation

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### 6.1.3 Rolling statistics

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## 6.2 Reliability and Validity

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## 6.3 Feature Selection

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# Chapter 7

## Mixed Modeling

EMA data are timeseries that are characterised by complex correlational structures, irregular sampling intervals, missing data, and substantive individual differences. Mixed models are well-suited to deal with these aspects. For this reason, they are often adopted in the analysis of EMA data.

This chapter provides a brief explanation of the mixed model analysis of EMA data. It shows how mixed models can be run in R, and how the output of these analyses can be interpreted.

### 7.1 The Mixed Model

Mixed modeling can be understood as a regression technique in which separate regression functions are estimated for each cluster in the data set. In EMA data, these clusters are defined by the participants. Data from the same participant are expected to be correlated, and one way to honour this correlation is to conceptualise a separate regression for each participant. This idea, in the most simple regression model, can be expressed as:

$$Y_{ij} = \text{intercept}_i + \epsilon_{ij} \quad (7.1)$$

This models the expected value of the  $j$ th measurement of participant  $i$  as the mean of all measurements of participant  $i$ , plus error. It defines a set of regression functions - one for each participant. The regression functions are, however, not independent:

$$\text{intercept}_i = \text{intercept}_g + \text{intercept}_i \quad (7.2)$$

This equation divides the intercepts of the individual participant regression functions into two parts: 1) the intercept of the group (the mean intercept of all regression functions), and 2) a participant-specific component (i.e., the difference between the intercept of the participant and the mean intercept of the group).

The group intercept is called the ‘fixed’ effect. If we would gather more data from the sampled population, we would expect to find approximately the same group intercept.

The participant-specific intercept is known as the ‘random’ effect. If we sample new data, we would not expect the individual intercepts to be the same. Rather, we would expect a similar *variance* of the participant-specific intercepts around the group intercept. This “mixing” of fixed and random effects is what gives mixed modeling its name.

The key to mixed models is to understand that it involves the estimation of fixed effects (a single value), random effects (systematic variance) and error (residual variance).

## 7.2 Simulating example data

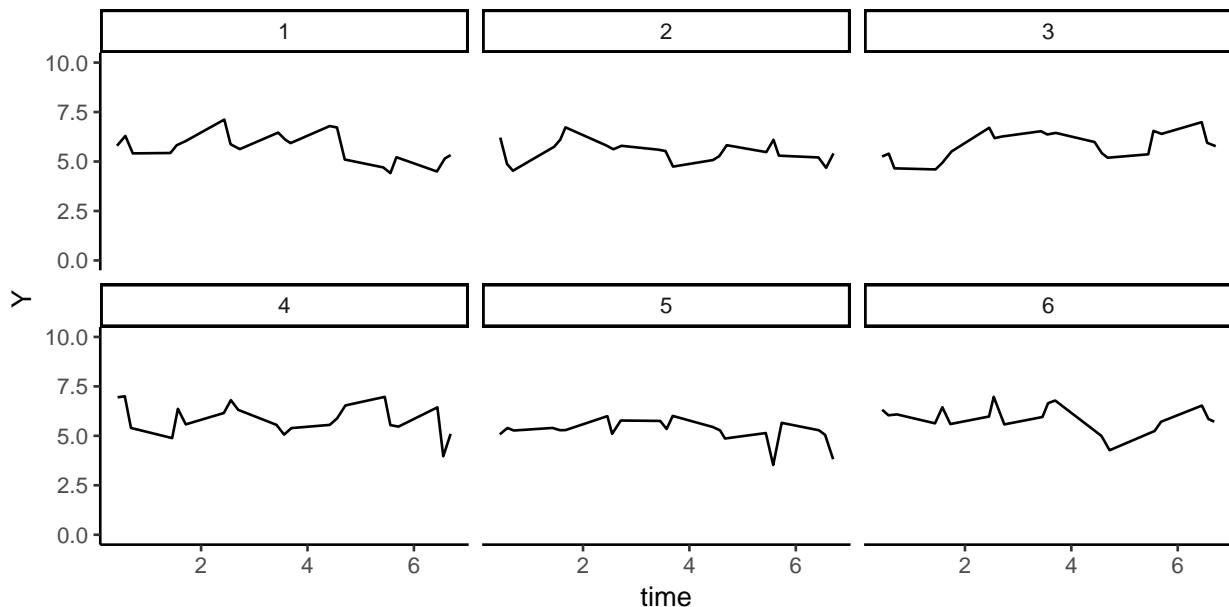
Suppose you want to determine the degree to which people with depression differ in their mean response to an EMA mood item. For this, you invite 100 people to rate their mood, three times per day, for one week.

For illustrative purposes, let's use the ‘sim\_ema’ function from package ‘emaph’ to simulate data in which the relevant model parameters are known. We set the mean mood (intercept\_g) to 5, the variance around this mean - var(intercept\_i) - to .5., and the average variance around these means within participants - the error - to .2.

```
# code snippet 7.1: simulating ema data
library(emaph)
plan <- sample_plan(n_participants = 100,
                     n_days = 7,
                     times = c("10:00-11:00",
                               "13:00-14:00",
                               "16:00-18:00"))

d1 <- sim_ema(plan,
               mm_par = list(fixed = c(intercept = 5),
                             random = c(intercept = 1),
                             phi = .5,
                             error = .5),
               lim = c(0, 10))
```

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## 7.3 Fitting a mixed model in R

Now, let's use R to fit a mixed model to the data, to see whether it our simulation parameters are detected. For this, we will use the 'lme' function, from package 'nlme':

```
# code snippet 7.1: fitting a mixed model with lme
library(nlme)
fm <- lme(Y ~ 1, random = ~ 1 | id,
            data = d1)
```

We can now extract the fixed effects regression coefficients table. The estimated intercept should be close to 5:

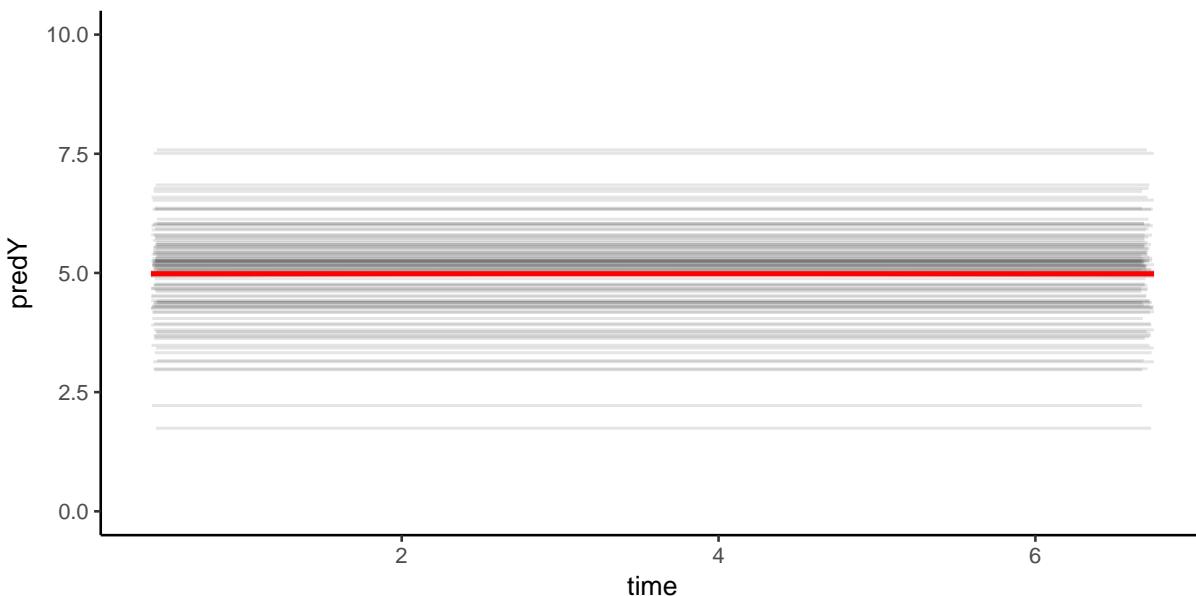
```
# code snippet 7.2: fitted fixed effects
summary(fm)$tTable
#>           Value Std.Error   DF t-value   p-value
#> (Intercept) 4.98     0.107 2000    46.8 3.95e-323
```

Random effects and residual variance are shown by the 'VarCorr' function. The random intercept variance should be close to .5 and the residual error variance should be close to .2:

```
# code snippet 7.3: fitted random effects
VarCorr(fm)
#> id = pdLogChol(1)
#>          Variance StdDev
#> (Intercept) 1.113    1.055
#> Residual    0.488    0.698
```

By plotting the predicted values, it becomes clear how the model 'thinks': it predicts a series of straight lines, one for each participant.

```
d1$predY <- predict(fm)
```



## 7.4 The intra-class correlation

The above reasoning does not immediately answer the question to what degree people with depression differ in their mean response to the EMA mood item. One way to quantify this, is to calculate the intra-class correlation, which is defined as the ratio between the random intercept variance and the total variance (i.e., the intercept variance and the residual variance):

```
# code snippet 7.4: intraclass correlation
vc <- VarCorr(fm)
intercept_var <- as.numeric(vc[1])
residual_var <- as.numeric(vc[2])

round(intercept_var / (intercept_var + residual_var), 2)
#> [1] 0.7
```

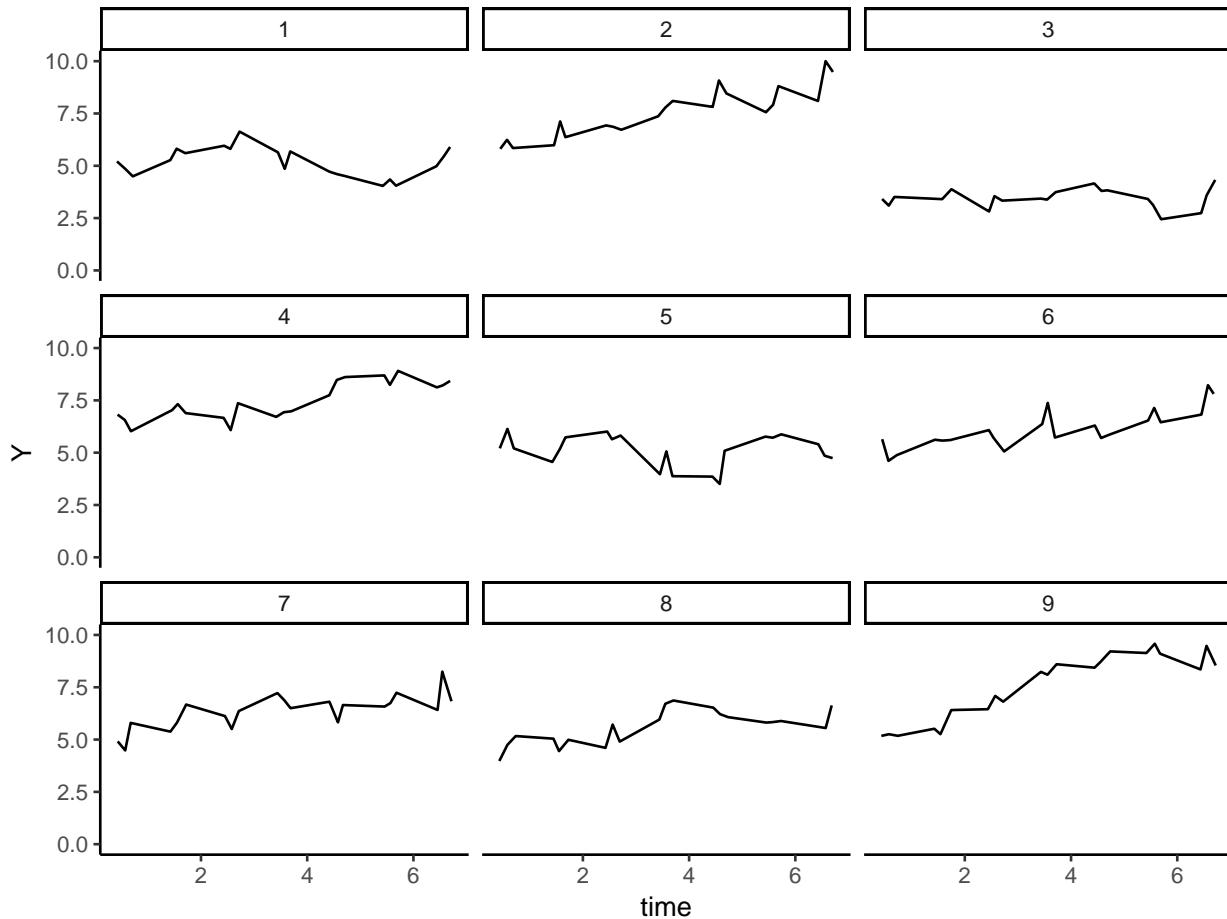
From this, we learn that 66% of the total variance in the dataset can be attributed to differences between individuals.

## 7.5 Adding time as a predictor

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```
d2 <- sim_ema(plan,
  mm_par = list(fixed  = c(intercept = 5, time = 0.5),
                 random = c(intercept = 1, time = 0.05),
                 phi = .5,
                 error = .5),
  lim = c(0, 10))

ggplot(subset(d2, id %in% unique(d2$id)[1:9]),
       aes(x = time, y = Y, group = id)) +
  geom_line() + ylim(c(0, 10)) +
  facet_wrap(~id) + theme_classic()
```



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```
# code snippet 7.6: a mixed model, with a random slope
library(nlme)
fm <- lme(Y ~ 1 + time, random = ~ 1 + time | id,
            data = d2)
summary(fm)$tTable
#>           Value Std.Error DF t-value p-value
#> (Intercept) 5.053     0.1078 1999    46.9 0.00e+00
#> time        0.437     0.0209 1999    20.9 4.81e-88
```

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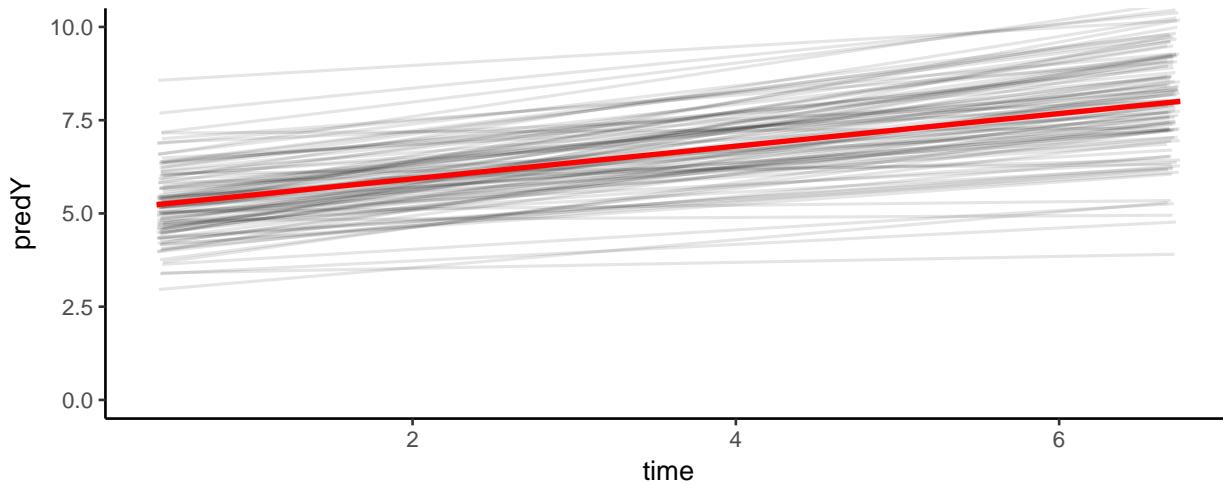
```
# code snippet 7.7: extracting random effects
VarCorr(fm)
#> id = pdLogChol(1 + time)
#>          Variance StdDev Corr
#> (Intercept) 1.067    1.033 (Intr)
#> time        0.038    0.195 -0.297
```

```
#> Residual    0.480    0.693
```

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```
d2$predY <- predict(fm)

ggplot(d2, aes(x = time, y = predY, group = id)) +
  geom_line(alpha = .1, size = .6) +
  geom_smooth(aes(group = NULL), method = "lm", color = "red") +
  coord_cartesian(ylim = c(0, 10)) + theme_classic()
```



## 7.6 Two groups

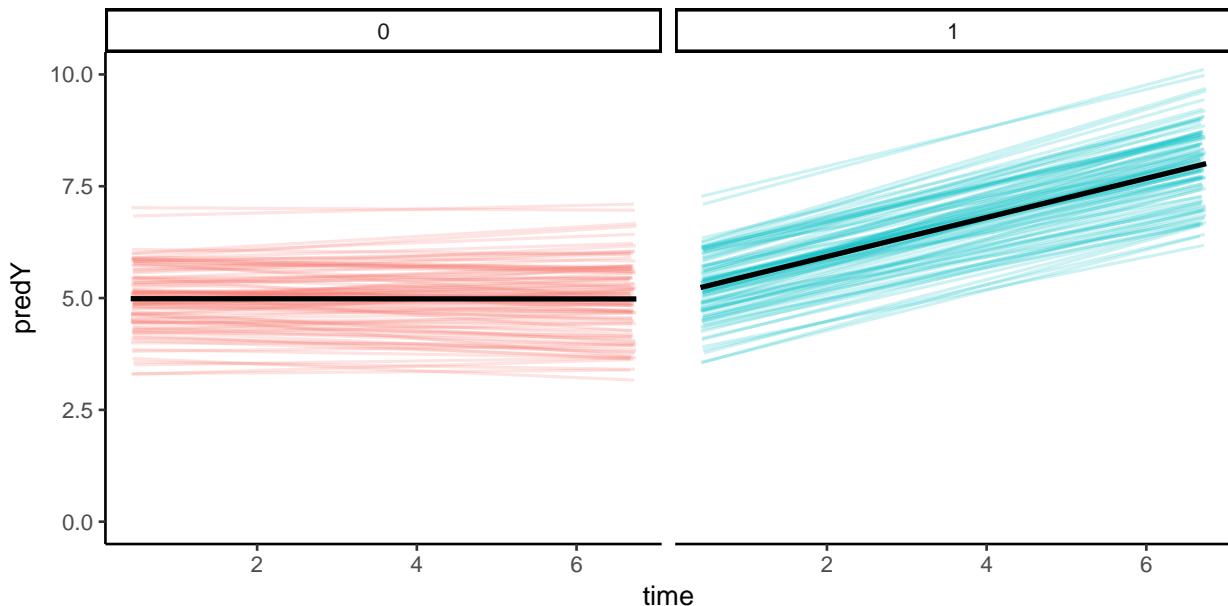
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```
# code snippet 7.7: two-group simulation
d3 <- rbind(d1, d2)
d3$group <- factor(c(rep(0, nrow(d1)), rep(1, nrow(d2))))
```

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```
# code snippet 7.8: a mixed model, with two groups
library(nlme)
fm <- lme(Y ~ 1 + time * group, random = ~ 1 + time | id,
            data = d3)
summary(fm)$tTable
#>           Value Std.Error   DF t-value   p-value
#> (Intercept) 4.986035  0.0874 4097 57.0570 0.00e+00
#> time        -0.000917  0.0138 4097 -0.0666 9.47e-01
#> group1       0.066844  0.0649 4097  1.0303 3.03e-01
#> time:group1  0.438328  0.0159 4097 27.6529 1.78e-154
```



## 7.7 Power analysis

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## 7.8 Further reading

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# Chapter 8

## Timeseries analysis

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## 8.2 AR1

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# Chapter 9

## Fitting Networks

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### 9.1 What are Networks?

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### 9.2 Fitting Networks on Single-Subject Repeated Measures Data

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```
# code snippet 9.1: Fitting symptom networks
library(graphicalVAR)

# Simulate model:
set.seed(2)
Mod <- randomGVARmodel(5, probKappaEdge = 0.8, probBetaEdge = 0.8)

# Simulate data:
d <- as.data.frame(graphicalVARsim(50, Mod$beta, Mod$kappa))

e <- gather(d) %>% group_by(key) %>% mutate(t = 1:n())
ggplot(data = e, aes(x = t, y = value)) +
  geom_point(size=.2) + geom_line() +
  facet_grid(key~.)
```

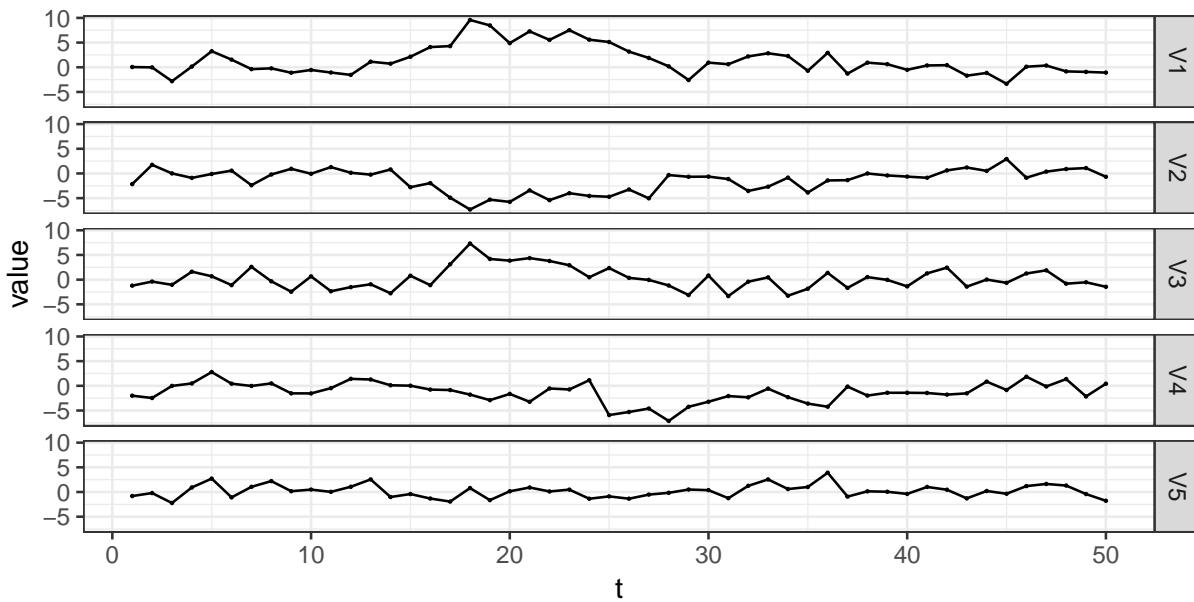


Figure 9.1: Simulated timeseries of 5 variables

### 9.2.1 Contemporaneous and Directed Correlations

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```
# code snippet 9.2: plotting symptom networks
Res <- graphicalVAR(data = d, gamma = 0,
                      nLambda = 10, verbose = FALSE)

# Show networks
plot(Res, title = FALSE)
```

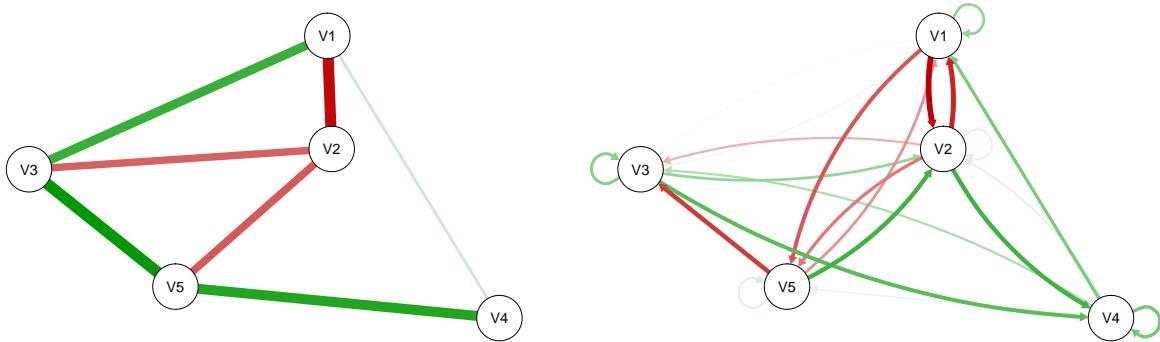


Figure 9.2: Partial Contemporaneous Correlations (left) and Partial Directed Correlations (right).

### 9.2.2 Node Analysis

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- Betweenness
- Closeness
- Strength

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- InStrength
- Outstrength

```
# code snippet 9.3: Node Centrality plots
library(qgraph)
centralityPlot(qgraph(Res$PCC, DoNotPlot = TRUE))
centralityPlot(qgraph(Res$PDC, DoNotPlot = TRUE))
```

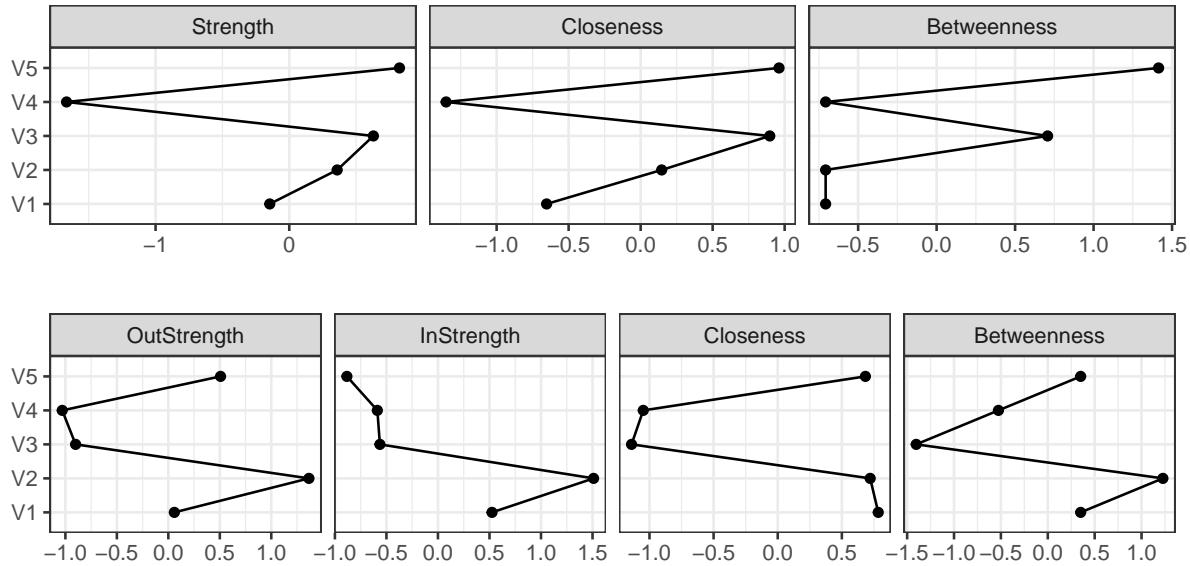


Figure 9.3: Centrality plot of Partial Contemporaneous (top) and Directed (bottom) Correlations.

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### 9.3 Fitting Networks on Multiple Subjects Repeated Measures Data

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```
# code snippet 9.4: Fitting symptom networks of multiple subjects
library("mlVAR")

Model <- mlVARsim(nPerson = 30, nNode = 5,
                   nTime = 50,    lag = 1)

fit1 <- mlVAR(Model$data,           vars = Model$vars,
              idvar = Model$idvar, verbose = FALSE,
              lags = 1,               temporal = "correlated")
```

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```
# code snippet 9.5: plotting symptom networks of multiple subjects
layout(matrix(c(1:6), ncol = 2, byrow = TRUE))

plot(Model, "contemporaneous", layout = "circle", verbose = FALSE)
plot(fit1, "contemporaneous", layout = "circle", verbose = FALSE)

plot(Model, "temporal", layout = "circle", verbose = FALSE)
plot(fit1, "temporal", layout = "circle", verbose = FALSE)

plot(Model, "between", layout = "circle")
plot(fit1, "between", layout = "circle")
```

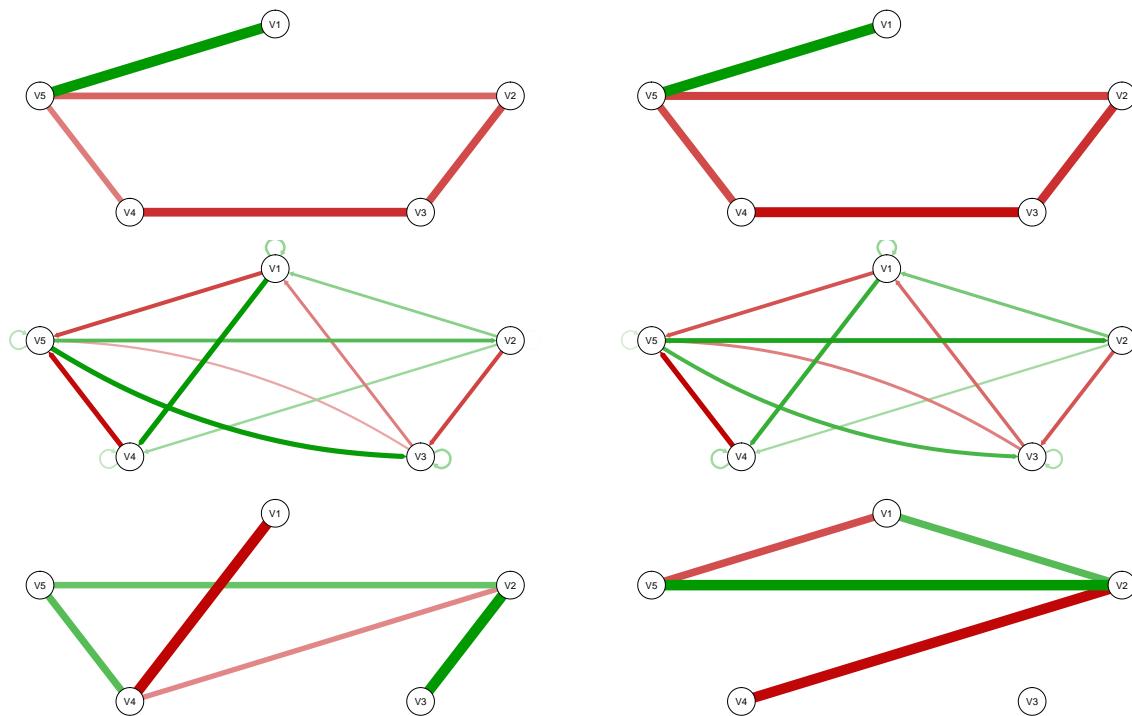


Figure 9.4: True (left) vs estimated (right) contemporaneous (top), temporal (middle) and between-subject relationships (bottom)

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## 9.4 Discussion

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#### 9.4.1 Pitfalls of Network Analysis

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#### 9.4.2 Subsection

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## **Part IV**

# **EMA Outcomes**



# Chapter 10

## Mood

Mood is a common outcome in EMA research (Myin-Germeys et al., 2016; Desmet et al., 2016). Having respondents rate their mood during the day allows researchers to assess mood fluctuation over time or reactivity to events and daily-stressors (Wenze and Miller, 2010). Often, it is studied in relation to depressive symptoms and mood disorders (aan het Rot et al., 2012). In addition, mood can be linked to other variables, such as substance abuse behaviour (Kirchner and Shiffman, 2013; Serre et al., 2015), somatic health (Engel et al., 2016; Moore et al., 2016) or activity patterns (Dunton, 2017; Marszalek et al., 2014).

The definition of mood varies across studies. Usually the concept refers to a general affective state such as arousal or valence. Following this line of reasoning, a distinction can be made between mood states (e.g. irritable, cheerful, relaxed, etc.) and discrete emotions (e.g. happy, sad, anxious, etc.), where moods are thought to be less specific and more subjective, enduring and related to context (Beedie et al., 2005; Cranford et al., 2006; Desmet et al., 2016).

Depending on the study focus and research questions, mood measurement can be operationalized in several ways. Therefore, it is vital to consider the goal of measuring mood in your own study and to choose an operationalisation that matches your hypothesis and theoretical framework. In this chapter, we will discuss the most commonly used constructs: 1) unidimensional mood assessment, 2) the Circumplex model, 3) negative and positive affect, and 4) the ‘bag of items’ approach.

### 10.1 Unidimensional mood assessment

Perhaps the most seemingly straight-forward method to measure mood is to ask ‘face-valid’ unidimensional questions such as “How is your mood right now” (van Ballegooijen et al., 2016) or “How are you feeling right now” (van de Ven et al., 2017).

Respondents rate these questions on a Likert scale or a Visual Analogue Scale (VAS), aimed to indicate mood intensity. Typically, VAS scales will range from zero (low or worst mood) to 10 or 100 (good or best mood).

Compared to classic paper-and-pencil methods, digital unidimensional EMA might lead to more accurate data on (in)variability of mood, because retrospective bias is thought to be less of an issue. Further, plotting this data in a graph is an easy way to visually inspect within-subject change in general mood. Combining data from various variables such as activity, sleep and mood in one graph can help respondents understand the interaction between mood and behaviour.

```
ggplot(csd, aes(x = date, y = as.numeric(mood_irritat))) +  
  geom_smooth(method = "loess", span = .05, se = FALSE) +  
  geom_point(size = .5, alpha = .5, position = position_jitter(height = .1)) +  
  scale_x_date() + scale_y_continuous(breaks = 1:7) +  
  xlab("Time") + ylab("Mood")
```

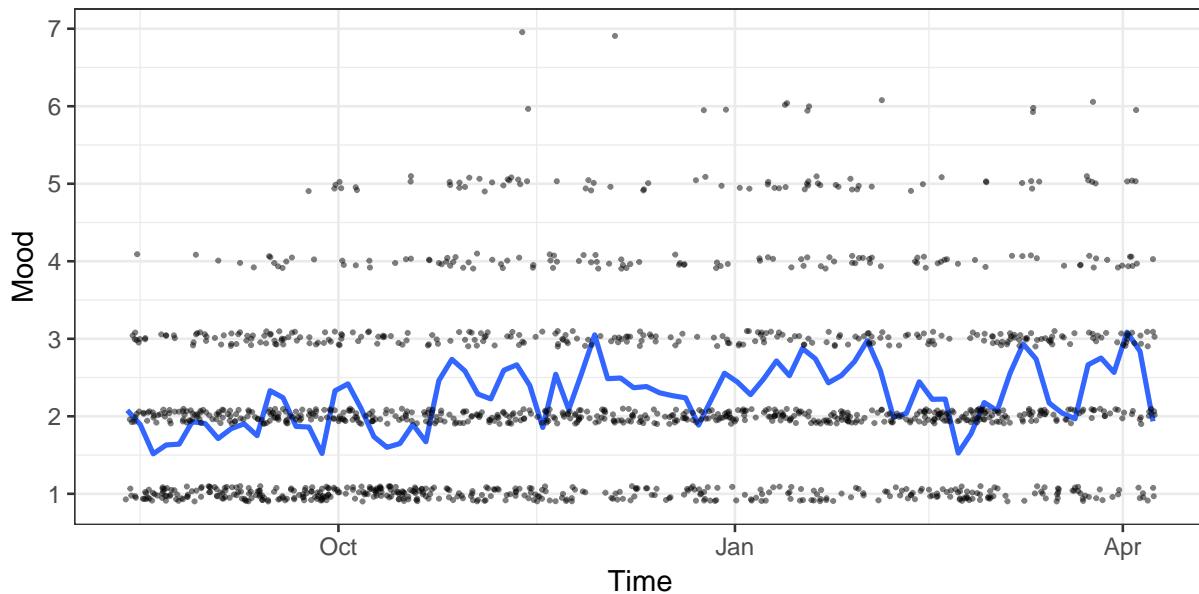


Figure 10.1: 34 weeks of mood data, from a single participant

A downside of unidimensional mood assessment is that it assumes that respondents instinctively understand the concept of general mood. Little is known about whether mood ratings are indeed comparable across respondents (between-subjects). In order to reduce bias and improve reliability, some studies implemented more specific questions, such as “How depressed are you feeling right now” or “How anxious are you feeling right now (Starr and Davila, 2012). However, this shifts focus from general mood to more specific mood states or emotions.

Another aspect to consider is that the middle of a VAS scale (e.g. 5 or 50) is considered a negative result, and only scores above 6 or 60 are considered acceptable or possible mood states (Groot, 2010). This contrasts with common Likert scales, where the centre often reflects a neutral response. In order to address this issue, some researchers have proposed to use scales ranging from -1 to 1, with 0 as a neutral scale centre. However, this scale implies a mood state that ranges from negative to positive, rather than absent to present.

Another option is to use bipolar-unidimensional items, which place two opposing mood states at each end of the scale, for example by asking “Please rate your current mood on a scale of 0 to 100, on which 0 indicates happy, and 100 indicates sad” (van Rijsbergen et al., 2014). The bipolar-unidimensional method was shown to be able to predict time to relapse over 5.5 years in recurrently depressed out-patients, with 6.3% of variance in time to relapse explained. This percentage was comparable to that of the HAM-D (Rijsbergen et al., 2012). Also the scale was able to detect relapse in patients with recurrent Major Depressive Disorder (based on SCID-I interview) at a cut-off score of 55, and outperformed the HAM-D and IDS-SR. However, 47% of patients indicated by the VAS scale did not fulfil formal criteria for relapse (false positives) (van Rijsbergen et al., 2014).

## 10.2 The Circumplex Model

The Circumplex Model of affect (Russell, 1980; Posner et al., 2005) also uses a bipolar dimensional scale to rate affect (ranging from unpleasant to pleasant). However, the model assumes that affective states are a linear combination of two independent underlying constructs, rather than one. Therefore, all states are scored both on a valence scale and an arousal scale (ranging from low to high arousal). Combining these scores

places the affective states in a circle on one of four quadrants (10.2). States within one quadrant are believed to be positively correlated, while states in the opposing quadrant are thought to be negatively correlated. When using this model in EMA research, one option is to have respondents rate valence and arousal on two VAS scales. The combination of the resulting scores than gives insight into the quadrant in which respondents affective states fall (10.2) - Low aroused - unpleasant - Low aroused - pleasant - High aroused - unpleasant - High aroused - pleasant

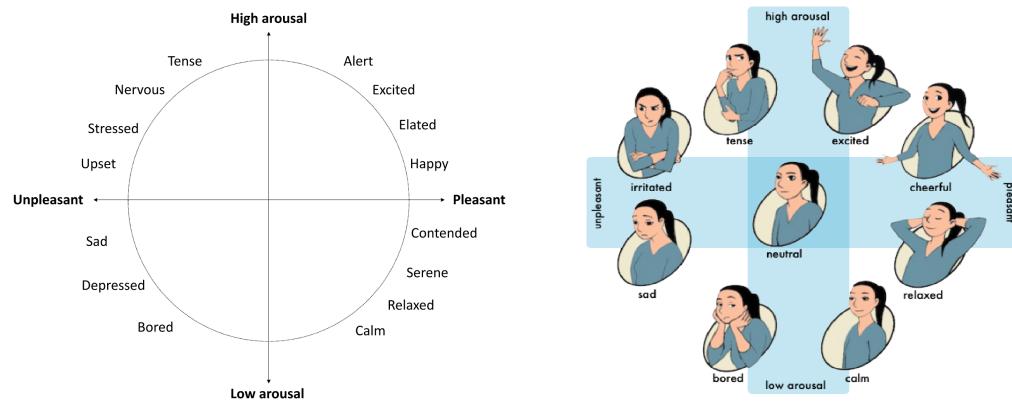


Figure 10.2: The four quadrants of the Circumplex model of affect.

A downside of this approach is that the words or concepts of valence and arousal can be hard to convey to respondents, especially when translated to other languages, such as Dutch. One alternative is to adjust the scale ends, for example using “extreme sleepiness” and “extreme high energy” (Sharar et al., 2016).

In order to facilitate studying affect, while avoiding the use of language, DeSmet and colleagues developed the pick-a-mood scale, which is a pictorial self-report scale. The scale builds on the circumplex model and adds the third dimension “dominance” (level of experienced control over the mood state), rendering eight different mood states and one neutral state.

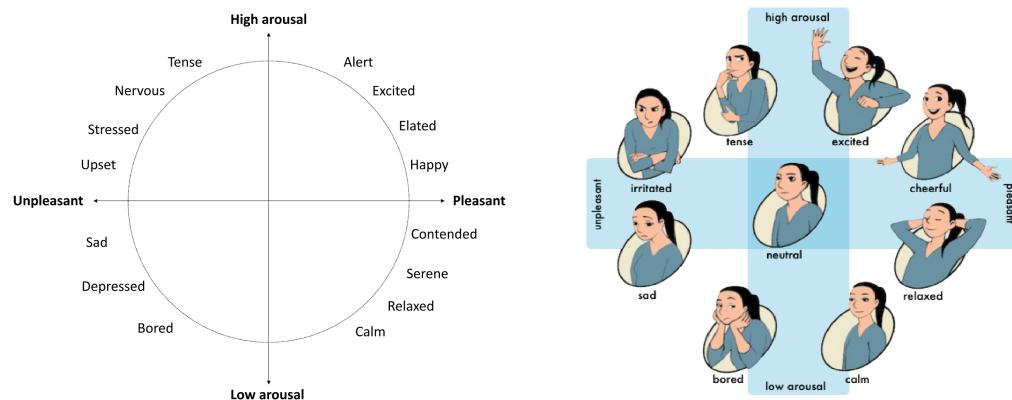


Figure 10.3: The Circumplex model of affect (left) and the The Pick-A-Mood Circumplex Mood Circle (right).

### 10.3 Negative & Positive Affect

Watson and Tellegen (Watson and Tellegen, 1985) further specified the Circumplex model, arguing that the diagonal quadrants represent Positive and Negative affect (PA/NA) and that these two terms are the main dimensions of affect (Watson, 1999). PA ranges from sadness to high energy, NA from calmness to distress (Watson et al., 1988). While bipolar-unidimensional assessment assumes that positive and negative affect are mutually exclusive, the PA/NA affect model assumes that these seemingly opposing mood states can occur simultaneously. Watson and Clark (Watson and Clark, 1997) for example, showed a moderate correlation between the two constructs (.32) and argued that while bipolar scales can be used for within-subject assessment, unipolar scales have superior convergent and discriminant validity in between-subject data.

In order to measure Positive and Negative Affect, the Positive and Negative Affect Schedule was developed by Watson, Clark and Tellegen (Watson et al., 1988). The PANAS consists of 20 items that are rated on a 5-point scale, ranging from 1 (very slightly or not at all) to 5 (very) (Watson, 1999): Negative Affect (10): afraid, scared, nervous, jittery, irritable, hostile, guilty, ashamed, upset, distressed Positive Affect (10): active, alert, attentive, determined, enthusiastic, excited, inspired, interested, proud, strong Two formal PANAS short forms exist, both containing 10 items (5 for each affect), one by Mackinnon and colleagues (Mackinnon et al., 1999) and one by Thompson and colleagues (Thompson, 2007). Wichers and colleagues based their 10 affect items on the PANAS and their own EMA studies. Based on factor analyses, Negative affect comprised of insecure, lonely, anxious, low, guilty, and suspicious. Positive affect comprised of cheerful, content, energetic, and enthusiastic. All items were rated on 7-point Likert scales. PA and NA were calculated as the average score across all five items, weighted for their factor loadings.

```
items <- csd %>%
  select(c(
    "mood_enthus", "mood_cheerf",
    "mood_strong", "mood_satisfi",
    "mood_lonely", "mood_anxious",
    "mood_guilty")) %>%
  scale(.) %>%
  as.tibble(.) %>%
  mutate_all(funs(residuals(stats::arima(., order = c(1,0,0)))))

correlations <- cor(items, use = "complete.obs")
fa = psych::fa(items,
               nfactors = 2,
               rotate = "oblimin",
               fm = "pa",
               scores = "regression")

psych::fa.diagram(fa,
                  simple = TRUE,
                  main = "")
```

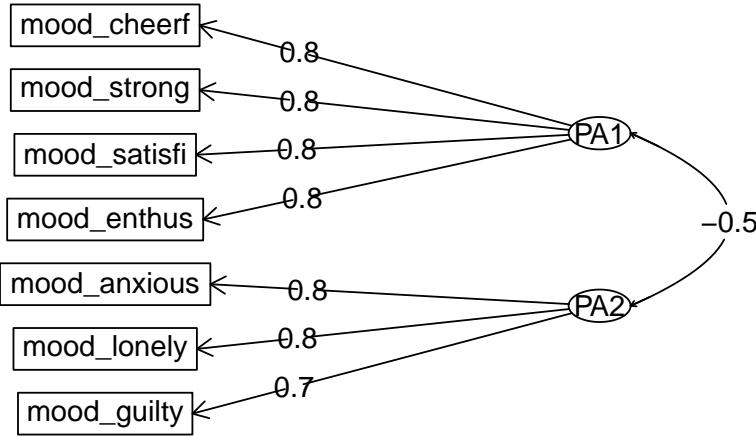


Figure 10.4: Factor analysis of 7 EMA items, revealing two factors: Positive Affect (PA) and Negative Affect (NA).

## 10.4 Bag-of-Items

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# Chapter 11

## Activity

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### 11.1 Accelerometry

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```
library(PhysicalActivity)
data(dataSec)

d <- dataCollapser(dataSec, TS = "TimeStamp", col = "counts", by = 60)

ggplot(d, aes(x = as.POSIXct(TimeStamp), y = counts)) +
  geom_smooth(method = "loess", span = .05, se = FALSE) +
  geom_point(size = .2, alpha = .25) +
  scale_x_datetime()
```

```
scale_y_sqrt(breaks = c(100, 1000, 3000, 6000, 9000)) +
  xlab("Time") + ylab("Activity")
```

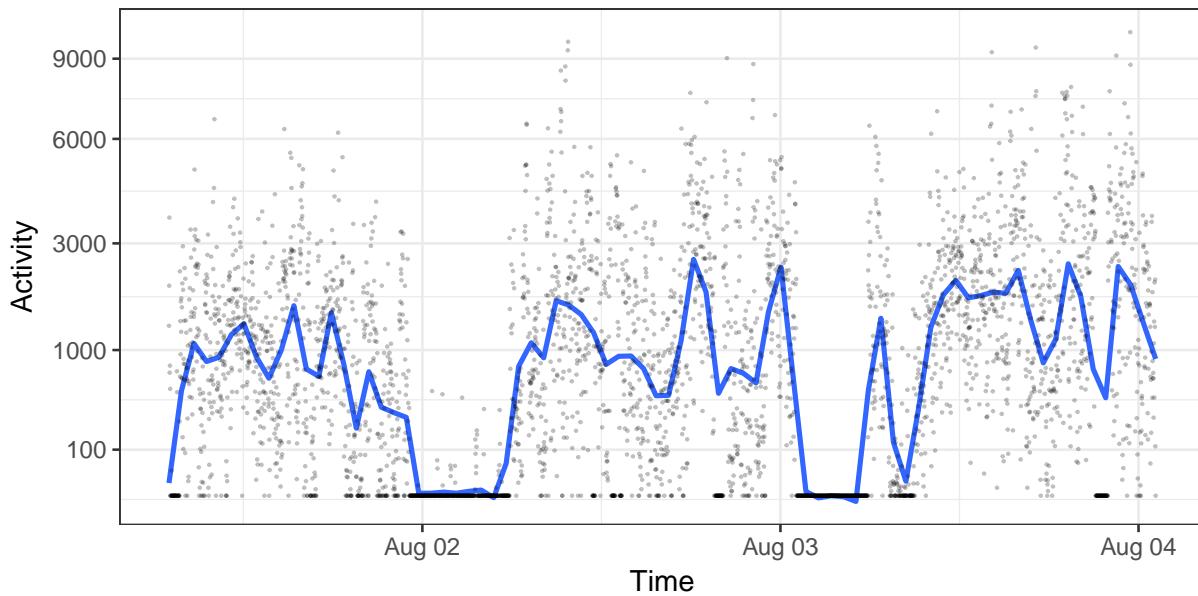


Figure 11.1: Three days of Accelerometer data.

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## 11.2 Global Positioning Systems (GPS)

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```
library(ggmap)

d <- subset(GPSdata, TimeStamp < "2017-07-01")
d <- round(d[c("lat", "lon")], 4)
d <- unique(d)

#zaandam <- get_map(location = 'Sloterdijk, Amsterdam', zoom = 12)
#gimap(zaandam, extent = "panel", darken = 0) +
#  geom_density2d(data = d, aes(x = lon, y = lat), size = .1, color = "black") +
#  stat_density2d(data = d, aes(x = lon, y = lat,
#                               fill = ..level.., alpha = ..level..),
#                 size = 0.01, bins = 200, geom = "polygon") +
#  scale_fill_gradientn(colours = topo.colors(10), guide = FALSE) +
#  scale_alpha(range = c(0, .3), guide = FALSE)
```



# Chapter 12

## Context

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## **Part V**

# **EMA Case Studies**



# Chapter 13

## Early Warning Signs of Depression

One of the promises of EMA is that it might detect signs of mental health deterioration in an early stage. Subtle changes in time series of mood variables, for example, might signal a depression relapse. If we can detect these changes, preventive interventions can be triggered to avoid the relapse.

But what changes, exactly, should we look for? What are these early warning signs?

### 13.1 Critical Slowing Down

Critical Slowing Down (CSD) is a concept from dynamic systems theory. In dynamic systems, state transitions are preceded by a change in which the system reacts to disturbances. In a stable state, the system quickly recovers from disturbances. Prior to a transition to a new state, however, the system takes more and more time to recover back to its current state: the variance and auto-correlation of the system increases (Scheffer et al., 2009; Dakos et al., 2008).

In this chapter, we re-analyze data from a study that aimed to demonstrate CSD in EMA-data of a single patient with a history of major depression (Groot, 2010, Kossakowski et al. (2017); Wichers et al., 2016). The patient, a 57-year old male, used EMA to monitor himself during a 239-day single-case double-blind medication reduction trial. During the experiment, he experienced a relapse, and Wichers and colleagues showed how variance and auto-correlation in the EMA data increased, several weeks prior to this relapse. The transition appeared to be preceded by CSD.

We will try to reconstruct the finding, using an alternative analysis strategy. One of the limitations of the Wicherts et al analysis is that autocorrelation was analysed at lag 1 only (i.e., only the correlation between  $t$  and  $t-1$  was considered). With another analysis technique, called ‘Detrended Fluctuation Analysis’, all lags can be considered.

To conduct the analysis, we need three R packages:

- Raw EMA data of this study were published in the public domain (Kossakowski et al., 2017). We included the data in the emaph package.
- To manipulate the raw data and reconstruct the plots of the article, we are going to use several functions from the tidyverse.
- DFA is implemented in package ‘nonlinearTseries’, so we will need that as well.

```
# Code snippet 13.1: required libraries for the CSD-study re-analysis.  
library(emaph)  
library(tidyverse)  
library(nonlinearTseries)
```

## 13.2 Plotting the course of depression

Let's take a look at the development of the depressive symptoms of the patient first. These were tapped with weekly assessments of the depression scale of the 'Symptom Checklist-90-Revised' (SCL-90-R; Derogatis, 1994), a well-established self-report questionnaire.

The code below reconstructs Figure 1 of the Wichers et al article. It plots the SCL90-R depression scale score over the time. Around day 120, the depression score increased considerable: the patient experienced a relapse.

```
# Code snippet 13.2: Plot depression score
dep <- csd %>% select(dayno, scl90r_dep) %>%
  filter(!is.na(scl90r_dep)) %>% unique

# plot dep + change point (day 120 in our data)
ggplot(dep, aes(x = dayno, y = scl90r_dep, group = 1)) +
  geom_step() + scale_colour_manual(values = c("black", "red")) +
  xlab("Days") + ylab("SCL-90-R Depression")
```

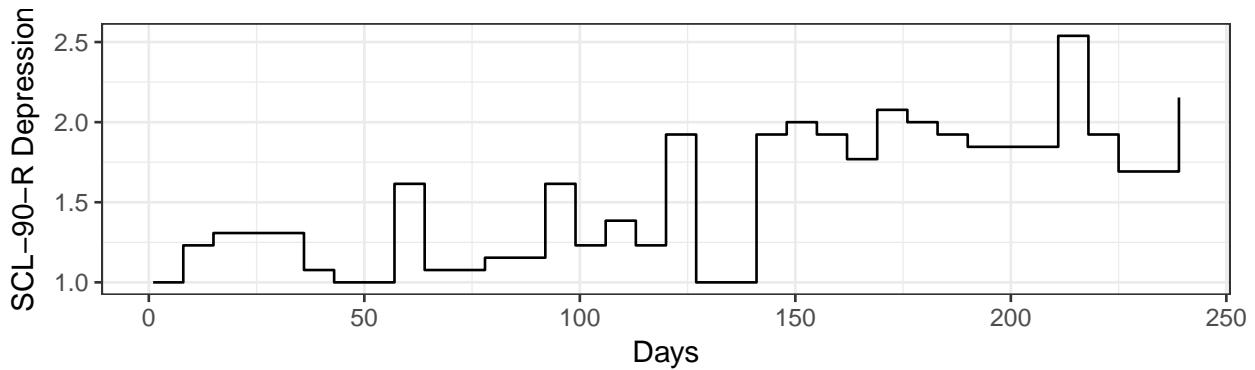


Figure 13.1: SCL-90 depression score, over the study period

## 13.3 Mental state EMA items

Wichers and colleagues selected 13 items from the full EMA dataset, which they grouped in 5 factors: positive affect (pa; 4 items), negative affect (na; 4 items), mental unrest (mu; 3 items), suspiciousness (su; 1 item), and worrying (wo; 1 item). From these factors, an overall mental state sum score can be calculated.

```
# Code snippet 13.3: mood states calculation

# positive affect
pa_items <- c("mood_enthus", "mood_cheerf",
             "mood_strong", "mood_satisfi")

csd$pa <- csd %>%
  select(pa_items) %>%
  rowMeans(., na.rm = TRUE)
csd$pa <- -csd$pa

# negative affect
na_items <- c("mood_lonely", "mood_anxious",
             "mood_guilty", "mood_doubt")
```

```

csd$na <- csd %>%
  select(na_items) %>%
  rowMeans(., na.rm = TRUE)

# mental unrest
mu_items <- c("mood_irritat", "pat_restl",
              "pat_agitate")
csd$mu <- csd %>%
  select(mu_items) %>%
  rowMeans(., na.rm = TRUE)

# 'single-item' states
csd$su <- csd$mood_suspic
csd$wo <- csd$pat_worry

# global mental state score
csd$ms <- rowSums(csd[c("pa", "na", "mu", "su", "wo")])

```

Rows, in which one or more of the factors have missing values, are removed from the analysis. In a full analysis, options to impute the missing values could and should be considered. However, since only 3 of the 1476 rows have missing item scores, not much is probably lost by running a simple complete-case analysis.

*# Code snippet 13.3: missing value removal*

```

# count number of items with missing items, per row
csd$nna <- csd %>%
  select(matches("mood_")) %>%
  is.na(.) %>% rowSums

# drop rows with missing values
csd <- csd %>% filter(nna == 0)

```

## 13.4 Running the DFA

```

# code snippet #13c: Running the DFA

# prepare result rows: one row for each day
d <- NULL
d <- csd %>%
  group_by(dayno) %>%
  summarise(ms = mean(ms))

d$ms_dfa = NA

# determine DFA, in a moving window of 32 days,
# in steps of 7 days
window <- 32
for (i in seq(window, max(csd$dayno), 7)) {

  # get the sliding window data
  w <- subset(csd, dayno > (i - window) & dayno <= i)

```

```
# dfa: ms
dfa.analysis <- dfa(time.series = w$ms,
                      npoints = 30,
                      window.size.range = c(10, nrow(w)),
                      do.plot = FALSE)

fgn.estimation <- estimate(dfa.analysis,
                            do.plot = FALSE,
                            fit.col = "blue", fit.lwd = 2, fit.lty = 2,
                            main = "Fitting DFA to fGn")

d$ms_dfa[d$dayno == i] <- fgn.estimation
}
```

## 13.5 Results

We can now plot the DFA indicator over time, to see whether it peaks prior to the onset of the relapse. As can be seen, the DFA-indicator clearly peaks prior to the onset of the relapse, around day 110. Interestingly, a second peak is reached at the end of the experiment, around day 239, possibly to indicate a recovery from the relapse.

*# Code snippet 13.8: Plot DFA results*

```
ggplot(na.omit(d),
       aes(x = dayno, y = ms_dfa,
            colour = factor(dayno < 120),
            group = 1)) +
  geom_point() +
  geom_line() +
  ylab("dfa (60-day window)") +
  xlim(c(0, 250)) +
  guides(color = FALSE)
```

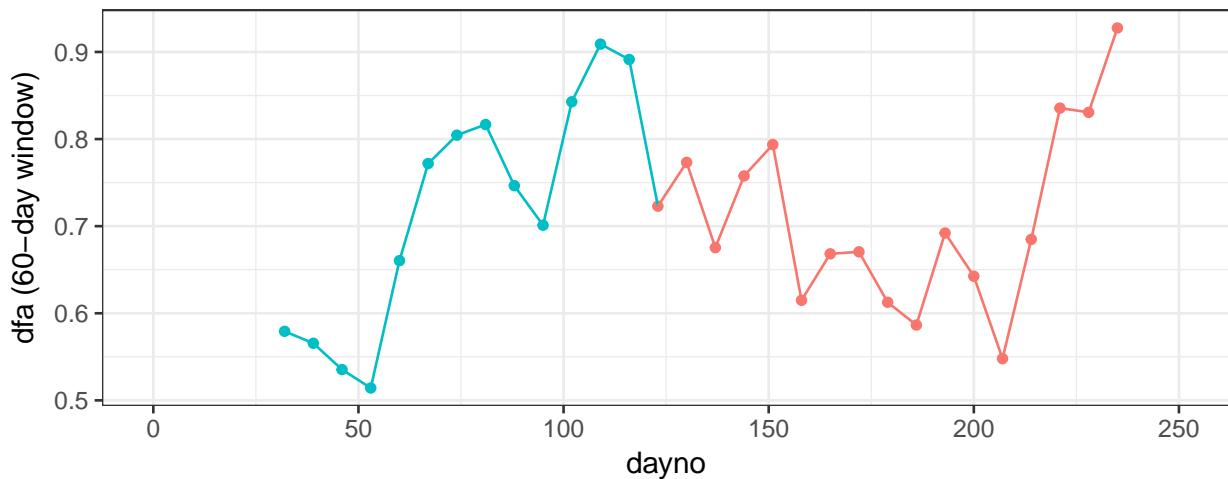


Figure 13.2: Results of the DFA analysis.

## 13.6 Discussion

Our re-analysis replicates the main finding of the Wichers et al article ((Wichers et al., 2016)): several weeks prior to a depression relapse, as predicted by complex systems theory, the variance and autocorrelation in EMA mood ratings increased.

One swallow does not make summer. Yes, in this case, the DFA-indicator peaked prior to the relapse. This could be a mere coincidence. The predictive power of CSD needs to be confirmed in larger samples. Given the theoretical background, successful applications of CSD in other domains, and the present finding, these studies seem warranted.

Important additional questions remain to be answered. When it predicts a state change, what is the expected delay between this prediction and the change? Does a critical DFA-value exist? Given that critical value, are false positive and false negative rates of this prediction acceptable? These are important questions that should be answered before any clinical application of DFA can be considered.

Re-analysis of data from completed clinical studies, in which EMA data were collected, may be a first step to further explore the value of CSD. One option, for example, would be to re-analyse data from the E-COMPARED study (Kleiboer et al., 2016). In this trial, patients, who were treated for major depression, completed weekly self-report questionnaires (the Patient Health Questionnaire; PHQ-8, Kroenke et al., 2009) and daily EMA mood ratings throughout treatment, which lasted up to 16-week. Since CSD is an indicator of *any* state change (i.e., irrespective of whether the change is clinically “good” or “bad”), theory would predict a (lagged) relationship between CSD (i.e., the DFA-score) and clinically significant changes in PHQ-scores (Jacobson and Truax, 1991).

Potential clinical applications, of course, are clear. If clinically relevant changes can be predicted algorithmically from EMA ratings, automated patient feedback systems could help to prevent pending deterioration or consolidate the path towards recovery.



# Chapter 14

## CASPAR

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```

# library(nlme)
#
d <- subset(caspar, substr(item, 1, 3) == "PHQ")
d <- d %>% group_by(id) %>%
  mutate(t = difftime(timestamp, timestamp[1], units = "days")) %>%
  mutate(t = as.numeric(t)) %>%
  mutate(t = round(t, 2))

fm1 <- nlme::lme(score ~ t, data = d, random = ~ 1 | id)
summary(fm1)
#> Linear mixed-effects model fit by REML
#> Data: d
#>   AIC   BIC logLik
#> 5804 5825 -2898
#>
#> Random effects:
#> Formula: ~1 | id
#>           (Intercept) Residual
#> StdDev:      1.14      1.62
#>
#> Fixed effects: score ~ t
#>             Value Std.Error DF t-value p-value
#> (Intercept) -0.873    0.1600 1409   -5.45  0.0000
#> t            -0.028    0.0106 1409   -2.68  0.0075
#> Correlation:
#>   (Intr)
#> t -0.443
#>
#> Standardized Within-Group Residuals:
#>   Min     Q1     Med     Q3    Max
#> -2.812 -0.666 -0.208  0.680  2.993
#>
#> Number of Observations: 1480
#> Number of Groups: 70

```

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# Chapter 15

## Homerange Estimation

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### 15.1 Section

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# **Part VI**

# **EMA Catalogues**



# Chapter 16

## EMA Research Groups within APH

This chapter summarises ongoing EMA research projects within the APH mental health consortium, as a guide to other researchers looking for nearby EMA-expertise and research collaboration.

### 16.1 Overview

Table 16.1: Overview of APH EMA research groups.

Name	Focus	URL	Organisation
CASPAR	Suicide	ilumivu.com	VU
Chronic Fatigue	Chronic Fatigue	???	AMC
E-COMPARED	Depression	ict4depression.eu	VU
FAntasTIGUE	Fatigue	tinyurl.com/ybb7up87	AMC
GROUP	Heart failure	-	AMC
IMPACT	Heart failure	impactonderzoek.nl	AMC
NESDA	Depression	nesda.nl	VuMC / GGz InGeest
Psychosystems	Symptom Networks	psychosystems.org	UvA
RADAR-CNS	Depression	radar-cns.org	VuMC / Ggz InGeest
TEMSTEM	Psychosis	tinyurl.com/ybac6flo	VU
VU-AMS	Stress & emotion	vu-ams.nl	VU

#### 16.1.1 The CASPAR Project (approval 16-02-2018)

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Aspect	Description
Project team	Dr. Wouter van Ballegooijen; Chani Nuij, MSc.; Prof.dr. Ad Kerkhof; Prof. dr Johannes Smit; Prof. dr. Heleen Riper
APH site	Vrije Universiteit Amsterdam, VUmc, GGZ inGeest
Full title	Continuous Assessment for Suicide Prevention and Research
Topic	Smartphone-enabled safety planning, self-monitoring, suicide
Status	Ongoing, 2016 - 2020

Aspect	Description
Target population	Adult suicidal patients (N = 80) with major depression or dysthymia and suicide risk in mental health care
Platform used	Ilumivu ( <a href="https://ilumivu.com">https://ilumivu.com</a> )
EMA active	Participants are prompted 3 times a day to answer 8 self-report items (e.g. 'I feel sad'). Items are based on existing questionnaires, such as the Patient Health Questionnaire (PHQ-9) and are rated on a 7-point Likert-scale, ranging from 'Not at all' to 'Very much'. Measured concepts include mood, rumination, hopelessness, defeat, entrapment, burdensomeness, belongingness, impulsiveness, suicidal imagery and suicidal ideation. Results are presented to patients in separate graphs.
EMA passive	Location data are gathered to indicate movement patterns and daily rhythm. Planned variables include accelerometer and smartphone usage patterns. These data are not visible to patients.
Data management	Patients receive a unique code to log in to the app. No names, phone numbers or other contact information are stored on the Ilumivu server. Patients are encouraged to show their graphs to their clinicians during treatment sessions.
Project goals	The primary objective of the CASPAR study is to test the feasibility of smartphone-based safety planning and real-time self-monitoring for patients with major depression or dysthymia and suicide risk in mental health care. Feasibility will be operationalised in terms of uptake, usage, acceptability, usability and patient satisfaction. EMA data will be used to (a) empirically validate hypothesised psychological processes and stages of suicide pathways, (b) identify individual pathways to suicidal behaviour, and (c) profile types of suicidal individuals.
Results	An interactive safety plan that patients can access 24/7, increased disease awareness of patients due to self-monitoring, and input for the national and international field of mental health care by sharing our results and our data, ultimately contributing to more personalised interventions according to precision medicine principles, and more effective suicide prevention.
Lessons learned	Constructing the right EMA items takes time. The constructs that you need to measure should be based on theory. Translate these concepts to momentary items in collaboration with EMA experts. Then test extensively among your target group.

### 16.1.2 Study on Chronic Fatigue Syndrome

Aspect	Description
Project team	Margreet Worm-Smeitink, MSc, ...., Prof. dr. Hans Knoop
APH site	AMC, Radboud UMC
Topic	Time series study on patients with chronic fatigue syndrome
Status	Completed (Period of study_____)
Target population	Patients attending the Expert Centre for Chronic Fatigue for diagnosis of Chronic Fatigue Syndrome (CFS, n = 102)
Platform used	RoQua ( <a href="https://www.roqua.nl">https://www.roqua.nl</a> )

Aspect	Description
EMA Measures	Participants were asked to complete an e-diary, 5 times a day, in a 2 week study period. Prompts were fixed in consultation with the participant, with a 3-hour break in between each. The e-diary assessed concepts such as fatigue, pain, anxiety, depression, functioning (physical, mental, social), focus on fatigue, fatigue catastrophising, self-efficacy, fear avoidance, and social incomprehension. Items were scored a 5-point Likert scale. In addition to the active self-report EMA, participants also contributed passive EMA data, by wearing an actimeter during the study period.
Data management	Participants received prompts on their smartphone, through a inviting SMS, with contained a link to the (web-based) e-diary.
Project goals	The objective of this study was to conduct time series analyses on fatigue, to investigate fatigue fluctuations over time.
Statistical methods	The R auto-var package (see ), was used to conduct network analyses
Results	Determinants of fatigue will be identified with the aim of personalizing treatment of fatigue in patients with CFS.
Lessons learned	Think carefully beforehand which variables to include for EMA as assessing too many variables will make it difficult to determine which variables to include in model. It also makes interpretation of results difficult. Prepare clear and detailed guideline/handbook for colleagues who will assist in including participants, and be aware of potential problems with the EMA app. This is to ensure that colleagues will be motivated to include participants into the study.

### 16.1.3 E-COMPARED (EU)

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### 16.1.4 FAntasTIGUE

Aspect	Description
Project team	Yvonne Goërtz, Melissa Thong, Daisy Janssen, Jeanette Peters, Jan Vercoulen, Chris Burtin, Yvonne Meertens-Kerris, Arnold Coors, Jean Muris, Emiel Wouters, Judith Prins, Mirjam Sprangers, Martijn Spruit
APH site	AMC (in collaboration with Ciro-Horn, Maastricht UMC, Radboud UMC, Hasselt University)
Full title	Fatigue in patients with chronic obstructive pulmonary disease: FAntasTIGUE study
Topic	Smartphone data collection
Status	Ongoing, 2017-2020
Target population	Patients with clinically stable chronic obstructive pulmonary disease (proposed: n = 60)

Aspect	Description
Platform used	Psymate ( <a href="https://psymate.eu">https://psymate.eu</a> )
Study design	Longitudinal with 4 data collection periods (baseline, 4, 8, 12 months)
EMA active	For each data collection period, participants are prompted 8 times a day at random moments between 7.30am and 22.30pm, for 5 consecutive days, to answer 19 items (including 9 contextual items). Measured concepts include fatigue, relaxed feeling, breathlessness, agitation, uncertainty, irritation, satisfaction, anxiety, feeling energetic, and feeling mentally fit. Items are rated on a 7-point Likert-scale, ranging from 'Not at all' to 'Very much'.
EMA passive	In conjunction with the self-reported questionnaire, patients are also asked to wear an actigraph (activity monitor) for 7 days, even during sleep.
Data management	During the data collection period, patients are provided with iPods installed with the EMA application.
Project goals	To capture possible diurnal fluctuations in fatigue.
Results	Future results will guide the development of interventions for the management of fatigue in this patient group.
Link to protocol paper	<a href="http://bmjopen.bmj.com/content/8/4/e021745.long">http://bmjopen.bmj.com/content/8/4/e021745.long</a>

### 16.1.5 The GROUP project

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### 16.1.6 MERITS (approval summary 12-03-2018)

Aspect	Description
Project team	Frank J. Snoek, PhD; Maartje de Wit, PhD; Daniel van Raalte, MD, PhD; Erik Serné, MD, PhD; Cati Racca, MD; L. Muijs, MSc
APH site	VUmc, AMC
Full title	MERITS - Momentary assessment of patient Experiences in Real life of Insulin Glargine 300 in Type 1 diabetes Study
Topic	Type 1 diabetes, relationship between blood glucose variability (continuous glucose measurement) and changes in mood and energy.
Status	Ongoing proof-of-concept study, 2018 - 2020
Target population	Adult patients (N=70) with type 1 diabetes
Platform used	Illumivu
EMA	Currently under development. Participants will be (randomly) prompted to answer questions on mood (based on POMS questionnaire), diabetes distress, fear of hypoglycaemia and sleep.

Aspect	Description
Project goals	Explore whether a) blood glucose variability (SD and CV) is related to changes in wellbeing (mood) during waking time, b) if switching to U-300 results in less glucose variability and translates into improved mood over time within patients, c) explore if individual differences (profiles) can be distinguished with regard to the (strength of the) association between glucose variability and changes in mood.

### 16.1.7 NESDA EMA Diary Study

Aspect	Description
Project team	Femke Lamers, Phd
APH site	VUmc, GGZ inGeest
Full title	the Netherlands Study of Depression and Anxiety (NESDA), Wave 6 diary study
Topic	Momentary assessment of people with depressive symptoms
Status: 2015 - 2017	
Target population	Selected sample of NESDA participants with symptoms of depression and healthy controls
Platform used	RoQua ( <a href="https://www.roqua.nl/">https://www.roqua.nl/</a> )
EMA active	The self-report questionnaire contained 31 items. Items were rated on a 7-point Likert scale, ranging from 'not [at all]' to 'very'. 1) Valance and arousal (2 items, "I'm feeling ...") which were scored on Likert scales ranging from very unpleasant to very pleasant and very calm to very excited; 2) Current state (12 items, "I feel relaxed", "I feel down", "I feel cheerful"), symptoms of depression/anxiety (4 items, "I worry a lot", "I am able to concentrate well", and physical condition (2 items, "I feel tired") scored on 7-point Linkert scales ranging from 1 (not) to 7 (very); 3) Social context (2 items, "Where are you now" (e.g. at the neighbour's house), "In who's company are you now") and a follow-up question (1 item, "I would rather have had company" or "I experience my company as being ..." (unpleasant - pleasant)); 4) Sleep (3 items on sleep quality and duration); 5) Daily uplifts/hassles, when rated with yes, participants were asked to elaborate (3 items on intensity, importance and internal or external cause); 5) Activities (1 multiple-choice item, including social interaction, additional (eating) and other (exercise); 6) Substance use: smoking, coffee and alcohol (number of units); 7) Eating (1 item at final daily prompt, "Did you eat more or less than usual"); And an evaluative addendum questionnaire: 1) Burden (1 item, "How disrupting was it to fill in this questionnaire"; 2) Open ended question for general comments on circumstances that might influence answers. Participants were prompted five times a day, for two weeks. Prompts consisted of a SMS, which contained a link to the EMA questions. Participants were asked to fill in the questionnaire within 15 minutes after the SMS. After 30 minutes a reminder was sent, and after 60 minutes the link would become inactive. Each questionnaire contained circa 35 items. Questions Q1 till Q14 have been used in a previous study; the Uncovering the Positive Potential of Emotional Reactivity (UPPER) study (Bennik (2015)). The other items are inspired on earlier EMA studies, such as the work by Mehl and colleagues (Mehl and Conner (2012)), van Os and colleagues (Wichers et al. (2012)) and studies performed at the Interdisciplinary Center of Psychopathology and Emotion regulation (ICPE), such as the Mood and Movement in Daily life (MOOVD) study (Booij (2015)).

Aspect	Description
Data management	EMA started within 31 days after the regular NESDA assessments (face-to-face interview and self-report measures). Participants could use their own smartphone if they had sufficient data, or access to WiFi for at least 80% of the two-week time period. If participants did not have a smartphone, they could borrow one. Patients were briefed on the EMA study during a face-to-face session with a research assistant (following standard NESDA data 9-year follow-up assessment). Participants needed to answer all questions before the questionnaire could be send to the secured server. In order to motivate participants to adhere to EMA, they were shown two examples of mood fluctuation reports, one with a 43% compliance rate and one with a 96% compliance rate. Personalized reports were sent via e-mail in a password protected document. During data collection, patients were contacted by a research assistant after 24 hours and 7 days in order to enquire whether problems had occurred with EMA. Research assistants actively monitored data collection and contacted participants if they missed three consecutive questionnaires. Data were stored in a secured web-environment of the University Medical Centre Groningen (UMCG).
EMA passive	In order to record the amount of physical activity during EMA monitoring, participants were asked to wear an accelerometer (GENEActiv) on their non-dominant wrist 24 hours a day for two weeks. Recording started on the evening prior to the first EMA assessment and continued until the morning after the last assessment. After data collection, participants mailed their watch to the research center. Data was extracted via a USB with GENEActiv software.
Results	EMA data will be used to assess a variety of research questions, concerning topics such as the dynamic interplay between cognitions, emotions, behavior and environment in daily life of individuals, the feasibility of EMA in participants with affective disorders, chronotype and diurnal patterns of activity in depressed versus non-depressed participants, and MDD subtypes.
Lessons learned and advice for other researchers	XXX

### 16.1.8 The Psycho-systems group

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### 16.1.9 Project RADAR-CNS (EU)

Aspect	Description
Dutch project team	XXX

Aspect	Description
APH site	VUmc, GGZ inGeest
Context	The project is jointly led by King's College London and Janssen Pharmaceutica NV. The project is funded by the Innovative Medicines Initiative, a Public Private Partnership set up between the European Federation of Pharmaceutical Industries and Associations (EFPIA) and the European Union). It includes 23 organizations from across Europe and the US.
Full title	RADAR-CNS: Remote Assessment of Disease and Relapse - Central Nervous System
Topic	Wearable devices to help prevent and treat depression, multiple sclerosis and epilepsy
Status	Ongoing, XXX
Target populations	Patients with major depressive disorder, epilepsy or multiple sclerosis (MS).
Project goals	Examine how remote measurement technologies can monitor and improve quality of life and psychological well-being for people with depression, epilepsy, or multiple sclerosis.
Technical goals	1) Built an end-to-end system with generalized data aggregation capabilities. The platform focuses on classes of data rather than specific devices, in order to enhance modularity and adaptability as new devices become available. The platform is delivered under an Apache 2 open source license. 2) Big data solutions.
Clinical goals	1) Continuous monitoring of patients, 2) predicting disease onset or relapse (prevention and risk assessment)
EMA active	EMA questionnaires via pRMT application, which was built with Cordova. Outcomes include variability in sleep quality, levels of activity, social interactions, mood, cognitive performance and stress as possible predictors of clinical course.
EMA passive	1) Location and movement (GPS) 2) Mood: voice recognition 3) Social interaction (call and message logs), and 4) App interaction and app usage.
Wearables	Skin temperature, heart rate (-variability), actigraphy (3-axis accelerometer, gyroscope), galvanic skin conductance (Empatica E4 Wristband, Pebble 2 Smartwatch, Biovotion VSM, Faros 180, and Fitbit devices). In the depression study a Fitbit will be used to measure sleep and activity.
Data management	Participants are requested to install three apps on their Android smartphone. Data is collected during a 2-year period. Active EMA will be activated every 6 weeks for 6 consecutive days. Four times per year a non-EMA follow-up is conducted, which contains (qualitative) interviews and self-report questionnaires. Log in is facilitated with token-based authentication and authorization. A dashboard app allows for live monitoring of results. Data is streamed and analyzed live.
Results	GGZ inGeest will participate in the depression study as a research site. Data will be used to assess a variety of research questions, concerning topics such as MDD subtypes, seasonal depression and predicting relapse
Lessons learned	When measuring over such a long timespan, extra attention should be paid to the possible burden for participants. Continuous monitoring via a Smartphone can severely impact battery life

### 16.1.10 TemStem (approval 08-03-2018)

Aspect	Description
Topics	Psychosis, auditory hallucinations, social participation in people with schizophrenia.

Aspect	Description
Project title	Temstem
Project team	Mark van der Gaag, PhD; Alyssa Jongeneel, MSc; David van den Berg, PhD; Dorien Scheffers, MSc
APH site	Vrije Universiteit Amsterdam, VUmc, GGZ inGeest, Parnassia Psychiatric Institute
Status	Ongoing, March 2016- July 2018
Target population	People who suffer from hearing voices and are obstructed by them in their daily life
Platform used	Temstem application. Developed by Reframing Studio, in collaboration with Parnassia Psychiatric Institute and TU Delft
EMI	Mobile application (Temstem) focuses on reducing distress and dysfunction caused by auditory verbal hallucinations (AVH). Components: 1) coping: addressing verbal working memory phonological loop with a language task, thereby blocking the hearing of voices, 2) positive reinforcement: decreasing self-reported negative self-esteem themes, 3) treatment: reducing emotional response to memories associated with voices by taxing the auditory working memory during recall of negative auditory memories (as in EMDR therapy). Users are encouraged to fill-in 9 self-report items on a daily basis.
EMA Outcomes	1) hearing voices: 6 items (e.g. "Today, the voices were disturbing"), 2) mood: 1 item ("I felt depressed"), 3) self-esteem: 1 item ("I was satisfied about myself"), 4) the use of Temstem ("I used Temstem today"). Items are rated on a 7-point Likert-scale. Items are based on existing EMA questionnaires. Results are presented to users in separate graphs, in order to support users in gaining insight in the pattern of AVH over time, or after use of Temstem.
Project goals	Examine the effect of the app on distress and dysfunction in a RCT. Investigate the effect of Temstem on frequency and severity of AVH, to determine working mechanisms, to identify predictors and mediators of effects, and to test the usability of Temstem.
Results	Reduce distress and dysfunction caused by auditory verbal hallucinations
Data management	Data is stored on a server hosted by Service Heroes (via Reframing Studio), under users' unique download numbers. Stored variables include, among others, scores of vividness of AVH pre and post use of Temstem, data on application use (duration), used function (e.g. 'Silencing' function which focuses on coping, or 'Challenging' function which is based on dual tasking), and how users feel when they hear voices. Users can choose to provide additional information on age, gender, which county in the Netherlands they are currently located, how they found the app, and why they want to use it (e.g. because they hear voices, because they are a clinician and they want to learn more about the app to support clients, etc.). Clinicians cannot access user data or graphs. Researchers can, but only in big data files. To see users' personal data (e.g. how many times they used the app, how vivid the voices were before and after the use of Temstem, etc.) researchers need the users' unique download number.
Lessons learned	Users need internet to use the app, because it works on an online platform. However, not all our users have wireless internet. If we had known this in time, we would have chosen to run it offline. Other lessons we have learned are that you have to resolve bugs as soon as possible, because otherwise it may take a long time before it is fixed. Be very explicit in what you want and expect from the app developers, even when you think that it is quite logic and clear.

### 16.1.11 VRETp trial (approval 02-03-2018)

Aspect	Description
Project	Effect of virtual reality exposure therapy on social participation in people with a psychotic disorder (VRETp)
Project team	Mark van der Gaag, PhD; Roos Pot-Kolder, MSc; Wim Veiling; Chris Geraets
APH site: Vrije Universiteit Amsterdam, VUmc, UMC Groningen	
Status	Completed, 2013-2016
Target population	Patients (n = 116) with psychotic disorders who fear social situations.
Platform	PsyMate ( <a href="http://www.psymate.eu/">http://www.psymate.eu/</a> )
Study information	EMA data was collected as part of a RCT comparing treatment as usual plus virtual reality therapy (VR-CBT) to treatment as usual for outpatients suffering from a psychotic disorder and paranoid ideation. EMA was used to assess the primary outcome social participation.
EMA active	1) Anxiety (1 item, e.g. "I feel anxious"), 2) Perceived social threat (4 items, e.g. "In this company, I feel accepted"), 3) Paranoia (3 items, e.g. "I feel suspicious"), and 4) Time spent with others (max. 3 multiple choice items inquiring about type of company (nobody, family, non-family, etc.). Patients were prompted 10 times a day, during 6 days. Anxiety, threat and paranoia Items were rated on a 7-point Likert scale, ranging from 1 ("not at all") to 7 ("very"). Reports had to be completed within 15 min of the beep. EMA items were used in previous studies (Collip et al., 2010).
Data management	To be included in the analysis, participants had to complete diary entries for at least one-third of the beeps (i.e., a minimum of 20 measurements). Because the PsyMate application was not finished at the time of the trial, participants were provided with a small palmtop device for the duration of EMA. Data was extracted with 4D software. Time spent with others was defined as the percentage of time participants were in company of others (excluding mental health care professionals). Other EMA measurements were only used when a participant reported being in a social situation. Information was stored on the PsyMate server, under a user-specific PsyMate-ID number. Researchers had access to a file matching study-ID to PsyMate-ID numbers, which allowed matching of information acquired via EMA with information acquired with regular self-report measures during the RCT study.
Project goals	Testing the effects of virtual-reality-based cognitive behavioural therapy (VR-CBT) on paranoid thoughts and social participation via momentary assessment.
Results	All 116 participants completed EMA measurements at baseline (mean number of completed self-assessments 46.1, SD 13.3), 96 participants completed the post-treatment assessment sufficiently (43.1, SD 10.1), and 87 participants completed the follow-up (43.2, SD 11.1). The trial results suggest that the addition of VR-CBT to standard treatment can reduce paranoid ideation and momentary anxiety in patients with a psychotic disorder.
Lessons learned	Participants reported not wanting to explain to others why they were using the palmtop (a small black hand-held computer) as a reason for non-compliance with EMA. This directly interfered with the primary aim, namely assessing social context. An app facilitates measurement without the participant having to explain to others what they are doing.
Trial registration	Current Controlled Trials: ISRCTN12929657. Date of registration: 8 September 2015.

### 16.1.12 VU-AMS (not yet checked by group 13-04-2018)

Aspect	Description
Project team	Eco de Geus, PhD; Gonneke Willemse, PhD; Martin Gevonden, PhD; Denise van der Mee, MSc.
APH site	Vrije Universiteit Amsterdam
Full title	VU University Monitoring System (VU-AMS)
Topic	Wearable for passive (non-evasive) ambulatory measurement of the autonomic nervous system for research purposes
Status	Ongoing (1990 - present)
Target population	Various target populations.
EMA passive	Heart Rate / Inter beat Interval (IBI), Heart Rate Variability (SDNN, RMSSD, IBI power spectrum: HF, LF), Respiratory Sinus Arrhythmia (RSA), Pre-Ejection Period (PEP), Left Ventricular Ejection Time (LVET), Respiration Rate (RR), Stroke Volume (SV) and Cardiac Output (CO), Skin Conductance Level (SCL) and Skin Conductance Responses (SCRs), Tri-Axial Accelerometry (Body Movement). The VU-AMS device is battery powered and can record 24 to 48 hours of data (4GB storage). Data is extracted with infrared to USB.
Data management	Users do not have access to data. The Data Analysis and Management System (DAMS) is used for data extraction and processing. The DAMS tool offers options for data inspection (visual inspection of raw data), automated detection of R-peaks in raw ECG signal and visual inspection of final IBI time series, labelling data, IBI spectral power calculation, automated scoring of parasympathetic tone (respiration scoring), impedance scoring and data export per label (to EXCEL or ASCII) <a href="http://www.vu-ams.nl/support/downloads/software/">http://www.vu-ams.nl/support/downloads/software/</a> .
Current VU-AMS projects	Validation of the Philips EmoGraphy technology to measure sympathetic nervous system activity in an ambulatory setting (van der Mee et al., ongoing, 2017 - 2021).
EMA passive	Wearable, which measures combined skin conductance and heart rate variability. Information on current stress situation is presented as a Stress Level Score to the user, alongside a one-hour prediction of changes in stress level and cognitive functioning (Cognitive Zone changes).
Results	The project aims to validate EmoGraphy by XXX (methods). The technology aims to “provide actionable insights that allow users to manage their emotional and physical stress so they can perform in the optimal cognitive zone in their daily activities” <a href="http://www.ip.philips.com/licensing/program/121">http://www.ip.philips.com/licensing/program/121</a> .
Lessons learned and advice for other researchers	XX

### 16.1.13 The IMPACT Onderzoek project

Aspect	Description
Project team	Iris Hartog, Tom Oreel, Pythia Nieuwkerk, Michael Scherer-Rath, José Henriques, Hanneke van Laarhoven, Mirjam Sprangers
APH site	AMC, VUmc
Full title	Improving the conceptualisation and measurement of quality of life of patients with multiple chronic morbidities, exemplified by patients with cardiac disease undergoing cardiac intervention
Topic	Smartphone data collection

Aspect	Description
Status	Ongoing, 2016-
Target population	Cardiac patients who underwent either angioplasty or bypass surgery (N= 37/320)
Platform used	Psymate ( <a href="https://psymate.eu">https://psymate.eu</a> )
Study design	Longitudinal with 3 data collection periods (pre-treatment, within 2 weeks after treatment, 3-6 months post-treatment)
EMA active	Participants are prompted to answer 9 general and 1 evening questionnaire per day for 7 consecutive days. During the day, patients are beeped randomly between 7.30 and 22.30 hours to complete the general questionnaire. The general questionnaire contains 19 items, including 5 contextual items. Concepts measured include agitation, relaxed feeling, anxiety, feeling down, feeling energetic, irritation, happiness, tiredness, worry, chest pain, other types of pain, shortness of breath, tightness in chest, feeling stuffy in the chest. Items are rated on a 7-point Likert-scale, ranging from 'Not at all' to 'Very much'. Patients are asked to complete the evening questionnaire just before the go to bed. The evening questionnaire has a different set of questions including the QoL of that day, items from the EQ5, and the health status of that day. The last item is rated on a visual analogue scale from 0 (worst) to 100 (best).
Data management	Participants are provided with iPods installed with the EMA application during data collection
Project goals	The project aims to compare QoL collected retrospectively through paper surveys with that collected via EMA. Data collected through EMA can also inform possible changes in daily QoL, taking contextual situations into account.
Statistical methods	R package used to conduct network analyses
Results	Potential results can offer personalized assessments or advice to patients at risk of poorer QoL following cardiac intervention. Prediction of
Lessons learned	To maintain response during follow-ups, it is important to maintain contact with patients between follow-ups. The quality of EMA data can be low due to significant amount of missing data. Besides missing data, lack of variation in answers from day-to-day (through use of a Likert scale) could also be an issue. Both missing data and lack of variation can be a problem if planning to run network analyses. Due to the amount of data collected via EMA, data cleaning can take up a significant amount of time.
website	<a href="http://www.impactonderzoek.nl/">http://www.impactonderzoek.nl/</a>



# Chapter 17

## EMA Instruments Catalogue

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### 17.1 Apps

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Table 17.1: EMA Instruments.

Name	Manufacturer	URL	Active	Passive	Backoffice
Illumivu	Illumivu.com	illumivu.com	YES	YES	YES
MoodBuster	ICT4D Consortium	moodbuster.eu	YES	YES	No
Movisense	MoviSence	movisense.org	YES	YES	YES
PsyMate	PsyMate	psymate.eu	YES	YES	No
Survey Signal		surveysignal.com	YES	NO	Yes

#### 17.1.1 Illumivu

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<https://illumivu.com/>

#### 17.1.2 MoodBuster

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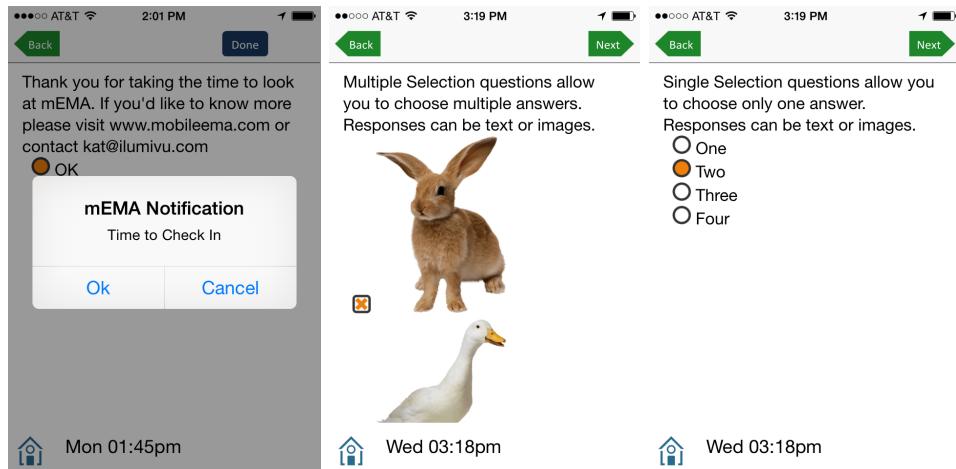


Figure 17.1: Illumivu App Screenshots

sem. Aenean lectus nunc, bibendum ut orci vel, tristique pellentesque arcu. Vestibulum id laoreet neque. Phasellus at ex velit. Vestibulum scelerisque nulla ut massa tempor, ac dapibus dui viverra.

<http://www.moodbuster.eu/>



Figure 17.2: MoodBuster App Screenshots

### 17.1.3 Movisense XS

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### 17.1.4 PsyMate

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Aliquam vehicula augue metus, in tincidunt urna luctus sit amet. Sed ultrices, erat at laoreet semper, sem tellus hendrerit mi, eget pulvinar massa nisl ac dolor. Nunc ac tellus nec tortor interdum porta. Vestibulum hendrerit tempus condimentum. Donec a mollis sem. Aenean lectus nunc, bibendum ut orci vel, tristique pellentesque arcu. Vestibulum id laoreet neque. Phasellus at ex velit. Vestibulum scelerisque nulla ut massa tempor, ac dapibus dui viverra.

<http://www.psymate.eu/>

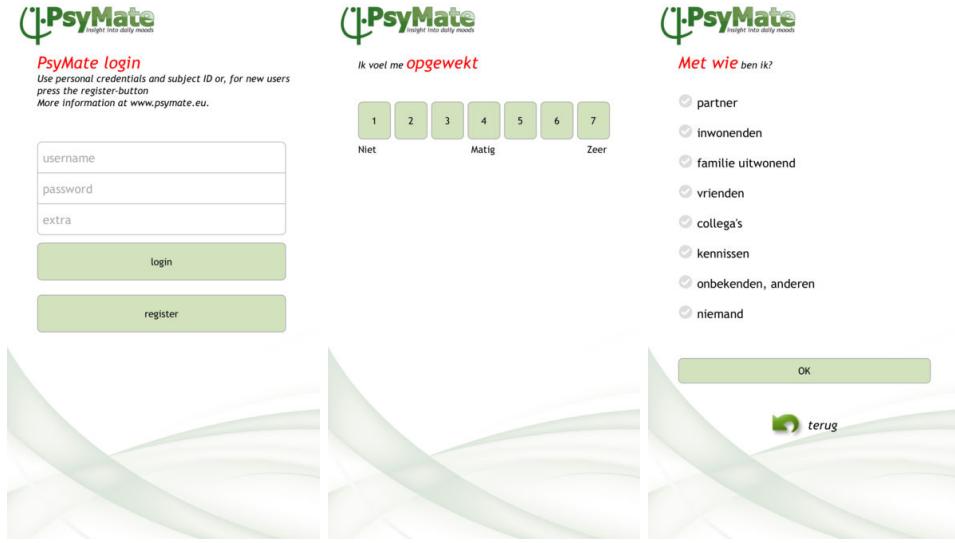


Figure 17.3: PsyMate App Screenshots

### 17.1.5 Survey Signal

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# Chapter 18

## R packages for EMA research

Many specialised R packages exist for EMA analysis. In this chapter, these packages are discussed. We provide a summary description, and example analysis code.

Table 18.1: Alphabetic list of specialised R packages that are useful for EMA research.

Name	Category	Description
adehabitatHR	Passive EMA data analysis	Developed for home range estimation of wild animals from GPS data. Useful for human data as well (see Chapter 15).
autovar	Symptom Networks	Automate the construction of vector autoregressive models.
bootnet	Symptom Networks analysis	Determine the stability of symptom networks.
GGIR	Accelerometer Data	Simplifies management and analysis of raw accelerometer data.
lme4	Mixed Modeling	Fit linear and nonlinear mixed effects models. More efficient reimplementation of package ‘nlme’, that also provides options for generalised modeling.
lomb	GPS data	Calculate the Lomb-Scargle Periodogram for unevenly sampled time series.
nlme	Mixed Modeling	Fit linear and nonlinear mixed effects models. Pre-dates package lme4, but is still used because it provides more advanced options to model correlational structures in the data.
powerlmm	Power analysis	power calculation for two- and three- level multilevel models with missing data.
simr	Power analysis	Simulation-based power calculations for mixed models
simstudy	Data simulation	Simulating study data.
tidyverse	Data Management & Visual Exploration	Well-managed set of packages for data management and data visualisation. Includes “ggplot2”, ‘dplyr’, and ‘haven’ (to read and write SPSS data files).
qgraph	Symptom Networks analysis	Estimate and plot symptom networks.

## 18.1 Data management & Visual Exploration

### 18.1.1 Package tidyverse

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```
# code snippet 18.1: loading the tidyverse package
library(tidyverse)
```

Vivamus enim turpis, pulvinar volutpat purus nec, lobortis <http://tidyverse.tidyverse.org>.

#### 18.1.1.1 Package ggplot2

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Aliquam vehicula augue metus, in tincidunt urna luctus sit amet. Sed ultrices, erat at laoreet semper, sem tellus hendrerit mi, eget pulvinar massa nisl ac dolor. Nunc ac tellus nec tortor interdum porta.

```
# code snippet 18.2: simple ggplot example
d = data.frame(
  ID      = rep(1:4, each = 25),
  time   = rep(1:25, 4),
  score  = rnorm(100, 0, 2))

# initialise the plot area and the data mapping
g <- ggplot(d, aes(x = time, y = score))
g

# add scatterplot
g <- g + geom_point()
g

# fit a smoothed line
g <- g + geom_smooth()
g

# split plot by ID
g + facet_wrap(~ ID)
```

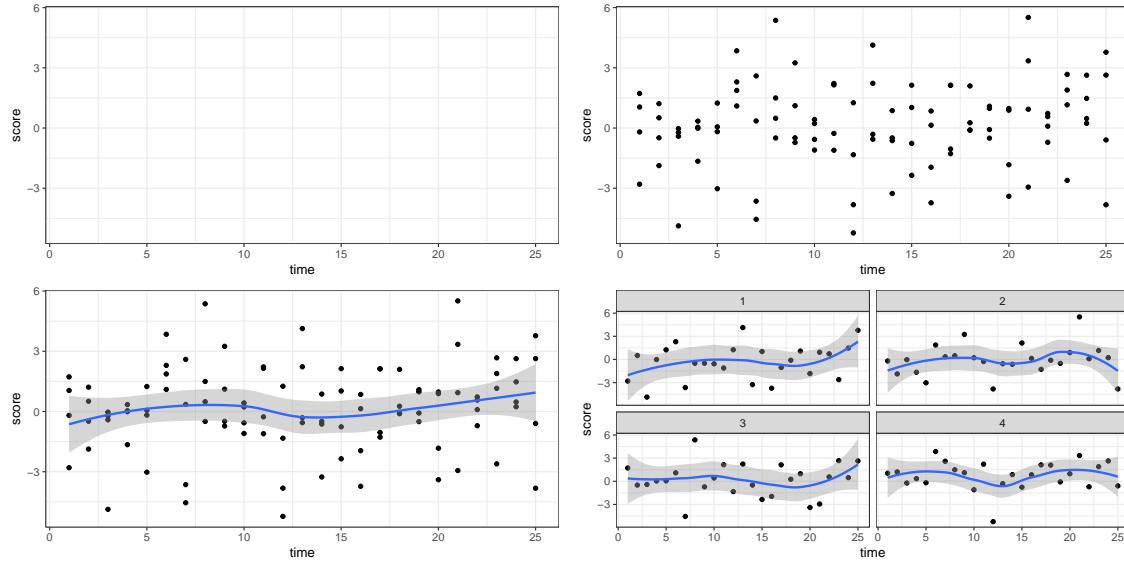


Figure 18.1: Plotting layers with ggplot2

Donec sed lectus at sem ultrices commodo. Proin a viverra metus, nec scelerisque odio. Morbi viverra tristique libero vel fringilla. Sed at varius erat, id consequat nibh. Ut eget leo blandit orci posuere tincidunt ac sed erat. Aenean metus metus, eleifend ut facilisis a, fringilla ut neque. Nunc hendrerit cursus eleifend at the tidyverse website. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas (Wickham, 2016).

### 18.1.1.2 Package dplyr

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Aliquam vehicula augue metus, in tincidunt urna luctus sit amet. Sed ultrices, erat at laoreet semper, sem tellus hendrerit mi, eget pulvinar massa nisl ac dolor. Nunc ac tellus nec tortor interdum porta.

```
# code snippet 18.3: aggregate data by group, through a 'pipe'
d %>%
  group_by(ID) %>%
  summarise(mean_score = mean(score)) %>%
  round(., 2)
#> # A tibble: 4 x 2
#>   ID    mean_score
#>   <dbl>      <dbl>
#> 1     1      -0.32
#> 2     2      -0.06
#> 3     3       0.17
#> 4     4       0.78
```

Donec sed lectus at sem ultrices commodo. Proin a viverra metus, nec scelerisque odio. Morbi viverra tristique libero vel fringilla. Sed at varius erat, id consequat nibh. Ut eget leo blandit orci posuere tincidunt ac sed erat. Aenean metus metus, eleifend ut facilisis a, fringilla ut neque. Nunc hendrerit cursus eleifend. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas.

## 18.2 Linear mixed modeling

Package **nlme** and **\*lme4** consectetur adipiscing elit. Aliquam vehicula augue metus, in tincidunt urna luctus sit amet. Sed ultrices, erat at laoreet semper, sem tellus hendrerit mi, eget pulvinar massa nisl ac dolor.

### 18.2.1 nlme

Package **nlme** ac tellus nec tortor interdum porta. Vestibulum hendrerit tempus condimentum. Donec a mollis sem (Pinheiro et al., 2018). Aenean lectus nunc, bibendum ut orci vel, tristique pellentesque arcu. Vestibulum id laoreet neque. Phasellus at ex velit. Vestibulum scelerisque nulla ut massa tempor, ac dapibus dui viverra. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Vivamus enim turpis, pulvinar volutpat purus nec, lobortis imperdiet diam.

```
# code snippet 18.4: fit a linear mixed model, with lme
library(nlme)
fm <- lme(distance ~ age + Sex, data = Orthodont, random = ~ 1)
summary(fm)

#> Linear mixed-effects model fit by REML
#> Data: Orthodont
#>   AIC BIC logLik
#> 448 461 -219
#>
#> Random effects:
#>   Formula: ~1 | Subject
#>             (Intercept) Residual
#> StdDev:       1.81      1.43
#>
#> Fixed effects: distance ~ age + Sex
#>                  Value Std.Error DF t-value p-value
#> (Intercept) 17.71     0.834 80  21.23  0.0000
#> age          0.66     0.062 80   10.72  0.0000
#> SexFemale   -2.32     0.761 25   -3.05  0.0054
#> Correlation:
#>           (Intr) age
#> age        -0.813
#> SexFemale -0.372  0.000
#>
#> Standardized Within-Group Residuals:
#>   Min     Q1     Med     Q3    Max
#> -3.7489 -0.5503 -0.0252  0.4534  3.6575
#>
#> Number of Observations: 108
#> Number of Groups: 27
```

### 18.2.2 lme4

Package **lme4** at sem ultrices commodo. Proin a viverra metus, nec scelerisque odio. Morbi viverra tristique libero vel fringilla (Bates et al., 2015). Sed at varius erat, id consequat nibh.

```
# code snippet 18.4: fit a linear mixed model, with lme
library(lme4)
```

```
fm <- lmer(distance ~ age + Sex + (1 | Subject), data = Orthodont)
summary(fm)
```

Ut eget leo blandit orci posuere tincidunt ac sed erat. Aenean metus metus, eleifend ut facilisis a, fringilla ut neque. Nunc hendrerit cursus eleifend. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Vivamus enim turpis, pulvinar volutpat purus nec, lobortis imperdiet diam.

## 18.3 Power analysis

### 18.3.1 Powerlmm

```
# code snippet 3.2: Power analysis of a two-group repeated measures design
# (analytical approach)
library(powerlmm)
p <- study_parameters(n1 = 24,
                      n2 = 40,
                      effect_size = cohend(0.5,
                                           standardizer = "pretest_SD"),
                      icc_pre_subject = 0.5,
                      var_ratio = 0.01)

get_power(p)
#>
#>     Power Analysis for Longitudinal Linear Mixed-Effects Models
#>             with missing data and unbalanced designs
#>
#>             n1 = 24
#>             n2 = 40 (treatment)
#>                     40 (control)
#>                     80 (total)
#>             dropout = No missing data
#>             icc_pre_subjects = 0.5
#>             var_ratio = 0.01
#>             effect_size = 0.5 (Cohen's d [SD: pretest_SD])
#>             df = 78
#>             alpha = 0.05
#>             power = 26 %
```

Note the two additional variables in the ‘study\_parameters’ call: ‘icc\_pre\_subject’, and ‘var\_ratio’. According to the package documentation (?study\_parameters), ‘icc\_pre\_subject’ refers to the ‘amount of baseline variance at the subject level’, and ‘var\_ratio’ refers to the ‘ratio of the random slope variance to the within-subject variance’.

### 18.3.2 Package ‘simr’

With package ‘simr’ (Green and MacLeod, 2016), power of mixed models can be determined via simulation:

```
# code snippet 3.3: Power analysis of a two-group repeated measures design
# (simulation approach)
library(simr)
```

```

# construct design matrix
t <- 1:24
s <- 1:40
X   <- expand.grid(t = t, s = s)
X$g <- c(rep(0, 24), rep(1, 24))

# fixed intercept and slope
b <- c(2, -0.1, -0.5)

# random intercept variance
V1 <- 0.5

# random intercept and slope variance-covariance matrix
V2 <- matrix(c(0.5, 0.05, 0.05, 0.1), 2)

# residual standard deviation
s <- 1

model1 <- makeLmer(y ~ t + g + (1 | s),
                     fixef = b,
                     VarCorr = V1,
                     sigma = s,
                     data = X)

powerSim(model1,
          fixed("g", "lr"),
          nsim = 10,
          progress = FALSE)
#> Power for predictor 'g', (95% confidence interval):
#>       60.00% (26.24, 87.84)
#>
#> Test: Likelihood ratio
#>       Effect size for g is -0.50
#>
#> Based on 10 simulations, (0 warnings, 0 errors)
#> alpha = 0.05, nrow = 960
#>
#> Time elapsed: 0 h 0 m 1 s

```

## 18.4 Analysis of passive EMA data

### 18.4.1 Accelerometer data: Package ‘GGIR’

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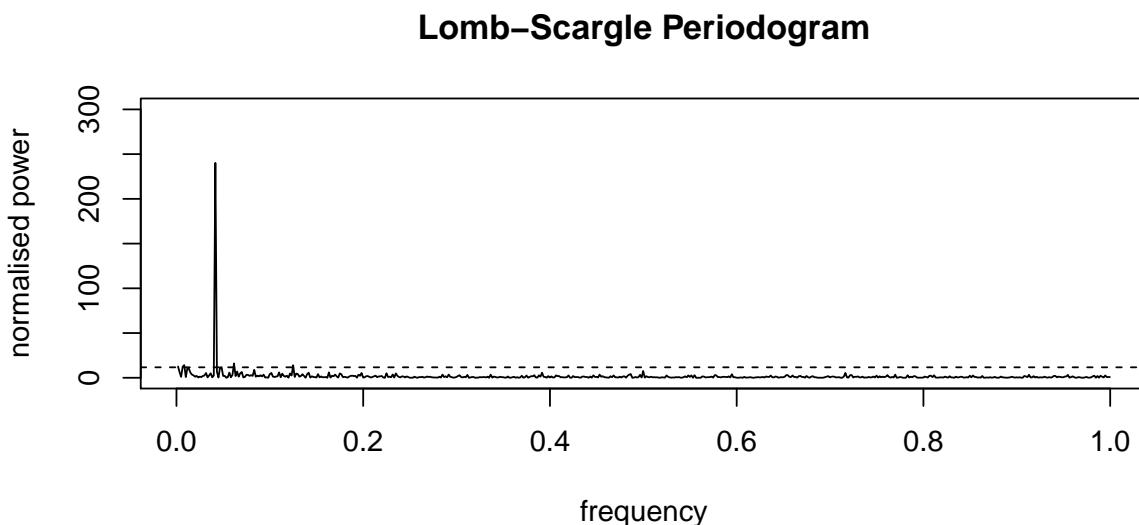
Donec sed lectus at sem ultrices commodo. Proin a viverra metus, nec scelerisque odio. Morbi viverra tristique libero vel fringilla. Sed at varius erat, id consequat nibh. Ut eget leo blandit orci posuere tincidunt ac sed erat. Aenean metus metus, eleifend ut facilisis a, fringilla ut neque. Nunc hendrerit cursus eleifend.

Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Vivamus enim turpis, pulvinar volutpat purus nec, lobortis imperdierat diam.

### 18.4.2 GPS data: Package ‘lomb’

Package **lomb** simplifies the computation of Lomb-Scargle periodograms. Proin a viverra metus, nec scelerisque odio (Ruf, 1999). Morbi viverra tristique libero vel fringilla. Sed at varius erat, id consequat nibh (Saeb et al., 2015). Ut eget leo blandit orci posuere tincidunt ac sed erat. Aenean metus metus, eleifend ut facilisis a, fringilla ut neque. Nunc hendrerit cursus eleifend. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Vivamus enim turpis, pulvinar volutpat purus nec, lobortis imperdierat diam.

```
# code snippet 18.5: calculating a Lomb-Scargle periodogram
data(ibex, package = "lomb")
lomb::lsp(ibex[2:3])
```



### 18.4.3 GPS data: Package adehabitatHR

Package **adehabitatHR** at sem ultrices commodo. Proin a viverra metus, nec scelerisque odio. Morbi viverra tristique libero vel fringilla (Calenge, 2006). Sed at varius erat, id consequat nibh. Ut eget leo blandit orci posuere tincidunt ac sed erat. Aenean metus metus, eleifend ut facilisis a, fringilla ut neque. Nunc hendrerit cursus eleifend. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Vivamus enim turpis, pulvinar volutpat purus nec, lobortis imperdierat diam.

```
library(adehabitatHR)
```

## 18.5 Symptom Network Analysis

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Aliquam vehicula augue metus, in tincidunt urna luctus sit amet. Sed ultrices, erat at laoreet semper, sem tellus hendrerit mi, eget pulvinar massa nisl ac dolor (see Chapter 9).

### 18.5.1 Package 'qgraph'

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Donec sed lectus at sem ultrices commodo. Proin a viverra metus, nec scelerisque odio. Morbi viverra tristique libero vel fringilla. Sed at varius erat, id consequat nibh. Ut eget leo blandit orci posuere tincidunt ac sed erat. Aenean metus metus, eleifend ut facilisis a, fringilla ut neque. Nunc hendrerit cursus eleifend. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Vivamus enim turpis, pulvinar volutpat purus nec, lobortis imperdiet diam.

### 18.5.2 Package 'bootnet'

Donec sed lectus at sem ultrices commodo. Proin a viverra metus, nec scelerisque odio. Morbi viverra tristique libero vel fringilla (Epskamp et al., 2018a). Sed at varius erat, id consequat nibh. Ut eget leo blandit orci posuere tincidunt ac sed erat. Aenean metus metus, eleifend ut facilisis a, fringilla ut neque. Nunc hendrerit cursus eleifend. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Vivamus enim turpis, pulvinar volutpat purus nec, lobortis imperdiet diam.

### 18.5.3 Package 'autovar'

Donec sed lectus at sem ultrices commodo. Proin a viverra metus, nec scelerisque odio. Morbi viverra tristique libero vel fringilla (van der Krieke et al., 2015). Sed at varius erat, id consequat nibh. Ut eget leo blandit orci posuere tincidunt ac sed erat. Aenean metus metus, eleifend ut facilisis a, fringilla ut neque. Nunc hendrerit cursus eleifend. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Vivamus enim turpis, pulvinar volutpat purus nec, lobortis imperdiet diam.

Vivamus enim turpis, pulvinar volutpat purus nec, lobortis <http://autovar.nl>

## **Part VII**

# **Closing Matters**



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*Jeroen Ruwaard, Lisa Kooistra & Melissa Thong*





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