```
# 1. Data import and exploration

## 1.1. Install packages

#install.packages(c("readr","tidyverse","psych",
#                   "semTools","lavaan", "corrplot", "lavaanExtra"))


## 1.2. Load packages
library(readr)
library(tidyverse)
library(psych)
library(lavaan)
library(semTools)
library(corrplot)
library(lavaanExtra)

## 1.3. Open txt file

Data <- read_delim("dades_ans.txt", delim = "\t",   escape_double = FALSE, trim_ws =
TRUE)
headTail(Data)

# 2. Data analysis for two-wave designs
## 2.1. Create a dataset with measures for two waves

dat <- Data %>%
  select(Measure1_T1:Measure3_T2)

## 2.2. Data description
describeBy(dat)

dat %>%
  pivot_longer(cols = everything()) %>%
  mutate(time = substr(name, nchar(name) - 1, nchar(name))) %>%
  mutate(name = factor(name, levels = names(Data))) %>%
  ggplot(aes(x = name, y = value)) +
  geom_violin() +
  theme_bw() +
  labs (x = "Variable", y = "Value")

corrplot(cor(dat), type = "lower",  method ="color", addCoef.col = 'black')

## 2.3 Measurement models and reliability
### 2.3.1 Unidimensional models
#### 2.3.1.1 Measurement model and reliability for T1

model_t1 <- '
T1 =~ Measure1_T1 + Measure2_T1 + Measure3_T1'

f_t1 <- cfa(model = model_t1, data = Data)
summary(f_t1, fit.measures = TRUE, standardized = TRUE)

compRelSEM(f_t1)

#### 2.3.1.2 Measurement model and reliability for T2

model_t2 <- '
T2 =~ Measure1_T2 + Measure2_T2 + Measure3_T2'

f_t2 <- cfa(model = model_t2, data = Data)
summary(f_t2, fit.measures = TRUE, standardized = TRUE)

compRelSEM(f_t2)

### 2.3.2 Two-wave models
#### 2.3.2.1 Testing the congeneric measurement model for 2 wave data
```

```
model_2w <-
  'F1 =~ Measure1_T1 + Measure2_T1 + Measure3_T1
F2 =~ Measure1_T2 + Measure2_T2 + Measure3_T2
Measure1_T1 ~~ Measure1_T2
Measure2_T1 ~~ Measure2_T2
Measure3_T1 ~~ Measure3_T2'

f_2w <- cfa(model = model_2w, data = dat)
summary(f_2w, fit.measures = TRUE, standardized = TRUE)

compRelSEM(f_2w)

#### 2.3.2.2 Testing the metric invariance across waves

model_2wmi <- '
# Factor loadings
F1 =~ L1*Measure1_T1 + L2*Measure2_T1 + L3*Measure3_T1
F2 =~ L1*Measure1_T2 + L2*Measure2_T2 + L3*Measure3_T2
Measure1_T1 ~~ Measure1_T2
Measure2_T1 ~~ Measure2_T2
Measure3_T1 ~~ Measure3_T2'

f_2wmi <- cfa(model = model_2wmi, data = dat)
summary(f_2wmi, fit.measures = TRUE, standardized = TRUE)

anova(f_2w,f_2wmi)

#### 2.3.2.3 Testing metric invariance and specifity stability across waves

model_2wmis <- '
# Factor loadings
F1 =~ L1*Measure1_T1 + L2*Measure2_T1 + L3*Measure3_T1
F2 =~ L1*Measure1_T2 + L2*Measure2_T2 + L3*Measure3_T2

# Loadings of item specificities
SP1 =~ NA*D1*Measure1_T1 + D1*Measure1_T2
SP2 =~ NA*D2*Measure2_T1 + D2*Measure2_T2
SP3 =~ NA*D3*Measure3_T1 + D3*Measure3_T2

# Fix variance of specific factors to 1 (for identification)
SP1 ~~ 1*SP1
SP2 ~~ 1*SP2
SP3 ~~ 1*SP3

# Specific factors constrained to be uncorrelated with all specific factors
SP1 ~~ 0*SP2 + 0*SP3
SP2 ~~ 0*SP3

#Specific factors constrained to be uncorrelated with all factors
SP1 ~~ 0*F1 + 0*F2
SP2 ~~ 0*F1 + 0*F2
SP3 ~~ 0*F1 + 0*F2
'
f_2wmis <- cfa(model = model_2wmis, data = dat)
summary(f_2wmis, fit.measures = TRUE, standardized = TRUE)


#### 2.3.2.4 Calculating specificty-improved reliability

model_2wmisR <- '
# Factor loadings
F1 =~ L1*Measure1_T1 + L2*Measure2_T1 + L3*Measure3_T1
F2 =~ L1*Measure1_T2 + L2*Measure2_T2 + L3*Measure3_T2


# Loadings of item specificities
SP1 =~ NA*D1*Measure1_T1 + D1*Measure1_T2
SP2 =~ NA*D2*Measure2_T1 + D2*Measure2_T2
SP3 =~ NA*D3*Measure3_T1 + D3*Measure3_T2
```

```
# Fix variance of specific factors to 1 (for identification)
SP1 ~~ 1*SP1
SP2 ~~ 1*SP2
SP3 ~~ 1*SP3

# Specific factors constrained to be uncorrelated with all specific factors
SP1 ~~ 0*SP2 + 0*SP3
SP2 ~~ 0*SP3

#Specific factors constrained to be uncorrelated with all factors
SP1 ~~ 0*F1 + 0*F2
SP2 ~~ 0*F1 + 0*F2
SP3 ~~ 0*F1 + 0*F2

# Label item errors
Measure1_T1 ~~ E1*Measure1_T1
Measure2_T1 ~~ E2*Measure2_T1
Measure3_T1 ~~ E3*Measure3_T1

Measure1_T2 ~~ E4*Measure1_T2
Measure2_T2 ~~ E5*Measure2_T2
Measure3_T2 ~~ E6*Measure3_T2

# Label latent factor variance
F1 ~~ Fv1*F1
F2 ~~ Fv2*F2

#Compute specificity-improved reliability
OSR1:= ((1 + L2 + L3 )^2*Fv1 + D1^2 + D2^2 + D3^2)/((1 + L2 + L3 )^2*Fv1 + D1^2 + D2^2
+ D3^2 + E1 + E2 + E3)
OSR2:= ((1 + L2 + L3 )^2*Fv2 + D1^2 + D2^2 + D3^2)/((1 + L2 + L3 )^2*Fv2 + D1^2 + D2^2
+ D3^2 + E4 + E5 + E6)
'

f_2wmisR <- cfa(model = model_2wmisR, data = dat)
summary(f_2wmisR, fit.measures = TRUE, standardized = TRUE)

set.seed(12345)
monteCarloCI(f_2wmisR)

#### 2.3.2.4 Testing scalar invariance

model_2wsi <- '
# Factor loadings
F1 =~ L1*Measure1_T1 + L2*Measure2_T1 + L3*Measure3_T1
F2 =~ L1*Measure1_T2 + L2*Measure2_T2 + L3*Measure3_T2
Measure1_T1 ~~ Measure1_T2
Measure2_T1 ~~ Measure2_T2
Measure3_T1 ~~ Measure3_T2

# Intercepts
Measure1_T1 + Measure1_T2  ~ i1*1
Measure2_T1 + Measure2_T2  ~ i2*1
Measure3_T1 + Measure3_T2  ~ i3*1

F1 ~ 0*1   # Fix mean of F1 to 0
F2 ~ 1     # Free F2 mean'

f_2wsi <- cfa(model = model_2wsi, data = dat)
summary(f_2wsi, fit.measures = TRUE, standardized = TRUE)

#### 2.3.2.5 Testing scalar invariance and specifity stability across waves

model_2wsis <- '
# Factor loadings
F1 =~ L1*Measure1_T1 + L2*Measure2_T1 + L3*Measure3_T1
F2 =~ L1*Measure1_T2 + L2*Measure2_T2 + L3*Measure3_T2
```

```
# Intercepts
Measure1_T1 + Measure1_T2  ~ i1*1
Measure2_T1 + Measure2_T2  ~ i2*1
Measure3_T1 + Measure3_T2  ~ i3*1

F1 ~ 0*1   # Fix mean of F1 to 0
F2 ~ 1     # Free F2 mean

# Loadings of item specificities
SP1 =~ NA*D1*Measure1_T1 + D1*Measure1_T2
SP2 =~ NA*D2*Measure2_T1 + D2*Measure2_T2
SP3 =~ NA*D3*Measure3_T1 + D3*Measure3_T2

# Fix variance of specific factors to 1 (for identification)
SP1 ~~ 1*SP1
SP2 ~~ 1*SP2
SP3 ~~ 1*SP3

# Specific factors constrained to be uncorrelated with all specific factors
SP1 ~~ 0*SP2 + 0*SP3
SP2 ~~ 0*SP3

#Specific factors constrained to be uncorrelated with all factors
SP1 ~~ 0*F1 + 0*F2
SP2 ~~ 0*F1 + 0*F2
SP3 ~~ 0*F1 + 0*F2 '

f_2wsis <- cfa(model = model_2wsis, data = dat)
summary(f_2wsis, fit.measures = TRUE, standardized = TRUE)

#### 2.3.2.6 Calculating specificty-improved reliability for scalar invariant measures

model_2wsisR <- '
# Factor loadings
F1 =~ L1*Measure1_T1 + L2*Measure2_T1 + L3*Measure3_T1
F2 =~ L1*Measure1_T2 + L2*Measure2_T2 + L3*Measure3_T2

# Intercepts
Measure1_T1 + Measure1_T2  ~ i1*1
Measure2_T1 + Measure2_T2  ~ i2*1
Measure3_T1 + Measure3_T2  ~ i3*1

# Loadings of item specificities
SP1 =~ NA*D1*Measure1_T1 + D1*Measure1_T2
SP2 =~ NA*D2*Measure2_T1 + D2*Measure2_T2
SP3 =~ NA*D3*Measure3_T1 + D3*Measure3_T2

# Fix variance of specific factors to 1 (for identification)
SP1 ~~ 1*SP1
SP2 ~~ 1*SP2
SP3 ~~ 1*SP3

# Specific factors constrained to be uncorrelated with all specific factors
SP1 ~~ 0*SP2 + 0*SP3
SP2 ~~ 0*SP3

#Specific factors constrained to be uncorrelated with all factors
SP1 ~~ 0*F1 + 0*F2
SP2 ~~ 0*F1 + 0*F2
SP3 ~~ 0*F1 + 0*F2

F1 ~ 0*1   # Fix mean of F1 to 0
F2 ~ 1     # Free F2 mean

# Label item errors
Measure1_T1 ~~ E1*Measure1_T1
Measure2_T1 ~~ E2*Measure2_T1
Measure3_T1 ~~ E3*Measure3_T1
```

```
Measure1_T2 ~~ E4*Measure1_T2
Measure2_T2 ~~ E5*Measure2_T2
Measure3_T2 ~~ E6*Measure3_T2

# Label latent factor variance
F1 ~~ Fv1*F1
F2 ~~ Fv2*F2

#Compute specificity-improved reliability
OSR1:= ((1 + L2 + L3 )^2*Fv1 + D1^2 + D2^2 + D3^2)/((1 + L2 + L3 )^2*Fv1 + D1^2 + D2^2
+ D3^2 + E1 + E2 + E3)
OSR2:= ((1 + L2 + L3 )^2*Fv2 + D1^2 + D2^2 + D3^2)/((1 + L2 + L3 )^2*Fv2 + D1^2 + D2^2
+ D3^2 + E4 + E5 + E6)
'

f_2wsisR <- cfa(model = model_2wsisR, data = dat)
summary(f_2wsisR, fit.measures = TRUE, standardized = TRUE)

set.seed(12345)
monteCarloCI(f_2wsisR)

# 3. Extension to four-wave designs

model_speR4 <- '
#Factor loadings
F1 =~ L1*Measure1_T1 + L2*Measure2_T1 + L3*Measure3_T1
F2 =~ L1*Measure1_T2 + L2*Measure2_T2 + L3*Measure3_T2
F3 =~ L1*Measure1_T3 + L2*Measure2_T3 + L3*Measure3_T3
F4 =~ L1*Measure1_T4 + L2*Measure2_T4 + L3*Measure3_T4

# Intercepts
Measure1_T1 + Measure1_T2 + Measure1_T3 + Measure1_T4 ~ i1*1
Measure2_T1 + Measure2_T2 + Measure2_T3 + Measure2_T4 ~ i2*1
Measure3_T1 + Measure3_T2 + Measure3_T3 + Measure3_T4 ~ i3*1

# Loadings of item specificities
SP1 =~ NA*D1*Measure1_T1 + D1*Measure1_T2 + D1*Measure1_T3 + D1*Measure1_T4
SP2 =~ NA*D2*Measure2_T1 + D2*Measure2_T2 + D2*Measure2_T3 + D2*Measure2_T4
SP3 =~ NA*D3*Measure3_T1 + D3*Measure3_T2 + D3*Measure3_T3 + D3*Measure3_T4

# Fix variance of specific factors to 1 (for identification)
SP1 ~~ 1*SP1
SP2 ~~ 1*SP2
SP3 ~~ 1*SP3

# Specific factors constrained to be uncorrelated with all factors
SP1 ~~ 0*SP2 + 0*SP3
SP2 ~~ 0*SP3

# Specific factors constrained to be uncorrelated with all factors
SP1 ~~ 0*F1 + 0*F2 + 0*F3 + 0*F4
SP2 ~~ 0*F1 + 0*F2 + 0*F3 + 0*F4
SP3 ~~ 0*F1 + 0*F2 + 0*F3 + 0*F4

F1 ~ 0*1   # Fix mean of F1 to 0
F2 ~ 1     # Free F2 mean
F3 ~ 1     # Free F3 mean
F4 ~ 1     # Free F4 mean

# Label item errors
Measure1_T1 ~~ E1*Measure1_T1
Measure2_T1 ~~ E2*Measure2_T1
Measure3_T1 ~~ E3*Measure3_T1

Measure1_T2 ~~ E4*Measure1_T2
Measure2_T2 ~~ E5*Measure2_T2
Measure3_T2 ~~ E6*Measure3_T2

Measure1_T3 ~~ E7*Measure1_T3
```

```
Measure2_T3 ~~ E8*Measure2_T3
Measure3_T3 ~~ E9*Measure3_T3

Measure1_T4 ~~ E10*Measure1_T4
Measure2_T4 ~~ E11*Measure2_T4
Measure3_T4 ~~ E12*Measure3_T4

# Label latent factor variance
F1 ~~ Fv1*F1
F2 ~~ Fv2*F2
F3 ~~ Fv3*F3
F4 ~~ Fv4*F4

# Compute specificity-improved reliability
OSR1:= ((1 + L2 + L3 )^2*Fv1 + D1^2 + D2^2 + D3^2)/((1 + L2 + L3 )^2*Fv1 + D1^2 + D2^2
+ D3^2 + E1 + E2 + E3)
OSR2:= ((1 + L2 + L3 )^2*Fv2 + D1^2 + D2^2 + D3^2)/((1 + L2 + L3 )^2*Fv2 + D1^2 + D2^2
+ D3^2 + E4 + E5 + E6)
OSR3:= ((1 + L2 + L3 )^2*Fv3 + D1^2 + D2^2 + D3^2)/((1 + L2 + L3 )^2*Fv3 + D1^2 + D2^2
+ D3^2 + E7 + E8 + E9 )
OSR4:= ((1 + L2 + L3 )^2*Fv4 + D1^2 + D2^2 + D3^2)/((1 + L2 + L3 )^2*Fv4 + D1^2 + D2^2
+ D3^2 + E10 + E11 + E12)
'

f_speR4 <- cfa(model = model_speR4, data = Data)
summary(f_speR4, fit.measures = TRUE, standardized = TRUE)
set.seed(12345)
monteCarloCI(f_speR4)
```