

Case Study Code

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Prompt (BLMR)

UCLA nurse blood pressure study. A study by Goldstein and Shapiro (2000) collected information from 203 registered nurses in the Los Angeles area between 24 and 50 years of age on blood pressure (BP) and potential factors that contribute to hypertension. This information includes family history, and whether the subject had one or two hypertensive parents, as well as a wide range of measures of the physical and emotional condition of each nurse throughout the day. **Researchers sought to study the links between BP and family history, personality, mood changes, working status, and menstrual phase.**

Data from this study provided by Weiss (2005) includes observations (40-60 per nurse) repeatedly taken on the 203 nurses over the course of a single day. The first BP measurement was taken half an hour before the subject's normal start of work, and BP was then measured approximately every 20 minutes for the rest of the day. At each BP reading, the nurses also rate their mood on several dimensions, including how stressed they feel at the moment the BP is taken. In addition, the activity of each subject during the 10 minutes before each reading was measured using an actigraph worn on the waist. Each of the variables in *nursebp.csv* is described below:

SNUM: subject identification number
SYS: systolic blood pressure (mmHg)
DIA: diastolic blood pressure (mmHg)
HRT: heart rate (beats per minute)
MNACT5: activity level (frequency of movements in 1-minute intervals, over a 10-minute period)
PHASE: menstrual phase (follicular-beginning with the end of menstruation and ending with ovulation, or
DAY: workday or non-workday
POSTURE: position during BP measurement—either sitting, standing, or reclining
STR, HAP, TIR: self-ratings by each nurse of their level of stress, happiness and tiredness at the time
AGE: age in years
FH123: coded as either NO (no family history of hypertension), YES (1 hypertensive parent), or YESYES (2 hypertensive parents)
time: in minutes from midnight
timept: number of the measurement that day (approximately 50 for each subject)
timepass: time in minutes beginning with 0 at time point 1

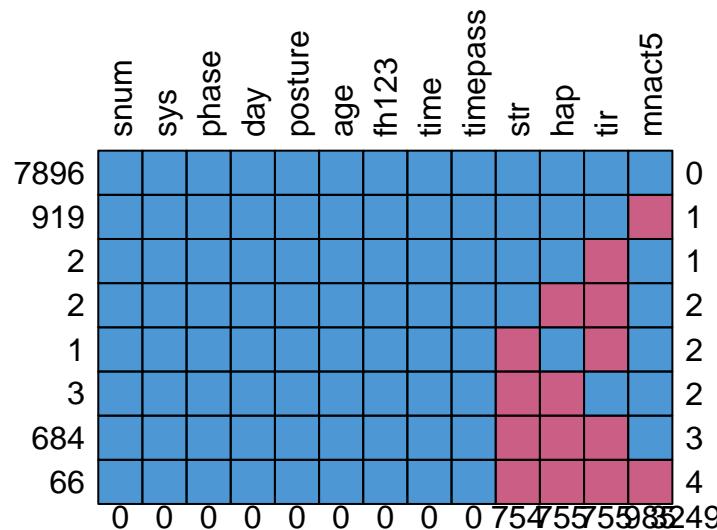
Using **systolic blood pressure as the primary response**, write a short report detailing factors that are significantly associated with higher systolic blood pressure. Be sure to support your conclusions with appropriate exploratory plots and multilevel models. In particular, **how are work conditions—activity level, mood, and work status—related to trends in BP levels?** As an appendix to your report, describe your modeling process—how did you arrive at your final model, which covariates are Level One or Level Two, what did you learn from exploratory plots, etc.?

Potential alternative directions: consider diastolic blood pressure or heart rate as the primary response variable, or even try modeling emotion rating using a multilevel model.

Modeling

Data Wrangling

```
nurse <- read.csv("https://math.carleton.edu/kstclair/data/bmlr/nursebp.csv",
  stringsAsFactors = TRUE) %>%
  as_tibble %>%
  select(-c(DIA, HRT, timept)) %>%
  janitor::clean_names() %>%
  mutate(snum = as.factor(snum))
glimpse(nurse)
## Rows: 9,573
## Columns: 13
## $ snum      <fct> 1002, 1002, 1002, 1002, 1002, 1002, 1002, 1002, 1~
## $ sys       <int> 136, 114, 130, 120, 117, 143, 118, 117, 91, 102, 118, 119, 14~
## $ mnact5    <dbl> NA, 230.4, 189.0, 228.8, 213.0, 247.4, 219.2, 203.6, 122.8, 1~
## $ phase     <fct> L, L~
## $ day       <fct> W, W~
## $ posture   <fct> SIT, STAND, STAND, STAND, STAND, STAND, STAND, STAND, ~
## $ str        <int> 1, 2, 1, 1, 1, 2, 1, 1, 2, 1, 1, NA, 1, 2, 1, 2, 2, ~
## $ hap        <int> 5, 4, 5, 5, 5, 5, 4, 5, 5, 1, 5, 5, NA, 5, 5, 5, 5, 5, ~
## $ tir        <int> 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, NA, 1, 1, 1, 1, 1, ~
## $ age        <int> 49, 49, 49, 49, 49, 49, 49, 49, 49, 49, 49, 49, 49, 49, 49, 49, ~
## $ fh123     <fct> YES, ~
## $ time       <int> 427, 450, 468, 489, 506, 527, 531, 549, 565, 569, 589, 610, 6~
## $ timepass  <int> 0, 23, 41, 62, 79, 100, 104, 122, 138, 142, 162, 183, 204, 20~
out <- md.pattern(nurse, rotate.names = T) #missingness pattern
```



```
nurse_complete <- nurse %>%
  drop_na() %>%
  mutate(mood = hap - (str + tir)/2, standing = case_when(posture ==
    "RECLINE" ~ 0, posture == "SIT" ~ 0, posture == "STAND" ~
    1))

nurse_filtered <- nurse_complete %>%
  mutate(age24 = age - 24, phase2 = if_else(phase == "F", 0,
  1), day2 = if_else(day == "W", 1, 0), posture2 = case_when(posture ==
```

```

    "RECLINE" ~ 0, posture == "SIT" ~ 1, posture == "STAND" ~
    2), fh123 = case_when(fh123 == "NO" ~ 0, fh123 == "YES" ~
    1, fh123 == "YESYES" ~ 2)) %>%
  mutate(fh123 = as.factor(fh123), phase2 = as.factor(phase2),
    day2 = as.factor(day2), posture2 = as.factor(posture2)) %>%
  mutate(day3 = if_else(day == "W", "Workday", "Non-Workday")) %>%
  mutate(standing = if_else(posture2 == 2, 1, 0), fh_yes = if_else(fh123 ==
    0, 0, 1)) %>%
  mutate(standing = as.factor(standing), fh_yes = as.factor(fh_yes)) %>%
  mutate(fh_2 = if_else(fh_yes == 1, "Yes", "No")) %>%
  drop_na()

nurse_bysubject <- nurse_filtered %>%
  mutate(phase3 = if_else(phase2 == 0, "Follicular", "Luteal"),
    day3 = if_else(day2 == 1, "Workday", "Non-Workday")) %>%
  group_by(snum) %>%
  summarize(mean_sys = mean(sys), phase3 = first(phase3), day3 = first(day3),
    age2 = first(age24), fh_2 = first(fh_2))

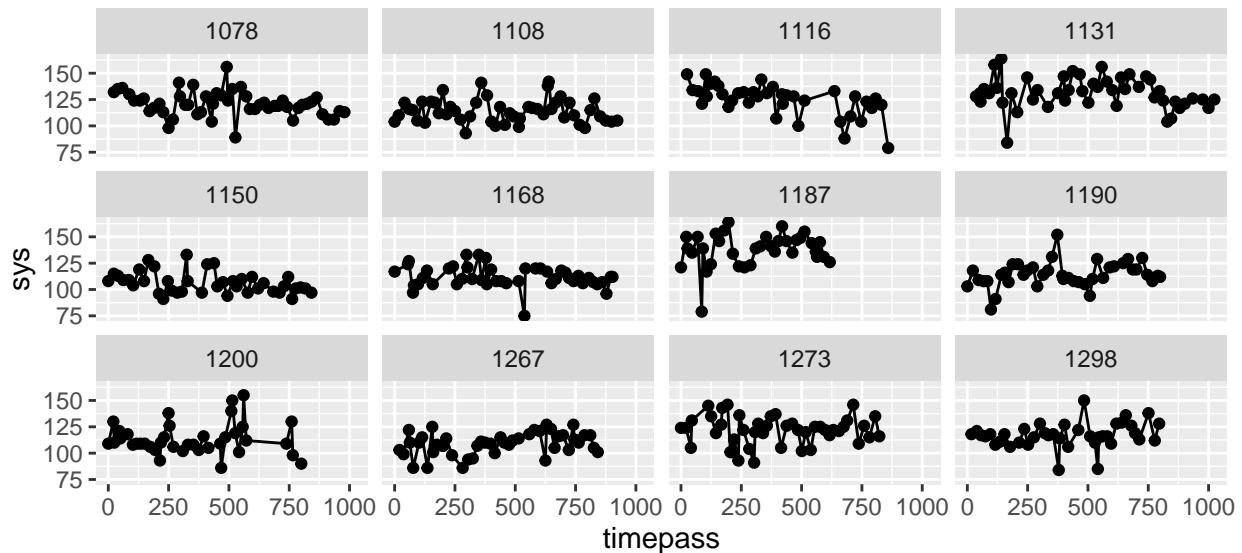
```

EDA

```

set.seed(93487303)
nurse_all <- nurse_filtered %>%
  distinct(snum) %>%
  pull()
random_snums <- sample(nurse_all, 12)
nurse_small <- nurse_filtered %>%
  filter(snum %in% random_snums)
ggplot(nurse_small, aes(x = timepass, y = sys)) + geom_point() +
  geom_line() + facet_wrap(~snum)

```

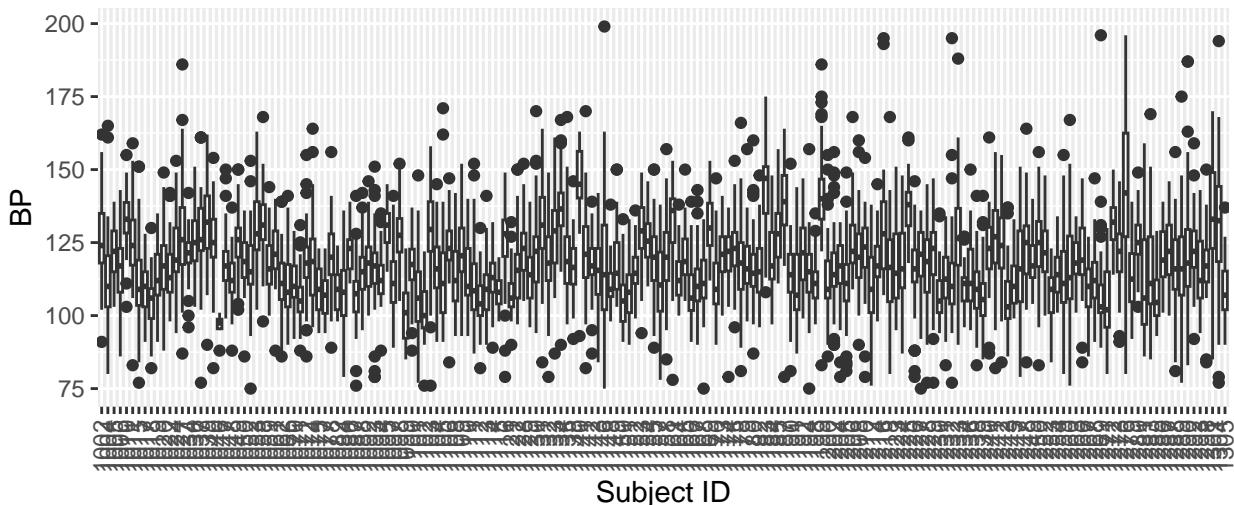


```

ggplot(nurse_filtered, aes(x = as.factor(snum), y = sys)) + geom_boxplot() +
  labs(x = "Subject ID", y = "BP", title = "BP by Subjects") +
  theme(axis.text.x = element_text(angle = 90, vjust = 0.5,
    hjust = 1))

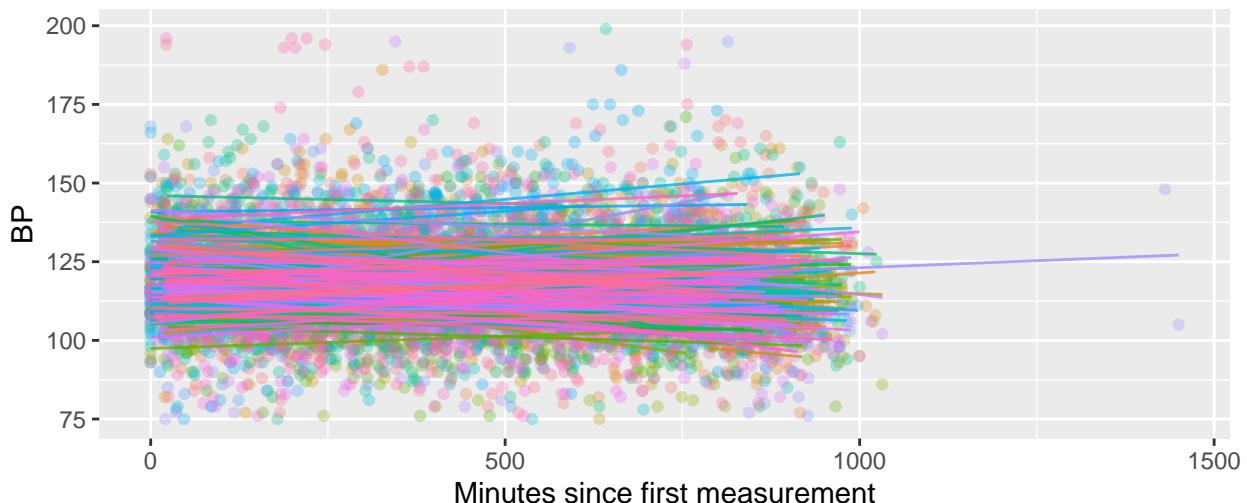
```

BP by Subjects



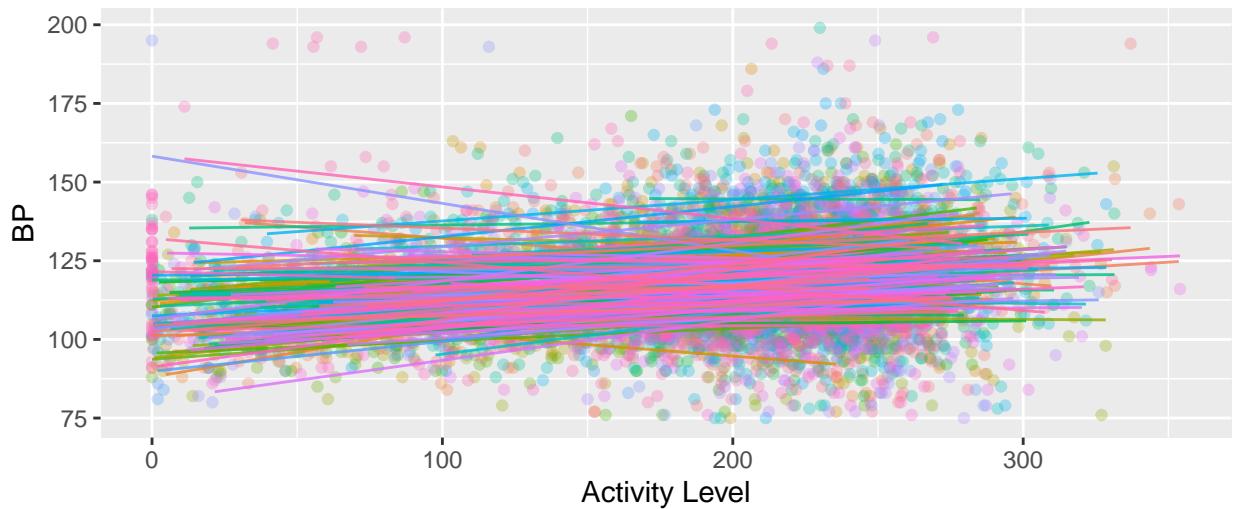
```
ggplot(nurse_filtered, aes(x = timepass, y = sys, color = as.factor(snum))) +  
  geom_point(alpha = 0.3) + geom_line(stat = "smooth", method = "lm",  
  se = F, alpha = 0.8) + labs(x = "Minutes since first measurement",  
  y = "BP", title = "BP vs. time passed by Subjects", color = "Subject ID") +  
  guides(color = "none")
```

BP vs. time passed by Subjects



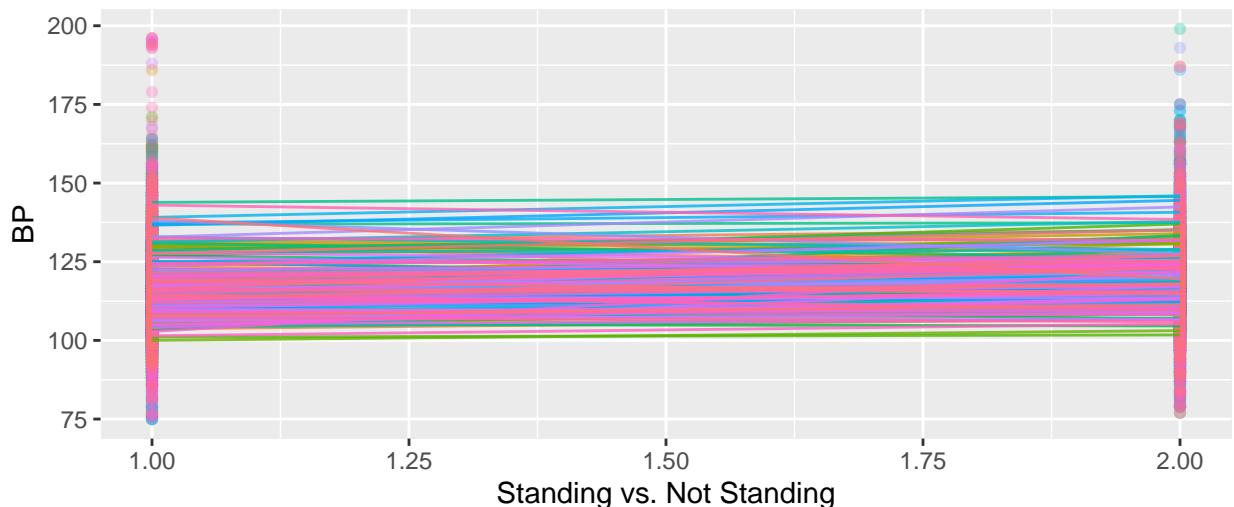
```
ggplot(nurse_filtered, aes(x = mnact5, y = sys, color = as.factor(snum))) +  
  geom_point(alpha = 0.3) + geom_line(stat = "smooth", method = "lm",  
  se = F, alpha = 0.8) + labs(x = "Activity Level", y = "BP",  
  title = "BP vs. Activity Level", color = "Subject ID") +  
  guides(color = "none")
```

BP vs. Activity Level



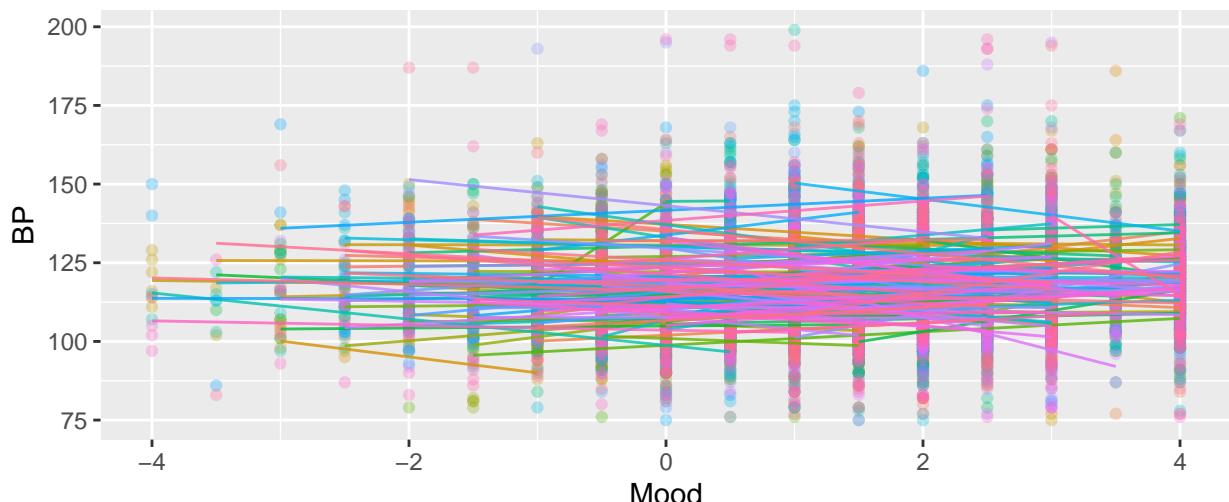
```
ggplot(nurse_filtered, aes(x = as.numeric(standing), y = sys,
color = as.factor(snum))) + geom_point(alpha = 0.3) + geom_line(stat = "smooth",
method = "lm", se = F, alpha = 0.8) + labs(x = "Standing vs. Not Standing",
y = "BP", title = "BP vs. Posture (2 Levels)", color = "Subject ID") +
guides(color = "none")
```

BP vs. Posture (2 Levels)



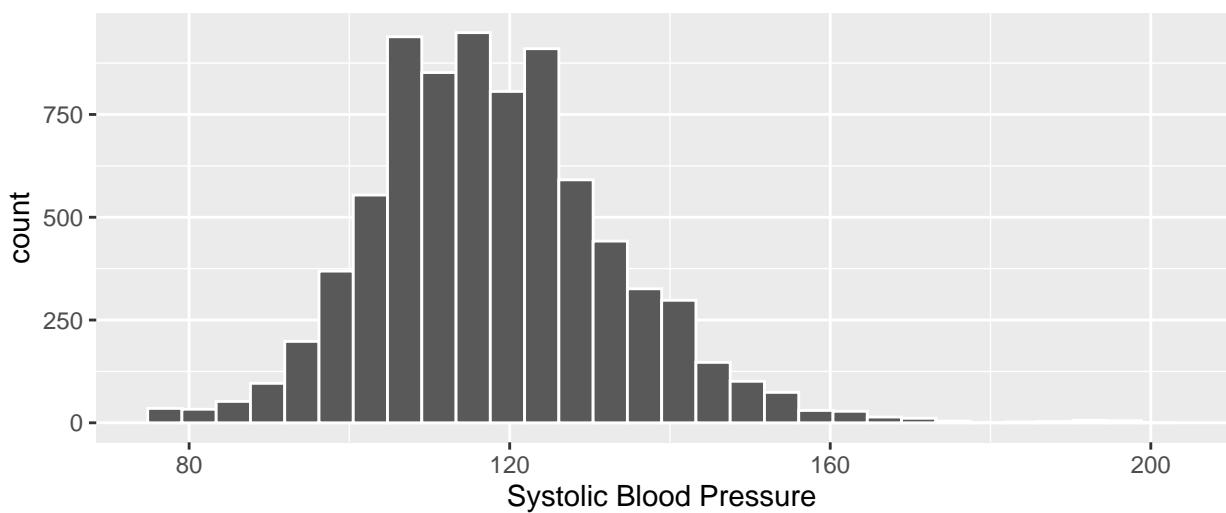
```
ggplot(nurse_filtered, aes(x = mood, y = sys, color = as.factor(snum))) +
geom_point(alpha = 0.3) + geom_line(stat = "smooth", method = "lm",
se = F, alpha = 0.8) + labs(x = "Mood", y = "BP", title = "BP vs. Mood",
color = "Subject ID") + guides(color = "none")
```

BP vs. Mood



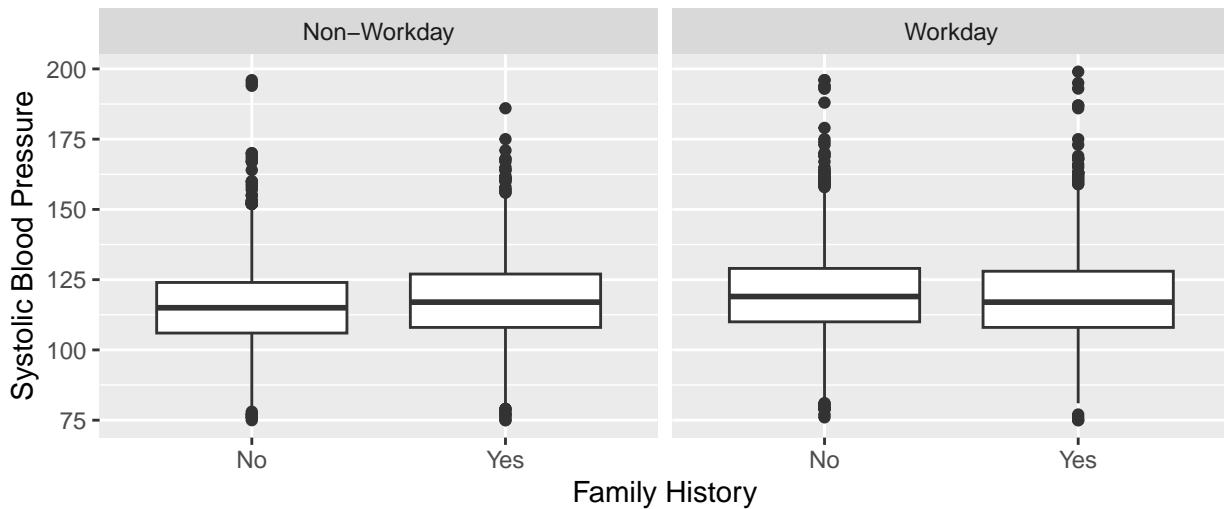
```
ggplot(nurse_filtered, aes(x = sys)) + geom_histogram(color = "white") +  
  labs(x = "Systolic Blood Pressure", title = "Level 1 BP Distribution")
```

Level 1 BP Distribution



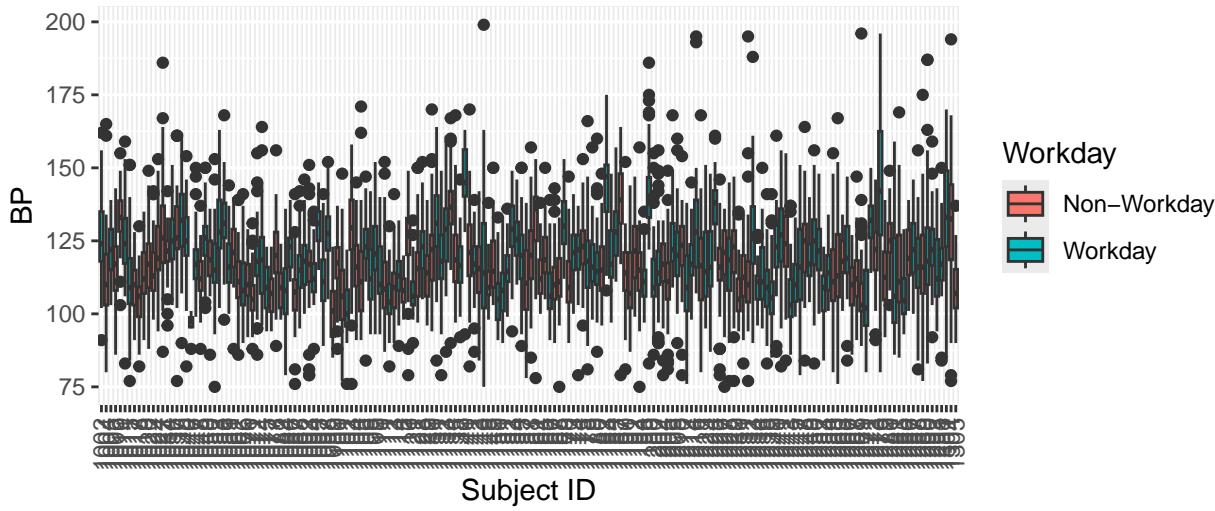
```
ggplot(nurse_filtered, aes(x = fh_2, y = sys)) + geom_boxplot() +  
  facet_wrap(~day3) + labs(x = "Family History", y = "Systolic Blood Pressure",  
  title = "Level 1 BP by Workday and Family History")
```

Level 1 BP by Workday and Family History



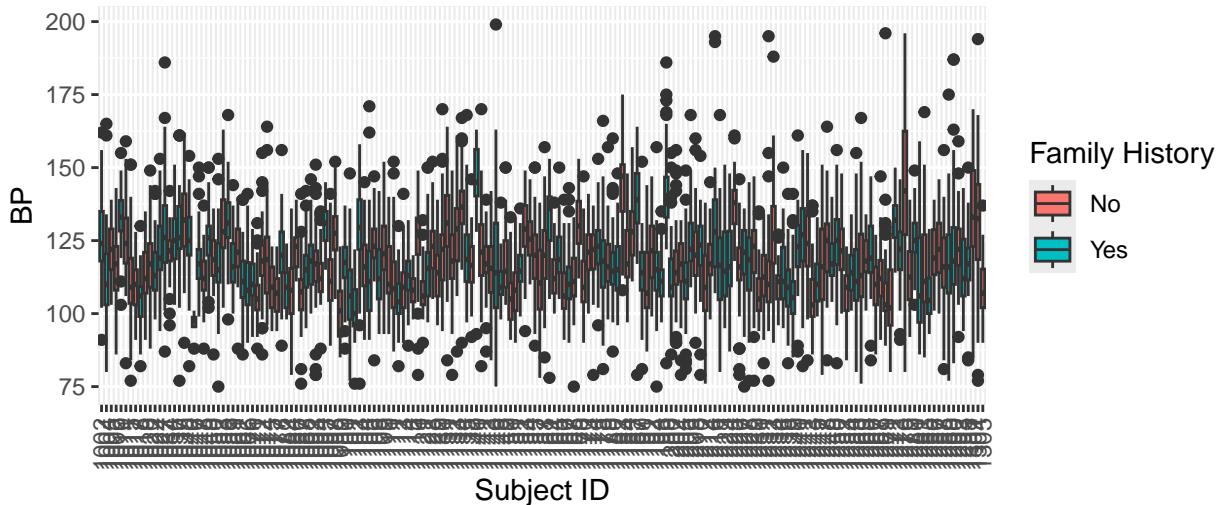
```
ggplot(nurse_filtered, aes(x = as.factor(snum), y = sys, fill = day3)) +
  geom_boxplot() + labs(x = "Subject ID", y = "BP", title = "Level 1 BP by Subjects and Workday",
  fill = "Workday") + theme(axis.text.x = element_text(angle = 90,
  vjust = 0.5, hjust = 1))
```

Level 1 BP by Subjects and Workday



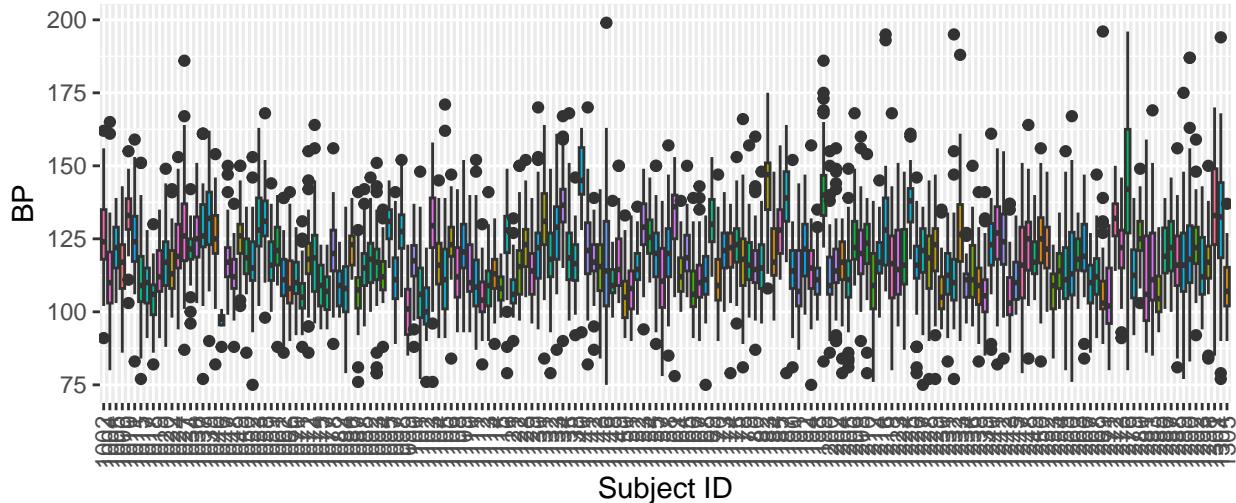
```
ggplot(nurse_filtered, aes(x = as.factor(snum), y = sys, fill = fh_2)) +
  geom_boxplot() + labs(x = "Subject ID", y = "BP", title = "Level 1 BP by Subjects and Workday",
  fill = "Family History") + theme(axis.text.x = element_text(angle = 90,
  vjust = 0.5, hjust = 1))
```

Level 1 BP by Subjects and Workday

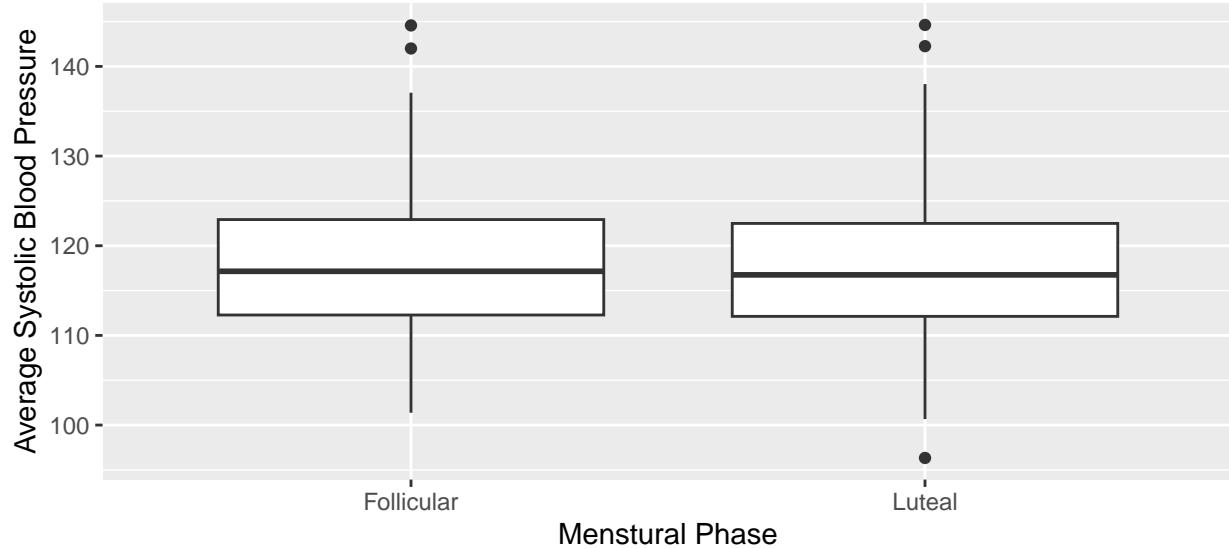


```
ggplot(nurse_filtered, aes(x = as.factor(snum), y = sys, fill = as.factor(age24))) +
  geom_boxplot() + labs(x = "Subject ID", y = "BP", title = "Level 1 BP by Subjects and Workday",
  fill = "Family History") + theme(axis.text.x = element_text(angle = 90,
  vjust = 0.5, hjust = 1)) + guides(fill = "none")
```

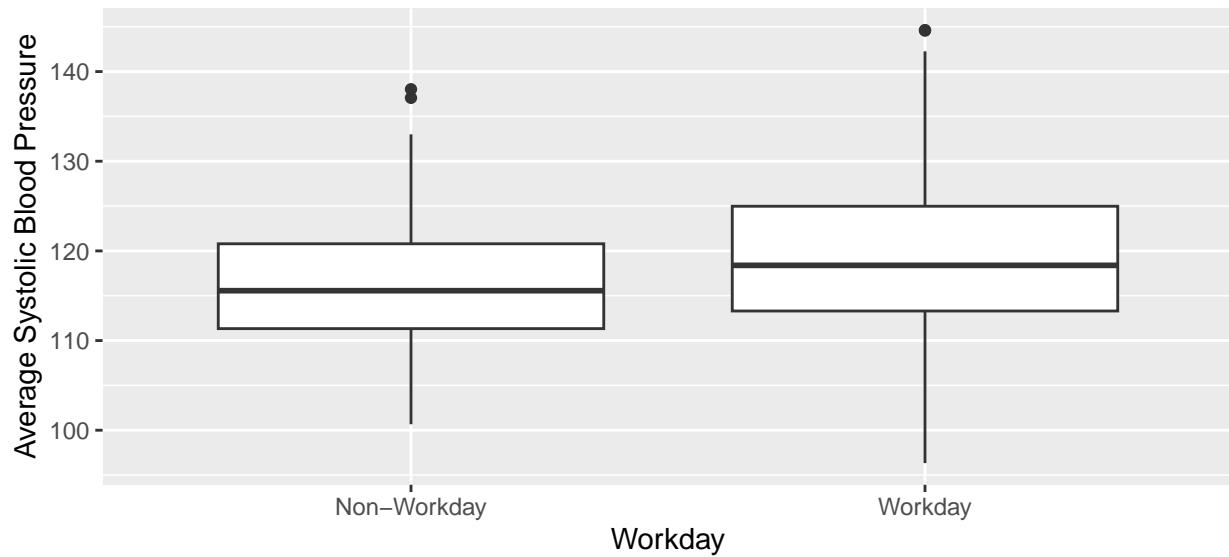
Level 1 BP by Subjects and Workday



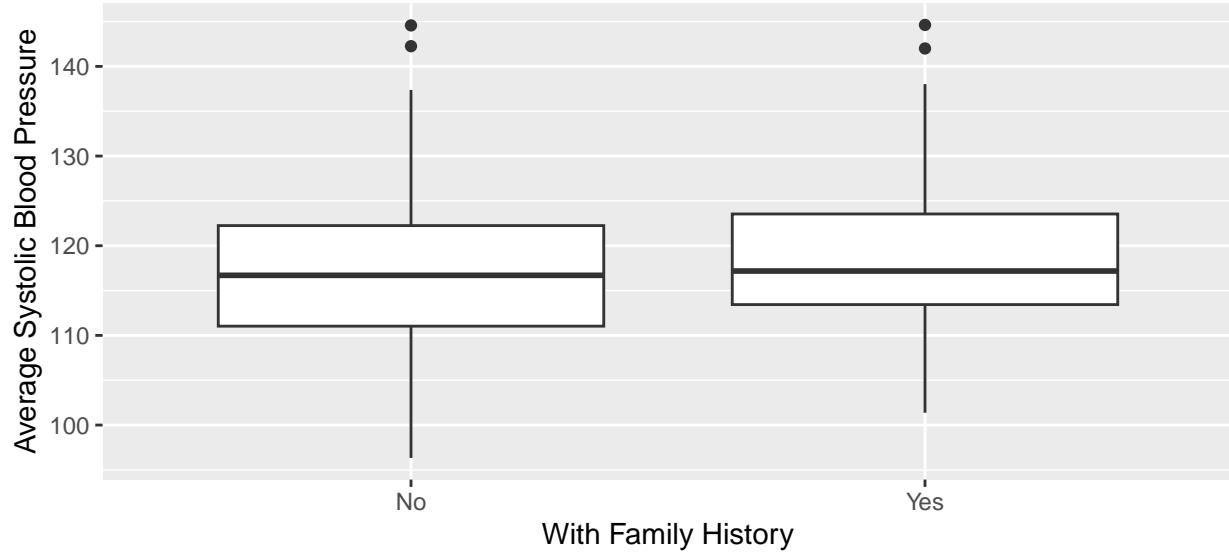
```
## Bivariate
ggplot(nurse_bysubject, aes(x = phase3, y = mean_sys)) + geom_boxplot() +
  labs(x = "Menstrual Phase", y = "Average Systolic Blood Pressure")
```



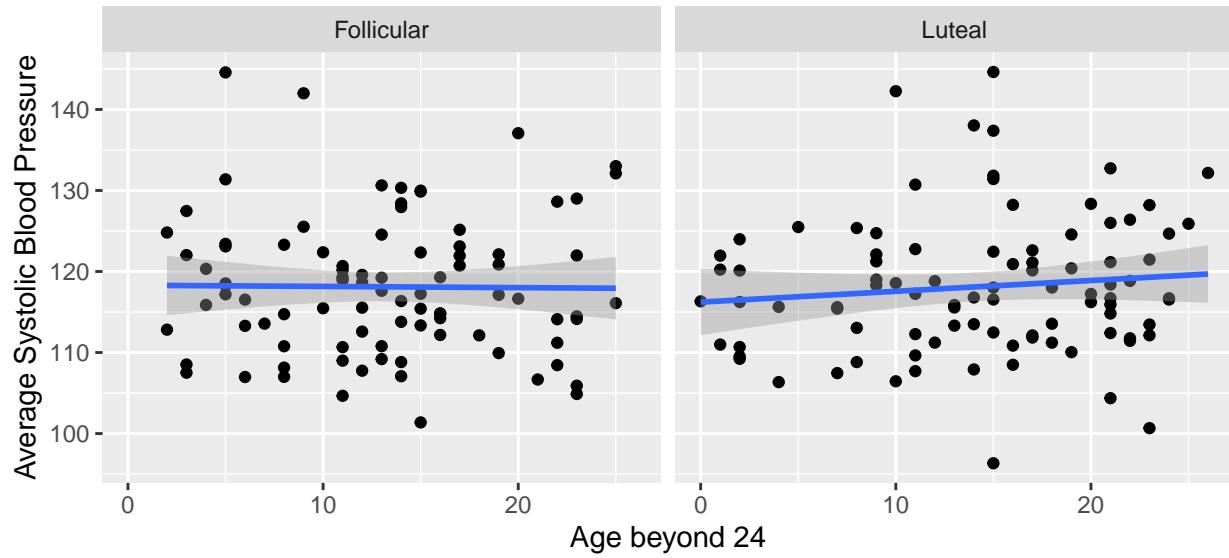
```
ggplot(nurse_bysubject, aes(x = day3, y = mean_sys)) + geom_boxplot() +
  labs(x = "Workday", y = "Average Systolic Blood Pressure")
```



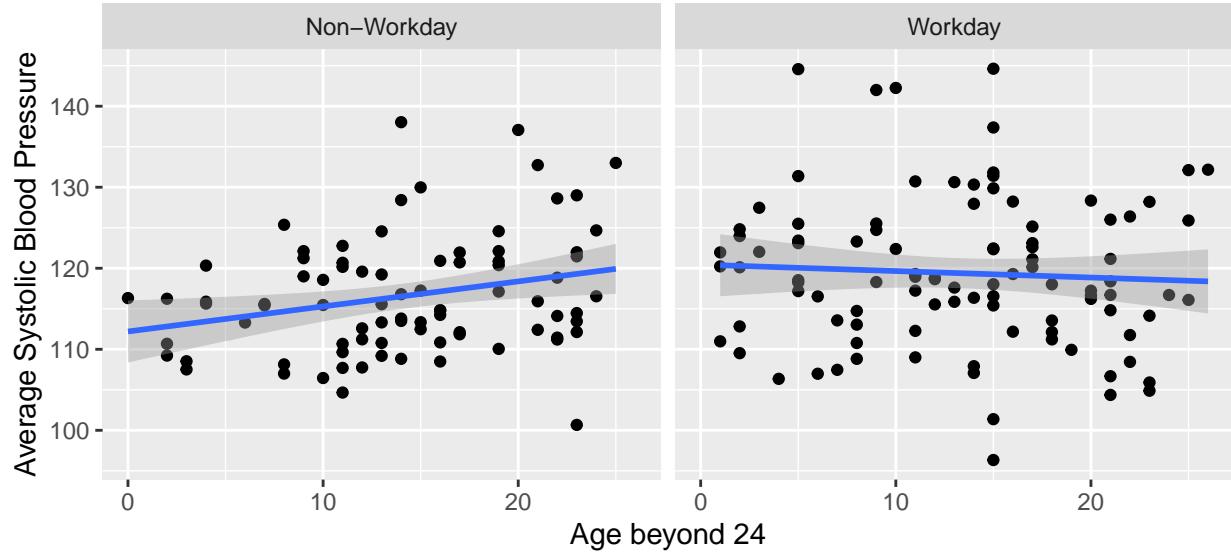
```
ggplot(nurse_bysubject, aes(x = fh_2, y = mean_sys)) + geom_boxplot() +
  labs(x = "With Family History", y = "Average Systolic Blood Pressure")
```



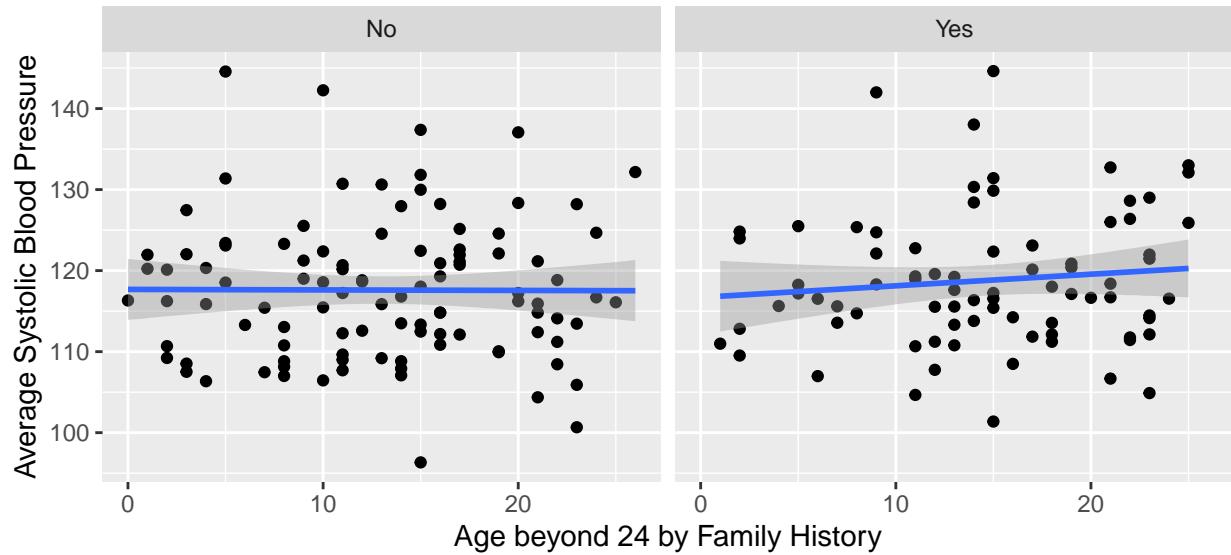
```
## By age
ggplot(nurse_bysubject, aes(x = age2, y = mean_sys)) + geom_point() +
  geom_smooth(method = "lm") + facet_wrap(~phase3) + labs(x = "Age beyond 24",
y = "Average Systolic Blood Pressure")
```



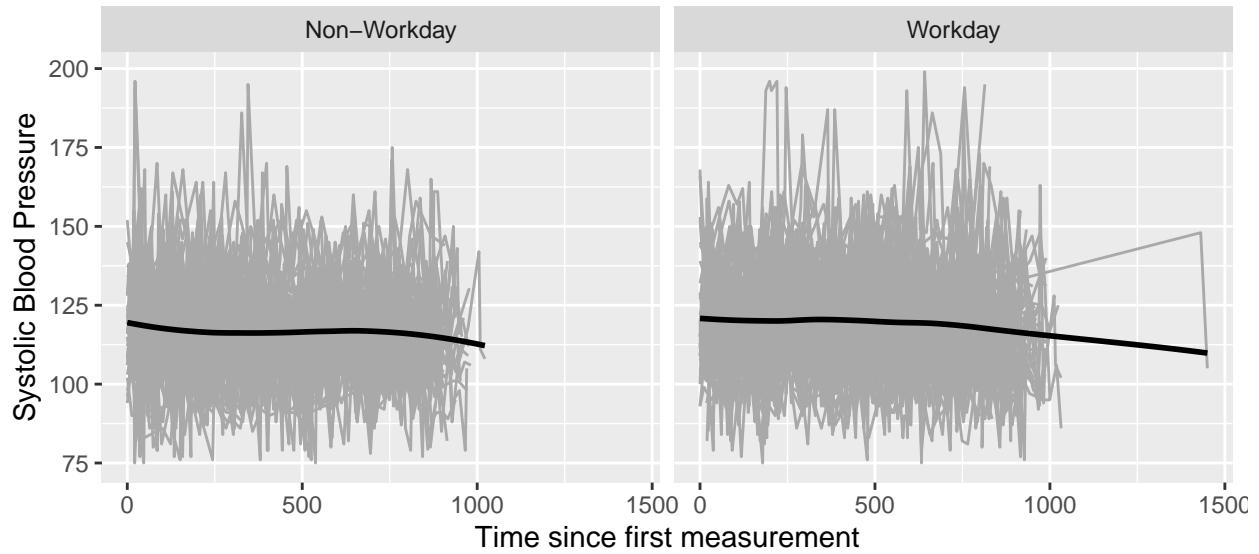
```
ggplot(nurse_bysubject, aes(x = age2, y = mean_sys)) + geom_point() +
  geom_smooth(method = "lm") + facet_wrap(~day3) + labs(x = "Age beyond 24",
y = "Average Systolic Blood Pressure")
```



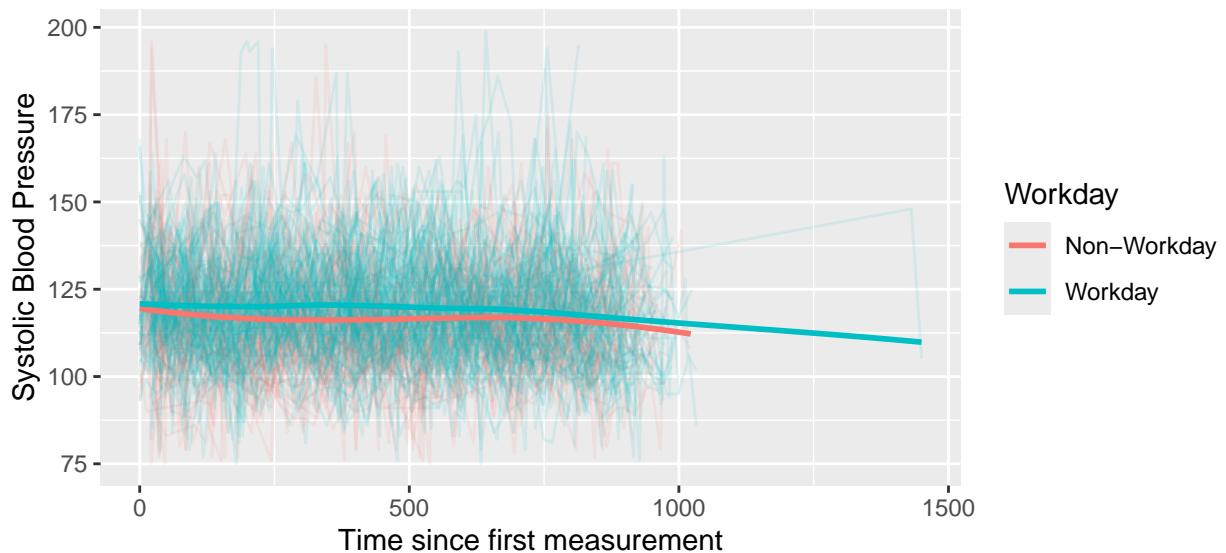
```
ggplot(nurse_bysubject, aes(x = age2, y = mean_sys)) + geom_point() +
  geom_smooth(method = "lm") + facet_wrap(~fh_2) + labs(x = "Age beyond 24 by Family History",
y = "Average Systolic Blood Pressure")
```



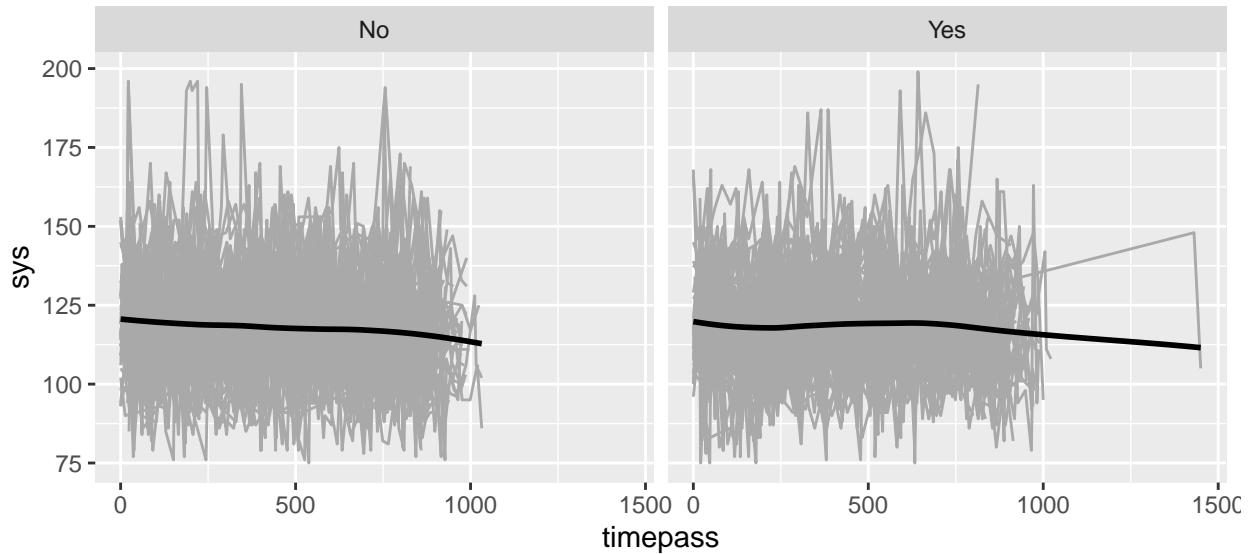
```
## Time
ggplot(nurse_filtered, aes(x = timepass, y = sys)) + geom_line(aes(group = snum),
color = "dark grey") + geom_smooth(method = "loess", color = "black",
se = F, size = 1) + facet_wrap(~day3) + labs(x = "Time since first measurement",
y = "Systolic Blood Pressure")
```



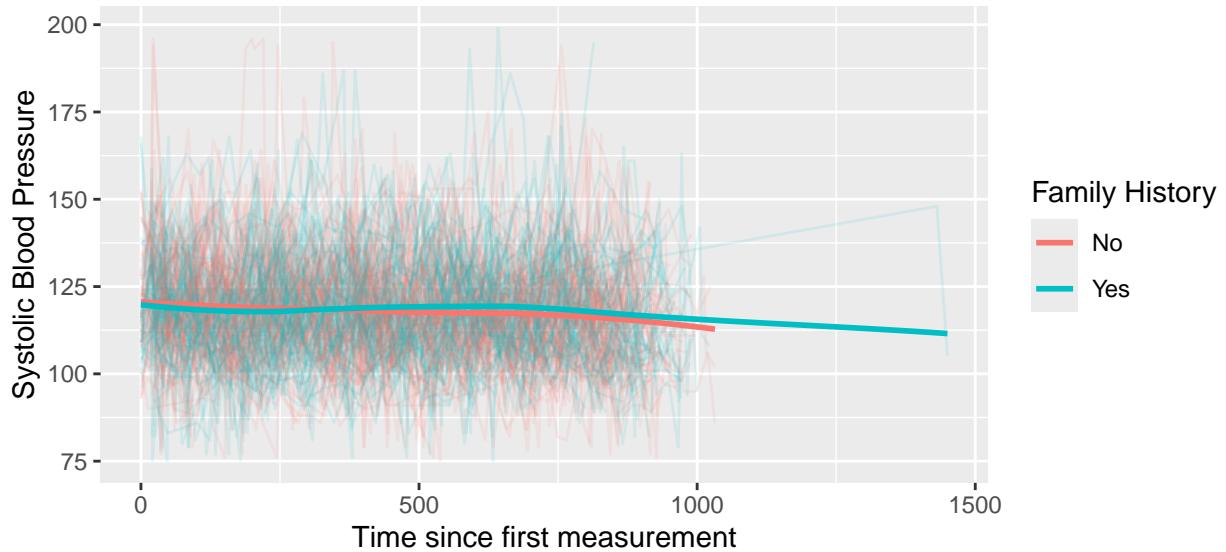
```
ggplot(nurse_filtered, aes(x = timepass, y = sys, color = as.factor(day3))) +
  geom_line(aes(group = interaction(snum, day)), alpha = 0.1) +
  geom_smooth(method = "loess", se = FALSE, size = 1) + labs(color = "Workday",
  x = "Time since first measurement", y = "Systolic Blood Pressure")
```



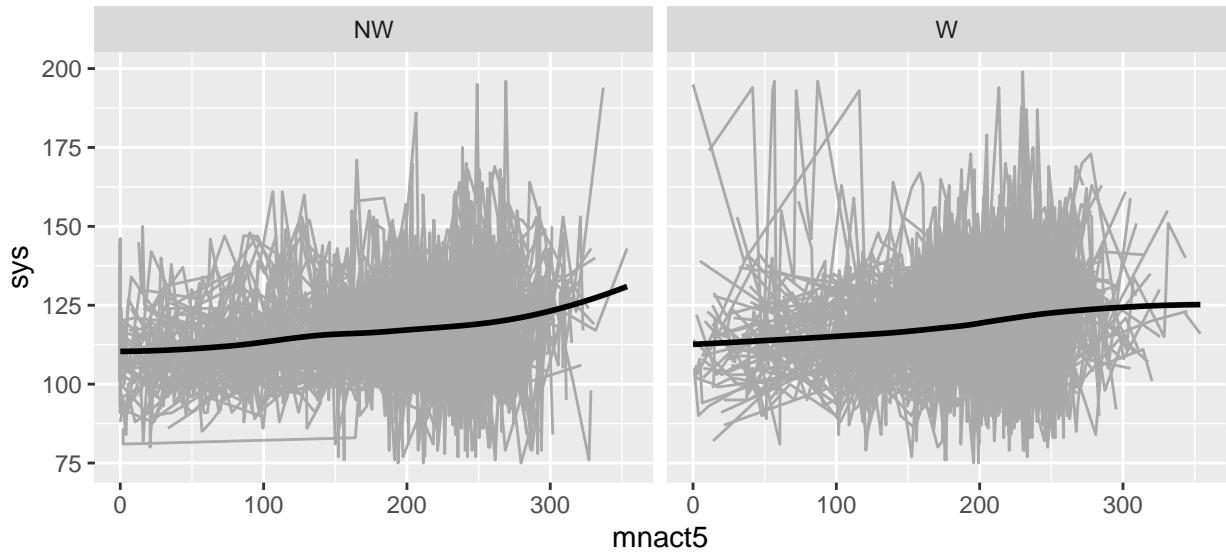
```
ggplot(nurse_filtered, aes(x = timepass, y = sys)) + geom_line(aes(group = snum),
  color = "dark grey") + geom_smooth(method = "loess", color = "black",
  se = F, size = 1) + facet_wrap(~fh_2)
```



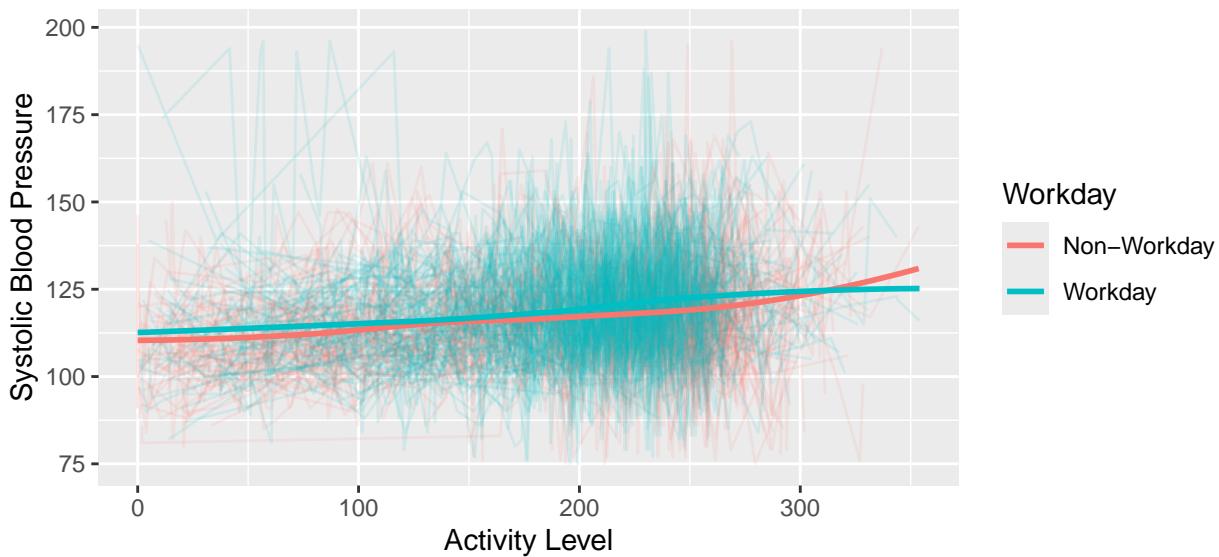
```
ggplot(nurse_filtered, aes(x = timepass, y = sys, color = as.factor(fh_2))) +
  geom_line(aes(group = interaction(snum, day)), alpha = 0.1) +
  geom_smooth(method = "loess", se = FALSE, size = 1) + labs(color = "Family History",
  x = "Time since first measurement", y = "Systolic Blood Pressure")
```



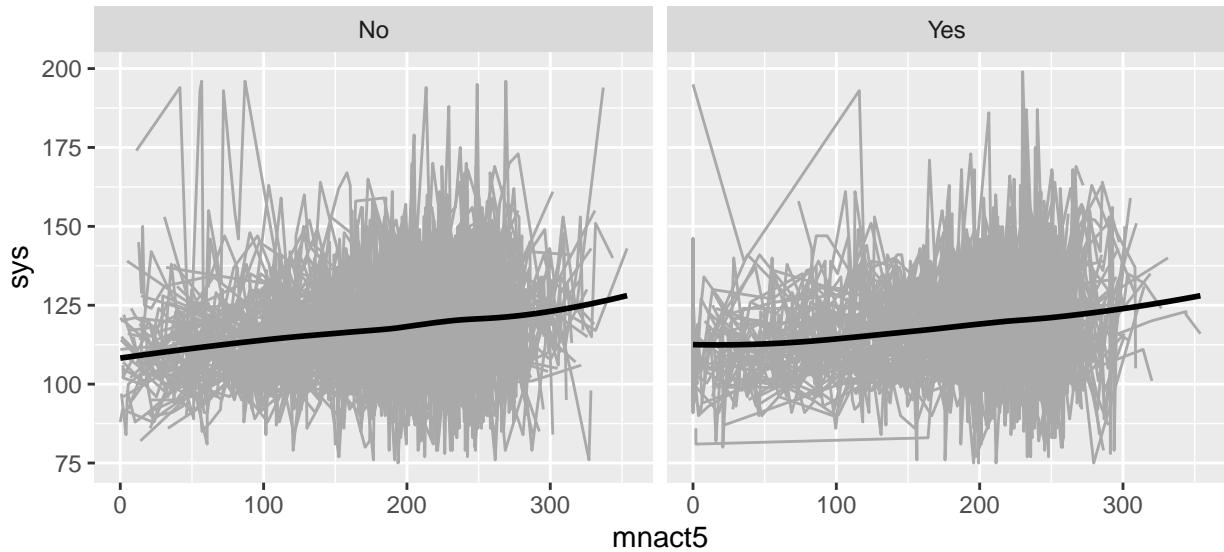
```
## Activity level
ggplot(nurse_filtered, aes(x = mnact5, y = sys)) + geom_line(aes(group = snum),
  color = "dark grey") + geom_smooth(method = "loess", color = "black",
  se = F, size = 1) + facet_wrap(~day)
```



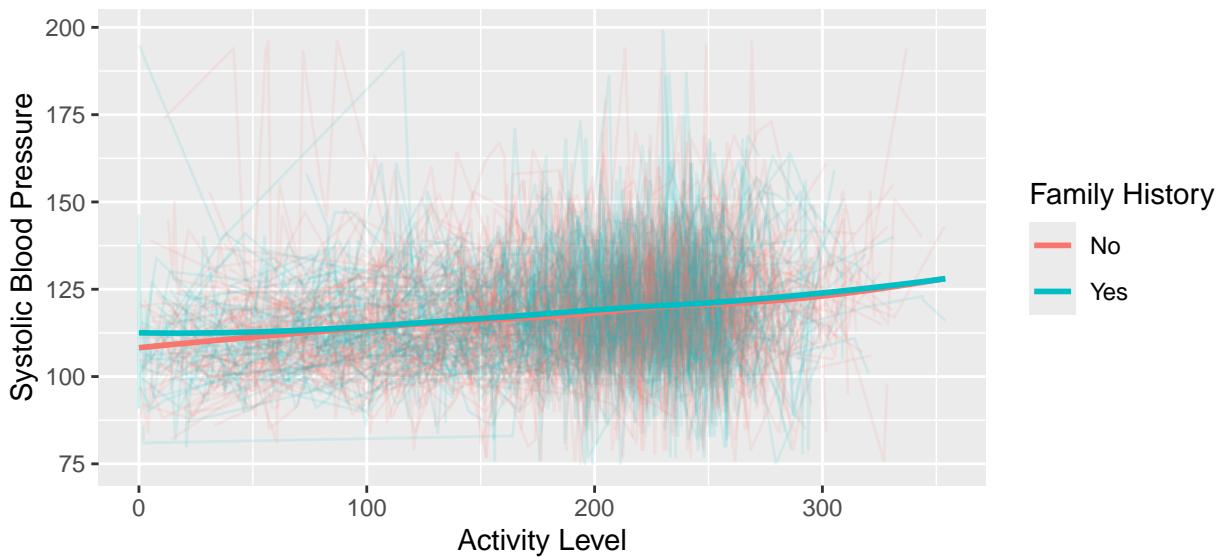
```
ggplot(nurse_filtered, aes(x = mnact5, y = sys, color = as.factor(day3))) +
  geom_line(aes(group = interaction(snum, day)), alpha = 0.1) +
  geom_smooth(method = "loess", se = FALSE, size = 1) + labs(color = "Workday",
  x = "Activity Level", y = "Systolic Blood Pressure")
```



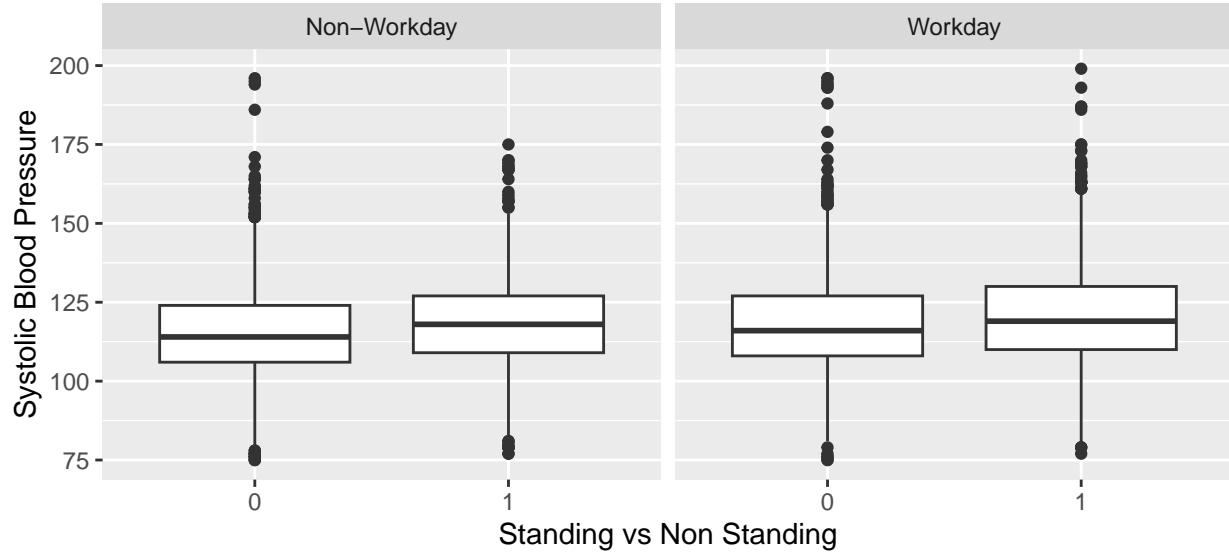
```
ggplot(nurse_filtered, aes(x = mnact5, y = sys)) + geom_line(aes(group = snum),
  color = "dark grey") + geom_smooth(method = "loess", color = "black",
  se = F, size = 1) + facet_wrap(~fh_2)
```



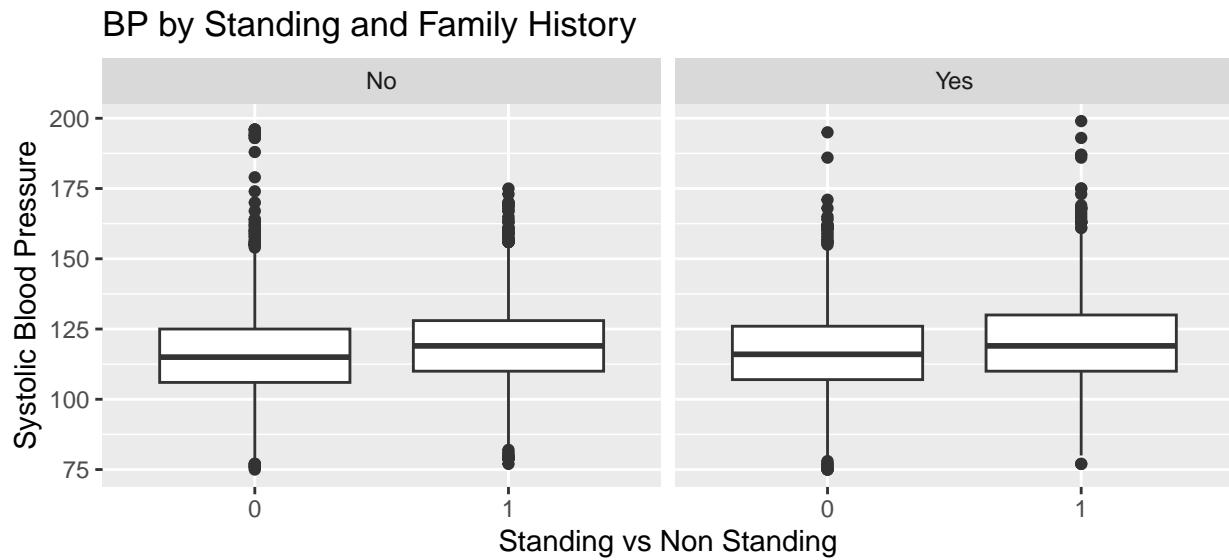
```
ggplot(nurse_filtered, aes(x = mnact5, y = sys, color = as.factor(fh_2))) +
  geom_line(aes(group = interaction(snum, day)), alpha = 0.1) +
  geom_smooth(method = "loess", se = FALSE, size = 1) + labs(color = "Family History",
  x = "Activity Level", y = "Systolic Blood Pressure")
```



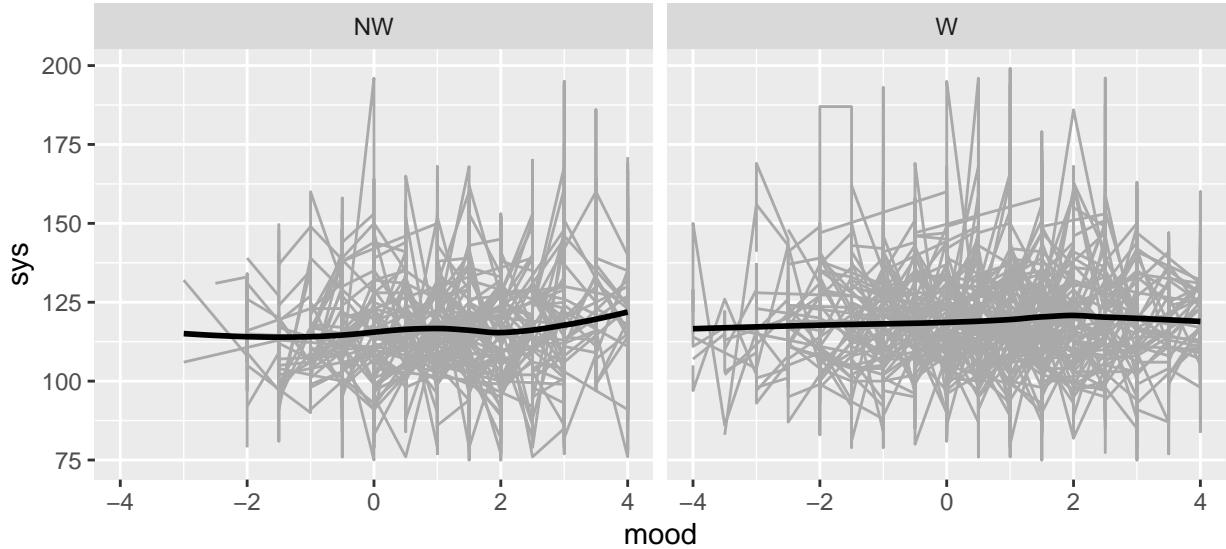
```
## Posture - 2 levels
ggplot(nurse_filtered, aes(x = standing, y = sys)) + geom_boxplot() +
  facet_wrap(~day3) + labs(x = "Standing vs Non Standing",
  y = "Systolic Blood Pressure")
```



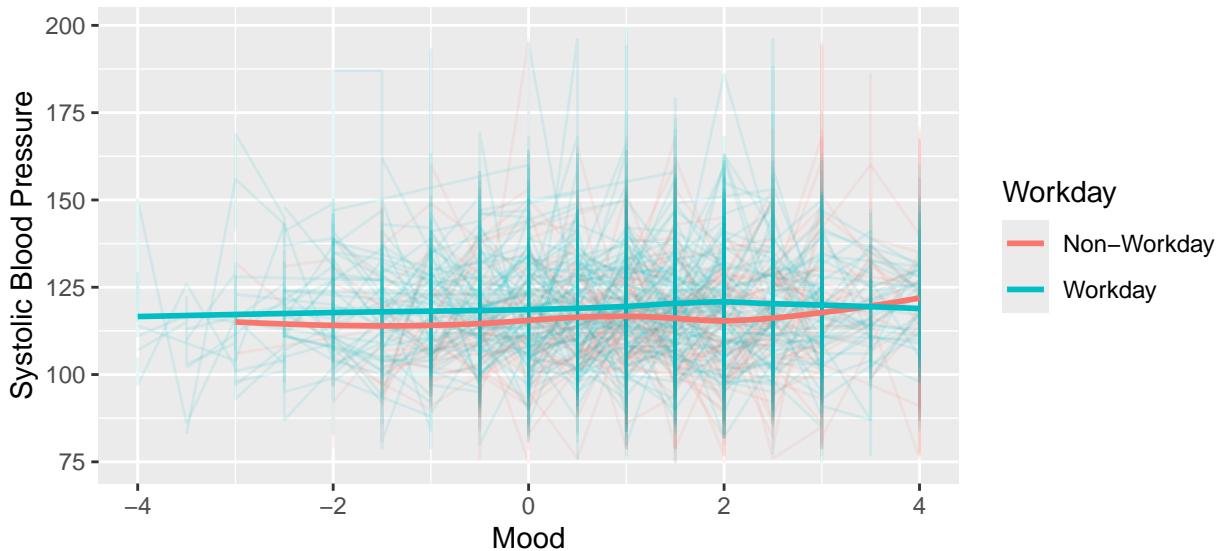
```
ggplot(nurse_filtered, aes(x = standing, y = sys)) + geom_boxplot() +
  facet_wrap(~fh_2) + labs(x = "Standing vs Non Standing",
  y = "Systolic Blood Pressure", title = "BP by Standing and Family History")
```



```
## Mood Ratings
ggplot(nurse_filtered, aes(x = mood, y = sys)) + geom_line(aes(group = snum),
  color = "dark grey") + geom_smooth(method = "loess", color = "black",
  se = F, size = 1) + facet_wrap(~day)
```

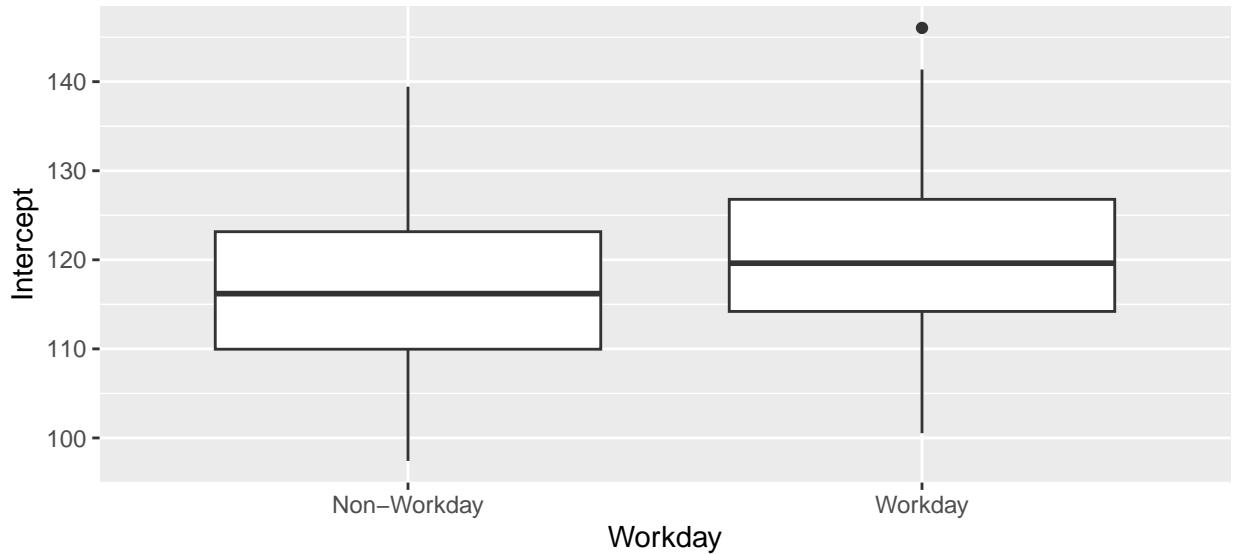


```
ggplot(nurse_filtered, aes(x = mood, y = sys, color = as.factor(day3))) +
  geom_line(aes(group = interaction(snum, day)), alpha = 0.1) +
  geom_smooth(method = "loess", se = FALSE, size = 1) + labs(color = "Workday",
  x = "Mood", y = "Systolic Blood Pressure")
```

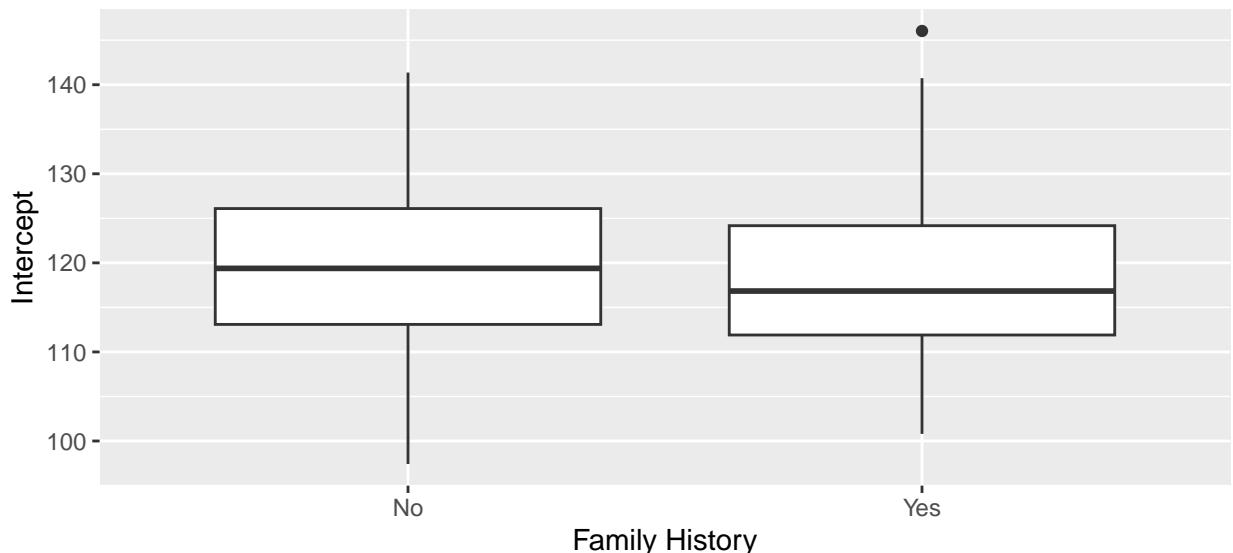


```
ls_fits_timepass <- group_modify(group_by(nurse_complete, snum),
  ~tidy(lm(sys ~ timepass, data = .x))[, 1:2])
ls_fits_timepass_final <- ls_fits_timepass %>%
  pivot_wider(names_from = term, values_from = estimate) %>%
  rename(Intercept = `Intercept`, Slope = timepass) %>%
  left_join(nurse_bysubject, by = "snum")

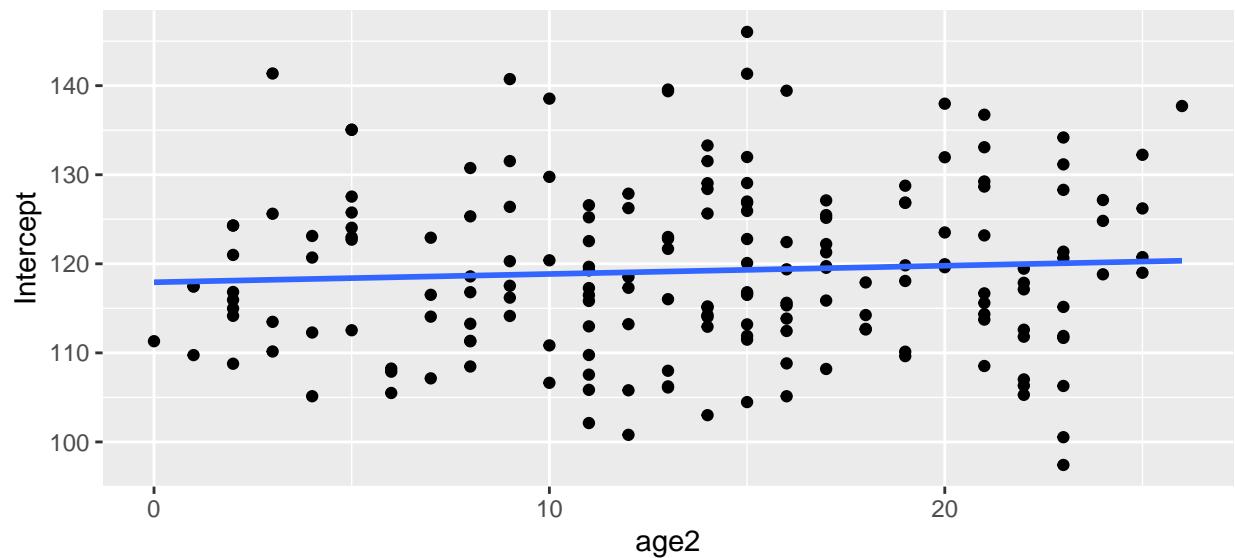
## Intercept
ggplot(ls_fits_timepass_final, aes(x = day3, y = Intercept)) +
  geom_boxplot() + labs(x = "Workday")
```



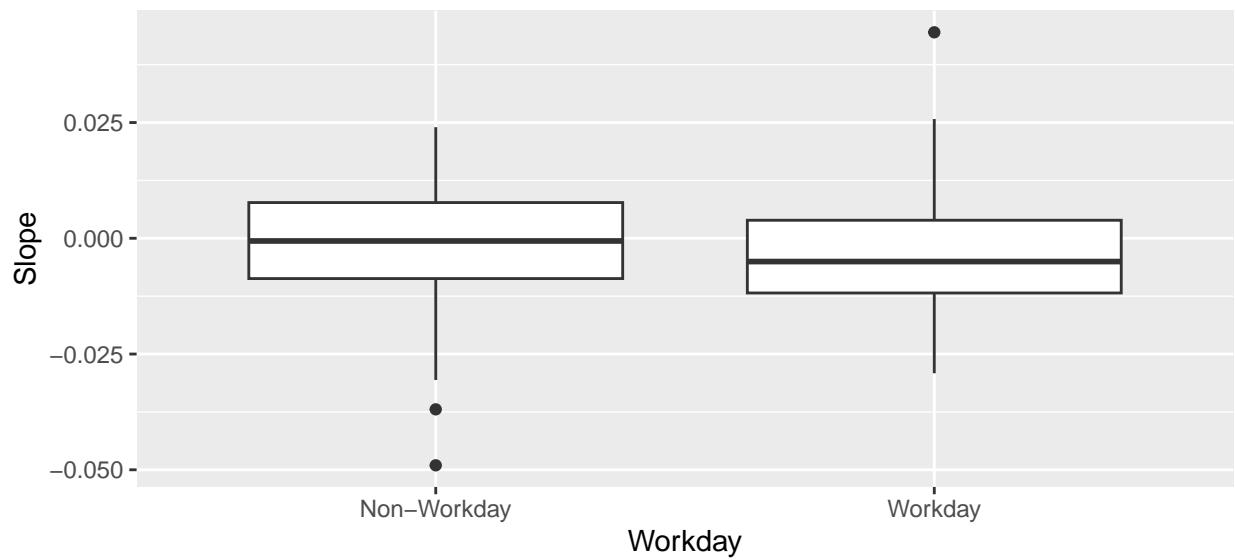
```
ggplot(ls_fits_timepass_final, aes(x = fh_2, y = Intercept)) +
  geom_boxplot() + labs(x = "Family History")
```



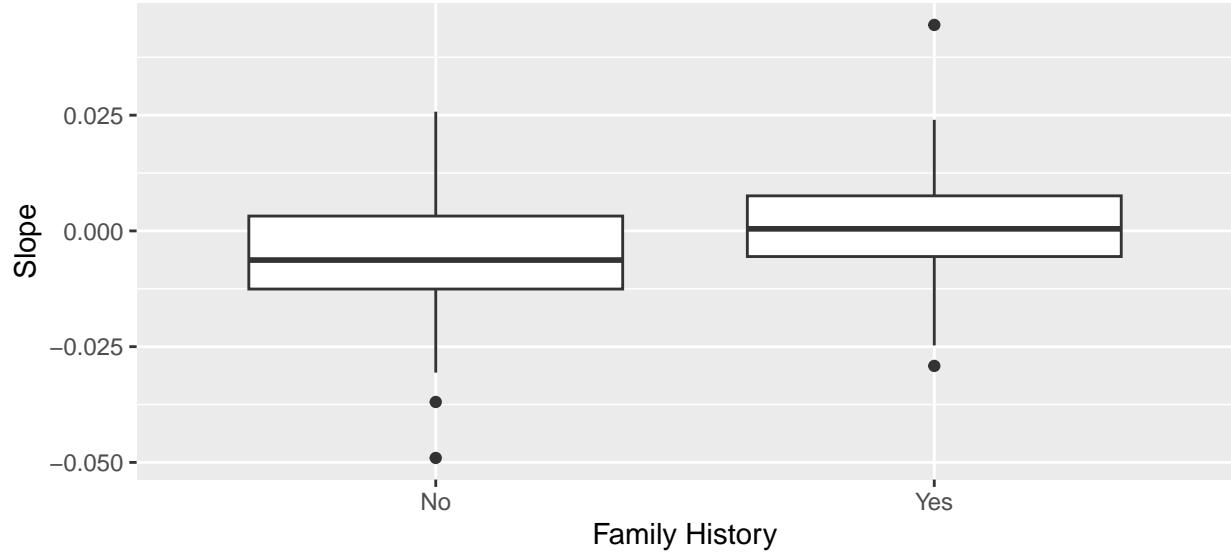
```
ggplot(ls_fits_timepass_final, aes(x = age2, y = Intercept)) +
  geom_point() + geom_smooth(method = "lm", se = F)
```



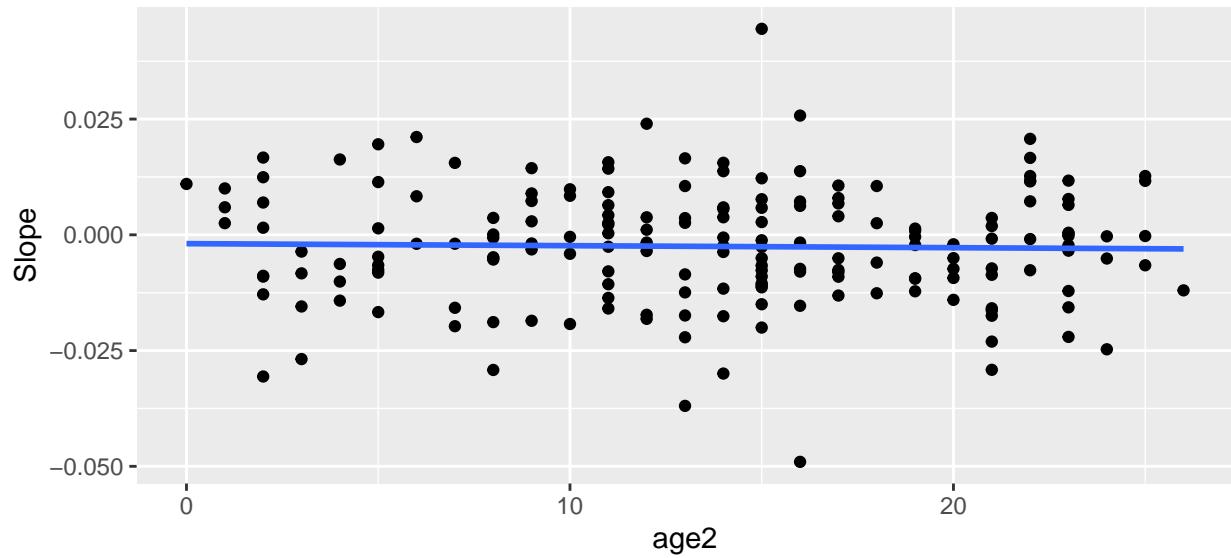
```
## Timepass
ggplot(ls.fits_timepass_final, aes(x = day3, y = Slope)) + geom_boxplot() +
  labs(x = "Workday")
```



```
ggplot(ls.fits_timepass_final, aes(x = fh_2, y = Slope)) + geom_boxplot() +
  labs(x = "Family History")
```

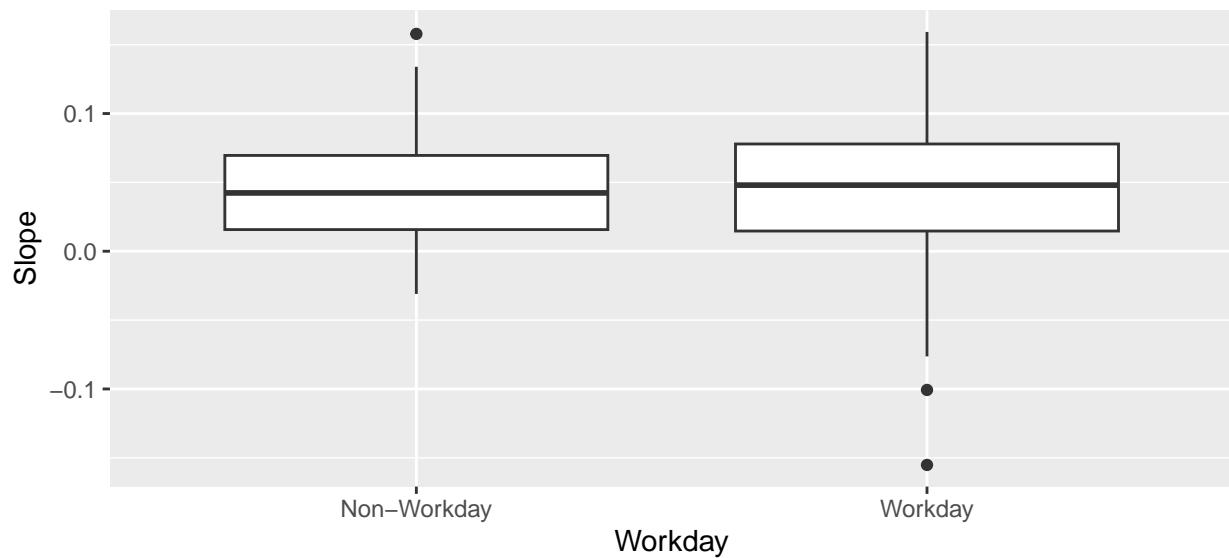


```
ggplot(ls.fits_timepass_final, aes(x = age2, y = Slope)) + geom_point() +
  geom_smooth(method = "lm", se = F)
```

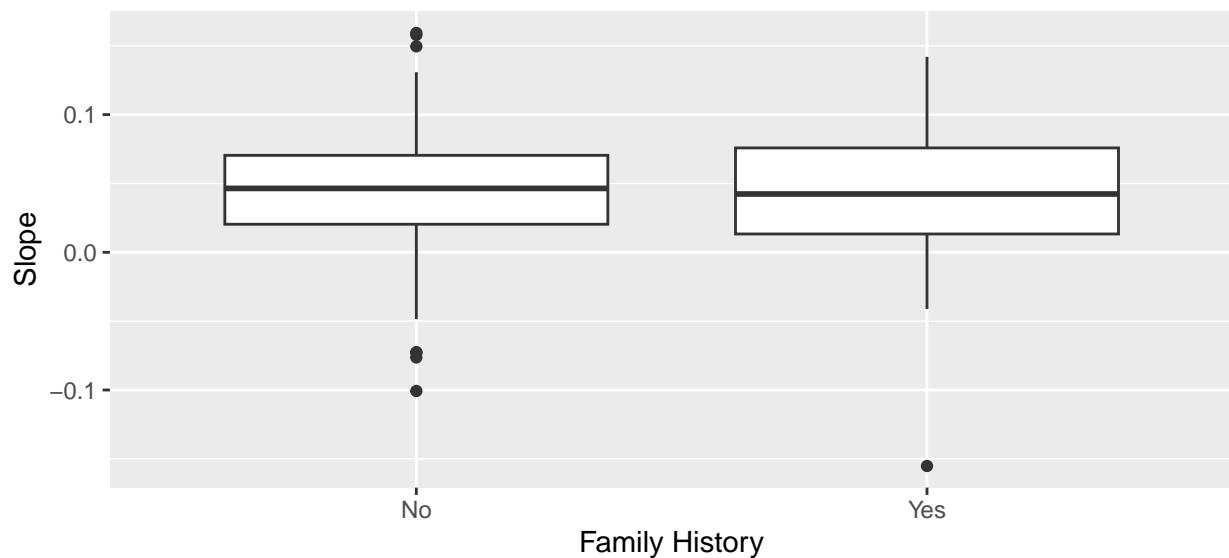


```
## Activity Level
ls.fits_act <- group_modify(group_by(nurse_complete, snum), ~tidy(lm(sys ~
  mnact5, data = .x))[, 1:2])
ls.fits_act_final <- ls.fits_act %>%
  pivot_wider(names_from = term, values_from = estimate) %>%
  rename(Intercept = `Intercept`, Slope = mnact5) %>%
  left_join(nurse_bysubject, by = "snum")

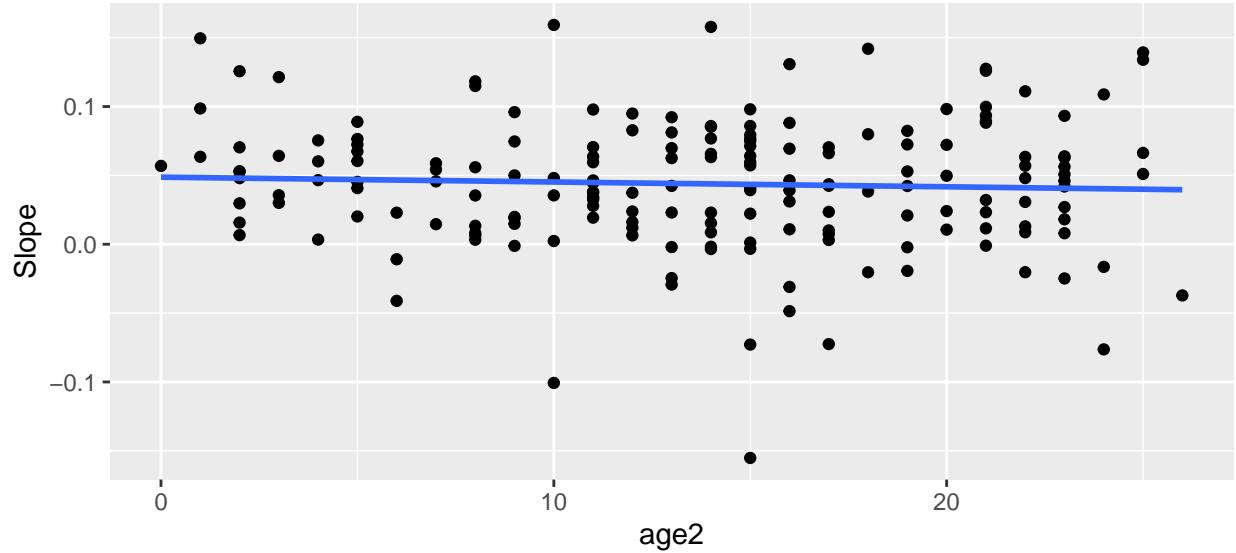
ggplot(ls.fits_act_final, aes(x = day3, y = Slope)) + geom_boxplot() +
  labs(x = "Workday")
```



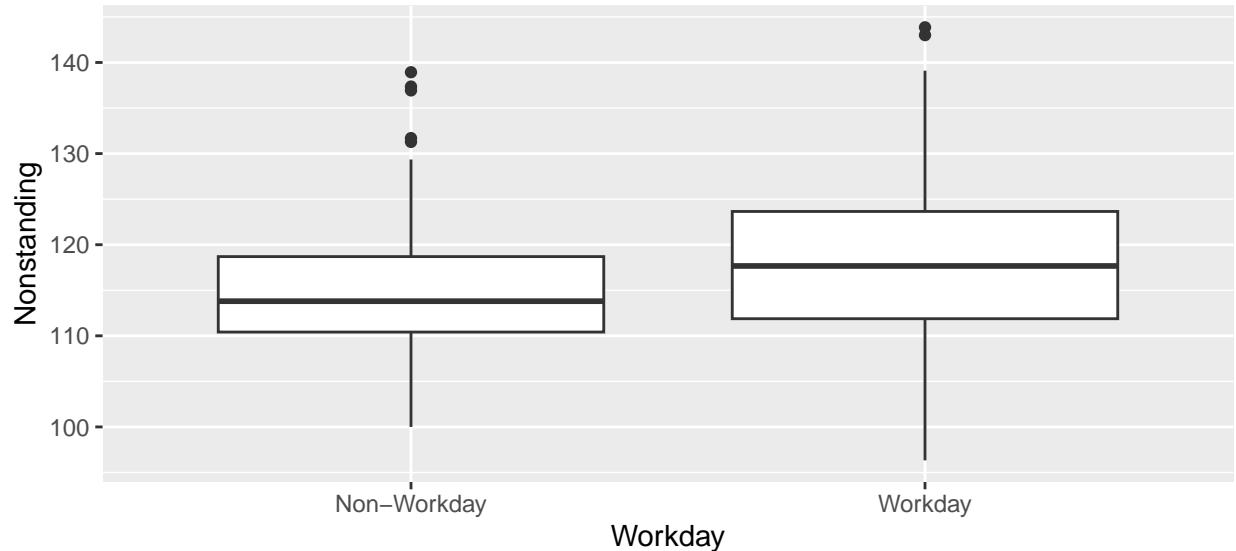
```
ggplot(ls_fits_act_final, aes(x = fh_2, y = Slope)) + geom_boxplot() +
  labs(x = "Family History")
```



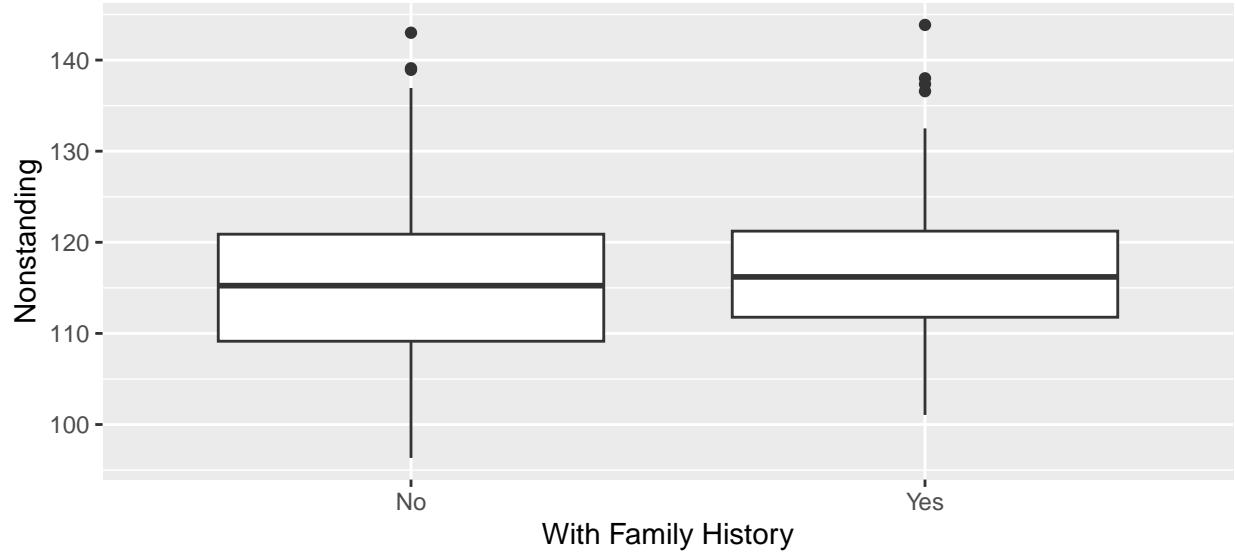
```
ggplot(ls_fits_act_final, aes(x = age2, y = Slope)) + geom_point() +
  geom_smooth(method = "lm", se = F)
```



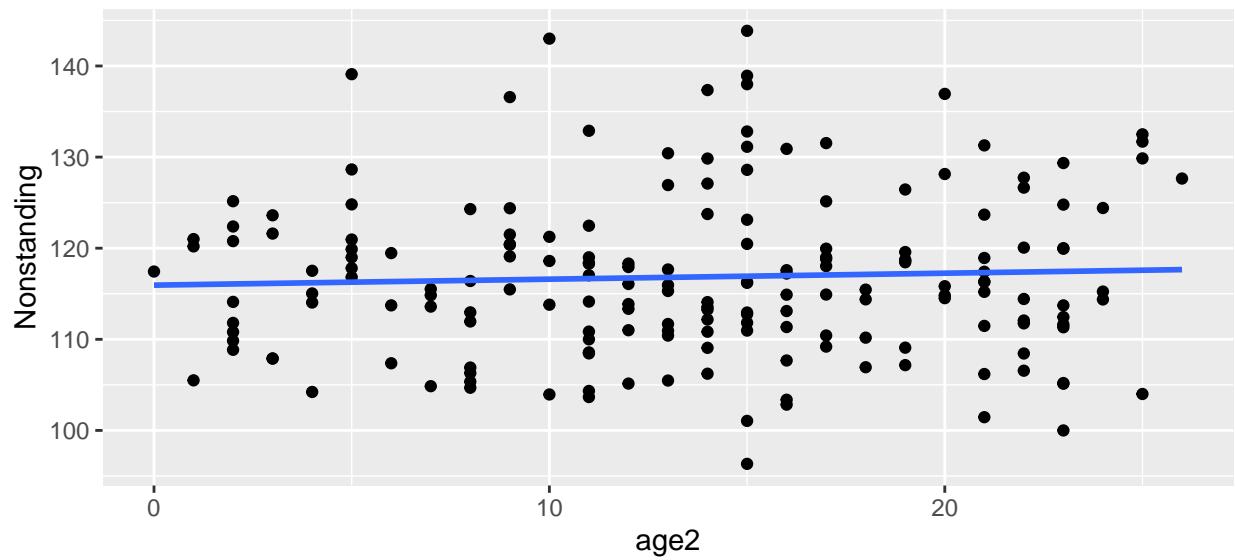
```
## Posture
ls_fits_post <- group_modify(group_by(nurse_complete, snum),
  ~tidy(lm(sys ~ standing, data = .x))[, 1:2])
ls_fits_post_final <- ls_fits_post %>%
  pivot_wider(names_from = term, values_from = estimate) %>%
  rename(Nonstanding = `Intercept`, Standing = standing) %>%
  left_join(nurse_bysubject, by = "snum")
### Non-standing
ggplot(ls_fits_post_final, aes(x = day3, y = Nonstanding)) +
  geom_boxplot() + labs(x = "Workday")
```



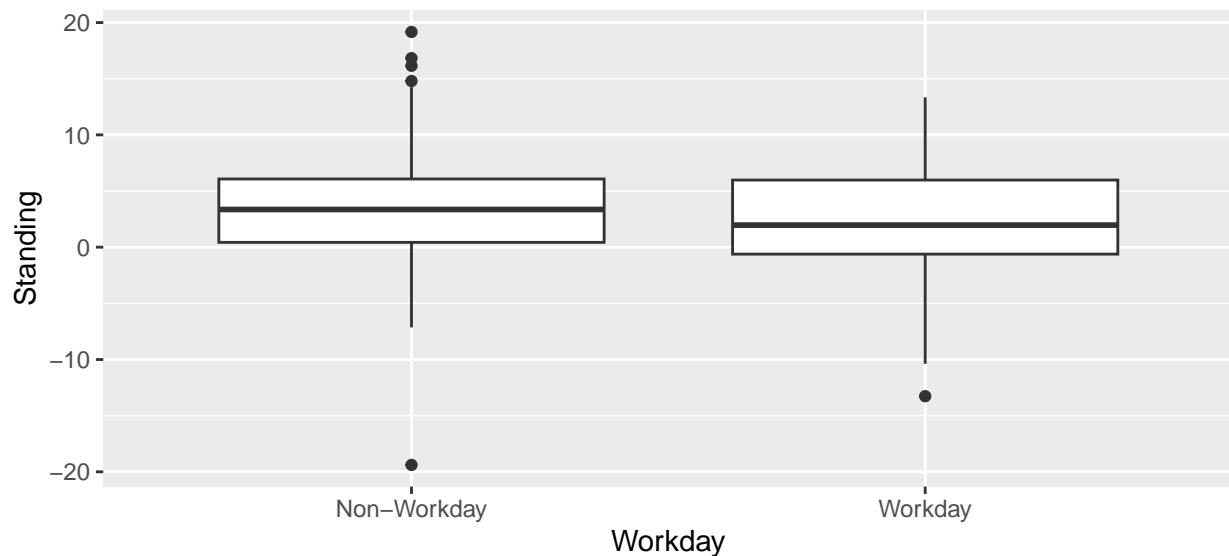
```
ggplot(ls_fits_post_final, aes(x = fh_2, y = Nonstanding)) +
  geom_boxplot() + labs(x = "With Family History")
```



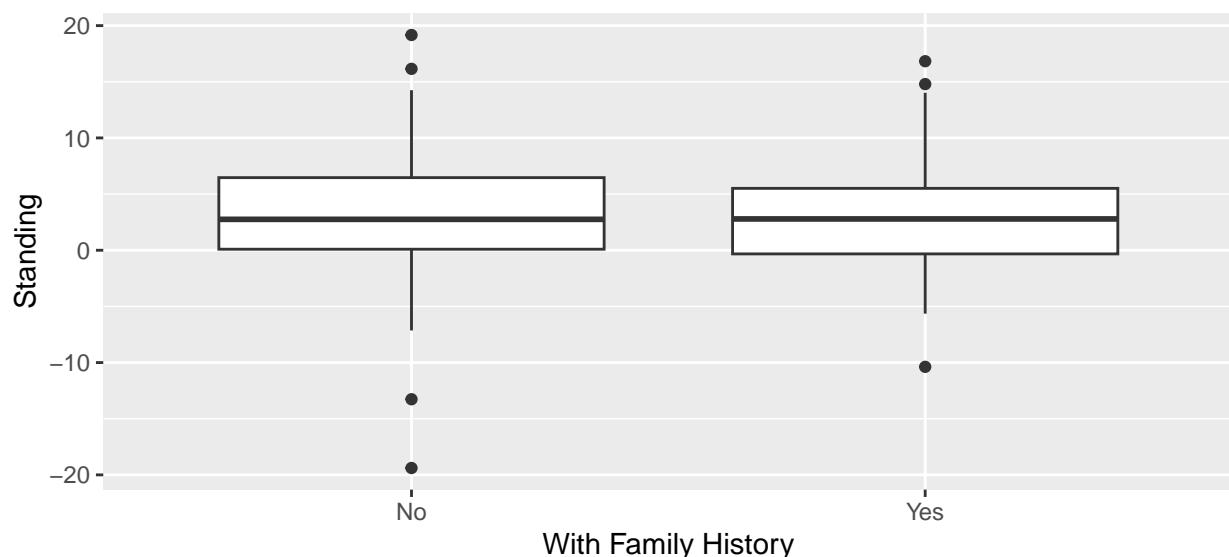
```
ggplot(ls.fits_post_final, aes(x = age2, y = Nonstanding)) +
  geom_point() + geom_smooth(method = "lm", se = F)
```



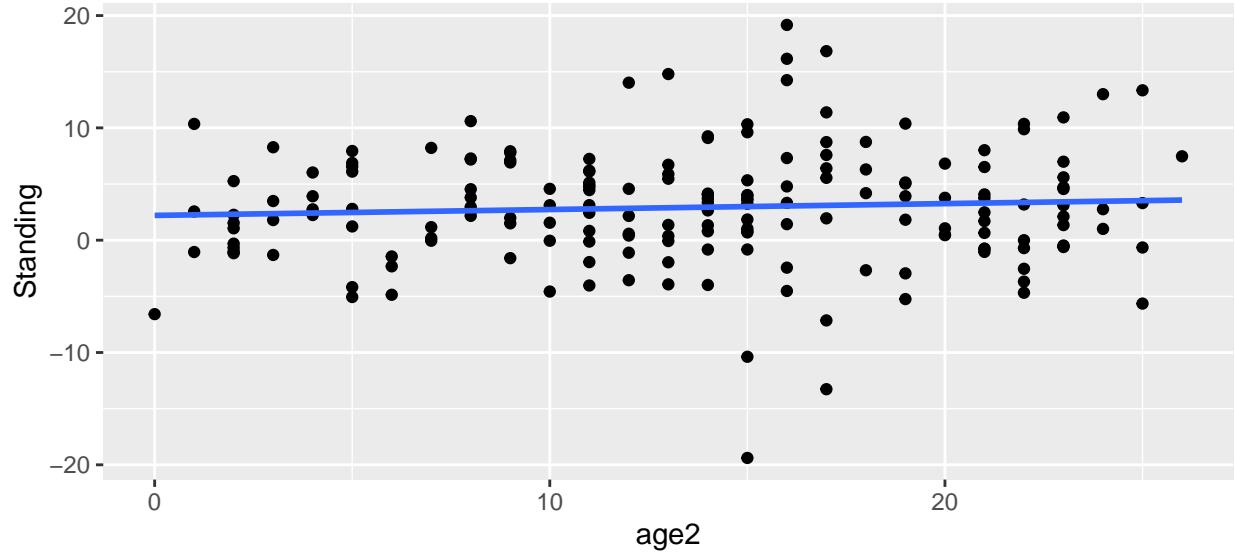
```
### Stand
ggplot(ls.fits_post_final, aes(x = day3, y = Standing)) + geom_boxplot() +
  labs(x = "Workday")
```



```
ggplot(ls_fits_post_final, aes(x = fh_2, y = Standing)) + geom_boxplot() +
  labs(x = "With Family History")
```

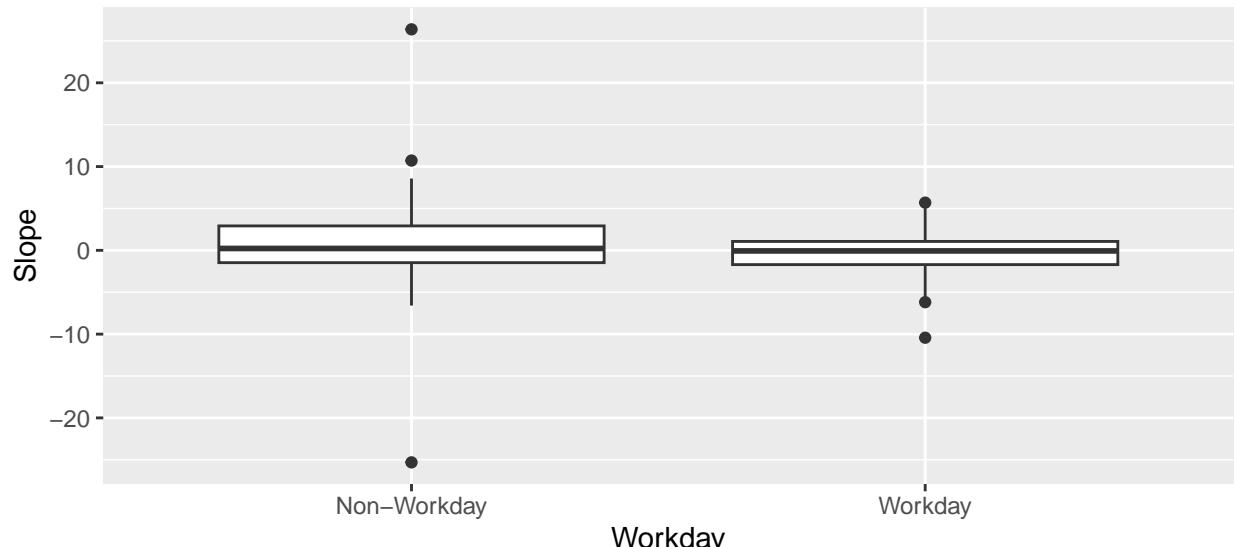


```
ggplot(ls_fits_post_final, aes(x = age2, y = Standing)) + geom_point() +
  geom_smooth(method = "lm", se = F)
```

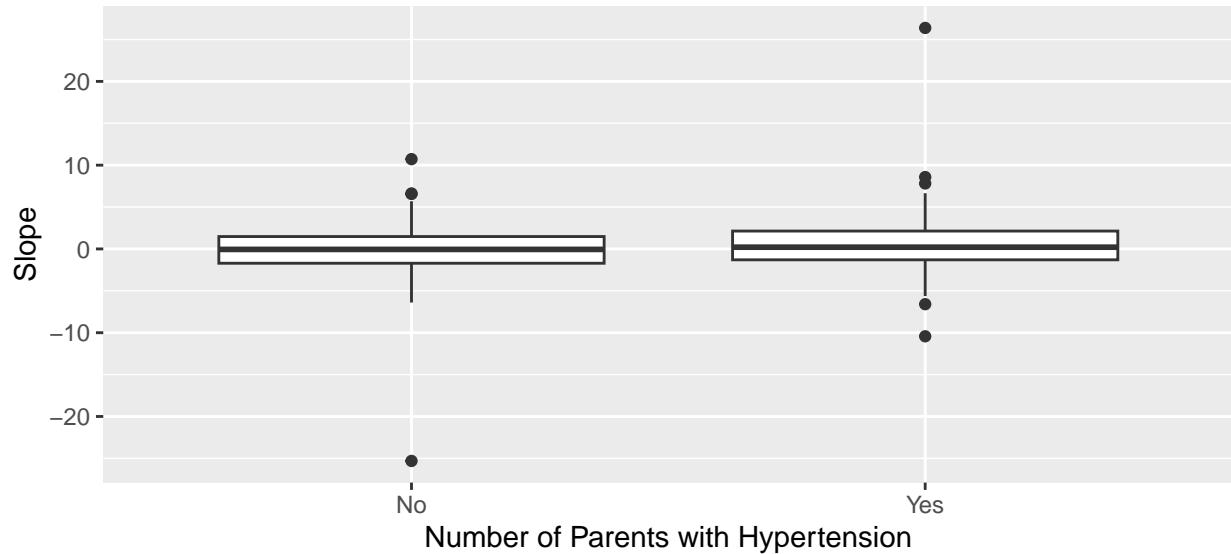


```
## Mood
ls_fits_mood <- group_modify(group_by(nurse_complete, snum),
  ~tidy(lm(sys ~ mood, data = .x))[, 1:2])
ls_fits_mood_final <- ls_fits_mood %>%
  pivot_wider(names_from = term, values_from = estimate) %>%
  rename(Intercept = `Intercept`, Slope = mood) %>%
  left_join(nurse_bysubject, by = "snum")

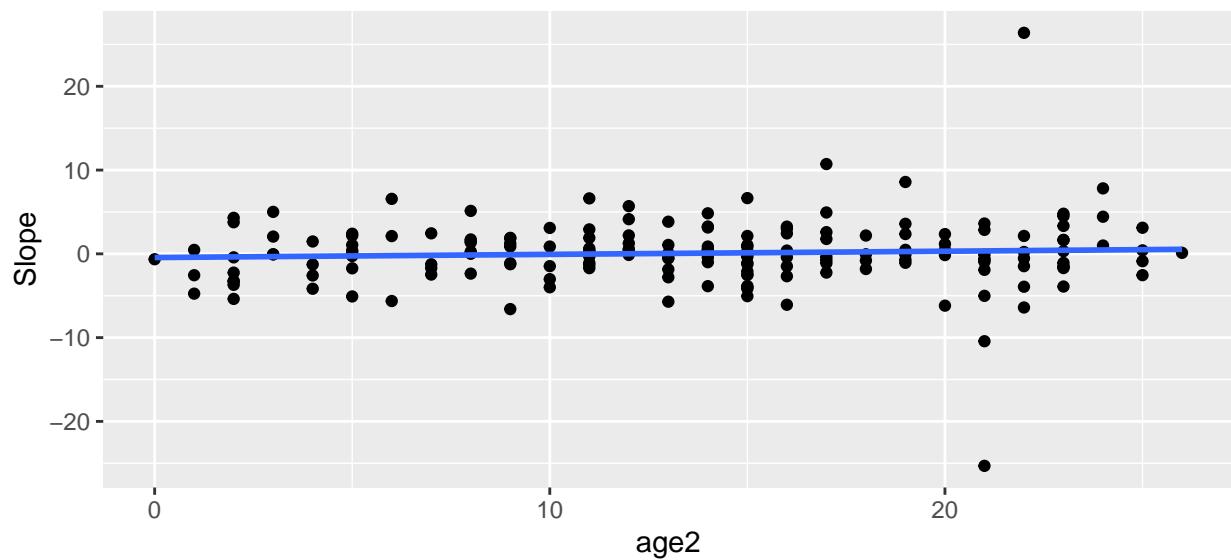
ggplot(ls_fits_mood_final, aes(x = day3, y = Slope)) + geom_boxplot() +
  labs(x = "Workday")
```



```
ggplot(ls_fits_mood_final, aes(x = fh_2, y = Slope)) + geom_boxplot() +
  labs(x = "Number of Parents with Hypertension")
```



```
ggplot(ls.fits_mood_final, aes(x = age2, y = Slope)) + geom_point() +
  geom_smooth(method = "lm", se = F)
```



Model Selection

Base Model (Random Intercept)

```
nurse_lmm_RI <- lmer(sys ~ timepass + (1 | snum), data = nurse_filtered)
summary(nurse_lmm_RI)
## Linear mixed model fit by REML ['lmerMod']
## Formula: sys ~ timepass + (1 | snum)
##   Data: nurse_filtered
##
## REML criterion at convergence: 63155.6
##
## Scaled residuals:
##       Min     1Q Median     3Q    Max 
## -4.6450 -0.5715 -0.0592  0.5358  6.5907
```

```

## 
## Random effects:
##   Groups    Name        Variance Std.Dev.
##   snum      (Intercept) 66.81     8.174
##   Residual             165.93    12.881
## Number of obs: 7877, groups: snum, 182
##
## 
## Fixed effects:
##                   Estimate Std. Error t value
## (Intercept) 1.193e+02 6.717e-01 177.631
## timepass   -2.603e-03 5.542e-04 -4.697
##
## Correlation of Fixed Effects:
##          (Intr)
## timepass -0.371

nurse_lm <- lm(sys ~ timepass, data = nurse_filtered)
summary(nurse_lm)
##
## Call:
## lm(formula = sys ~ timepass, data = nurse_filtered)
##
## Residuals:
##    Min     1Q Median     3Q    Max
## -44.459 -10.182 -1.283  8.910  81.390
##
## 
## Coefficients:
##                   Estimate Std. Error t value Pr(>|t|)
## (Intercept) 119.521347  0.335984 355.735 < 2e-16 ***
## timepass    -0.002976  0.000642 -4.636 3.61e-06 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 15.16 on 7875 degrees of freedom
## Multiple R-squared:  0.002722, Adjusted R-squared:  0.002595
## F-statistic: 21.49 on 1 and 7875 DF, p-value: 3.61e-06

(lrt_RI <- as.numeric(2 * (logLik(nurse_lmm_RI, REML = TRUE) -
  logLik(nurse_lm, REML = TRUE))))
## [1] 2044.143
0.5 * (1 - pchisq(lrt_RI, df = 0)) + 0.5 * (1 - pchisq(lrt_RI,
  df = 1))
## [1] 0

```

Random Intercept with Level 1 Covariates

```

nurse_lmm_RI_lv1 <- lmer(sys ~ timepass + mnact5 + standing +
  mood + (1 | snum), data = nurse_filtered)

summary(nurse_lmm_RI_lv1)
## Linear mixed model fit by REML ['lmerMod']
## Formula: sys ~ timepass + mnact5 + standing + mood + (1 | snum)

```

```

##      Data: nurse_filtered
##
## REML criterion at convergence: 62803.1
##
## Scaled residuals:
##      Min     1Q Median     3Q    Max
## -4.9291 -0.5545 -0.0339  0.5256  6.4425
##
## Random effects:
## Groups   Name        Variance Std.Dev.
## snum     (Intercept) 66.3      8.142
## Residual           158.3     12.583
## Number of obs: 7877, groups: snum, 182
##
## Fixed effects:
##              Estimate Std. Error t value
## (Intercept) 1.099e+02 8.622e-01 127.514
## timepass    -6.072e-04 5.600e-04 -1.084
## mnact5      4.245e-02 2.476e-03 17.144
## standing1   1.143e+00 3.154e-01  3.626
## mood        -9.358e-02 1.409e-01 -0.664
##
## Correlation of Fixed Effects:
##          (Intr) timpss mnact5 stndn1
## timepass -0.418
## mnact5   -0.533  0.132
## standing1 -0.056  0.115 -0.286
## mood      -0.269  0.154 -0.006  0.035
anova(nurse_lmm_RI, nurse_lmm_RI_lv1)
## Data: nurse_filtered
## Models:
## nurse_lmm_RI: sys ~ timepass + (1 | snum)
## nurse_lmm_RI_lv1: sys ~ timepass + mnact5 + standing + mood + (1 | snum)
##                   npar AIC BIC logLik deviance Chisq Df Pr(>Chisq)
## nurse_lmm_RI      4 63151 63179 -31572    63143
## nurse_lmm_RI_lv1  7 62792 62841 -31389    62778 365.37  3 < 2.2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

nurse_lmm_RI_noMood <- lmer(sys ~ timepass + mnact5 + standing +
  (1 | snum), data = nurse_filtered)
anova(nurse_lmm_RI_noMood, nurse_lmm_RI_lv1)
## Data: nurse_filtered
## Models:
## nurse_lmm_RI_noMood: sys ~ timepass + mnact5 + standing + (1 | snum)
## nurse_lmm_RI_lv1: sys ~ timepass + mnact5 + standing + mood + (1 | snum)
##                   npar AIC BIC logLik deviance Chisq Df Pr(>Chisq)
## nurse_lmm_RI_noMood 6 62790 62832 -31389    62778
## nurse_lmm_RI_lv1    7 62792 62841 -31389    62778 0.4349  1     0.5096

nurse_lmm_RI_noMoodTime <- lmer(sys ~ mnact5 + standing + (1 |
  snum), data = nurse_filtered)
anova(nurse_lmm_RI_noMoodTime, nurse_lmm_RI_noMood)

```

```

## Data: nurse_filtered
## Models:
## nurse_lmm_RI_noMoodTime: sys ~ mnact5 + standing + (1 | snum)
## nurse_lmm_RI_noMood: sys ~ timepass + mnact5 + standing + (1 | snum)
##          npar   AIC   BIC logLik deviance Chisq Df Pr(>Chisq)
## nurse_lmm_RI_noMoodTime      5 62789 62824 -31390    62779
## nurse_lmm_RI_noMood       6 62790 62832 -31389    62778  0.99  1     0.3197
## anova(nurse_lmm_RI_noMoodTime, nurse_lmm_RI_lv1)
## Data: nurse_filtered
## Models:
## nurse_lmm_RI_noMoodTime: sys ~ mnact5 + standing + (1 | snum)
## nurse_lmm_RI_lv1: sys ~ timepass + mnact5 + standing + mood + (1 | snum)
##          npar   AIC   BIC logLik deviance Chisq Df Pr(>Chisq)
## nurse_lmm_RI_noMoodTime      5 62789 62824 -31390    62779
## nurse_lmm_RI_lv1           7 62792 62841 -31389    62778 1.4249  2     0.4904

```

Random Intercept and Slope

```

nurse_lmm_RIS_mood <- lmer(sys ~ timepass + mnact5 + standing +
  mood + (1 + mood | snum), data = nurse_filtered)
summary(nurse_lmm_RIS_mood)
## Linear mixed model fit by REML ['lmerMod']
## Formula: sys ~ timepass + mnact5 + standing + mood + (1 + mood | snum)
##   Data: nurse_filtered
##
## REML criterion at convergence: 62793.2
##
## Scaled residuals:
##    Min     1Q Median     3Q    Max
## -4.9301 -0.5530 -0.0336  0.5242  6.4664
##
## Random effects:
##   Groups   Name        Variance Std.Dev. Corr
##   snum     (Intercept) 70.337   8.387
##           mood         1.321   1.149   -0.27
##   Residual           157.060  12.532
## Number of obs: 7877, groups: snum, 182
##
## Fixed effects:
##             Estimate Std. Error t value
## (Intercept) 1.100e+02 8.844e-01 124.339
## timepass    -6.877e-04 5.676e-04 -1.212
## mnact5      4.226e-02 2.478e-03 17.052
## standing1   1.127e+00 3.156e-01   3.570
## mood        -2.696e-02 1.730e-01  -0.156
##
## Correlation of Fixed Effects:
##          (Intr) timepass mnact5 stndn1
## timepass -0.408
## mnact5   -0.520  0.134
## standing1 -0.055  0.115 -0.284
## mood      -0.336  0.114 -0.008  0.028

```

```

(lrt_RIS_mood <- as.numeric(2 * (logLik(nurse_lmm_RIS_mood, REML = TRUE) -
  logLik(nurse_lmm_RI, REML = TRUE))))
## [1] 362.3544
0.5 * (1 - pchisq(lrt_RI, df = 1)) + 0.5 * (1 - pchisq(lrt_RI,
  df = 2))
## [1] 0

nurse_lmm_RIS_mood_stand <- lmer(sys ~ timepass + mnact5 + standing +
  mood + (1 + mood + standing | snum), data = nurse_filtered)
summary(nurse_lmm_RIS_mood_stand)
## Linear mixed model fit by REML ['lmerMod']
## Formula: sys ~ timepass + mnact5 + standing + mood + (1 + mood + standing | 
##   snum)
##   Data: nurse_filtered
##
## REML criterion at convergence: 62760.9
##
## Scaled residuals:
##    Min     1Q Median     3Q    Max
## -4.9054 -0.5530 -0.0325  0.5242  6.4776
##
## Random effects:
## Groups   Name        Variance Std.Dev. Corr
## snum     (Intercept) 77.283   8.791
##          mood         1.219   1.104   -0.35
##          standing1   10.025   3.166   -0.33  0.70
## Residual           154.812  12.442
## Number of obs: 7877, groups: snum, 182
##
## Fixed effects:
##             Estimate Std. Error t value
## (Intercept) 1.100e+02 9.054e-01 121.493
## timepass    -7.030e-04 5.677e-04 -1.238
## mnact5      4.215e-02 2.488e-03 16.944
## standing1   1.153e+00 3.935e-01  2.931
## mood        -3.004e-02 1.700e-01 -0.177
##
## Correlation of Fixed Effects:
##          (Intr) timepass mnact5 stndn1
## timepass -0.403
## mnact5   -0.511  0.139
## standing1 -0.185  0.089 -0.228
## mood      -0.354  0.116 -0.012  0.228

(lrt_RIS_mood_stand <- as.numeric(2 * (logLik(nurse_lmm_RIS_mood_stand,
  REML = TRUE) - logLik(nurse_lmm_RIS_mood, REML = TRUE))))
## [1] 32.35688
0.5 * (1 - pchisq(lrt_RIS_mood_stand, df = 2)) + 0.5 * (1 - pchisq(lrt_RIS_mood_stand,
  df = 3))
## [1] 2.671291e-07

```

Random Intercept and Slope with Level 2 Covariates

```

nurse_lmm_RIS_age <- lmer(sys ~ timepass + mnact5 + standing +
  mood + age24 + (1 + mood + standing | snum), data = nurse_filtered)

summary(nurse_lmm_RIS_age)
## Linear mixed model fit by REML ['lmerMod']
## Formula: sys ~ timepass + mnact5 + standing + mood + age24 + (1 + mood +
##   standing | snum)
##   Data: nurse_filtered
##
## REML criterion at convergence: 62762.6
##
## Scaled residuals:
##    Min     1Q Median     3Q    Max
## -4.9027 -0.5515 -0.0328  0.5237  6.4821
##
## Random effects:
##   Groups   Name        Variance Std.Dev. Corr
##   snum     (Intercept) 77.668   8.813
##           mood         1.221   1.105  -0.36
##           standing1   10.070   3.173  -0.33  0.69
##   Residual          154.805  12.442
## Number of obs: 7877, groups: snum, 182
##
## Fixed effects:
##             Estimate Std. Error t value
## (Intercept) 1.087e+02 1.588e+00 68.438
## timepass    -7.015e-04 5.677e-04 -1.236
## mnact5      4.218e-02 2.488e-03 16.953
## standing1   1.150e+00 3.938e-01  2.921
## mood        -3.780e-02 1.702e-01 -0.222
## age24       9.949e-02 9.576e-02  1.039
##
## Correlation of Fixed Effects:
##            (Intr) timepass mnact5 stndn1 mood
## timepass  -0.232
## mnact5    -0.301  0.139
## standing1 -0.101  0.089 -0.228
## mood      -0.171  0.116 -0.012  0.228
## age24     -0.821  0.002  0.012 -0.006 -0.041
anova(nurse_lmm_RIS_mood_stand, nurse_lmm_RIS_age)
## Data: nurse_filtered
## Models:
## nurse_lmm_RIS_mood_stand: sys ~ timepass + mnact5 + standing + mood + (1 + mood + standing | snum)
## nurse_lmm_RIS_age: sys ~ timepass + mnact5 + standing + mood + age24 + (1 + mood + standing | snum)
##                npar AIC BIC logLik deviance Chisq Df Pr(>Chisq)
## nurse_lmm_RIS_mood_stand 12 62761 62844 -31368    62737
## nurse_lmm_RIS_age        13 62762 62852 -31368    62736 1.0788  1      0.299

nurse_lmm_RIS_day <- lmer(sys ~ day2 * (timepass + standing) +
  mnact5 + mood + (1 + mood + standing | snum), data = nurse_filtered)

summary(nurse_lmm_RIS_day)

```

```

## Linear mixed model fit by REML ['lmerMod']
## Formula: sys ~ day2 * (timepass + standing) + mnact5 + mood + (1 + mood +
##   standing | snum)
## Data: nurse_filtered
##
## REML criterion at convergence: 62760.8
##
## Scaled residuals:
##   Min     1Q Median     3Q    Max
## -4.8984 -0.5475 -0.0321  0.5274  6.5335
##
## Random effects:
## Groups   Name        Variance Std.Dev. Corr
## snum     (Intercept) 75.245   8.674
##         mood         1.249   1.117   -0.32
##         standing1   10.276   3.206   -0.33  0.67
## Residual           154.694  12.438
## Number of obs: 7877, groups: snum, 182
##
## Fixed effects:
##             Estimate Std. Error t value
## (Intercept) 1.081e+02  1.172e+00 92.239
## day21       3.579e+00  1.411e+00  2.537
## timepass    6.532e-04  8.423e-04  0.775
## standing1   1.261e+00  5.794e-01  2.176
## mnact5      4.237e-02  2.496e-03 16.974
## mood        -4.565e-02  1.716e-01 -0.266
## day21:timepass -2.468e-03  1.128e-03 -2.187
## day21:standing1 -3.106e-01  7.591e-01 -0.409
##
## Correlation of Fixed Effects:
##          (Intr) day21  timpss stndn1 mnact5 mood   dy21:t
## day21    -0.638
## timepass  -0.388  0.273
## standing1 -0.170  0.185  0.039
## mnact5    -0.393 -0.006  0.134 -0.200
## mood      -0.261 -0.010  0.020  0.102 -0.012
## day21:tmpss  0.245 -0.380 -0.738 -0.029 -0.051  0.081
## dy21:stndn1  0.127 -0.291 -0.039 -0.730  0.060  0.072  0.096
anova(nurse_lmm_RIS_mood_stand, nurse_lmm_RIS_day)
## Data: nurse_filtered
## Models:
## nurse_lmm_RIS_mood_stand: sys ~ timepass + mnact5 + standing + mood + (1 + mood + standing | snum)
## nurse_lmm_RIS_day: sys ~ day2 * (timepass + standing) + mnact5 + mood + (1 + mood + standing | snum)
##   npar   AIC   BIC logLik deviance Chisq Df Pr(>Chisq)
## nurse_lmm_RIS_mood_stand 12 62761 62844 -31368   62737
## nurse_lmm_RIS_day        15 62758 62863 -31364   62728 8.2278  3   0.04153
##
## nurse_lmm_RIS_mood_stand
## nurse_lmm_RIS_day      *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

```

```

nurse_lmm_RIS_day_nostand <- lmer(sys ~ day2 * (timepass) + standing +
  mnact5 + mood + (1 + mood + standing | snum), data = nurse_filtered)
anova(nurse_lmm_RIS_day, nurse_lmm_RIS_day_nostand)
## Data: nurse_filtered
## Models:
## nurse_lmm_RIS_day_nostand: sys ~ day2 * (timepass) + standing + mnact5 + mood + (1 + mood + standing | snum)
## nurse_lmm_RIS_day: sys ~ day2 * (timepass + standing) + mnact5 + mood + (1 + mood + standing | snum)
##   npar AIC BIC logLik deviance Chisq Df Pr(>Chisq)
## nurse_lmm_RIS_day_nostand 14 62757 62854 -31364 62729
## nurse_lmm_RIS_day          15 62758 62863 -31364 62728 0.1649 1 0.6847
anova(nurse_lmm_RIS_day_nostand, nurse_lmm_RIS_mood_stand)
## Data: nurse_filtered
## Models:
## nurse_lmm_RIS_mood_stand: sys ~ timepass + mnact5 + standing + mood + (1 + mood + standing | snum)
## nurse_lmm_RIS_day_nostand: sys ~ day2 * (timepass) + standing + mnact5 + mood + (1 + mood + standing | snum)
##   npar AIC BIC logLik deviance Chisq Df Pr(>Chisq)
## nurse_lmm_RIS_mood_stand 12 62761 62844 -31368 62737
## nurse_lmm_RIS_day_nostand 14 62757 62854 -31364 62729 8.0629 2 0.01775
##
## nurse_lmm_RIS_mood_stand
## nurse_lmm_RIS_day_nostand *
## ---
## Signif. codes: 0 '****' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

nurse_lmm_RIS_day_nointer <- lmer(sys ~ day2 + timepass + standing +
  mnact5 + mood + (1 + mood + standing | snum), data = nurse_filtered)
anova(nurse_lmm_RIS_day_nostand, nurse_lmm_RIS_day_nointer)
## Data: nurse_filtered
## Models:
## nurse_lmm_RIS_day_nointer: sys ~ day2 + timepass + standing + mnact5 + mood + (1 + mood + standing | snum)
## nurse_lmm_RIS_day_nostand: sys ~ day2 * (timepass) + standing + mnact5 + mood + (1 + mood + standing | snum)
##   npar AIC BIC logLik deviance Chisq Df Pr(>Chisq)
## nurse_lmm_RIS_day_nointer 13 62759 62850 -31367 62733
## nurse_lmm_RIS_day_nostand 14 62757 62854 -31364 62729 4.6367 1 0.0313
##
## nurse_lmm_RIS_day_nointer
## nurse_lmm_RIS_day_nostand *
## ---
## Signif. codes: 0 '****' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

nurse_lmm_RIS_day_fh <- lmer(sys ~ (day2 + fh_yes) * timepass +
  standing + mnact5 + mood + (1 + mood + standing | snum),
  data = nurse_filtered)
anova(nurse_lmm_RIS_day_fh, nurse_lmm_RIS_day_nostand)
## Data: nurse_filtered
## Models:
## nurse_lmm_RIS_day_nostand: sys ~ day2 * (timepass) + standing + mnact5 + mood + (1 + mood + standing | snum)
## nurse_lmm_RIS_day_fh: sys ~ (day2 + fh_yes) * timepass + standing + mnact5 + mood + (1 + mood + standing | snum)
##   npar AIC BIC logLik deviance Chisq Df Pr(>Chisq)
## nurse_lmm_RIS_day_nostand 14 62757 62854 -31364 62729
## nurse_lmm_RIS_day_fh        16 62745 62856 -31356 62713 15.756 2 0.000379
##
## nurse_lmm_RIS_day_nostand
## nurse_lmm_RIS_day_fh      ***

```

```

## ---
## Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
anova(nurse_lmm_RIS_day_fh, nurse_lmm_RIS_mood_stand)
## Data: nurse_filtered
## Models:
## nurse_lmm_RIS_mood_stand: sys ~ timepass + mnact5 + standing + mood + (1 + mood + standing | snum)
## nurse_lmm_RIS_day_fh: sys ~ (day2 + fh_yes) * timepass + standing + mnact5 + mood + (1 + mood + stand
## npar AIC BIC logLik deviance Chisq Df Pr(>Chisq)
## nurse_lmm_RIS_mood_stand 12 62761 62844 -31368 62737
## nurse_lmm_RIS_day_fh 16 62745 62856 -31356 62713 23.819 4 8.684e-05
##
## nurse_lmm_RIS_mood_stand
## nurse_lmm_RIS_day_fh ***

## ---
## Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

nurse_lmm_RIS_day_fh_noint <- lmer(sys ~ day2 * timepass + fh_yes +
standing + mnact5 + mood + (1 + mood + standing | snum),
data = nurse_filtered)
anova(nurse_lmm_RIS_day_fh, nurse_lmm_RIS_day_fh_noint)
## Data: nurse_filtered
## Models:
## nurse_lmm_RIS_day_fh_noint: sys ~ day2 * timepass + fh_yes + standing + mnact5 + mood + (1 + mood + stand
## nurse_lmm_RIS_day_fh: sys ~ (day2 + fh_yes) * timepass + standing + mnact5 + mood + (1 + mood + stand
## npar AIC BIC logLik deviance Chisq Df
## nurse_lmm_RIS_day_fh_noint 15 62758 62862 -31364 62728
## nurse_lmm_RIS_day_fh 16 62745 62856 -31356 62713 15.088 1
## Pr(>Chisq)
## nurse_lmm_RIS_day_fh_noint
## nurse_lmm_RIS_day_fh 0.0001026 ***
##
## Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

nurse_lmm_RIS_day_fh_nocorr <- lmer(sys ~ (day2 + fh_yes) * timepass +
standing + mnact5 + mood + (1 + mood + standing || snum),
data = nurse_filtered)
anova(nurse_lmm_RIS_day_fh, nurse_lmm_RIS_day_fh_nocorr, refit = FALSE)
## Data: nurse_filtered
## Models:
## nurse_lmm_RIS_day_fh_nocorr: sys ~ (day2 + fh_yes) * timepass + standing + mnact5 + mood + ((1 / snum) * (day2 + fh_yes))
## nurse_lmm_RIS_day_fh: sys ~ (day2 + fh_yes) * timepass + standing + mnact5 + mood + (1 + mood + stand
## npar AIC BIC logLik deviance Chisq Df
## nurse_lmm_RIS_day_fh_nocorr 15 62796 62900 -31383 62766
## nurse_lmm_RIS_day_fh 16 62788 62900 -31378 62756 9.5907 1
## Pr(>Chisq)
## nurse_lmm_RIS_day_fh_nocorr
## nurse_lmm_RIS_day_fh 0.001956 **
##
## Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

```

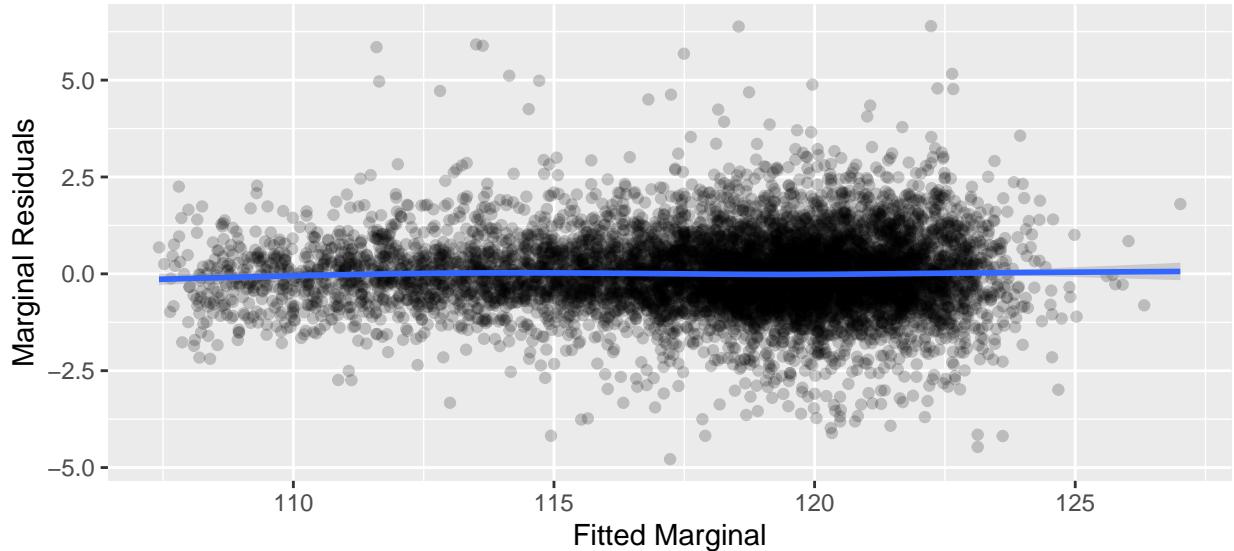
Model Diagnostics

Residual Analysis

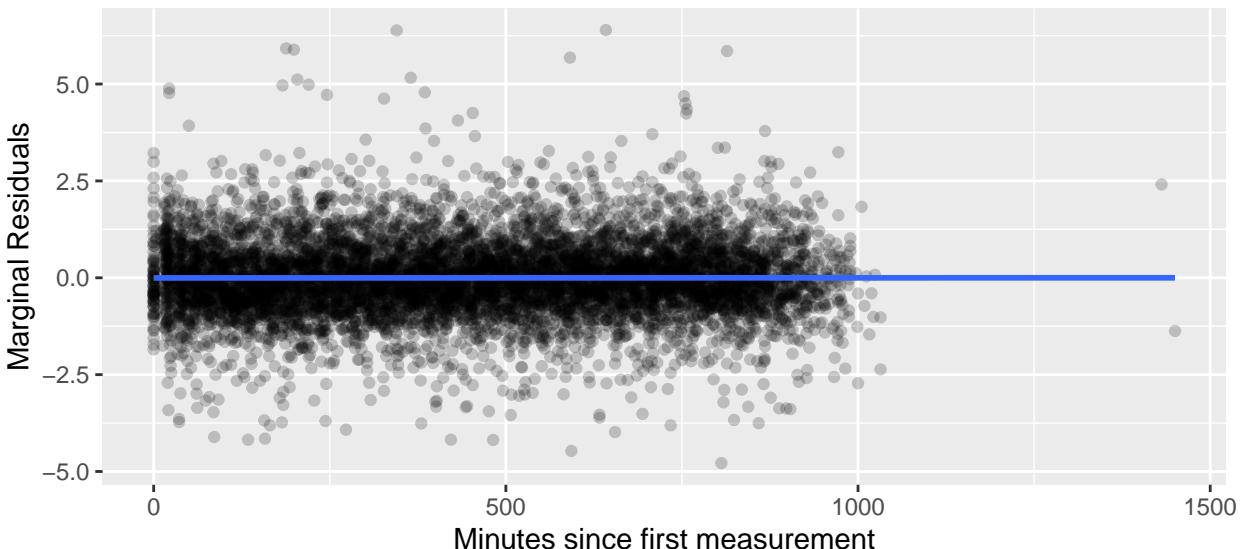
```
final_model <- nurse_lmm_RIS_day_fh

nurse_resid1 <- hlm_resid(final_model, level = 1, standardize = TRUE)
nurse_resid2 <- hlm_resid(final_model, level = "snum", include.ls = FALSE)

ggplot(data = nurse_resid1, aes(x = .mar.fitted, y = .chol.mar.resid)) +
  geom_point(alpha = 0.2) + geom_smooth() + labs(x = "Fitted Marginal",
  y = "Marginal Residuals")
```

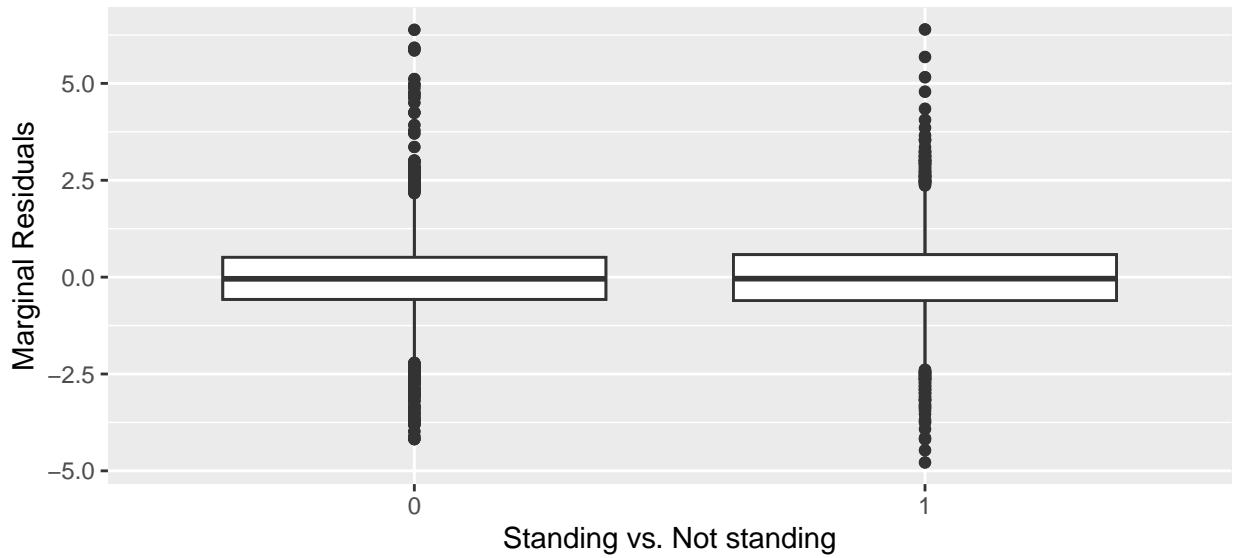


```
ggplot(data = nurse_resid1, aes(x = timepass, y = .chol.mar.resid)) +
  geom_point(alpha = 0.2) + geom_smooth() + labs(x = "Minutes since first measurement",
  y = "Marginal Residuals")
```

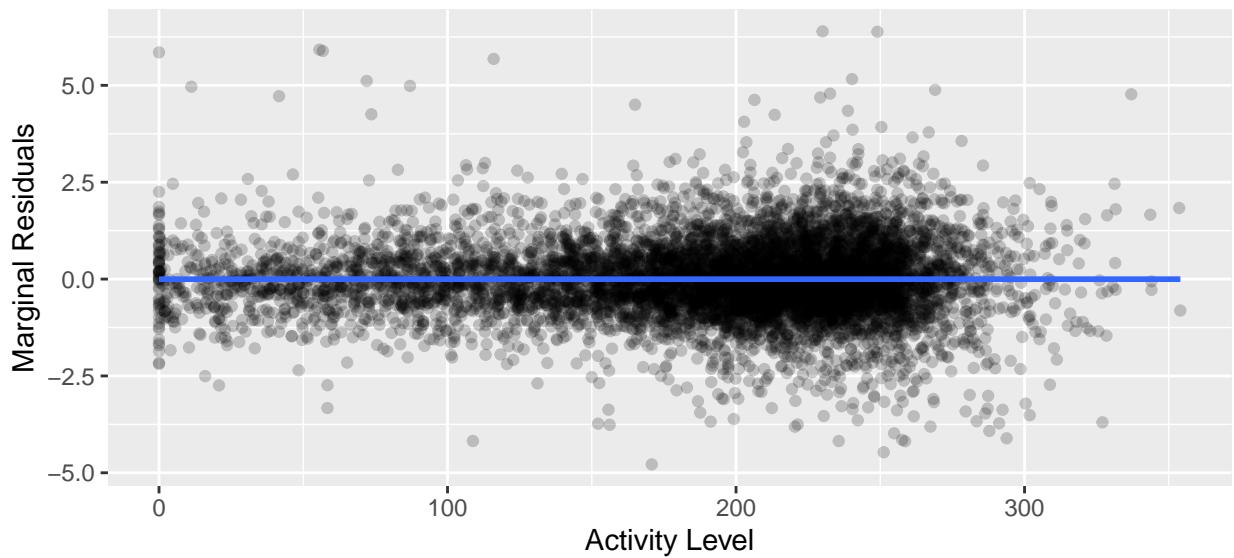


```
ggplot(data = nurse_resid1, aes(x = as.factor(standing), y = .chol.mar.resid)) +
  geom_boxplot() + # geom_smooth() + geom_boxplot() + #
  geom_boxplot() + # geom_smooth() + geom_smooth() +
```

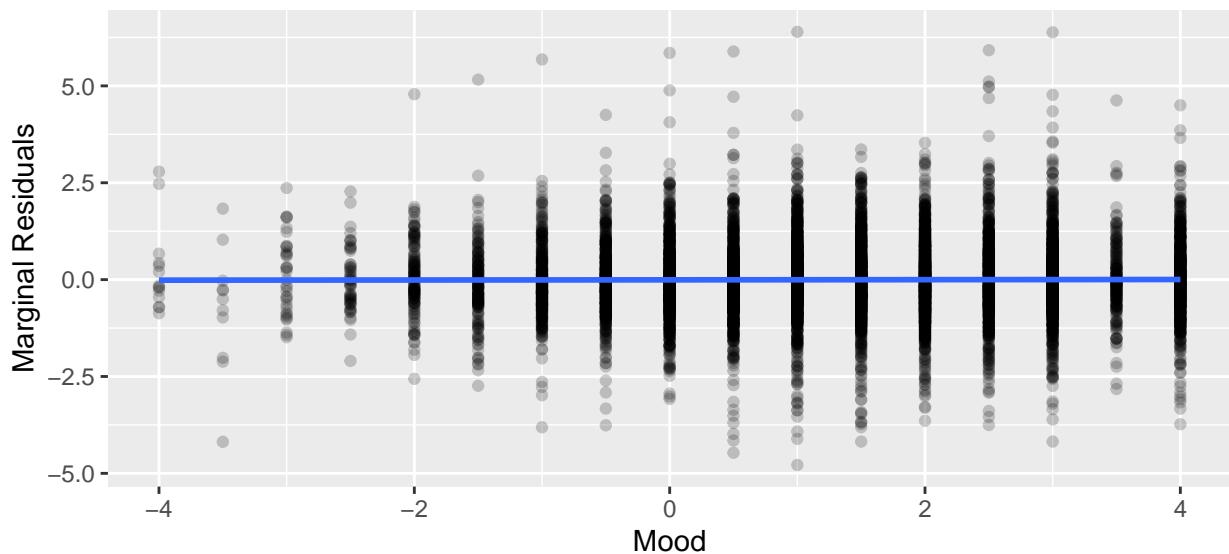
```
labs(x = "Standing vs. Not standing", y = "Marginal Residuals")
```



```
ggplot(data = nurse_resid1, aes(x = mnact5, y = .chol.mar.resid)) +  
  geom_point(alpha = 0.2) + geom_smooth() + labs(x = "Activity Level",  
    y = "Marginal Residuals")
```

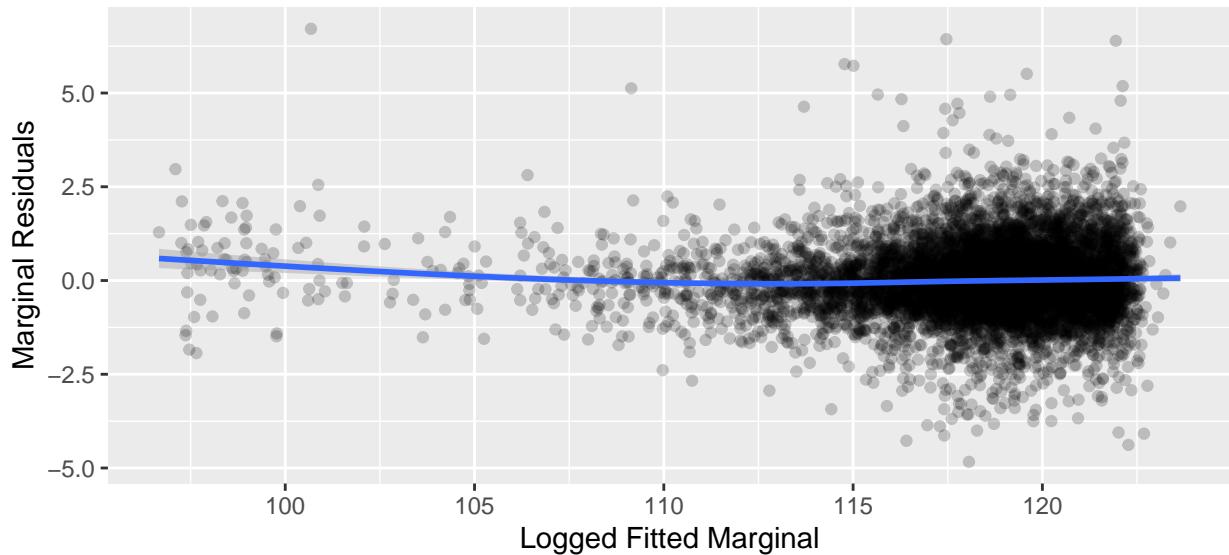


```
ggplot(data = nurse_resid1, aes(x = mood, y = .chol.mar.resid)) +  
  geom_point(alpha = 0.2) + geom_smooth() + labs(x = "Mood",  
    y = "Marginal Residuals")
```

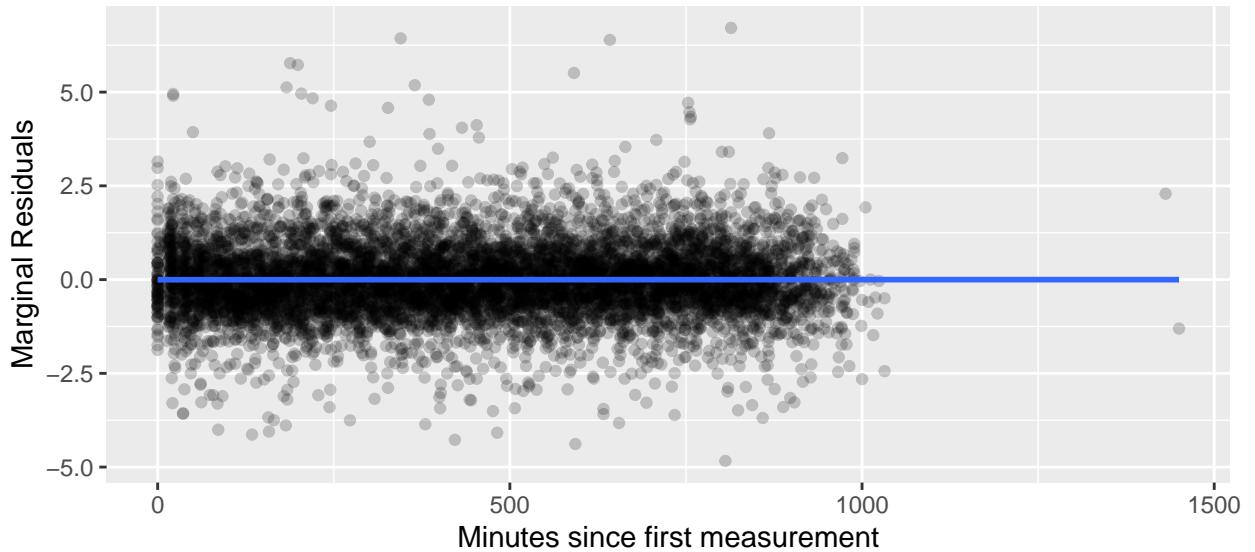


```
nurse_lmm_RIS_logx <- lmer(sys ~ (day2 + fh_yes) * timepass +
  standing + log(mnact5 + 1) + mood + (1 + mood + standing |
  snum), data = nurse_filtered)
nurse_resid1_log <- hlm_resid(nurse_lmm_RIS_logx, level = 1,
  standardize = TRUE)

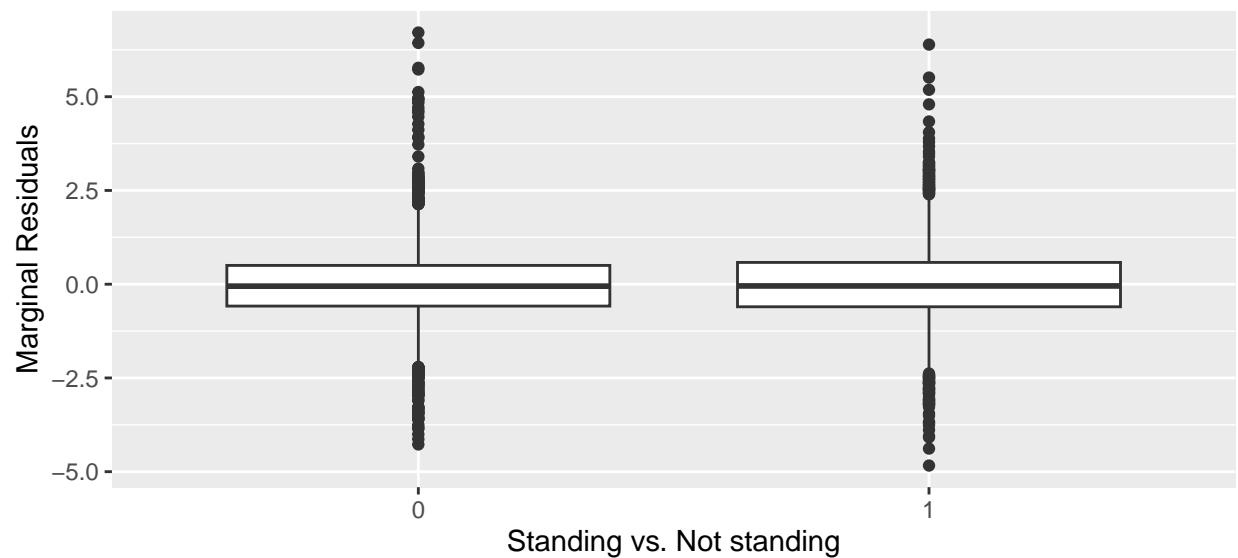
ggplot(data = nurse_resid1_log, aes(x = .mar.fitted, y = .chol.mar.resid)) +
  geom_point(alpha = 0.2) + geom_smooth() + labs(x = "Logged Fitted Marginal",
  y = "Marginal Residuals")
```



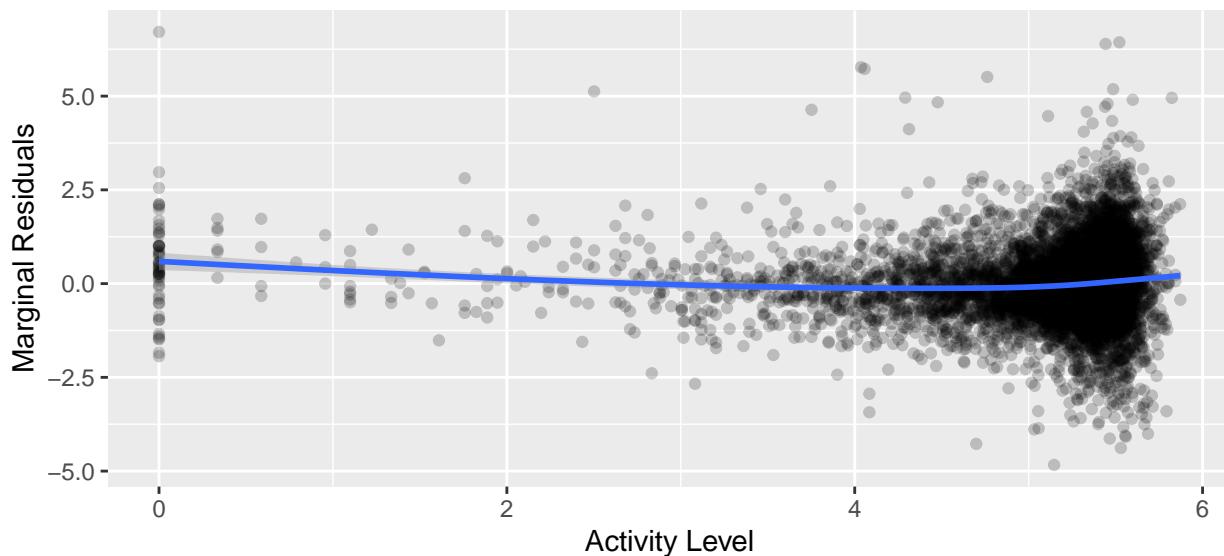
```
ggplot(data = nurse_resid1_log, aes(x = timepass, y = .chol.mar.resid)) +
  geom_point(alpha = 0.2) + geom_smooth() + labs(x = "Minutes since first measurement",
  y = "Marginal Residuals")
```



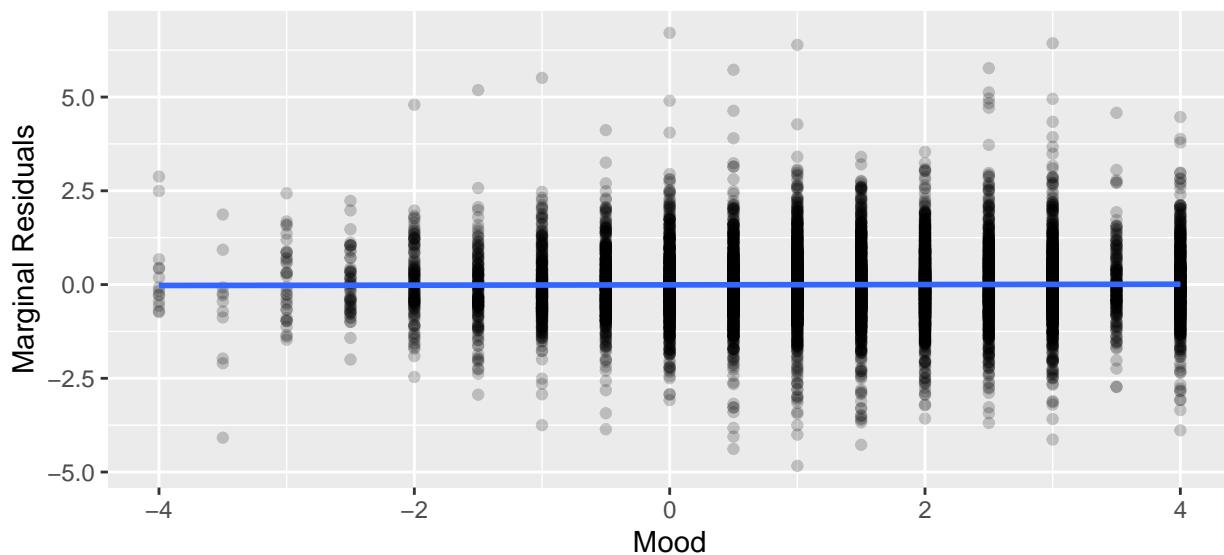
```
ggplot(data = nurse_resid1_log, aes(x = as.factor(standing),
y = .chol.mar.resid)) + geom_boxplot() + labs(x = "Standing vs. Not standing",
y = "Marginal Residuals")
```



```
ggplot(data = nurse_resid1_log, aes(x = `log(mnact5 + 1)`, y = .chol.mar.resid)) +
  geom_point(alpha = 0.2) + geom_smooth() + labs(x = "Activity Level",
y = "Marginal Residuals")
```

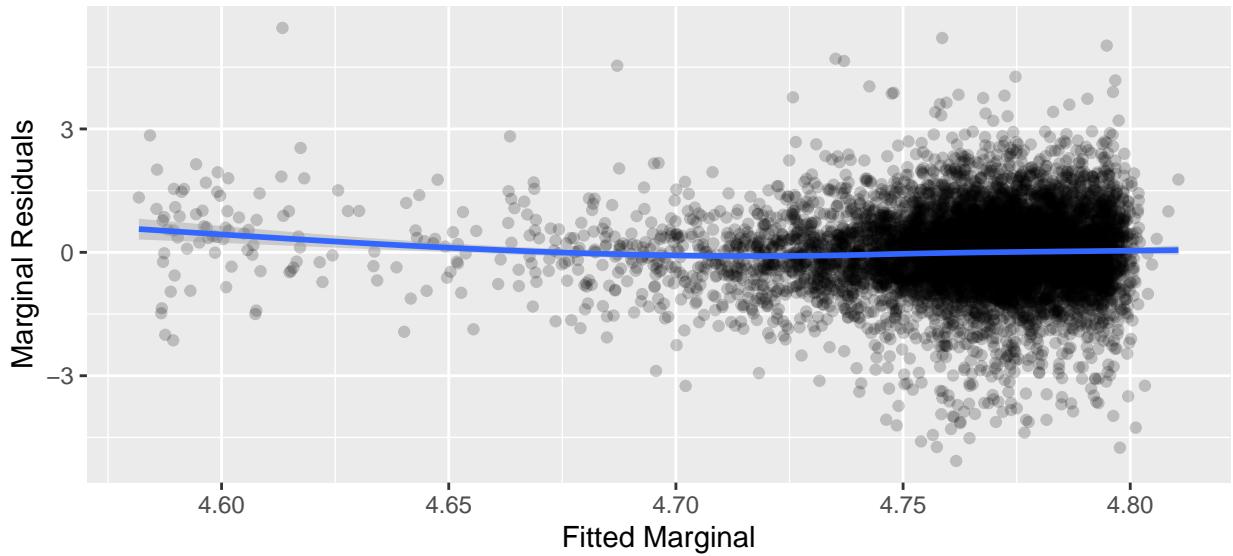


```
ggplot(data = nurse_resid1_log, aes(x = mood, y = .chol.mar.resid)) +
  geom_point(alpha = 0.2) + geom_smooth() + labs(x = "Mood",
y = "Marginal Residuals")
```

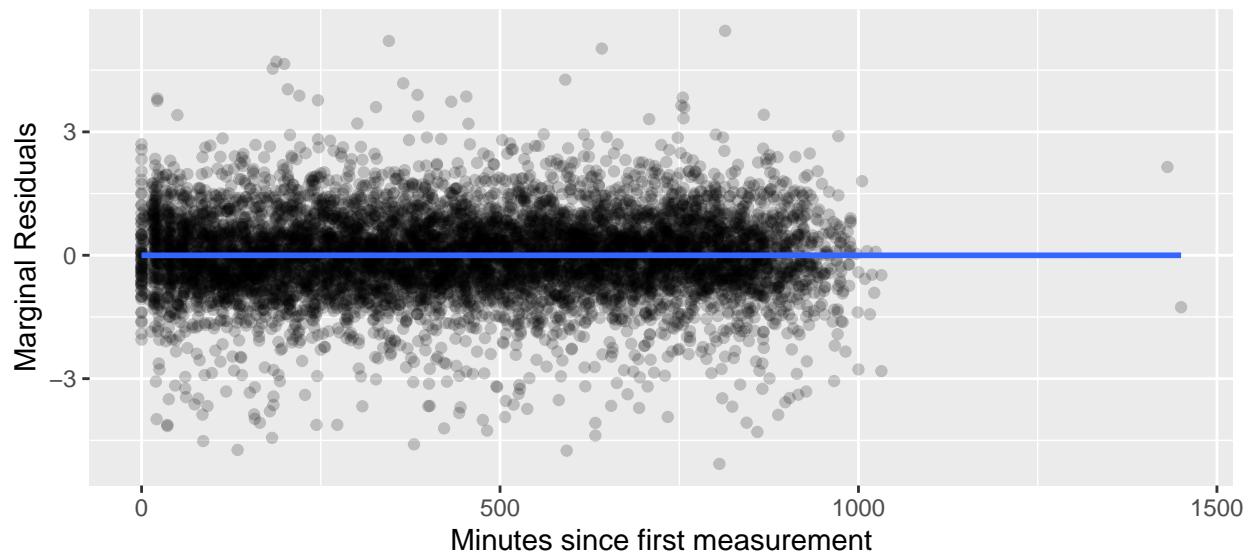


```
nurse_lmm_RIS_loglog <- lmer(log(sys) ~ (day2 + fh_yes) * timepass +
  standing + log(mnact5 + 1) + mood + (1 + mood + standing |
  snum), data = nurse_filtered)
nurse_resid1_loglog <- hlm_resid(nurse_lmm_RIS_loglog, level = 1,
  standardize = TRUE)
```

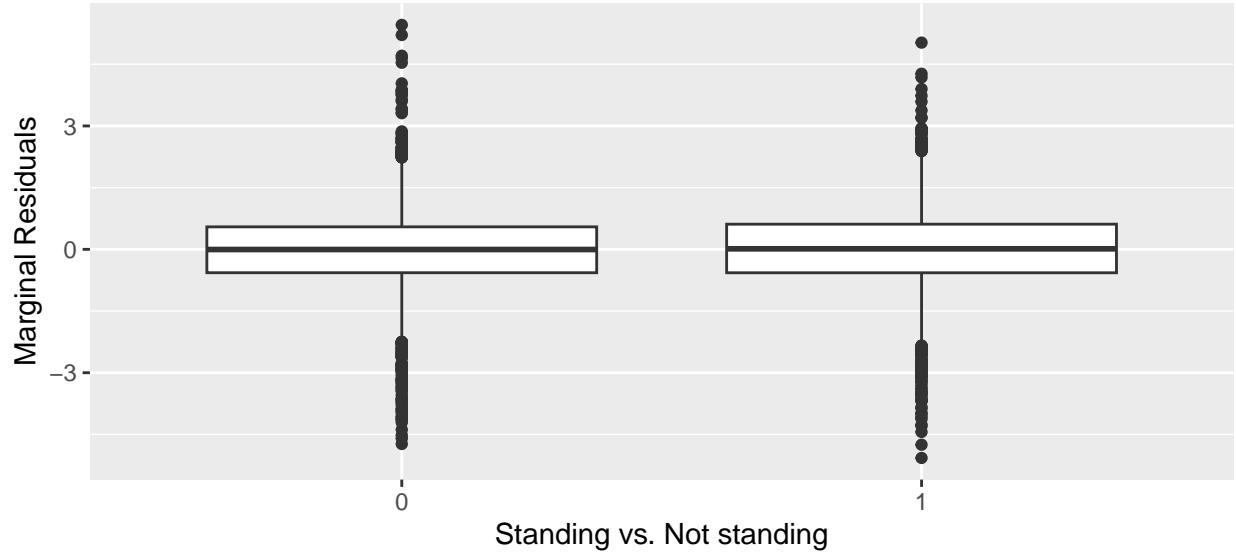
```
ggplot(data = nurse_resid1_loglog, aes(x = .mar.fitted, y = .chol.mar.resid)) +
  geom_point(alpha = 0.2) + geom_smooth() + labs(x = "Fitted Marginal",
y = "Marginal Residuals")
```



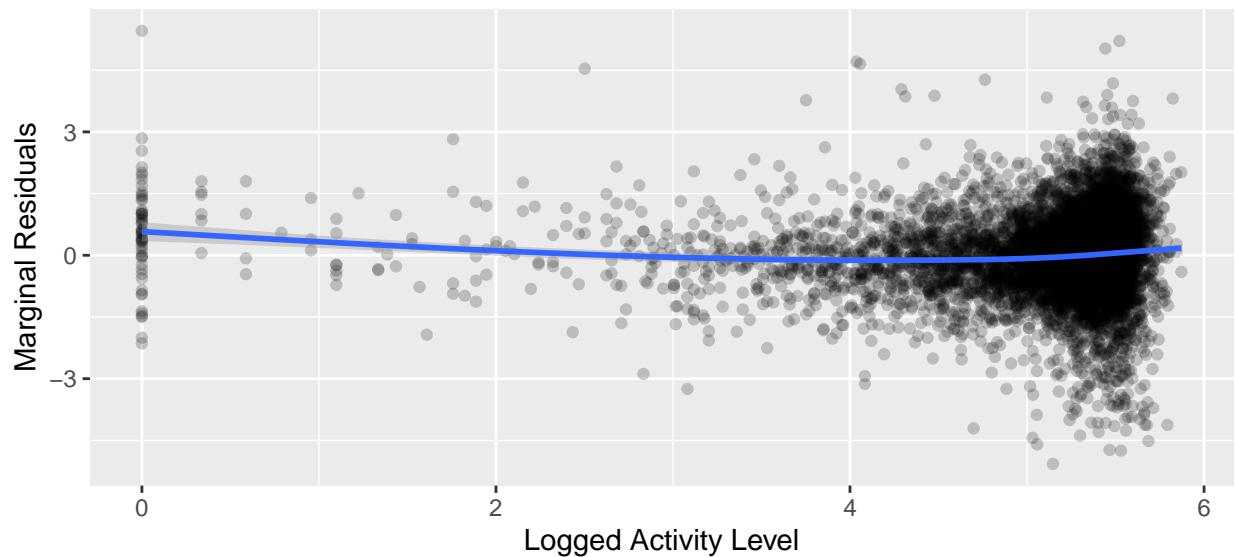
```
ggplot(data = nurse_resid1_loglog, aes(x = timepass, y = .chol.mar.resid)) +
  geom_point(alpha = 0.2) + geom_smooth() + labs(x = "Minutes since first measurement",
y = "Marginal Residuals")
```



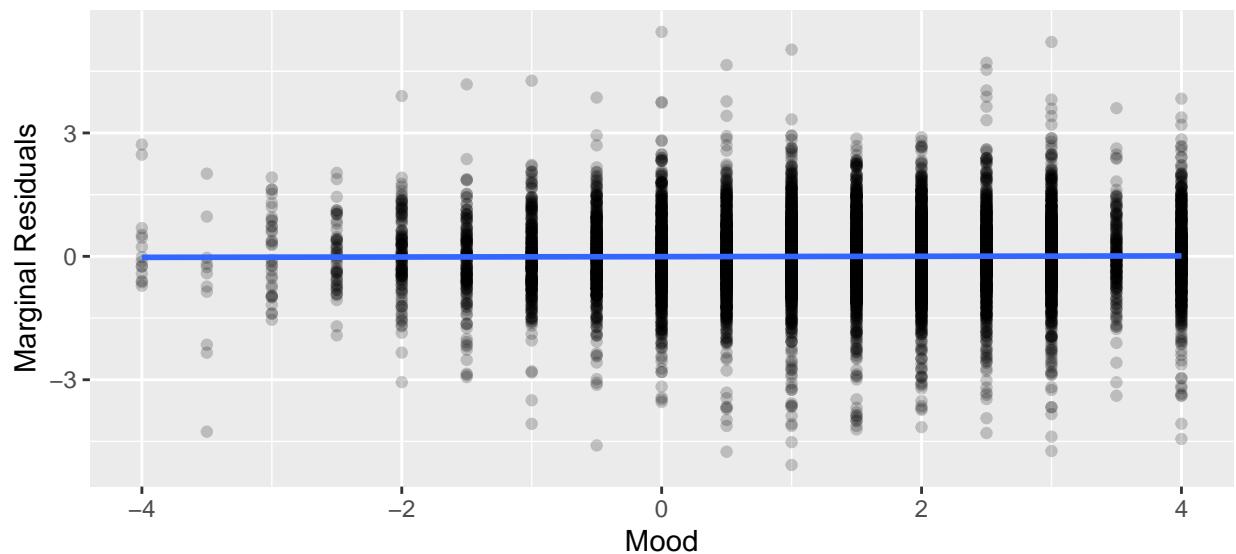
```
ggplot(data = nurse_resid1_loglog, aes(x = as.factor(standing),
y = .chol.mar.resid)) + geom_boxplot() + labs(x = "Standing vs. Not standing",
y = "Marginal Residuals")
```



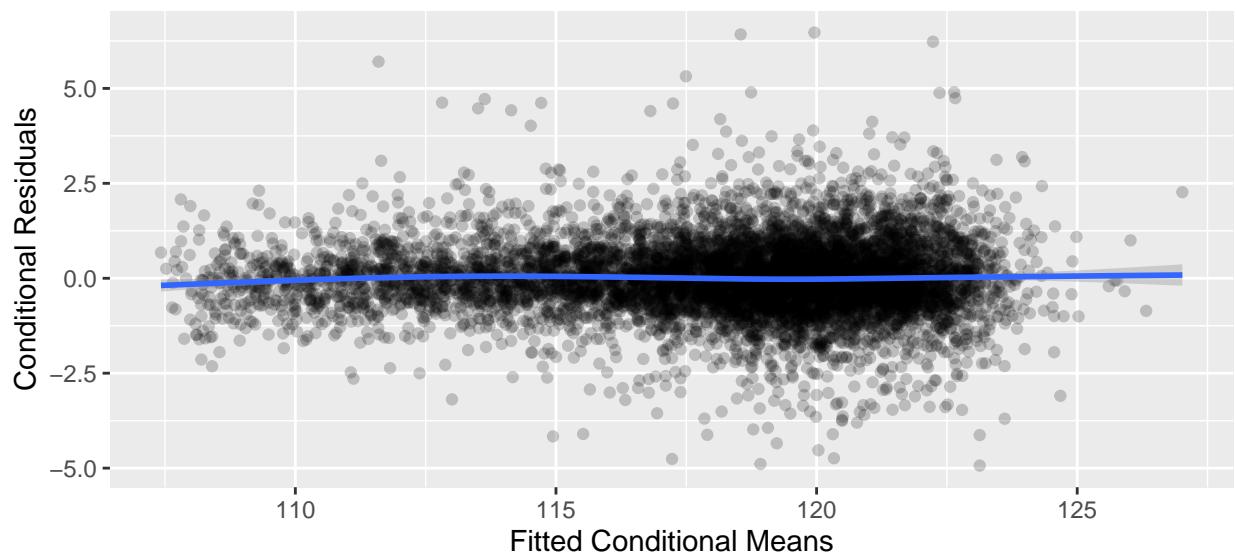
```
ggplot(data = nurse_resid1_loglog, aes(x = `log(mnact5 + 1)`,
y = .chol.mar.resid)) + geom_point(alpha = 0.2) + geom_smooth() +
labs(x = "Logged Activity Level", y = "Marginal Residuals")
```



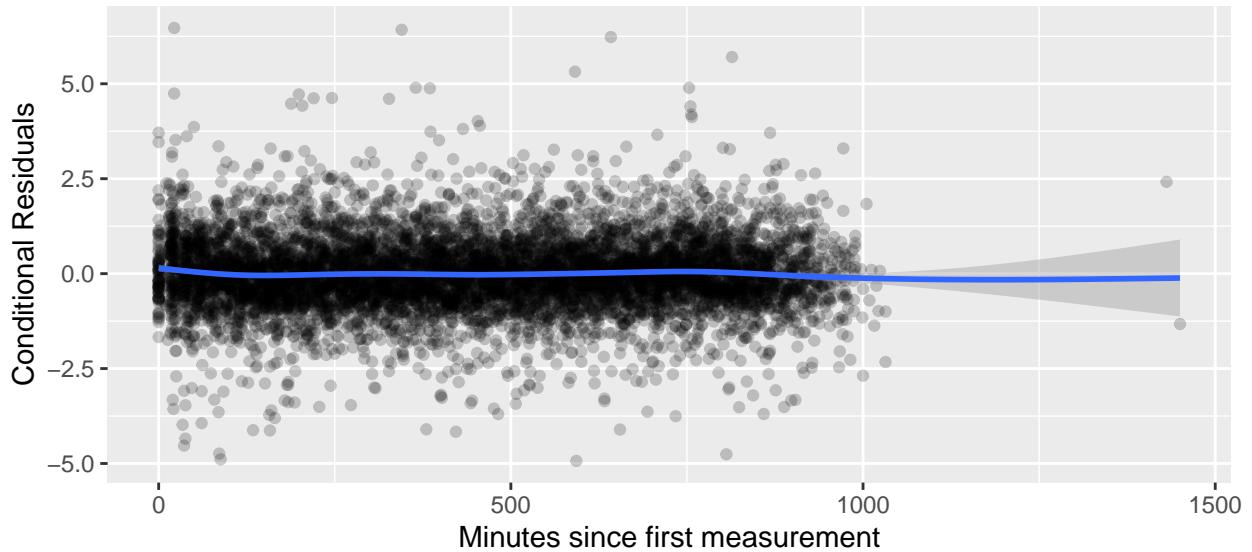
```
ggplot(data = nurse_resid1_loglog, aes(x = mood, y = .chol.mar.resid)) +
geom_point(alpha = 0.2) + geom_smooth() + labs(x = "Mood",
y = "Marginal Residuals")
```



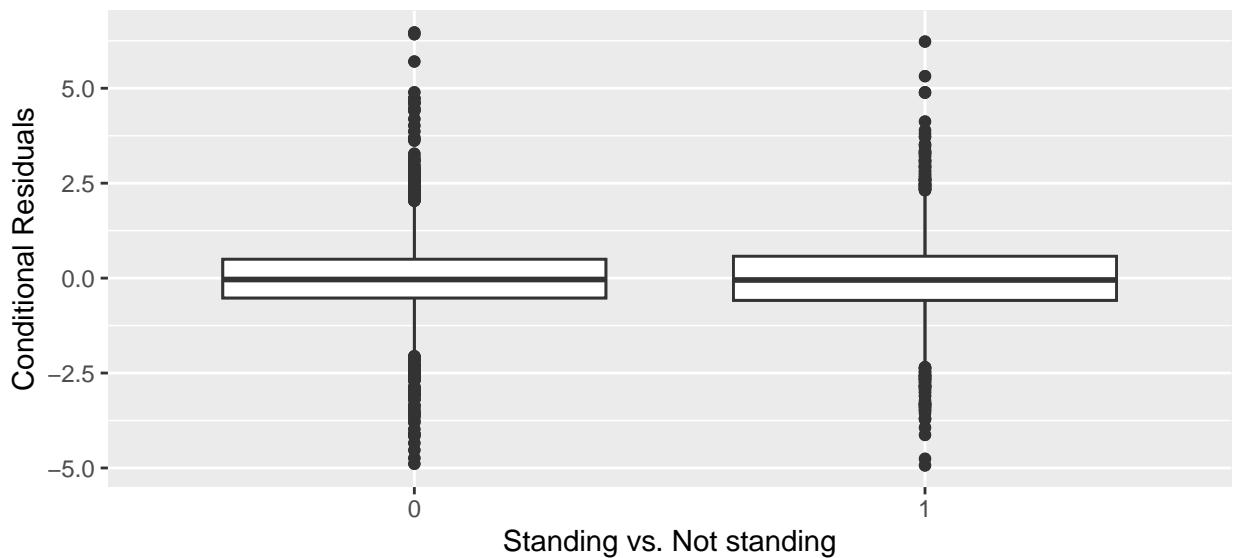
```
ggplot(data = nurse_resid1, aes(x = .mar.fitted, y = .std.resid)) +
  geom_point(alpha = 0.2) + geom_smooth() + labs(x = "Fitted Conditional Means",
y = "Conditional Residuals")
```



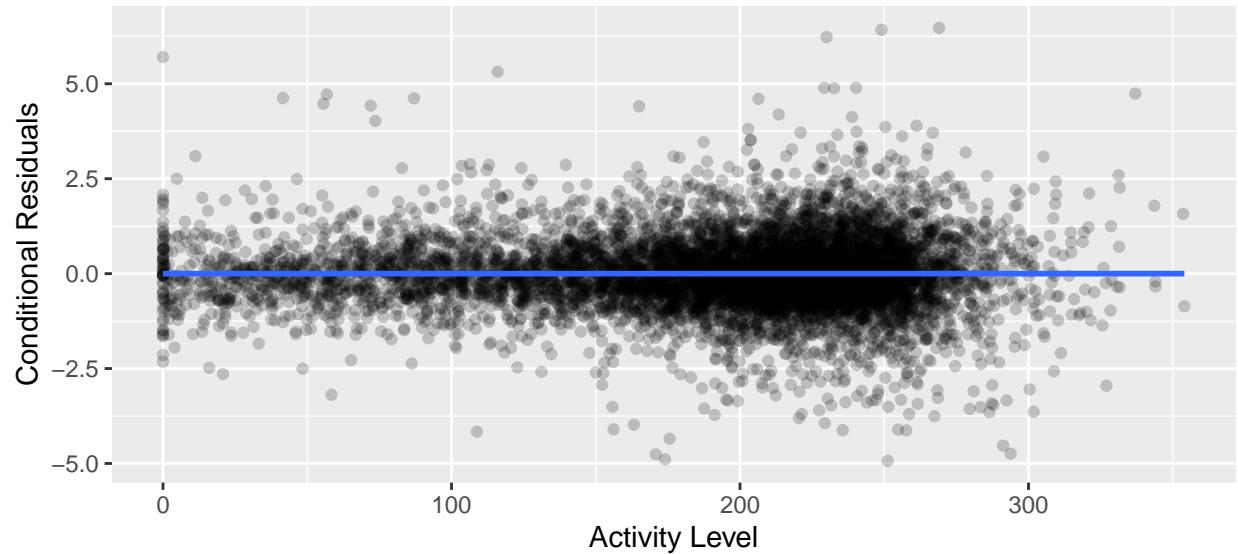
```
ggplot(data = nurse_resid1, aes(x = timepass, y = .std.resid)) +
  geom_point(alpha = 0.2) + geom_smooth() + labs(x = "Minutes since first measurement",
y = "Conditional Residuals")
```



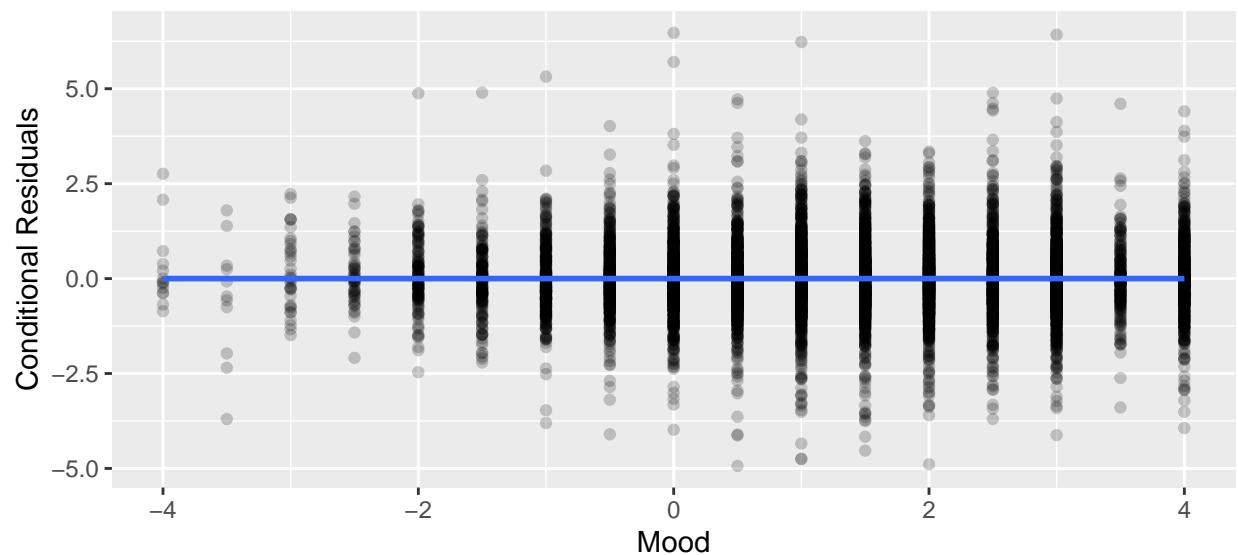
```
ggplot(data = nurse_resid1, aes(x = as.factor(standing), y = .std.resid)) +
  geom_boxplot() + # geom_smooth() + geom_boxplot() + #
  geom_boxplot() + # geom_smooth() + geom_smooth() +
  labs(x = "Standing vs. Not standing", y = "Conditional Residuals")
```



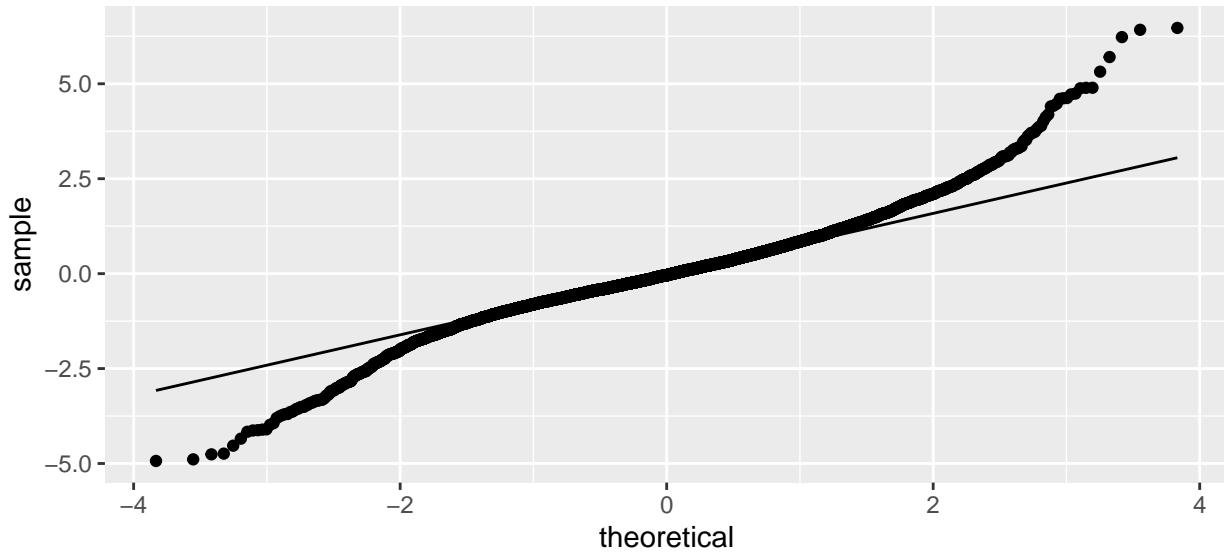
```
ggplot(data = nurse_resid1, aes(x = mnact5, y = .std.resid)) +
  geom_point(alpha = 0.2) + geom_smooth() + labs(x = "Activity Level",
  y = "Conditional Residuals")
```



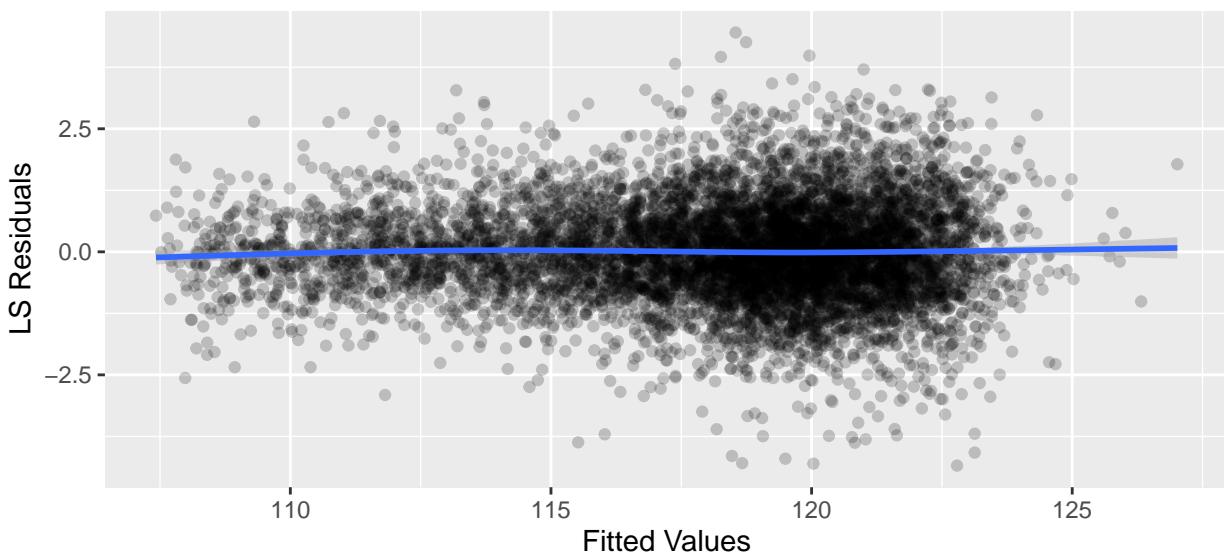
```
ggplot(data = nurse_resid1, aes(x = mood, y = .std.resid)) +
  geom_point(alpha = 0.2) + geom_smooth() + labs(x = "Mood",
  y = "Conditional Residuals")
```



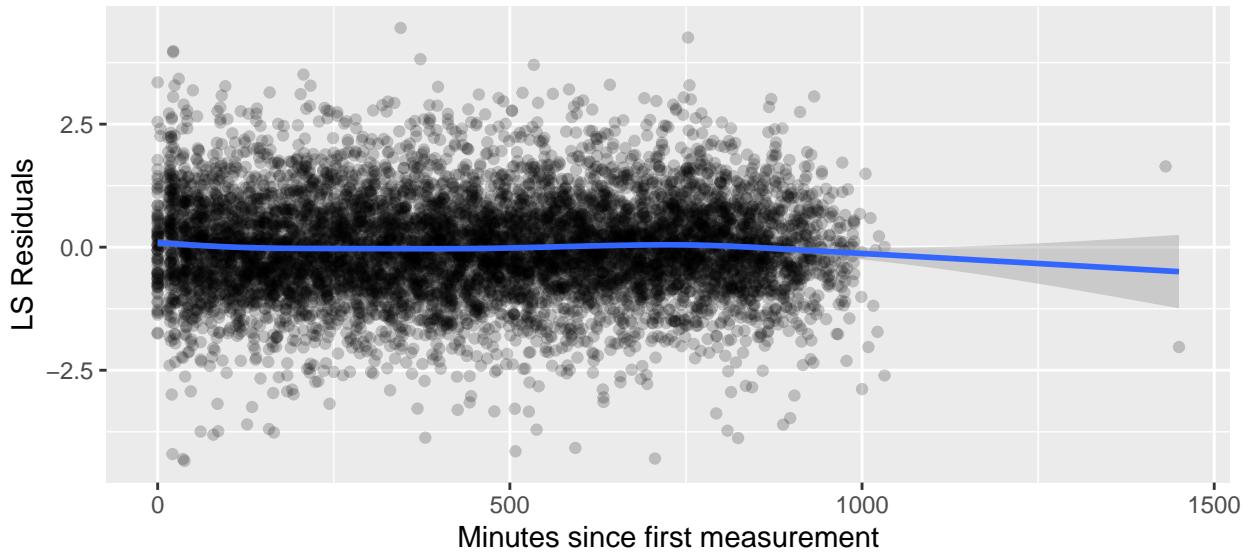
```
ggplot(nurse_resid1, aes(sample = .std.resid)) + stat_qq_line() +
  stat_qq()
```



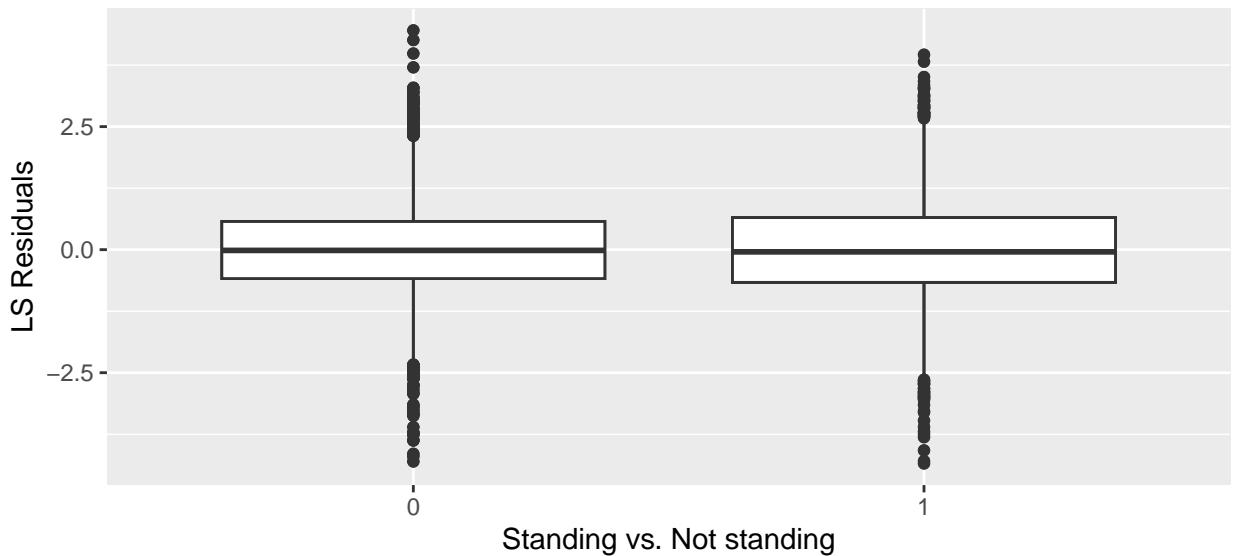
```
ggplot(data = nurse_resid1, aes(x = .mar.fitted, y = .std.ls.resid)) +
  geom_point(alpha = 0.2) + geom_smooth() + labs(x = "Fitted Values",
  y = "LS Residuals")
```



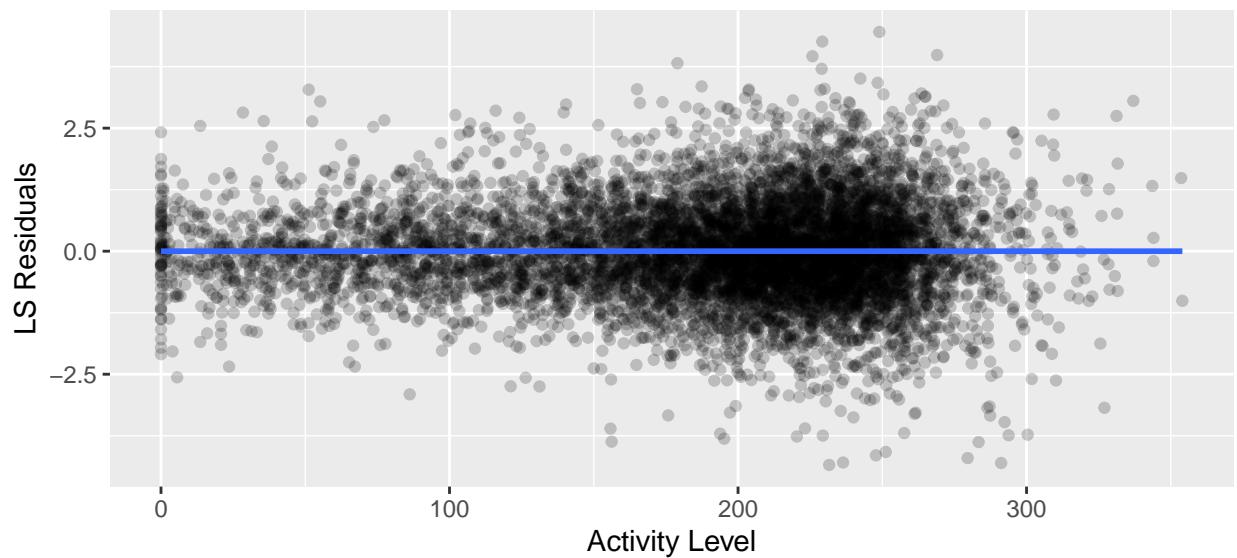
```
ggplot(data = nurse_resid1, aes(x = timepass, y = .std.ls.resid)) +
  geom_point(alpha = 0.2) + geom_smooth() + labs(x = "Minutes since first measurement",
  y = "LS Residuals")
```



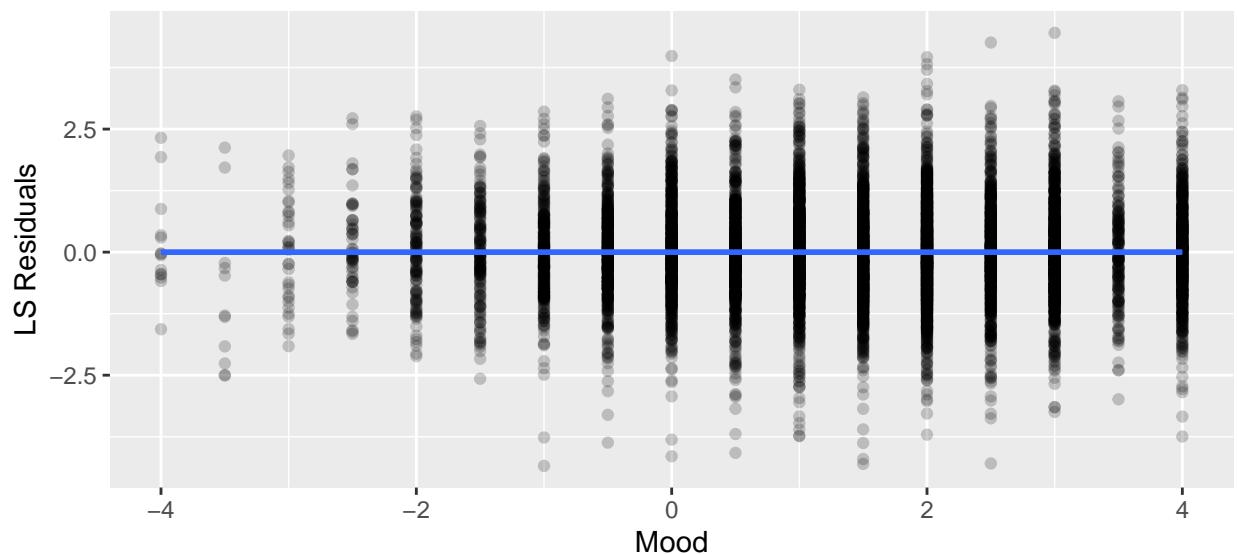
```
ggplot(data = nurse_resid1, aes(x = as.factor(standing), y = .std.ls.resid)) +
  geom_boxplot() + # geom_smooth() + geom_boxplot() + #
  geom_boxplot() + # geom_smooth() + geom_smooth() +
  labs(x = "Standing vs. Not standing", y = "LS Residuals")
```



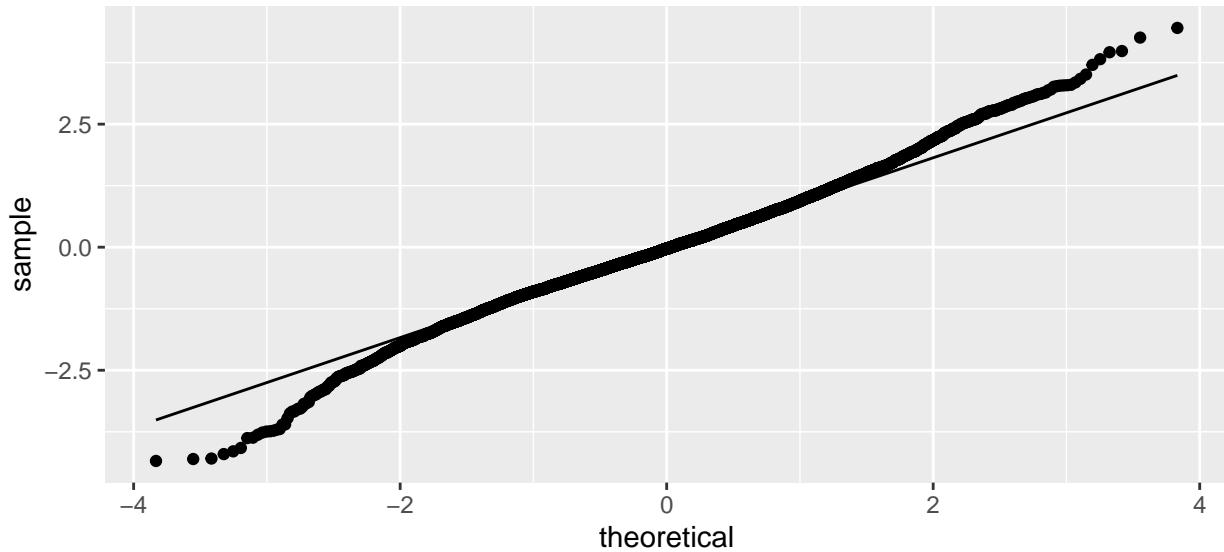
```
ggplot(data = nurse_resid1, aes(x = mnact5, y = .std.ls.resid)) +
  geom_point(alpha = 0.2) + geom_smooth() + labs(x = "Activity Level",
  y = "LS Residuals")
```



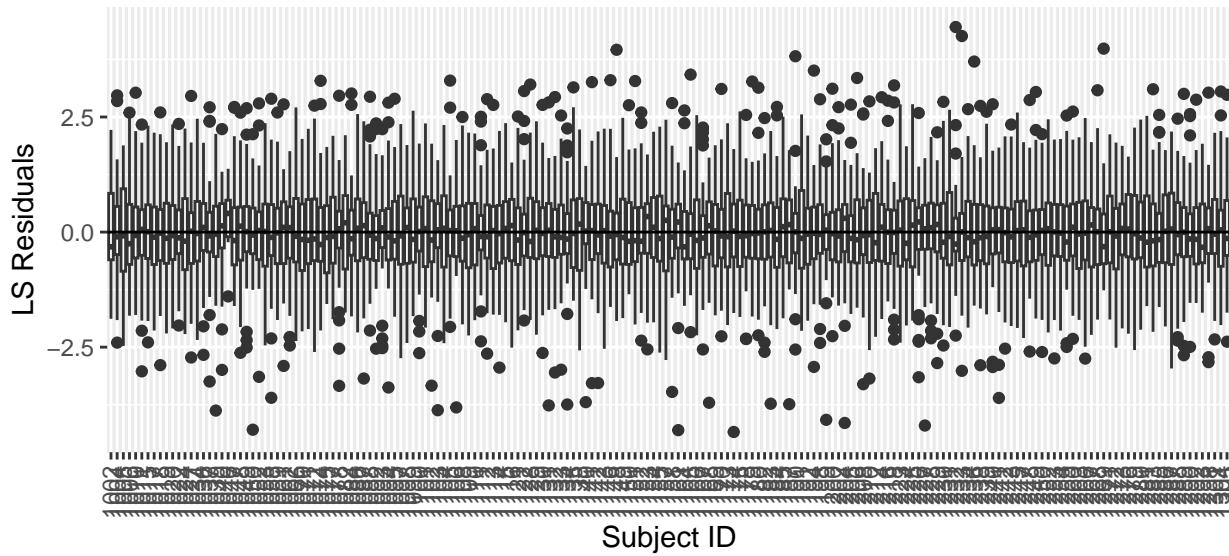
```
ggplot(data = nurse_resid1, aes(x = mood, y = .std.ls.resid)) +
  geom_point(alpha = 0.2) + geom_smooth() + labs(x = "Mood",
  y = "LS Residuals")
```



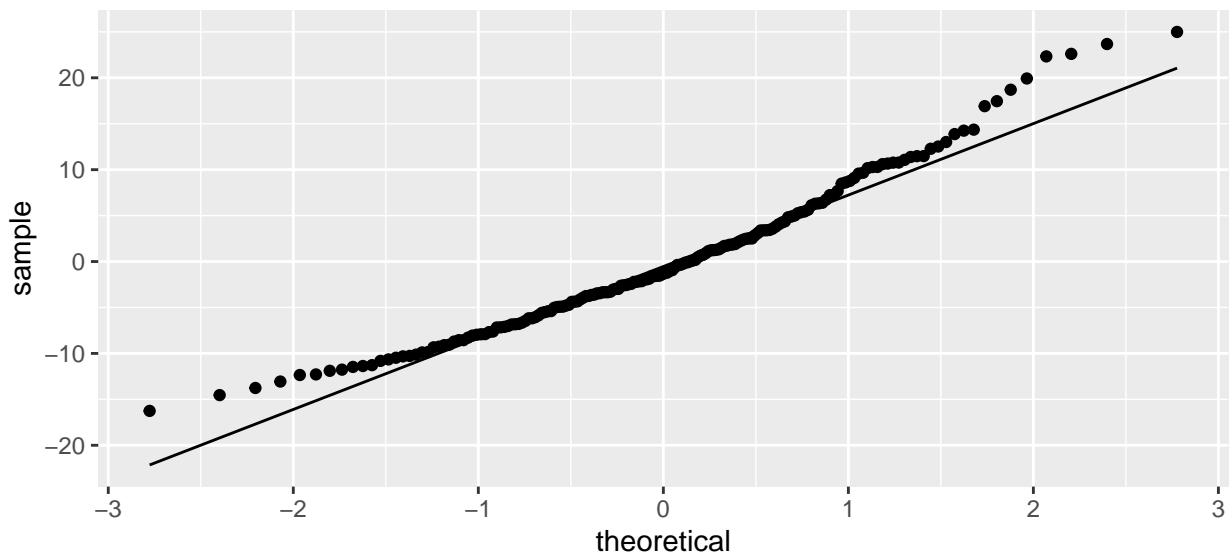
```
ggplot(nurse_resid1, aes(sample = .std.ls.resid)) + stat_qq_line() +
  stat_qq()
```



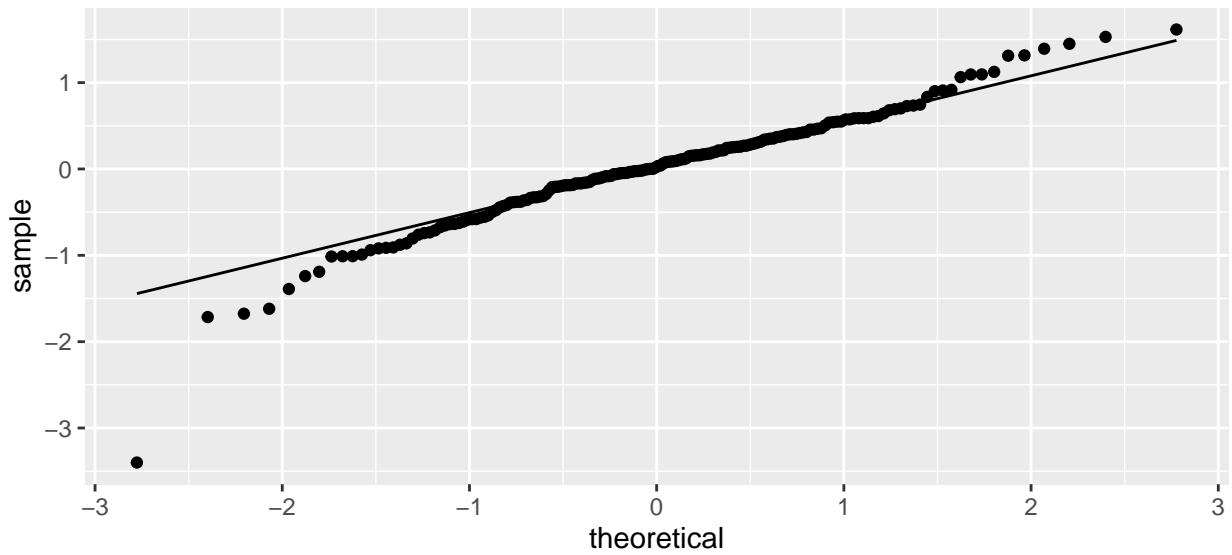
```
ggplot(nurse_resid1, aes(x = as.factor(snum), y = .std.ls.resid)) +
  geom_boxplot() + geom_hline(yintercept = 0) + labs(x = "Subject ID",
  y = "LS Residuals") + theme(axis.text.x = element_text(angle = 90,
  vjust = 0.5, hjust = 1))
```



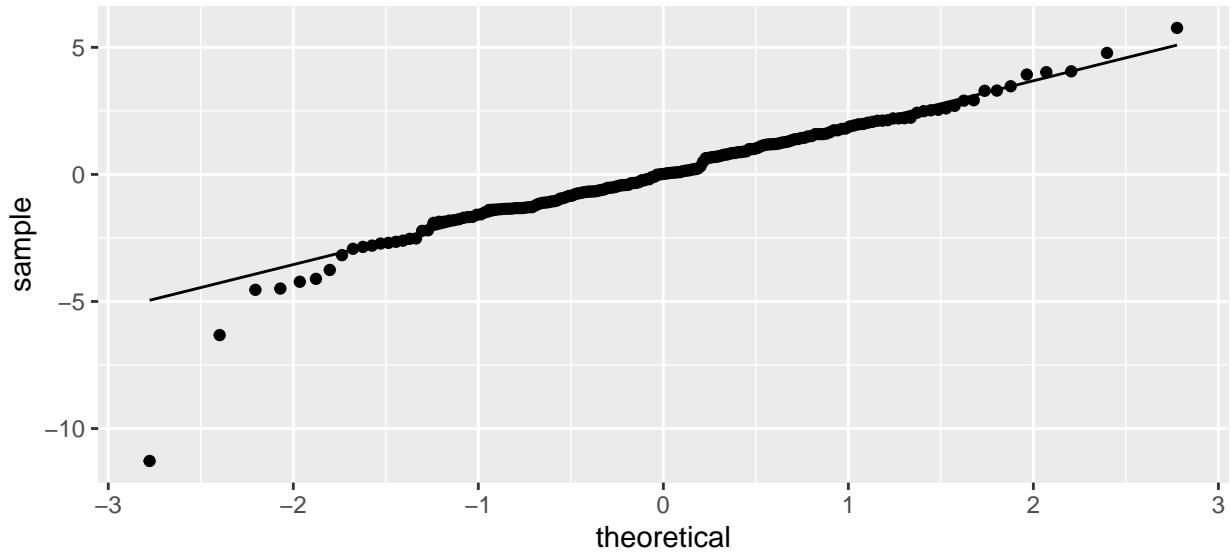
```
ggplot(nurse_resid2, aes(sample = .ranef.intercept)) + stat_qq_line() +
  stat_qq()
```



```
ggplot(nurse_resid2, aes(sample = .ranef.mood)) + stat_qq_line() +  
  stat_qq()
```



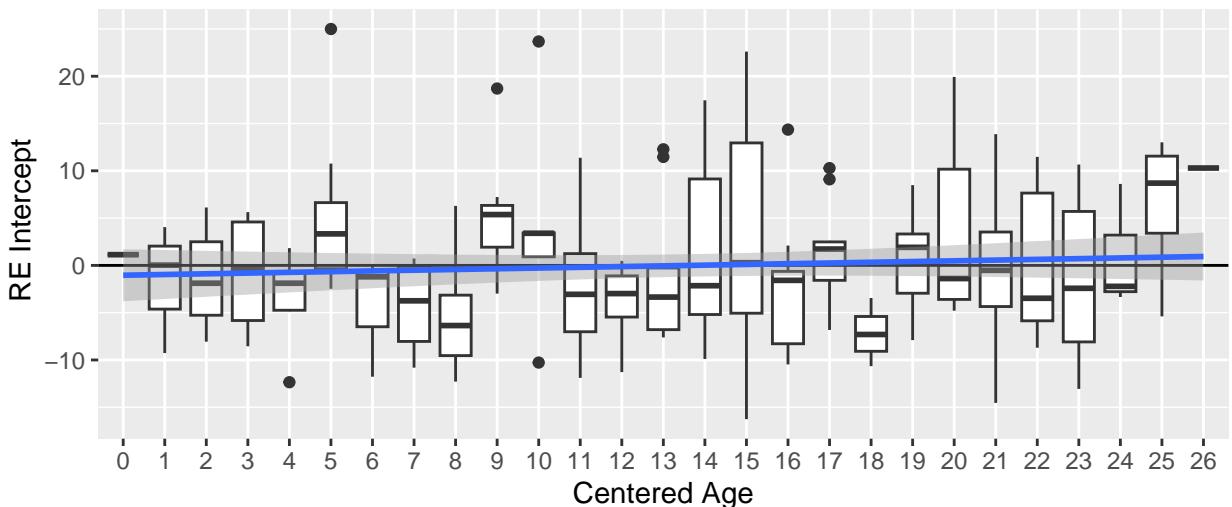
```
ggplot(nurse_resid2, aes(sample = .ranef.standing1)) + stat_qq_line() +  
  stat_qq()
```



```
nurse_age_phase <- nurse_filtered %>%
  mutate(snum = as.character(snum)) %>%
  group_by(snum) %>%
  summarize(nurse_age = first(age24), nurse_phase = first(phase)) %>%
  left_join(nurse_resid2, by = "snum")

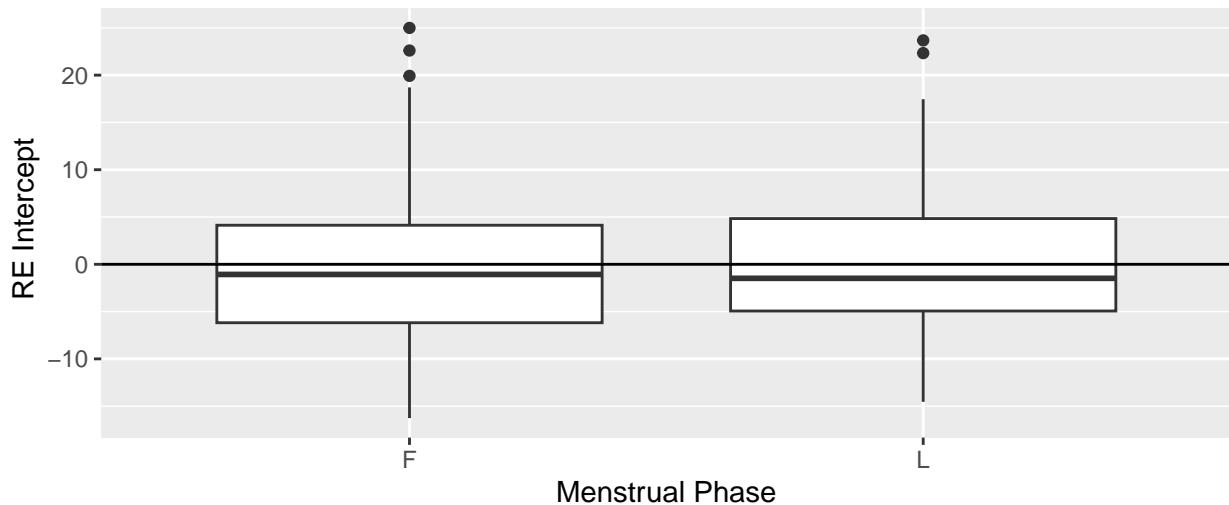
## Intercept
ggplot(nurse_age_phase, aes(x = as.factor(nurse_age), y = .ranef.intercept)) +
  geom_boxplot() + geom_hline(yintercept = 0) + geom_smooth(method = "lm",
  se = TRUE, aes(group = 1)) + labs(title = "RE intercept vs Centered Age",
  x = "Centered Age", y = " RE Intercept")
```

RE intercept vs Centered Age



```
ggplot(nurse_age_phase, aes(x = nurse_phase, y = .ranef.intercept)) +
  geom_boxplot() + geom_hline(yintercept = 0) + labs(title = "RE intercept vs Centered Age",
  x = "Menstrual Phase", y = " RE Intercept")
```

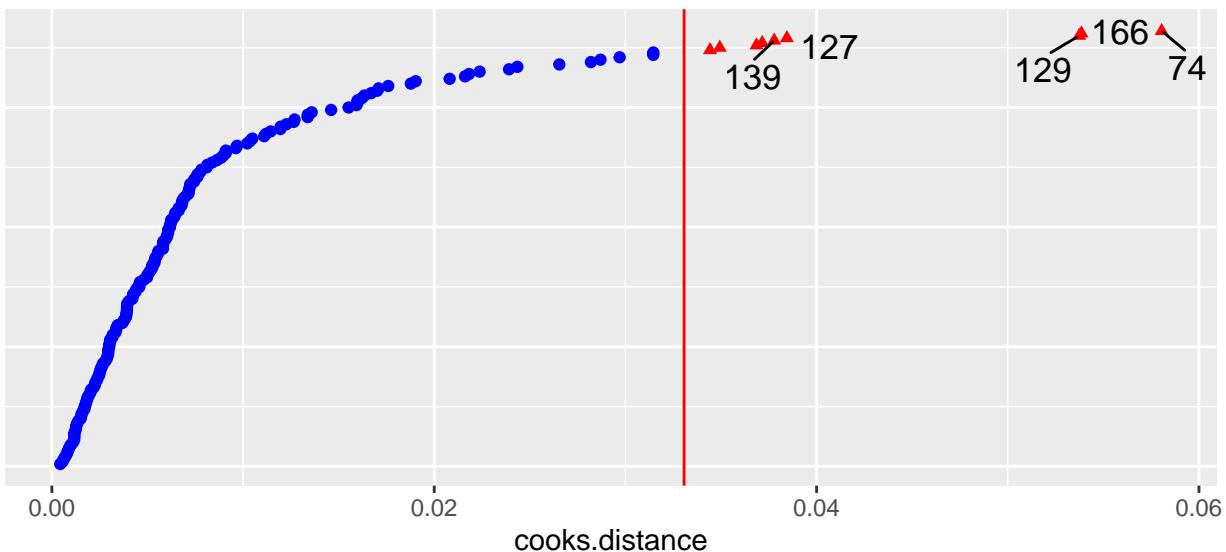
RE intercept vs Centered Age



Influential Statistics

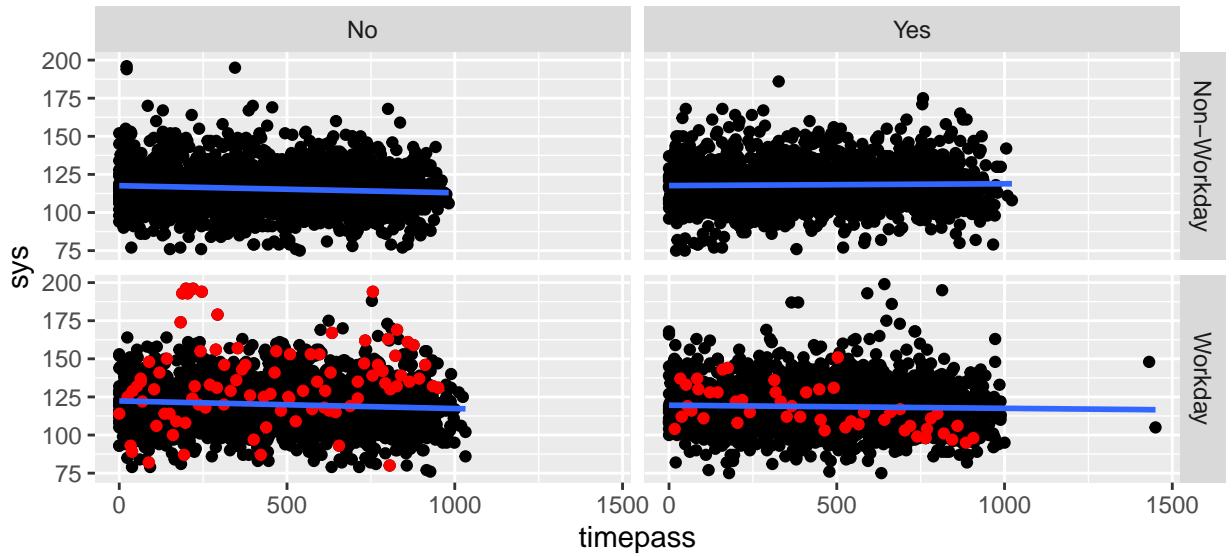
```
nurse_infl2 <- hlm_influence(final_model, level = "snum", approx = FALSE,
    leverage = c("overall", "fixef", "ranef.uc"))

dotplot_diag(nurse_infl2$cooksdi, name = "cooks.distance", cutoff = "internal")
```

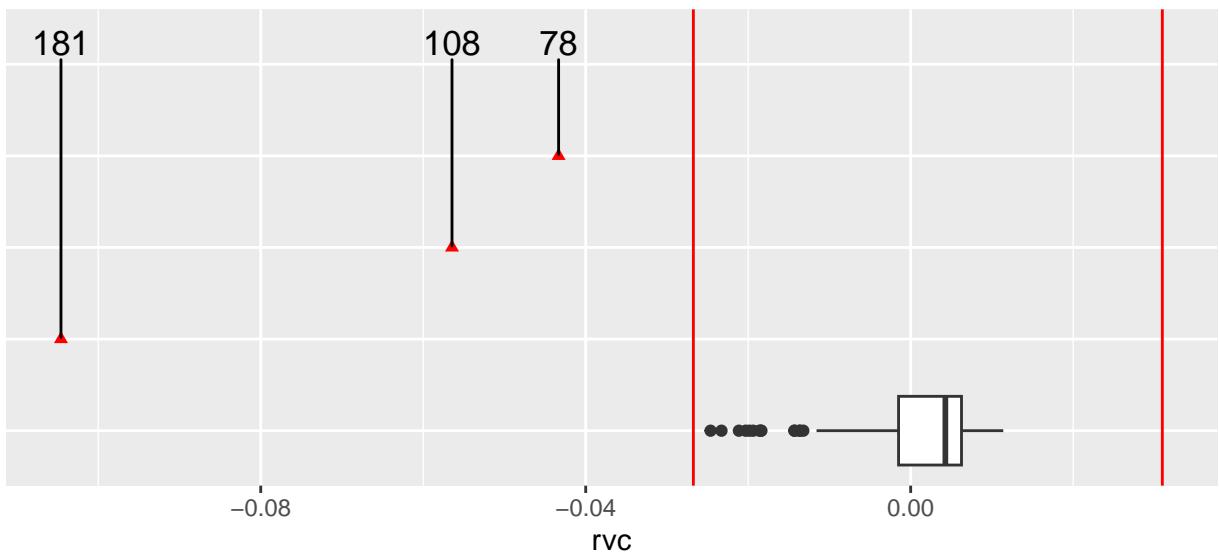


```
cd_flagged <- nurse_infl2 %>%
    arrange(desc(cooksdi)) %>%
    slice(1:3) %>%
    pull(snum)

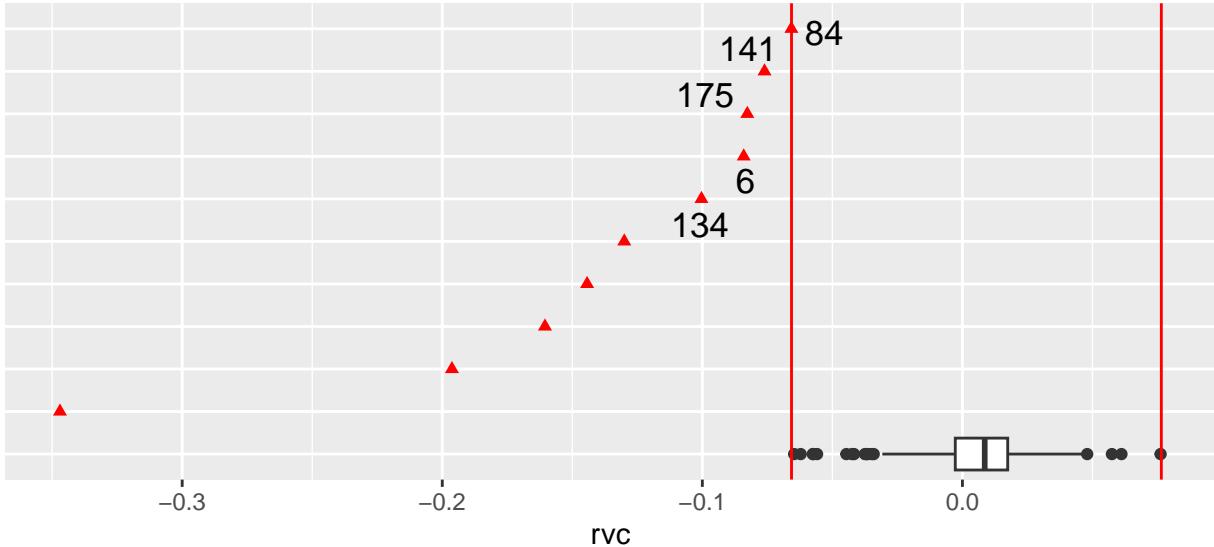
ggplot(nurse_filtered, aes(x = timepass, y = sys)) + geom_point() +
    geom_point(data = nurse_filtered %>%
        filter(snum %in% cd_flagged), color = "red") + geom_smooth(method = "lm",
    se = F) + facet_grid(rows = vars(day3), cols = vars(fh_2))
```



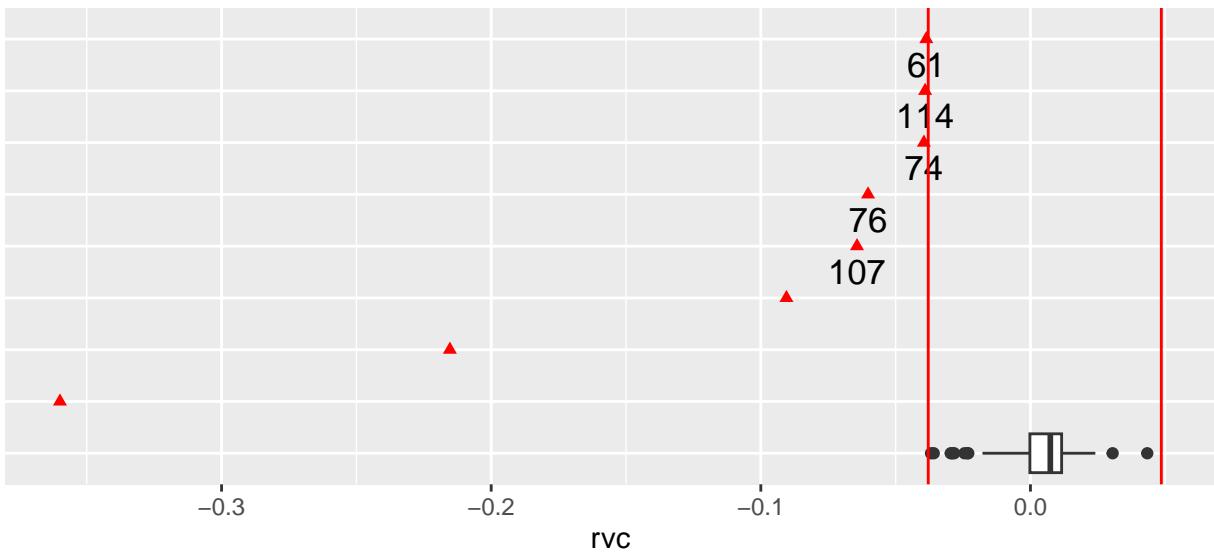
```
dotplot_diag(nurse_infl2$rvc.D11, name = "rvc", cutoff = "internal",
             modify = "boxplot")
```



```
dotplot_diag(nurse_infl2$rvc.D22, name = "rvc", cutoff = "internal",
             modify = "boxplot")
```



```
dotplot_diag(nurse_infl2$rvc.D33, name = "rvc", cutoff = "internal",
             modify = "boxplot")
```



```
# rvc1_flagged <- nurse_infl2 %>% arrange(rvc.D11) %>%
# slice(1:3) rvc2_flagged <- nurse_infl2 %>%
# arrange(rvc.D22) %>% slice(1) %>% full_join(rvc1_flagged)
# rvc3_flagged <- nurse_infl2 %>% arrange(rvc.D33) %>%
# slice(1:2) %>% full_join(rvc2_flagged) %>% pull(snum)

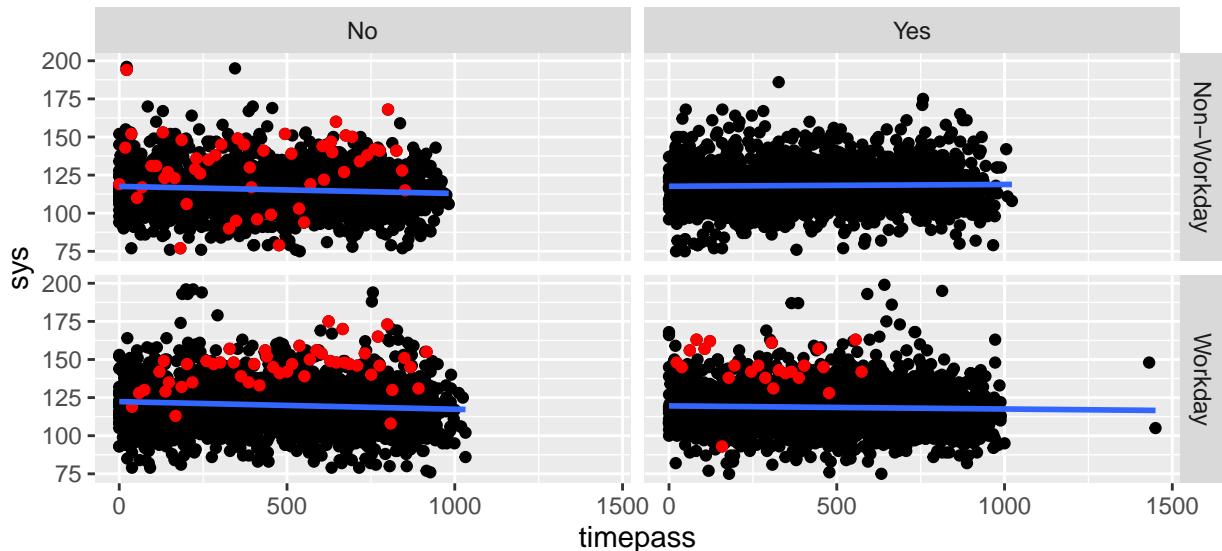
rvc1_flagged <- nurse_infl2 %>%
  arrange(rvc.D11) %>%
  slice(1:3) %>%
  pull(snum)
rvc2_flagged <- nurse_infl2 %>%
  arrange(rvc.D22) %>%
  slice(1) %>%
  pull(snum)
rvc3_flagged <- nurse_infl2 %>%
```

```

arrange(rvc.D33) %>%
slice(1:2) %>%
pull(snum)

ggplot(nurse_filtered, aes(x = timepass, y = sys)) + geom_point() +
geom_point(data = nurse_filtered %>%
filter(snum %in% rvc1_flagged), color = "red") + geom_smooth(method = "lm",
se = F) + facet_grid(rows = vars(day3), cols = vars(fh_2))

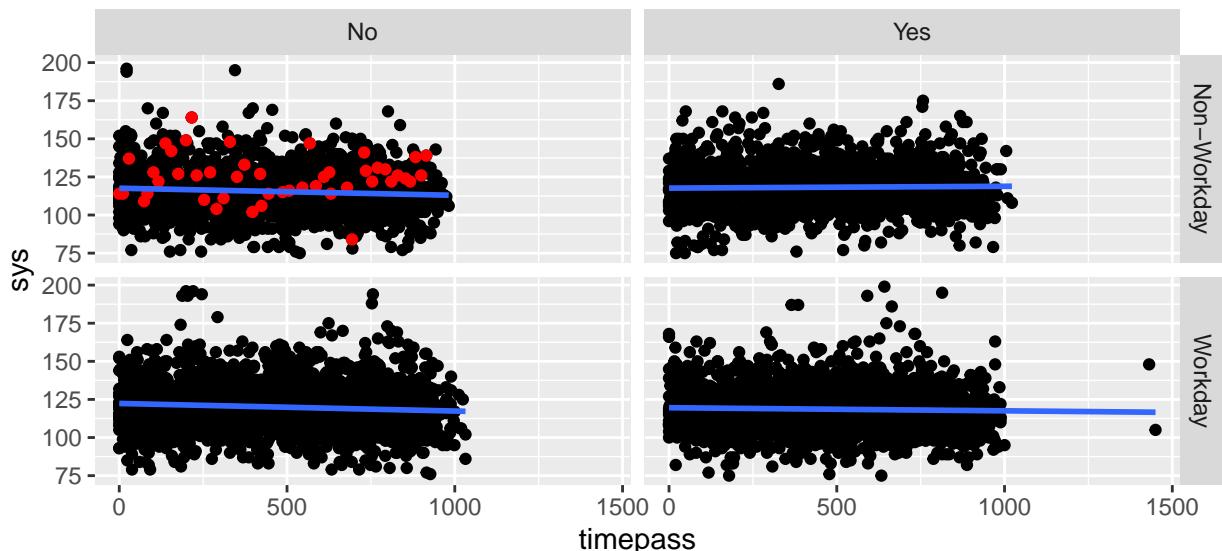
```



```

ggplot(nurse_filtered, aes(x = timepass, y = sys)) + geom_point() +
geom_point(data = nurse_filtered %>%
filter(snum %in% rvc2_flagged), color = "red") + geom_smooth(method = "lm",
se = F) + facet_grid(rows = vars(day3), cols = vars(fh_2))

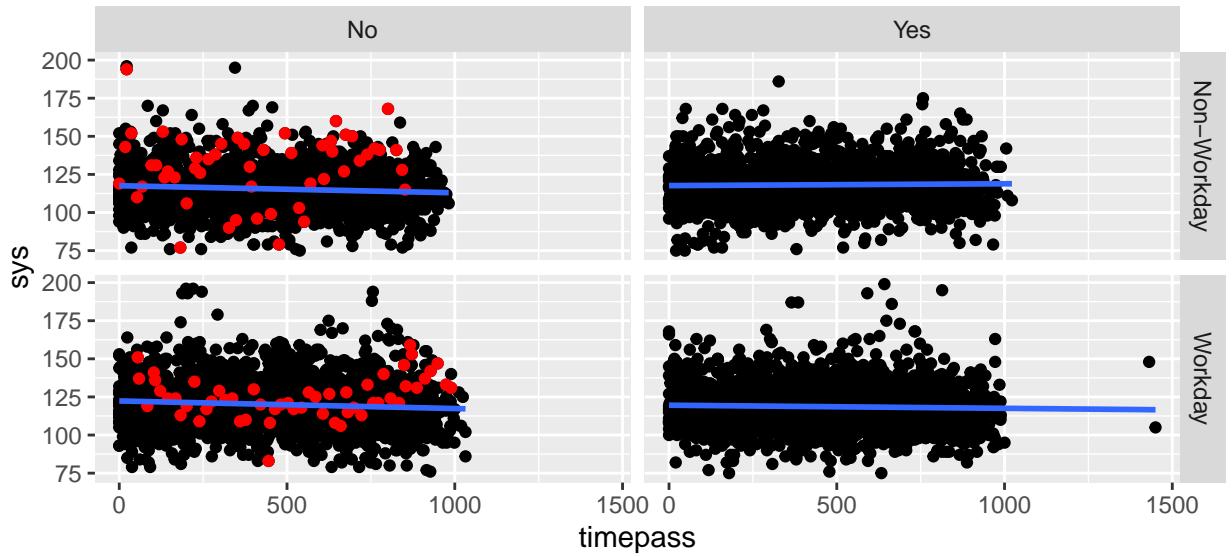
```



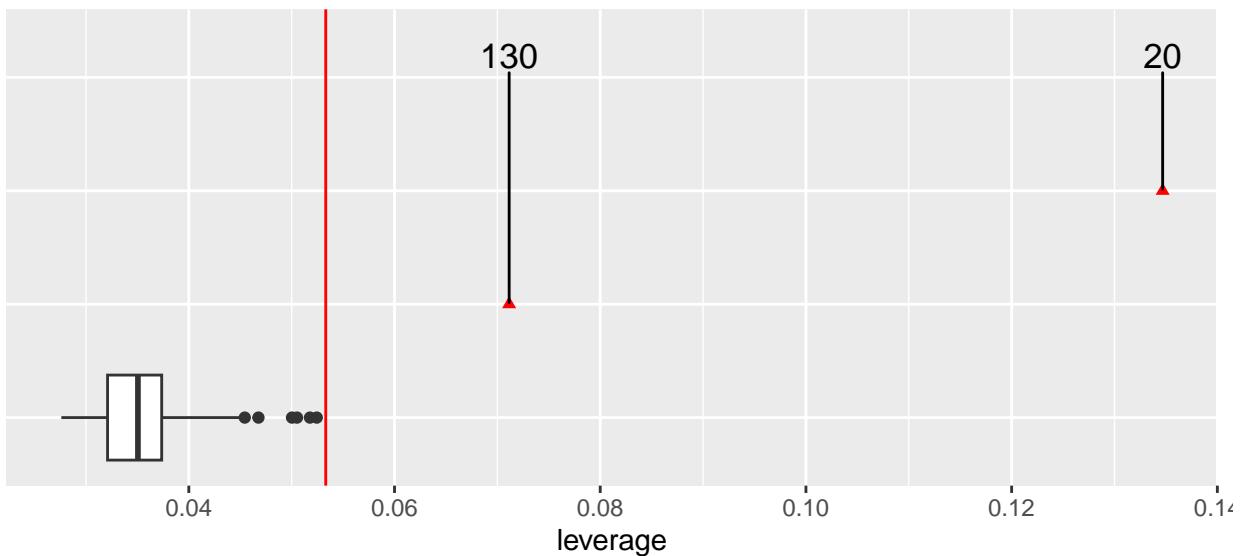
```

ggplot(nurse_filtered, aes(x = timepass, y = sys)) + geom_point() +
geom_point(data = nurse_filtered %>%
filter(snum %in% rvc3_flagged), color = "red") + geom_smooth(method = "lm",
se = F) + facet_grid(rows = vars(day3), cols = vars(fh_2))

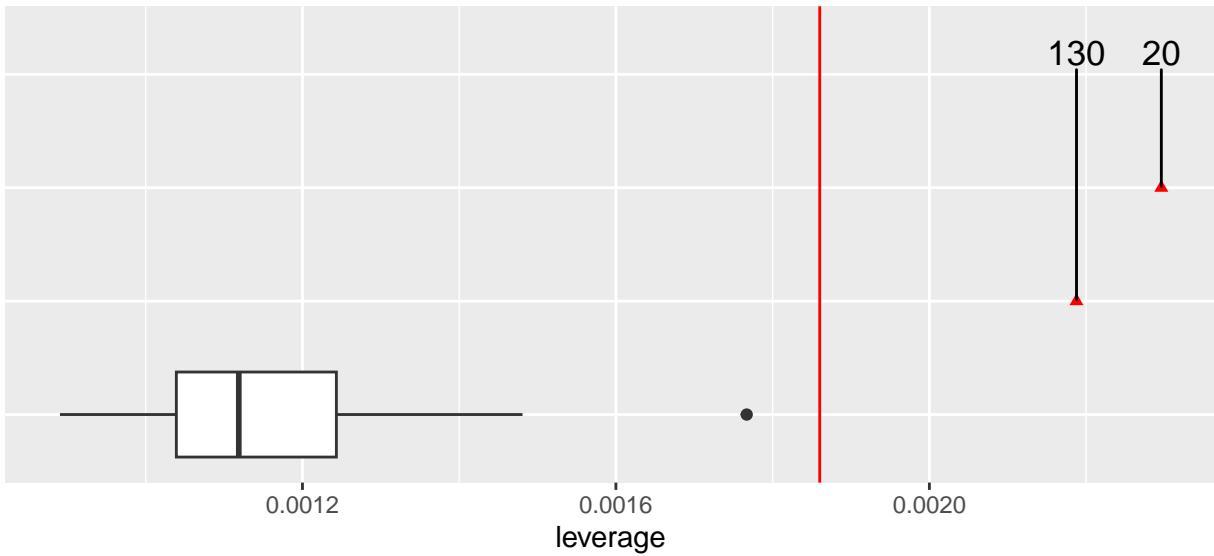
```



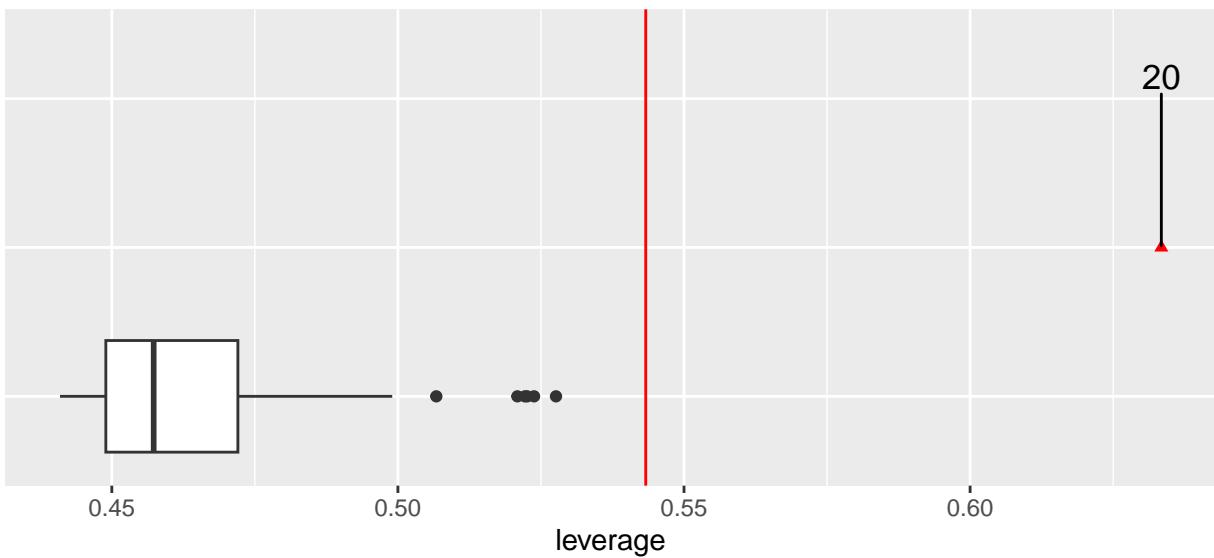
```
dotplot_diag(nurse_infl2$leverage.overall, name = "leverage",
             cutoff = "internal", modify = "boxplot")
```



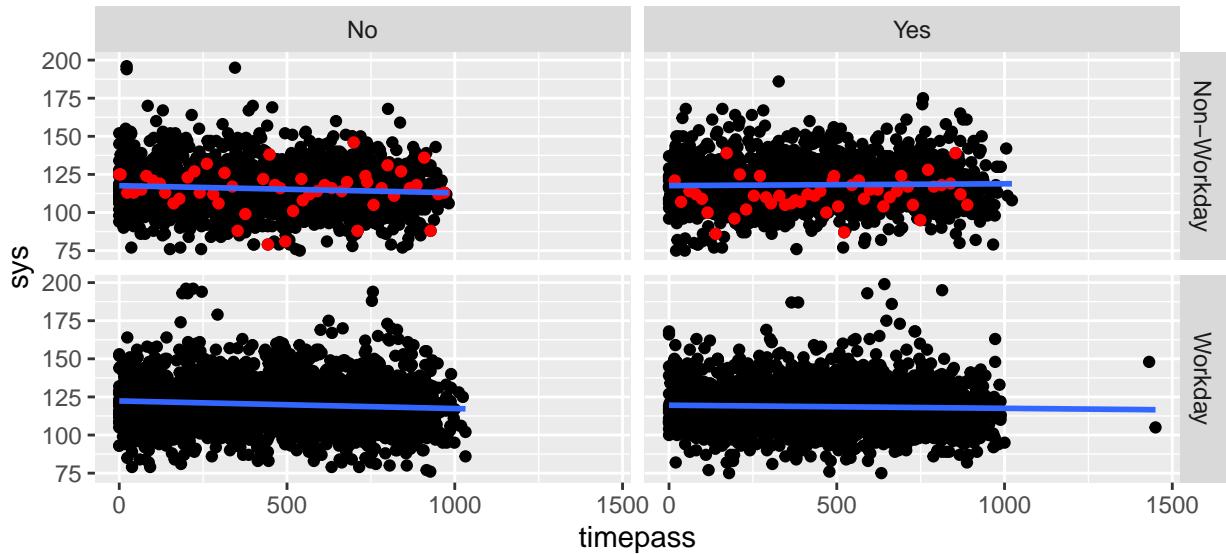
```
dotplot_diag(nurse_infl2$leverage.fixef, name = "leverage", cutoff = "internal",
             modify = "boxplot")
```



```
dotplot_diag(nurse_infl2$leverage.ranef.uc, name = "leverage",
  cutoff = "internal", modify = "boxplot")
```



```
ggplot(nurse_filtered, aes(x = timepass, y = sys)) + geom_point() +
  geom_point(data = nurse_filtered %>%
    filter(snum == 1062 | snum == 1226), color = "red") +
  geom_smooth(method = "lm", se = F) + facet_grid(rows = vars(day3),
  cols = vars(fh_2))
```



Effects Interpretation

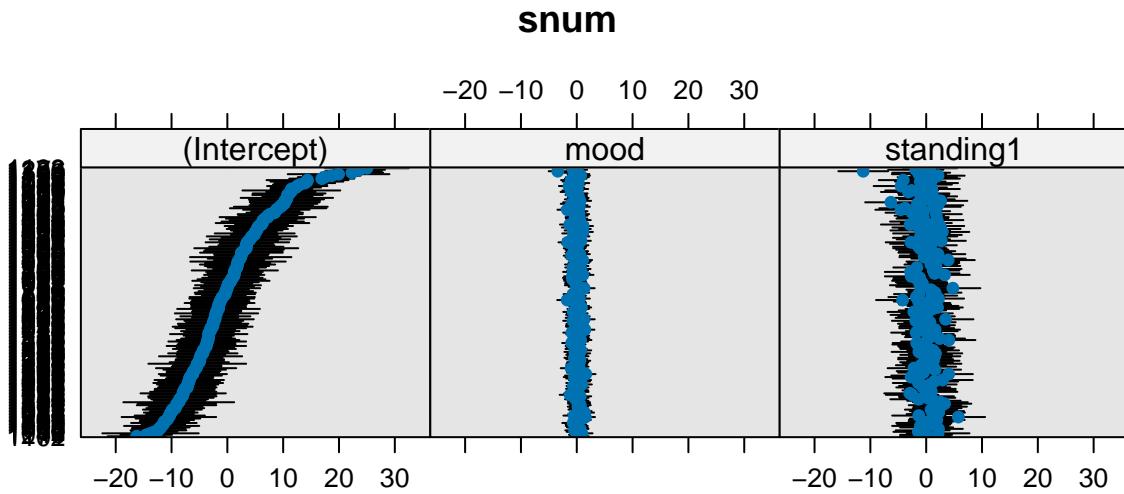
Confidence Intervals

```

confint(final_model, parm = "beta_", method = "boot")
##                   2.5 %      97.5 %
## (Intercept)    105.982691057  1.110715e+02
## day21          1.056963259  6.009611e+00
## fh_yes1        -3.652721144  1.924226e+00
## timepass       -0.003212703  8.028508e-04
## standing1      0.268327963  1.872354e+00
## mnact5         0.037855666  4.754936e-02
## mood            -0.394761118  3.033029e-01
## day21:timepass -0.004897662 -1.901534e-04
## fh_yes1:timepass  0.002197884  6.507437e-03
confint(final_model, parm = "beta_")
##                   2.5 %      97.5 %
## (Intercept)    106.059427620  1.111460e+02
## day21          0.742354356  6.064681e+00
## fh_yes1        -3.564823785  1.740751e+00
## timepass       -0.003106332  6.840398e-04
## standing1      0.295222880  1.839125e+00
## mnact5         0.0374449875  4.721434e-02
## mood            -0.395164951  2.862227e-01
## day21:timepass -0.004724771 -3.239513e-04
## fh_yes1:timepass  0.002160031  6.559976e-03

lattice::dotplot(ranef(final_model))
## $snum

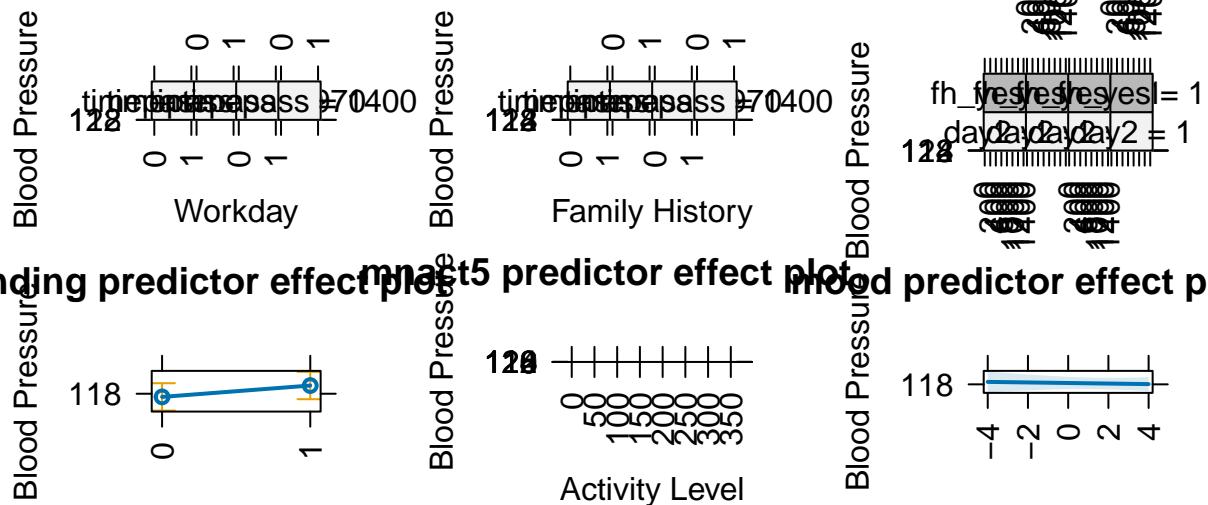
```



Effects Plots

```
timepass_all <- nurse_filtered %>%
  distinct(timepass) %>%
  pull()
random_timepass <- sample(timepass_all, 3)
# plot(predictorEffects(final_model, xlevels =
# list(timepass = random_timepass)))
plot(predictorEffects(final_model, xlevels = 4), axes = list(x = list(rug = F,
  rotate = 90, day2 = list(lab = "Workday"), fh_yes = list(lab = "Family History"),
  timepass = "Time Passed", standing = "Standing", mnact5 = list(lab = "Activity Level"),
  mood = "Mood"), y = list(ticks = list(at = c(110, 114, 118,
  122, 126)), lab = "Blood Pressure")))
```

lay2 predictor effect plot yes predictor effect plot



```
nurse_filtered <- nurse_filtered %>%
  # predicted means with RE
  mutate(fit_cond = predict(final_model), fit_marg = predict(final_model,
    re.form = NA))
# predicted means without RE
```

```

ggplot(nurse_filtered, aes(x = timepass, y = sys)) + geom_point() +
  geom_line(aes(y = fit_cond, group = snum), color = "darkgrey") +
  geom_line(aes(y = fit_marg), color = "red", size = 1, alpha = 0.5) +
  facet_grid(rows = vars(day3), cols = vars(fh_2)) + labs(title = "Blood Pressure vs Time Passed, by Workday",
  x = "Minutes since first measurement", y = "Systolic Blood Pressure") +
  theme_minimal(base_size = 17)

```

