Aim I - All Analysis

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```
knitr::opts_knit$set(root.dir = getwd())
```

Ensure quality clinical assessments

First check the norms:

```
library(dplyr)
```

```
##
## Attaching package: 'dplyr'
```

```
## The following objects are masked from 'package:stats':
```

```
##
##     filter, lag
```

```
## The following objects are masked from 'package:base':
##
##     intersect, setdiff, setequal, union
```

```
library(lemon)
knit_print.data.frame <- lemon_print
```

Check Clincial Assessment Norms

We pull in norms from papers for the Box and Block Test (BBT) and Grip Strength (GS) Assessment. We need to make sure those numbers are accurate.

BBT

These come from:

- doi.org/10.5014/ajot.39.6.386
- doi.org/10.1177/000841748505200505
- doi.org/10.5014/ajot.2013.006643

```
source("../r_utility_functions/bbt_norms.r")
bbt_norms %>%
  tidyr::pivot_wider(id_cols = c(age, gender), names_from = arm, values_from = c(mean, sd)) %>%
  arrange(age, gender)
```

age	gender	mean_left	mean_right	sd_left	sd_right
3	female	22.8	24.2	6.6	7.4
3	male	22.8	24.2	6.6	7.4
4	female	34.1	35.7	8.8	7.3
4	male	34.1	35.7	8.8	7.3
5	female	38.7	40.6	5.8	6.7
5	male	38.7	40.6	5.8	6.7
6	female	54.2	57.9	5.6	5.3
6	male	50.7	54.4	6.3	6.6
8	female	60.4	62.8	5.2	5.1
8	male	60.1	63.4	4.9	4.3
10	female	67.6	70.0	8.6	7.6
10	male	65.9	68.4	6.8	6.9
12	female	70.5	73.6	6.2	8.1
12	male	72.4	74.6	8.2	8.3
14	female	72.1	75.4	7.6	8.5
14	male	74.6	76.6	7.9	8.7
16	female	74.3	77.0	9.1	9.0
16	male	77.6	80.3	5.1	8.7
18	female	76.0	77.9	8.5	9.4
18	male	79.2	79.9	8.8	8.9
20	female	83.4	88.0	7.9	8.3
20	male	86.4	88.2	8.5	8.8
25	female	80.9	86.0	6.4	7.4
25	male	84.1	85.0	7.1	7.5
30	female	80.2	85.2	5.6	7.4
30	male	81.3	81.9	8.1	9.0
35	female	83.5	84.8	6.1	6.1
35	male	79.8	81.9	9.7	9.5
40	female	79.7	81.1	8.8	8.2
40	male	80.0	83.0	8.8	8.1
45	female	78.3	82.7	7.6	7.5
45	male	75.8	76.9	7.8	9.2
50	female	74.3	77.7	9.9	10.7
50	male	77.0	79.0	9.2	9.7
55	female	73.6	74.7	7.8	8.9
55	male	73.8	75.2	10.5	11.9
60	female	73.6	76.1	6.4	6.9
60	male	70.5	71.3	8.1	8.8

age	gender	mean_left	mean_right	sd_left	sd_right
65	female	71.3	72.0	7.7	6.2
65	male	67.4	68.4	7.8	7.1
70	female	68.3	68.6	7.0	7.0
70	male	64.3	66.3	9.8	9.2
75	female	63.6	65.0	7.4	7.1
75	male	61.3	63.0	8.4	7.1

GS

Comes from:

- doi.org/10/f94zw7
- doi.org/10/gd7bfk

```
source("../r_utility_functions/gs_norms.r")
grip_strength_norms %>% arrange(age.lower)
```

gender	age.lower	age.upper	dominant	dominant.sd	nondominant	nondominant.sd
male	3	3	8.818480	4.188778	8.377556	4.188778
female	3	3	7.936632	3.086468	7.936632	3.747854
male	4	4	12.566334	4.850164	11.904948	4.850164
female	4	4	10.802638	3.968316	10.582176	3.747854
male	5	5	16.314188	5.070626	16.093726	5.070626
female	5	5	15.432340	4.850164	14.770954	4.409240
male	6	6	21.825738	6.393398	21.384814	6.834322
female	6	6	19.841580	6.613860	19.180194	6.172936
male	7	7	24.691744	7.495708	24.030358	7.495708
female	7	7	25.132668	8.377556	24.250820	7.275246
male	8	8	29.321446	8.157094	29.100984	7.716170
female	8	8	27.998674	7.495708	26.675902	6.613860
male	9	9	35.714844	9.259404	34.171610	8.598018
female	9	9	32.187452	7.275246	31.085142	7.936632
male	10	10	39.242236	9.479866	37.478540	9.479866
female	10	10	38.580850	9.700328	36.376230	9.700328
male	11	11	46.076558	10.582176	43.871938	9.700328
female	11	11	44.753786	10.361714	42.549166	9.479866
male	12	12	53.351804	14.330030	50.926722	14.109568
female	12	12	51.808570	10.361714	48.501640	10.361714
male	13	13	65.036290	17.196036	63.493056	16.314188
female	13	13	55.115500	11.684486	52.690418	10.361714
male	14	14	75.398004	17.416498	69.665992	16.314188
female	14	14	59.304278	13.227720	54.895038	13.448182
male	15	15	83.114174	19.621118	78.925396	19.180194
female	15	15	61.949822	11.684486	56.879196	11.243562
male	16	16	90.389420	22.046200	85.098332	20.282504
female	16	16	62.170284	11.904948	58.201968	11.904948
male	17	17	98.105590	22.046200	92.373578	19.841580
female	17	17	62.611208	12.786796	59.304278	13.889106
male	18	24	103.617140	17.857422	98.987438	17.196036
female	18	24	61.949822	15.652802	58.642892	14.109568
male	25	29	109.569614	25.573592	102.514830	21.164352
female	25	29	65.256752	15.432340	61.508898	14.550492
male	30	34	102.514830	26.675902	100.971596	24.912206
female	30	34	63.713518	13.668644	61.067974	13.007258
male	35	39	103.837602	26.234978	100.310210	24.250820
female	35	39	64.374904	13.668644	61.729360	13.227720
male	40	44	102.955754	25.794054	98.987438	25.794054
female	40	44	65.918138	13.668644	63.713518	14.109568
male	45	49	94.357736	24.030358	90.830344	22.046200
female	45	49	63.493056	15.873264	60.406588	15.432340
male	50	54	97.003280	22.707586	93.255426	23.368972
female	50	54	62.170284	13.889106	58.422430	14.330030
male	55	59	89.728034	22.928048	84.877870	21.164352
female	55	59	55.335962	13.668644	52.029032	14.109568

gender	age.lower	age.upper	dominant	dominant.sd	nondominant	nondominant.sd
male	60	64	84.657408	22.707586	82.011864	20.062042
female	60	64	52.029032	14.330030	50.485798	13.889106
male	65	69	81.130016	23.148510	78.043548	22.707586
female	65	69	48.722102	14.550492	46.297020	14.550492
male	70	74	76.500314	19.841580	74.957080	20.943890
female	70	74	47.399330	11.243562	44.533324	12.125410
male	75	79	72.091074	22.266662	66.799986	21.825738
female	75	79	43.210552	13.227720	41.226394	12.786796
male	80	85	61.949822	20.062042	59.745202	20.723428
female	80	85	43.871938	9.700328	42.769628	8.818480

Check how we handle challenging color trails values:

```
rm(list = ls())
source("utility_scripts/setup.r")
```

```
## [1] "Only including subjects with complete consent forms"
## [1] "Excluding subjec # <=10 (pilot trial cohort)"
## [1] "n=44"
## [1] "Excluding Subjects:"
## [1] "    excluding subject 50"
## [1] "    excluding subject 47"
## [1] "Corrected Subject 22 Survey Assignment"
## [1] "Fixing subject 60 post experiment"
## [1] "final number of subjects: 42"
## [1] "Filling in for subjects too young for color trails:"
## [1] "    Subject 15, reported no impairment, marking no impairment"
## [1] "    subject 23, reported motor impairment only, BBT -2.56 z, marking motor impairment"
## [1] "    Subject 66, reported motor impairment only (Left hemiparesis), marking motor impairment"
```

Fix challenging Color Trails Scores

```
messy_data <- combined_data %>%
  filter(color_trails_1_standard < (-3) | is.na(color_trails_1_standard) | color_trails_2_standard < (-3) | is.na(color_trails_2_standard)) %>%
  select(record_id, age, years_education, color_trails_1_time, color_trails_1_standard, color_trails_2_time, color_trails_2_standard, impairment)
messy_data
```

record_id	age	years_education	color_trails_1_time	color_trails_1_standard	color_trails_2_time	color_trails_2_standard	impairment
12	75	14	133.00	-3.2	223.0	-3.1	Cognitive
15	5	0	73.00	NA	162.0	NA	None
23	4	0	151.00	NA	NA	NA	Motor
39	48	14	87.50	-2.9	193.0	-3.5	Motor
41	8	2	79.00	-5.0	57.0	-0.3	Motor and Cognitive
44	7	2	58.00	-3.8	135.0	-4.7	Motor and Cognitive
45	16	9	NA	-5.0	NA	-5.0	Motor and Cognitive
48	15	9	85.70	-5.0	164.9	-5.0	Motor and Cognitive
63	14	8	35.00	-4.0	72.0	-4.1	Motor and Cognitive
66	5	0	110.00	NA	NA	NA	Motor
68	16	10	59.42	-3.8	98.0	-3.8	Motor

12

```
messy_data %>% filter(record_id == 12)
```

record_id	age	years_education	color_trails_1_time	color_trails_1_standard	color_trails_2_time	color_trails_2_standard	impairment
12	75	14	133	-3.2	223	-3.1	Cognitive

```
ctt_norm <- data.frame(t = c(23, 22, 21, 20), ctt1.low = c(121, 123, 125, 128), ctt1.high = c(122, 124, 127, 129), ctt2.low = c(207, 211, 214, 218), ctt2.high = c(210, 213, 217, 220))
ctt1_low <- lm(t ~ ctt1.low, data = ctt_norm)
ctt1_high <- lm(t ~ ctt1.high, data = ctt_norm)
```

```
predict(ctt1_low, newdata = data.frame(ctt1.low = c(133)))
```

```
##        1
## 17.73832
```

```
predict(ctt1_high, newdata = data.frame(ctt1.high = c(133)))
```

```
##        1
## 18.39655
```

```
ctt2_low <- lm(t ~ ctt2.low, data = ctt_norm)
ctt2_high <- lm(t ~ ctt2.high, data = ctt_norm)
predict(ctt2_low, newdata = data.frame(ctt2.low = c(223)))
```

```
##        1
## 18.59231
```

```
predict(ctt2_high, newdata = data.frame(ctt2.high = c(223)))
```

```
##        1
## 19.15517
```

For CTT1: 18 For CTT2: 19

15

```
messy_data %>% filter(record_id == 15)
```

record_id	age	years_education	color_trails_1_time	color_trails_1_standard	color_trails_2_time	color_trails_2_standard	impairment
15	5	0	73	NA	162	NA	None

Too Young

23

```
messy_data %>% filter(record_id == 23)
```

record_id	age	years_education	color_trails_1_time	color_trails_1_standard	color_trails_2_time	color_trails_2_standard	impairment
23	4	0	151	NA	NA	NA	Motor

Too Young

39

```
messy_data %>% filter(record_id == 39)
```

record_id	age	years_education	color_trails_1_time	color_trails_1_standard	color_trails_2_time	color_trails_2_standard	impairment
39	48	14	87.5	-2.9	193	-3.5	Motor

```
ctt_norm <- data.frame(t = c(23, 22, 21, 20), ctt2.low = c(172, 175, 177, 180), ctt2.high = c(174, 176, 179, 182))

ctt2_low <- lm(t ~ ctt2.low, data = ctt_norm)
ctt2_high <- lm(t ~ ctt2.high, data = ctt_norm)
predict(ctt2_low, newdata = data.frame(ctt2.low = c(193)))
```

```
##  1
## 15
```

```
predict(ctt2_high, newdata = data.frame(ctt2.high = c(193)))
```

```
##        1
## 15.89796
```

For CTT2: 15

41

```
messy_data %>% filter(record_id == 41)
```

record_id	age	years_education	color_trails_1_time	color_trails_1_standard	color_trails_2_time	color_trails_2_standard	impairment
41	8	2	79	-5	57	-0.3	Motor and Cognitive

```
ctt_norm <- data.frame(t = c(23, 22, 21, 20), ctt1 = c(47, 48, 49, 50))
ctt1 <- lm(t ~ ctt1, data = ctt_norm)
predict(ctt1, newdata = data.frame(ctt1 = c(79)))
```

```
##  1
## -9
```

For CTT1: 0 This subject is a bit odd, their CTT1 is awful, but CTT2 is good. Not 100% sure how to handle that.

44

```
messy_data %>% filter(record_id == 44)
```

record_id	age	years_education	color_trails_1_time	color_trails_1_standard	color_trails_2_time	color_trails_2_standard	impairment
44	7	2	58	-3.8	135	-4.7	Motor and Cognitive

Too young by 1 year, can probably use the 8 year old norms and be OK.

```
ctt_norm <- data.frame(t = c(23, 22, 21, 20), ctt1.low = c(47, 48, 49, 50), ctt2.low = c(101, 103, 104, 106), ctt2.high = c(102, 103, 105, 107))
ctt1_low <- lm(t ~ ctt1.low, data = ctt_norm)
predict(ctt1_low, newdata = data.frame(ctt1.low = c(58)))
```

```
##  1
## 12
```

```
ctt2_low <- lm(t ~ ctt2.low, data = ctt_norm)
ctt2_high <- lm(t ~ ctt2.high, data = ctt_norm)
predict(ctt2_low, newdata = data.frame(ctt2.low = c(135)))
```

```
##        1
## 2.115385
```

```
predict(ctt2_high, newdata = data.frame(ctt2.high = c(135)))
```

```
##        1
## 3.779661
```

CTT1: 12 CTT2: 3

45

```
messy_data %>% filter(record_id == 45)
```

record_id	age	years_education	color_trails_1_time	color_trails_1_standard	color_trails_2_time	color_trails_2_standard	impairment
45	16	9	NA	-5	NA	-5	Motor and Cognitive

Significant cog impairment, unable to complete color trails.

48

```
messy_data %>% filter(record_id == 48)
```

record_id	age	years_education	color_trails_1_time	color_trails_1_standard	color_trails_2_time	color_trails_2_standard	impairment
48	15	9	85.7	-5	164.9	-5	Motor and Cognitive

```r
ctt_norm <- data.frame(t = c(26, 24, 22, 20), ctt1.low = c(25, 26, 27, 28), ctt2.low = c(50, 52, 54, 56))
ctt1_low <- lm(t ~ ctt1.low, data = ctt_norm)
predict(ctt1_low, newdata = data.frame(ctt1.low = c(85.7)))
```

```
##     1
## -95.4
```

```r
ctt2_low <- lm(t ~ ctt2.low, data = ctt_norm)
predict(ctt2_low, newdata = data.frame(ctt2.low = c(164.9)))
```

```
##     1
## -88.9
```

For CTT1: 0 For CTT2: 0

63

```r
messy_data %>% filter(record_id == 63)
```

record_id	age	years_education	color_trails_1_time	color_trails_1_standard	color_trails_2_time	color_trails_2_standard	impairment
63	14	8	35	-4	72	-4.1	Motor and Cognitive

```r
ctt_norm <- data.frame(t = c(26, 24, 22, 20), ctt1.low = c(27, 28, 29, 30), ctt2.low = c(55, 57, 59, 61))
ctt1_low <- lm(t ~ ctt1.low, data = ctt_norm)
predict(ctt1_low, newdata = data.frame(ctt1.low = c(35)))
```

```
##  1
## 10
```

```r
ctt2_low <- lm(t ~ ctt2.low, data = ctt_norm)
predict(ctt2_low, newdata = data.frame(ctt2.low = c(72)))
```

```
## 1
## 9
```

For CTT1: 10 For CTT2: 9

66

```r
messy_data %>% filter(record_id == 66)
```

record_id	age	years_education	color_trails_1_time	color_trails_1_standard	color_trails_2_time	color_trails_2_standard	impairment
66	5	0	110	NA	NA	NA	Motor

Too Young

Check to make sure all color trails values were correctly entered:

Just pulling color trails data to make it easier to verify that data was entered correctly.

```r
rm(list = ls())
source("utility_scripts/setup.r")
```

```
## [1] "Only including subjects with complete consent forms"
## [1] "Excluding subjec # <=10 (pilot trial cohort)"
## [1] "n=44"
## [1] "Excluding Subjects:"
## [1] "    excluding subject 50"
## [1] "    excluding subject 47"
## [1] "Corrected Subject 22 Survey Assignment"
## [1] "Fixing subject 60 post experiment"
## [1] "final number of subjects: 42"
## [1] "Filling in for subjects too young for color trails:"
## [1] "    Subject 15, reported no impairment, marking no impairment"
## [1] "    subject 23, reported motor impairment only, BBT -2.56 z, marking motor impairment"
## [1] "    Subject 66, reported motor impairment only (Left hemiparesis), marking motor impairment"
```

Check Color Trails Recorded Values

Here we plot with the T-scores, since that is what is in the handbooks

```
combined_data %>% select(record_id, age, years_education, color_trails_1_time, color_trails_1_t, color_trails_2_time, color_trails_2_t)
```

record_id	age	years_education	color_trails_1_time	color_trails_1_t	color_trails_2_time	color_trails_2_t
12	75	14	133.00	18	223.00	19
13	62	14	79.00	35	154.00	35
14	31	16	19.60	60	50.50	61
15	5	0	73.00	NA	162.00	NA
16	30	20	25.60	52	63.60	51
17	34	20	22.70	54	48.50	59
20	81	18	84.00	35	117.00	42
21	69	14	58.50	46	116.00	47
22	64	17	33.00	55	73.00	55
23	4	0	151.00	NA	NA	NA
25	76	14	35.00	62	52.80	67
28	49	18	46.10	41	73.70	51
29	57	20	25.00	56	51.30	61
30	49	18	22.00	58	54.40	60
31	60	16	35.90	56	69.00	60
32	29	18	27.60	48	49.00	55
34	46	17	39.00	46	48.90	62
35	70	18	61.00	40	115.00	39
36	10	4	32.00	33	50.00	45
38	67	16	26.00	61	73.80	58
39	48	14	87.50	21	193.00	15
40	56	18	22.00	58	54.30	60
41	8	2	79.00	0	57.00	47
42	19	13	54.60	29	87.40	45
43	14	9	30.00	20	43.70	37
44	7	2	58.00	12	135.00	3
45	16	9	NA	0	NA	0
46	18	10	45.90	45	112.60	42
48	15	9	85.70	0	164.90	0
49	16	10	18.00	41	47.00	25
52	27	15	32.71	51	97.82	40
54	28	18	26.00	50	48.00	55
55	73	18	32.00	56	80.00	52
58	8	3	20.29	54	38.30	57
59	13	8	7.59	64	23.47	57
60	8	3	35.00	37	52.00	50
61	14	9	20.00	40	27.00	53
63	14	8	35.00	10	72.00	9
64	13	7	18.00	45	51.18	34
66	5	0	110.00	NA	NA	NA
68	16	10	59.42	12	98.00	12
69	9	4	33.40	35	72.00	35

I need a second set of eyes to check this

Open Ended Comments

Need to check these to start

**Note: We are choosing

```
rm(list = ls())
process_exclusions <- FALSE
source("utility_scripts/setup.r")
```

```
## [1] "Only including subjects with complete consent forms"
## [1] "Excluding subjec # <=10 (pilot trial cohort)"
## [1] "n=44"
```

```
## Warning in eval(ei, envir): Not processing exclusions
```

```
## [1] "Corrected Subject 22 Survey Assignment"
## [1] "Fixing subject 60 post experiment"
## [1] "final number of subjects: 44"
## [1] "Filling in for subjects too young for color trails:"
## [1] "    Subject 15, reported no impairment, marking no impairment"
## [1] "    subject 23, reported motor impairment only, BBT -2.56 z, marking motor impairment"
## [1] "    Subject 66, reported motor impairment only (Left hemiparesis), marking motor impairment"
```

Open Ended Questions

We pull all of the open ended answer results in one place. They are ordered by age then impairment. The experimental order is shown.

- subj-FTF: subject comments after the FTF condition
- exp-FTF: surveyor comments after the FTF condition

...

- subj-exit: subject comments after the exit survey
- exp-exit: surveyor comments after the end of the experiments

```
knitr::kable(
  post_exp %>% select(record_id, redcap_event_name, exp_notes_other) %>% tidyr::pivot_wider(names_from = redcap_event_name, values_from = exp_notes_other) %>%
    rename(
      "exp-FTF" = after_in_person_arm_1,
      "exp-SRAT" = after_augmented_arm_1,
      "exp-CT" = after_classical_arm_1
    ) %>%
    full_join(
      post_exp %>%
        select(record_id, redcap_event_name, post_comments) %>% tidyr::pivot_wider(names_from = redcap_event_name, values_from = post_comments) %>%
        rename(
          "subj-FTF" = after_in_person_arm_1,
          "subj-SRAT" = after_augmented_arm_1,
          "subj-CT" = after_classical_arm_1
        ),
      by = "record_id"
    ) %>%
    full_join(
      combined_data %>% select(
        record_id,
        age,
        order.factor,
        impairment.measured,
        exit_feedback,
        exp_final_notes,
        injury_class
      ) %>%
        rename(
          "order" = order.factor,
          "impairment" = impairment.measured,
          "subj-exit" = exit_feedback,
          "exp-exit" = exp_final_notes,
          "inj" = injury_class
        ),
      by = "record_id"
    ) %>% full_join(order_preference, by = "record_id")
    %>%
    rename("ID" = record_id) %>% select(
      ID,
      age,
      impairment,
      inj,
      order,
      "subj-FTF",
      "exp-FTF",
      "subj-CT",
```

```
      "exp-CT",
      "subj-SRAT",
      "exp-SRAT",
      "subj-exit",
      "exp-exit",
      preference
    ) %>% mutate(
      order = ifelse(order == "Augmented (Humanoid) First", "SRAT first", "CT first")
    ) %>% arrange(age, impairment),
  longtable = TRUE
) %>%
  kableExtra::column_spec(1, width = ".15in") %>%
  kableExtra::column_spec(2, width = ".15in") %>%
  kableExtra::column_spec(3, width = ".3in") %>%
  kableExtra::column_spec(4, width = ".75in") %>%
  kableExtra::column_spec(5, width = ".25in") %>%
  kableExtra::column_spec(6:13, width = "1.25in") %>%
  kableExtra::row_spec(0, bold = TRUE, hline_after = TRUE) %>%
  kableExtra::kable_styling(latex_options = c("hold_position", "repeat_header"))
```

```
## Warning in !is.null(rmarkdown::metadata$output) && rmarkdown::metadata$output %in% : 'length(x) = 2 > 1' in coercion to 'logical(1)'
```

ID	age	impairment	injury	order	subj-FTF	exp-FTF	subj-CT	exp-CT	subj-SRAT	exp-SRAT	subj-exit	exp-exit	preference
23	4	Motor	Peripheral Injury	SRAT first	No		I'm tired from doing all the experiments for so long.		No.	Technical issue at beginning of test, robot disconnected.	I like to play with lil flo.	Shows good ability to follow instructions during target touch ability but has difficulty differentiating between right and left hands. Subject distracted for the survey after classical so responses were somewhat arbitrary. Parent - " Robot would be really useful for kids with more mobility issues than current sub who has minimal issues". Subject didn't really understand many of the questions for the post experiment survey.	SRAT-CT-FTF

(continued)

ID	age	impairment	injury	order	subj-FTF	exp-FTF	subj-CT	exp-CT	subj-SRAT	exp-SRAT	subj-exit	exp-exit	preference
66	5	Motor	Unknown	CT first	The subject didn't cooperate and hadn't complete the Simon says game. Only the second game was completed.The subject seems tired and was not wiling to cooperate at the end. He said he didn't like the games at all but still enjoy this kind of in person activity, also, he replied negatively to the last 5 questions (change answers several times from eg. from an absolute yes to a definite no for the same problem).	The subject say yes on taking mood-altering medication question. But didn't provide the details. Simon says game not complete because subject give up due to tiredness. Also, respond negatively to after survey.	Subject mentioned the volume is too high at the beginning of the Simon says, adjusted the volume. Experienced significant background noise at the beginning. The subject said he's tired and did not want to complete the remaining questions.		Subject said he was exhausted and gave up the remaining surveys. He mentioned several times he didn't want to stay and want to back to his room, also mentioned he played too much.		Subject said super exhausted and gave up the survey.		NA
15	5	None	No Injury	CT first					Lil 'Flo was nice. She was very encouraging.			Surveys too long. Subject felt too bored. Did not know the meaning of rehab, etc. The guardian pointed out that surveys made her not bring her grandparents. Also did not see the point in asking the patient if they were anxious etc For intake survey child level of excitement, child started to answer low excitement/sleepy until parent encouraged child to rate higher.	SRAT-FTF-CT
44	7	Motor and Cog-ni-tive	Brain Injury	CT first	None		The activity was quite enjoyable but also very frustrating		None				SRAT-FTF-CT
41	8	Motor	Brain Injury	CT first	It was very very fun	Caretaker not super attentive during surveys.	"It was fun"		None	Subjects friend/fellow patient at CHOP was watching during a part of the target touch activity which was a source of distraction (one incident)		Experiment run at chop. Sub takes melatonin to regulate sleep but caretaker mentioned that it wouldn't really count as a mood or focus altering medication.	SRAT-FTF-CT

(continued)

ID	age	impairment	injury	order	subj-FTF	exp-FTF	subj-CT	exp-CT	subj-SRAT	exp-SRAT	subj-exit	exp-exit	preference
58	8	Motor	Peripheral Injury	CT first		No go pro recording for clinical assessments and in person condition, real sense recording for in person condition does exist.						Subject has ASM. Subject didn't really focus on answering final surveys	SRAT-CT-FTF
60	8	Motor	No Injury	SRAT first	No	Sometimes needed to repeat in target touch	She said she liked the other robot		It was fun and the robot is very cute	Subject sometimes confused right and left arms; forgot to put the gopro on the robot; record happened only with the real sense; note the mom read the questions and subject answered	No	Visual cues for left and right hand. Multilingual. Daily living activities like unbutton... Adjust prompts and number of steps for younger subjects.	SRAT-CT-FTF
69	9	None	Other	CT first		Did this activity on the second day at chop due to technical issues on the first day, all three modalities performed on the second day	"This game was amazing"					All three modalities done on the second day at chop	SRAT-FTF-CT
36	10	Motor	Psychological Disorder	SRAT first	"I did enjoy the interaction "		"I enjoyed that but I really love John (the robot) and he had to leave"		"Im happy "	Sub involved interviewer in a lot of the interactions with the robot.	" I'm building a robot", " John is the best robot I've ever seen"	Intake survey subject is for subject with caretaker, subject named robot John during the intake survey. Subject rapidly switched between extreme responses for many of the survey questions, may come up as an outlier because of This. As the trials progressed sub became less and less attentive. Sub was quite afraid of robot at beginning of aug trial but was very very friendly with it after, introduced it to the survey interviewer.	SRAT-FTF-CT
64	13	Motor	Peripheral Injury	SRAT first			"Hard to hear (operator) through screen and words not clear" Could hear the robot better				The robot was helpful and could be helpful to other people		SRAT-FTF-CT
59	13	None	NA	SRAT first							I would not like to see a robot like this that's more human than this(more anthropomorphic)		FTF-SRAT-CT

(continued)

ID	age	impairment	injury	order	subj-FTF	exp-FTF	subj-CT	exp-CT	subj-SRAT	exp-SRAT	subj-exit	exp-exit	preference
43	14	Motor	Brain Injury	CT first	None		"I think it was a good experience, something new"		"It was good, when I met the robot I was saying, it was the same as talking to a person"		(Sub would put in classical and augmented tele at the same level) "I think it was all good"		FTF-SRAT-CT
61	14	Motor	No Injury	SRAT first		Her mom was not focused watching every interaction	It was hard tryin to remember the automated voice but I messed up more this time so.		It was a little harder , being able to hear it from a human was a little easier , hearing and knowing it was a robot made it a little harder.	System issues before we began	No	Tasks could be difficult for young children (4yo)	FTF-SRAT-CT
63	14	Motor and Cog-ni-tive	Brain Injury	SRAT first						Web interface error, the operator image did not show on the screen on flo. Even after entering. Exiting the flo interface. Flo would still work and be able to give verbal instructions, the operator could still see their video on the web interface. Rebooted the system after the trial began to rectify this, still did not work with Operator's laptop, switching to another laptop fixed this issue, indicating this is an issue with operators laptop and not with the system. The microphone was not working in the first few minutes of the trial, flos face was also in the sleep expression for half of the Simon says exercise.			CT-SRAT-FTF
48	15	Motor and Cog-ni-tive	Unknown	CT first	Filled by Michael		Binary questions		Binary		Confident in person was best. Not as sure about other two All answers binary	Subject H 1 E 1 S 1 Dad H 1 E 3 S 7 Kid loves switch based mario	FTF-CT-SRAT
45	16	Motor and Cog-ni-tive	Brain Injury	SRAT first	None							Sub was very confused in selecting ranking of three interactions, so responses might not be valid.	SRAT-FTF-CT

(continued)

ID	age	impairment	injury	order	subj-FTF	exp-FTF	subj-CT	exp-CT	subj-SRAT	exp-SRAT	subj-exit	exp-exit	preference
49	16	Motor and Cognitive	Brain Injury	CT first	Effort was mostly having to think. Nothing hard, just had to listen before moving. Put your mind to it. Be patience. Fun bc competitive				It was fun Could hear it better, very understandable. Maybe Flo's voice is clearer than Ajay		Very cute and adorable (flo). Very self motivated to adhere to care plan. Going to do her therapy no matter what, because it is for her.	H: 7 E: 6 S: 7	FTF-SRAT-CT
68	16	Motor and Cognitive	Stroke	SRAT first					Subject says it was pretty cool and really enjoy seeing the actual movement.		Subject said it is interesting.		SRAT-CT-FTF
46	18	Motor	Peripheral Injury	SRAT first	It was all good It was interesting bc first time Enjoy bc person doing activity w me		Same thoughts	Seemed more fluid than with flo ajays driving improved	Overall good. Everything is good nothing bad. Good to help with some things	Ajays first time Motors are misaligned badly Needs a way to auto position relative to patient Congrats phrasing repeats too often Ajay really bad at driving		Said classical was easier. Much more engaged in Simon says. Seems to really favor face to face Day 2 H 1 E 3 D 1	FTF-CT-SRAT
47	18	NA	NA	CT first			What was cool? Robot coming in, being able to see video and drive around. Workhed ok? I think so, yeah		Needs more time (work)			Day 2 H 6 E 6 D 5	SRAT-FTF-CT
42	19	Motor	Psychological Disorder	CT first	"It (the activity) makes you think about what you are doing, you have to use your brain a lot"	A friend/fellow patient of the subject was outside the room window, the sub was facing this window during the classical experiment, this could have a source of distraction/experimental deviation. Changed to having subject face the outside window after this trial	In between classical and aug subject made a really funny comment that the "robot was like a vacuum cleaner when it was rolling in and it was really loud. For taller people you can find a way to move the board up and down"	Sub very tired from the beginning of day 2 of trials due to a long day with PT, OT and behavioral therapy.	Same as last time + "robot should be able to move up and down for eye level of older kids who could be a bit taller, while doing some of the physical stuff it should actually be able to get there (like reaching shoulder, instead of that it collided hands)"		"It would be a better reading if the voice wasn't choppy, it sounds like a computer, it would be better if it sounded like what Siri and Alexa talk more like a human"		FTF-SRAT-CT
50	19	NA	NA	NA	She liked playing the games; moving into the new chair made her nervous; sitting in front of the camera made her nervous; took a little bit of time to understand instructions for the tasks		NA	NA	NA	NA	NA	NA	NA
52	27	Motor	Brain Injury	CT first	Enjoyable, fun. Rehab is supposed to be fun		Kids might listen better because it can move and they can fun with it.		Makes me have more fun. More realistic in this day and age. A younger person might listen better.		Study was conducted well, good assort of tools you used to conduct this, the order of how you did it was good, saved best for last		CT-FTF-SRAT

(continued)

ID	age	impairment	injury	order	subj-FTF	exp-FTF	subj-CT	exp-CT	subj-SRAT	exp-SRAT	subj-exit	exp-exit	preference
54	28	Motor	Peripheral Injury	SRAT first	Useful for kids, not for adults		It's better than with the robot, easier, more natural.		Blue light on the face was too bright, might distract				FTF-CT-SRAT
32	29	None	No Injury	CT first	None		"It was hard to tell the difference between shoulder flexion and abduction in the small screen during the telepresence, Instructions like "move your arm to the side" were better than instructions like " move your arm like this" "		"During simon says, in classical telepresence or in person micheal kept doing the action such as swinging in his arm but with flo she stopped so it might cause confusions on whether to continue doing the action."		" I was a little distracted by the robot since I'm so used to one on one therapy."	Sub looked to survey interviewer for cues more than usual during the three trails, might be worthwhile to explore having interviewer outside the room after setting up the cameras so as to not affect the interaction.	FTF-SRAT-CT
16	30	Motor	Brain Injury	CT first	" as rehab, probably better to make it more repetitive, it would also be good to have a gradation to make it harder for people who find it easy and easier for people who find it hard" , "the feedback on how I was doing was also good, like telling me to raise my hand higher etc"		"The screen was kinda small, would have been nice to have a larger screen where I could see all of his body, part of it were cut off by the small screen, could here him perfectly fine, nice he could move it around, but than that it was similar to doing the activities in person"		" the system looks really good, in the beginning I was kinda distracted by the robots movement and how different it was from a humans, it was distracting at the beginning"		" instead of having the robot instead of the human it would be nice to have the robot with the human" as a aid		FTF-CT-SRAT
14	31	None	No Injury	SRAT first	Add pizza		Give out robots		Double pay		Classical telepresence would be better with at least the full torso in view		FTF-SRAT-CT

(continued)

ID	age	impairment	injury	order	subj-FTF	exp-FTF	subj-CT	exp-CT	subj-SRAT	exp-SRAT	subj-exit	exp-exit	preference
17	34	Motor	Brain Injury	SRAT first			Unexpectedly, felt more comfortable with a human than the robot voice. Felt more comfortable talking to a person than robot even through the screen. "Interacting through video felt less weird". "While it is nice to have the robot arms, if you can see the screen clearly its sufficient." "I'd prefer telehealth than trying to interact with robot" . I assume there is nuances with posture and muscle focus that a human can pick up better than robot. More comforting to have a live conversation (valued live-feedback) vs. robot feels like a prescribed exercise where someone will look at it later and get back to you with comments.		Clumsiness of robot hands (too big); for ex : cover mouth + wave arm can't happen at the same time is distracting... "I am going to do do what you said but your arms don't work" // hard when you are supposed to mirror the motions but the robot can't do it well it is distracting. "It would be nice if the robot can be asked to repeat the instructions". "I can see how it could be frustrating for older people". "I hate talking to robots, but interacting isn't as weird". "I would respond if it asked me to talk but I wouldn't naturally talk to it" . I feel self-conscious if I knew someone were going to watch it live or have a recording compared to interacting with a person. "The one part when it said "lets try to do it a little bit better" I thought that was fine and it did push me to work harder. It would work"... Major changes that would help her would be have the arms not hit/clunk/smaller hands when covering mouth.			Operator was back in room for final survey	FTF-CT-SRAT

(continued)

ID	age	impairment	diagnosis	order	subj-FTF	exp-FTF	subj-CT	exp-CT	subj-SRAT	exp-SRAT	subj-exit	exp-exit	preference
34	46	None	Neurodegenerative Disorder	CT first	" I was very anxious and I am anxious still, I feel like I am getting very tired and I shouldn't be, I feel an off period on coming, also because of my Parkinson's I have a lot of tension in my neck and even though it wasn't the focus of this activity, I feel pain in my neck, it's very still, I am going to take an injection of medication to prevent discomfort "		"I was a little bit easier to do as I already knew what to do even though I still had some anxiety"		" it was more difficult to understand flo in the middle of the experiment and I had a brief "off" episode in the middle of the experiment (for 5 secs-1min) during which I took a break"		" I believe humor and jokes make doctor visits better, for Parkinson's patients like me, jokes which are not well though of could be difficult on the patient. It is something sociologists, psychologists and doctors must concentrate on, the social interaction. Also in future robots should be able to make identification of specialty medications which most medical professionals have difficultly understand. Future is in telehealth and robots in medicine but needs a lot from psychologists as well."		FTF-SRAT-CT
39	48	Motor and Cog-ni-tive	Peripheral Injury	SRAT first	None		None		None	Sub climbed over fence and tore finger, it was stitched back incorrectly, got infected and had to be amputated.	" flo's arms could have been longer" or like extendable arms which could be extended or retracted		FTF-SRAT-CT
28	49	Motor	Brain Injury	SRAT first	"Simon says would be good if I didn't have any arm activity but since I do its not super useful, the target touch activity was very useful."	Even though all other forms of cognition seem good including Simon says activity, during target touch subject has great difficulty remembering sequences over 2 actions.	"If I'm remote this is a good way to go about doing rehab but If I can access a physical person, I would prefer that, but if this was a lower cost alternative I might still choose tele-rehab."		"I liked the robot, I liked the faces, voices have matured and grown up vs the older (synthesized) voices which were very monotone(like Rosie from jetsons) " "would be good to have some sort of electro mechanical sensor on the touch pads on flo for people who can't press hard enough to register a touch on the targets"	Sub Can't recite numbers but can write them down (over 1000$). Has trouble spelling as well.	"If it was lower cost, tele-health would change I manage my medical needs, or if I was in a remote area." Could use finger specification to make target touch harder and include fine motor	Sub had a really hard time picking between classical and augmented telepresence in the ranking. " Flo's hands can do chip clip rehab, to strengthen opening and closing of hands"	FTF-SRAT-CT

(continued)

ID	age	impairment	diagnosis	order	subj-FTF	exp-FTF	subj-CT	exp-CT	subj-SRAT	exp-SRAT	subj-exit	exp-exit	preference
30	49	None	Neurodegenerative Disorder	SRAT first	None		It was easier for me than the robot because I didn't have the distraction of the robot's arms moving up and down, although once I get used to it, it shouldn't be as much of a distraction.		"For myself I was so distracted by watching the robot move that I was unable to concentrate on the task that I was given." The robot was very fascinating but it distracted from doing the actual rehab activities.		The robot was very polite and had good facial expressions. I would love to see an adult version of the robot (this might be because interviewer mentioned this in future plans)	The creativity behind what you want to use lil flo for is definitely relevant especially in light of the last year (the pandemic) - this could be very useful for telehealth. Ideas to use the robot, have the robot linked to a rehab center to be booked for sessions. Another modality could to be to have flo delivered to patients home for rehab sessions. Robots like this could really change the way telehealth and telerehab is done in the future.	FTF-SRAT-CT
40	56	None	Neurodegenerative Disorder	SRAT first	Not really no		" this is an effective method of rehab for certain types of disabilities/mobility issues"- sub mentioned multiple times with survey questions.		The robot would probably be more helpful for younger people(or children) or people more introverted who would prefer to avoid human interaction, personally I'm very extroverted and would much rather have a human being to interact with.		None		FTF-CT-SRAT
29	57	None	Neurodegenerative Disorder	CT first	None		None	1 WiFi disconnect for a very short time.			None	Sub seemed to get very fatigued as the experiment progressed, she mentioned it was because we did the experiments after a long day at work.	FTF-SRAT-CT
31	60	Motor	Neurodegenerative Disorder	SRAT first	None		None		None		None	Subject seemed cognitively impaired (which may be age related)	SRAT-FTF-CT

(continued)

ID	age	impairment	diagnosis	order	subj-FTF	exp-FTF	subj-CT	exp-CT	subj-SRAT	exp-SRAT	subj-exit	exp-exit	preference
13	62	Motor	Brain Injury	CT first	The colors exercise was difficult when switching from left to right arm "dawning/tense". "It didn't hurt me but my mind was tired".		It's challenging after the pandemic to get back on the saddle and get back into rehabilitation ("sloshing during the pandemic"), slowed down after not doing rehab during the pandemic.		"Speaking personally, I have a problem with my left and right" but " when the robot tells me what to do I can watch it and do what it does", " It was more intense compared to the previous exercise" , " it was easier to follow along with the telepresence than with the robot", " its a little bit scary to me because I'm not used to it (robots), I'm more used to people but I think I can get used to it"."The robot and the people at the same time would be cool , it would help with the stress of rehab, helps relive stress and anxiety"		"Robot did a good job in keeping me interested in the therapy" "All in all a good experience and a whole lot of other people in my group would not be intimidated by the robot"		FTF-CT-SRAT
22	64	Motor	Brain Injury	CT first	No.		If the screen on the classical telepresence robot was a little bigger it would increase its efficiency.	This set of surveys is actually for the classical experiment	The robot didn't give feedback as often as Michael did in the classical telepresence. Had to wait for her to say go which challenged memory. Would be interesting to not be able to see Michaels face when working with lil flo. It was interesting working with the robot.	This set of surveys is actually for the augmented experiment	Having the facial expressions was helpful.		FTF-SRAT-CT

(continued)

ID	age	impairment	diagnosis	order	subj-FTF	exp-FTF	subj-CT	exp-CT	subj-SRAT	exp-SRAT	subj-exit	exp-exit	preference
38	67	Motor	Neurodegenerative Disorder	CT first	None		None		None		None	Subject mentioned that she can do n-remembering tasks such as n-back or target touch activities up to 4 instances to remember but not 5, she tried target touch with Michael with 5 instances after the in person interaction. "The humanoid plus telepresence is second best but It's always better to have a human present to ask questions of" - exit survey. Subject interacted quite a bit with survey interviewer during the 2 telepresence modalities as well (talking to, asking questions of) Subject definitely wants to be contacted for future surveys. Also mentioned Michael j fox foundation that lists clinical studies.	FTF-SRAT-CT
21	69	Motor	Brain Injury	SRAT first	None		Doing the activities for so long contributed to mental fatigue leading to not being able to follow instructions as well "my mental fatigue contributed to my difficulties with it"		None		No	The subject enjoyed the interaction with robot more but rates it the lowest of the three methods trialed today. As tests progressed the subject mentioned how both the physical and mental strain accumulated by fatigue made both his performance worse as well as increased his frustration with the tests.	FTF-CT-SRAT

(continued)

ID	age	impairment	diagnosis	order	subj-FTF	exp-FTF	subj-CT	exp-CT	subj-SRAT	exp-SRAT	subj-exit	exp-exit	preference
35	70	Motor	Neurodegenerative Disorder	SRAT first	None	None	None	None	None		None	-Color trails -> Need to hold down paper for the subject due to Parkinson's related instability in the left arm ***In Person: -Left arm flexion only from 90-180 instead of 0-180 -Arms out of sync on some flexion/abduction tasks -Asked for clarification on target touch task -One specific task in which subject was unable to do the task 3x; subject reiterated that she didn't understand why she couldn't do it -Subject mentioned being stressed about testing ***Augmented: -Waves back at flo on entry; laughs upon waving -Asks if Michael built flow -Says flo is 'gorgeous' -Laughs at flo saying 'might try to trick you' -Waves finger saying no, not gonna get treated (2x) -Chuckles at flo saying "can't get you" -Needed more clarification from Michael on arm abduction (on greater range of motion) -"Can tell she really means it" -Subject on Flo complimenting inject on doing well -"Didn't see there were colors" - subject after doing first color touching exercise -"You're good at this" - Flo; "No I'm dyslexic" - Subject (2x) -1 Error on target touch -Waves back to Flo on exit ***Classical: -"I dislike the board" - Subject as the telehealth system comes in (Mentions dyslexia again) -Subject asked for	FTF-CT-SRAT

(continued)

ID	age	impairment	injury	order	subj-FTF	exp-FTF	subj-CT	exp-CT	subj-SRAT	exp-SRAT	subj-exit	exp-exit	preference
55	73	Motor	Brain Injury	SRAT first			Screen was too small to see the "therapist's" arms sometimes		Distracting noise in background, "I would like to have a robot like this not just for rehabilitation but just to bring me drinks stuff at home" , "This robot is the perfect size for me"	The subject will probably have a higher failure rate in the augmented condition as we had issues with the audio, first few words were cut off in most of the trial.		"I would like to have a robot like this not just for rehabilitation but just to bring me drinks stuff at home" , "This robot is the perfect size for me"	SRAT-FTF-CT
12	75	Motor and Cog-ni-tive	Brain Injury	SRAT first		Subject mentioned she did nor have arm function loss so could not answer that survey question.				"Would you like to do the interaction again" - patient said I don't really care.		With lil'flo the subject was giggling and dancing in her chair at certain instances.	SRAT-CT-FTF
25	76	None	Peripheral Injury	CT first	None		None		None as long as lil flo has no problems	Had to reboot the system once as the face on lil flo would not change.	None	Had a few redcap issues during the intake survey, the images would not load. Subject mentioned during the intake survey that she is quite hard of hearing. Sub hungry during interactions. She also has a shoulder injury - rotator cuff injury and also tendinitis and is undergoing rehab for it, she may need to get a replacement shoulder in future. Sub had a very hard choosing between classical vs augmented for ranking them, if given an option would have ranked them equally.	FTF-CT-SRAT
20	81	None	Brain Injury	CT first	Simple exercises like this really help with rehab.		"It was fun, fun to talk to a robot"	Bad WiFi caused lag at the beginning of the experiment, did classical first.	This sort of rehab would be very helpful to people who are unable to do any motion at all.		None [2021-06-14] Hi Michael, Andrew and I really enjoyed our session and on our walk to the Capital Grill it occurred to me that Flo is perfect for working with folks with disabilities because she is entirely non judgemental. She is unaware of age, race, intelligewnce,etc. Incidentally, lunch was great. Best wishes, –	While subject does not go to rehab per say, she does go to physical activity classes like water aerobics which helps with rehabilitation.	FTF-SRAT-CT

Exclusions

Full Experiment

- 48: Subject did not have sufficient comprehension for surveys, answers were binary.
- 47: System broke down badly, subject wasn't able to fully experience SRAT
- 50: Only did FTF condition

Borderline

I need input here, should we exclude these, how much so (all questions, certain questions)?

- 63: lot's of system failures in SRAT
- 45: "confused in selecting ranking of three interactions"

Synthessis

Challenges w/ interactions

- 60: confused left and right

Interesting

- 36: named the robot "John" on their own and really liked John. Initially was afraid of it.
- 49: claimed easier to understand robot than human operator
- 16: Suggests having the social robot with in-person interactions to assist
- 28: Voice works well on SRAT, better than older synthesized voices
- 22: Would want to try SRAT but without operator/human
- 35, 12: Strong engagement with Flo

Challenges w/ SRAT

- 61: harder to hear instructions from robot voice (MJS: I don't think this is audio so much as voice quality)
- 42, 17: Robot can't accurately complete all tasks "like reaching shoulder, instead of that it collided hands"
- 42: "It would be a better reading if the voice wasn't choppy, it sounds like a computer, it would be better if it sounded like what Siri and Alexa talk more like a human"
- 42: Robot should adjust height to patient height
- 54: Eyes on robot too bright
- 32: Robot should keep demoing motion until complete, especially for repetitive motions like swinging arms
- 32, 30: robot can be distracting
- 16: Robot distracting at first
- 17: Subject should be asked to repeat instructions
- 17: Awkward to be recorded
- 34: More difficult to understand Flo
- 40: For subjects who are outgoing/social, other modalities are better
- 13: Robot is a bit scary at first (62 yrs old)

Benefits w/ SRAT

- 49: Very cute and adorable (flo)
- 55: Flo is just the right size
- 20: Subject sent email after trial: Flo is good for working with people with disabilities because it is non-judgemental, not biased

Benefits w/ CT

- 54: "It's better than with the robot, easier, more natural."
- 17: Conversation is easier
- 17: With a human, more comforting, with live feedback

Challenges w/ CT

- 32, 16, 55: small screen made it hard to tell what similar motions were asking for
- 14: For CT, should have a full torso view
- 64: Easier to hear robot than operator

Analysis notes

- 22: surveys flipped, corrected in data cleaning
- 55: Issue with speaker for trial (they used bluetooth), but trial was able to be completed

Subjects

Setup

```
rm(list = ls())
source("utility_scripts/setup.r")
```

```
## [1] "Only including subjects with complete consent forms"
## [1] "Excluding subjec # <=10 (pilot trial cohort)"
## [1] "n=44"
## [1] "Excluding Subjects:"
## [1] "    excluding subject 50"
## [1] "    excluding subject 47"
## [1] "Corrected Subject 22 Survey Assignment"
## [1] "Fixing subject 60 post experiment"
## [1] "final number of subjects: 42"
## [1] "Filling in for subjects too young for color trails:"
## [1] "    Subject 15, reported no impairment, marking no impairment"
## [1] "    subject 23, reported motor impairment only, BBT -2.56 z, marking motor impairment"
## [1] "    Subject 66, reported motor impairment only (Left hemiparesis), marking motor impairment"
```

Analysis

Number of subjects

```
combined_data %>%
  select(record_id) %>%
  unique() %>%
  nrow()
```

```
## [1] 42
```

Demographics Table

```
demo_data <- combined_data %>%
  select(age_group, impairment, impairment.measured, gender.factor, injury_class)

demo_tbl <- gtsummary::tbl_summary(demo_data, by = age_group, missing = "no", label = c(gender.factor ~ "Gender", impairment ~ "Reported Impairment", impairment.measured ~ "Measured Impairment", injury_class ~ "Class of Co
  gtsummary::modify_header(label = "") %>% # update the column header
  gtsummary::add_overall(last = TRUE) %>%
  gtsummary::bold_labels()
demo_tbl
```

```
## Table printed with `knitr::kable()`, not {gt}. Learn why at
## https://www.danieldsjoberg.com/gtsummary/articles/rmarkdown.html
## To suppress this message, include `message = FALSE` in code chunk header.
```

	Young Children, N = 9	**Teens-Young Adults**, N = 11	**Adults**, N = 15	**Older Adults**, N = 7	**Overall**, N = 42
___Reported Impairment___					
Cognitive	0 (0%)	1 (9.1%)	0 (0%)	1 (14%)	2 (4.8%)
Motor	4 (44%)	5 (45%)	4 (27%)	4 (57%)	17 (40%)
Motor and Cognitive	3 (33%)	3 (27%)	5 (33%)	2 (29%)	13 (31%)
None	2 (22%)	2 (18%)	6 (40%)	0 (0%)	10 (24%)
___Measured Impairment___					
Motor	6 (67%)	5 (45%)	8 (53%)	4 (57%)	23 (55%)
Motor and Cognitive	1 (11%)	5 (45%)	1 (6.7%)	1 (14%)	8 (19%)
None	2 (22%)	1 (9.1%)	6 (40%)	2 (29%)	11 (26%)
___Gender___					
Male	6 (67%)	7 (64%)	5 (33%)	1 (14%)	19 (45%)
Female	3 (33%)	4 (36%)	10 (67%)	6 (86%)	23 (55%)
Other	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
___Class of Condition___					
Brain Injury	2 (22%)	4 (40%)	6 (40%)	4 (57%)	16 (39%)
Neurodegenerative Disorder	0 (0%)	0 (0%)	5 (33%)	2 (29%)	7 (17%)
No Injury	2 (22%)	1 (10%)	2 (13%)	0 (0%)	5 (12%)
Other	1 (11%)	0 (0%)	0 (0%)	0 (0%)	1 (2.4%)
Peripheral Injury	2 (22%)	2 (20%)	2 (13%)	1 (14%)	7 (17%)
Psychological Disorder	1 (11%)	1 (10%)	0 (0%)	0 (0%)	2 (4.9%)
Stroke	0 (0%)	1 (10%)	0 (0%)	0 (0%)	1 (2.4%)
Unknown	1 (11%)	1 (10%)	0 (0%)	0 (0%)	2 (4.9%)

```
demo_tbl %>%
  gtsummary::as_gt() %>%
  gt::gtsave(filename = file.path(out_dir, "tbl_demographics.tex"))
```

```
race_data <- combined_data %>% select(record_id, starts_with("intake_race___") & !ends_with("factor"))
colnames(race_data) <- label(race_data)
race_data <- race_data %>%
  rename(record_id = `Study ID`) %>%
  mutate_at(vars(-record_id), as.numeric) %>%
  tidyr::pivot_longer(!record_id, names_to = "race") %>%
  filter(value == 1) %>%
  left_join(combined_data, by = "record_id") %>%
  select(age_group, race)

race_data
```

```
## # A tibble: 49 x 2
##    age_group      race
##    <fct>          <chr>
##  1 Older Adults   Black or African American
##  2 Adults         American Indian or Alaska Native
##  3 Adults         Black or African American
##  4 Adults         White
##  5 Adults         White
##  6 Young Children White
##  7 Adults         Hispanic or Latino
##  8 Adults         White
##  9 Adults         White
## 10 Older Adults   White
## # ... with 39 more rows
```

```
race_tbl <- gtsummary::tbl_summary(race_data, by = age_group, missing = "no", statistic = list(race ~ "{n}")) %>%
  #   gtsummary::modify_header(label = "") %>% # update the column header
  gtsummary::add_overall(last = TRUE)
# %>%
#   gtsummary::bold_labels()
race_tbl
```

```
## Table printed with `knitr::kable()`, not {gt}. Learn why at
## https://www.danieldsjoberg.com/gtsummary/articles/rmarkdown.html
## To suppress this message, include `message = FALSE` in code chunk header.
```

Characteristic	**Young Children**, N = 10	**Teens-Young Adults**, N = 12	**Adults**, N = 20	**Older Adults**, N = 7	**Overall**, N = 49
race					
American Indian or Alaska Native	1	0	1	0	2
Asian	0	0	2	0	2
Black or African American	3	5	3	1	12
Hispanic or Latino	1	0	1	0	2
Middle Eastern or North African	0	1	0	0	1
prefer not to answer	0	2	0	0	2
White	5	4	13	6	28

```
race_tbl %>%
  gtsummary::as_gt() %>%
  gt::gtsave(filename = file.path(out_dir, "tbl_race.tex"))
```

Classify impairments Some info to help

Manual classification is done in utility_scripts/clean_data.r

Check all the details:

```
combined_data %>% select(record_id, injury_class, diagnosis_concat, motor_impairment.factor, motor_diagnosis, cognitive_impairment.factor, motor_diagnosis_2, diagnostic_notes)
```

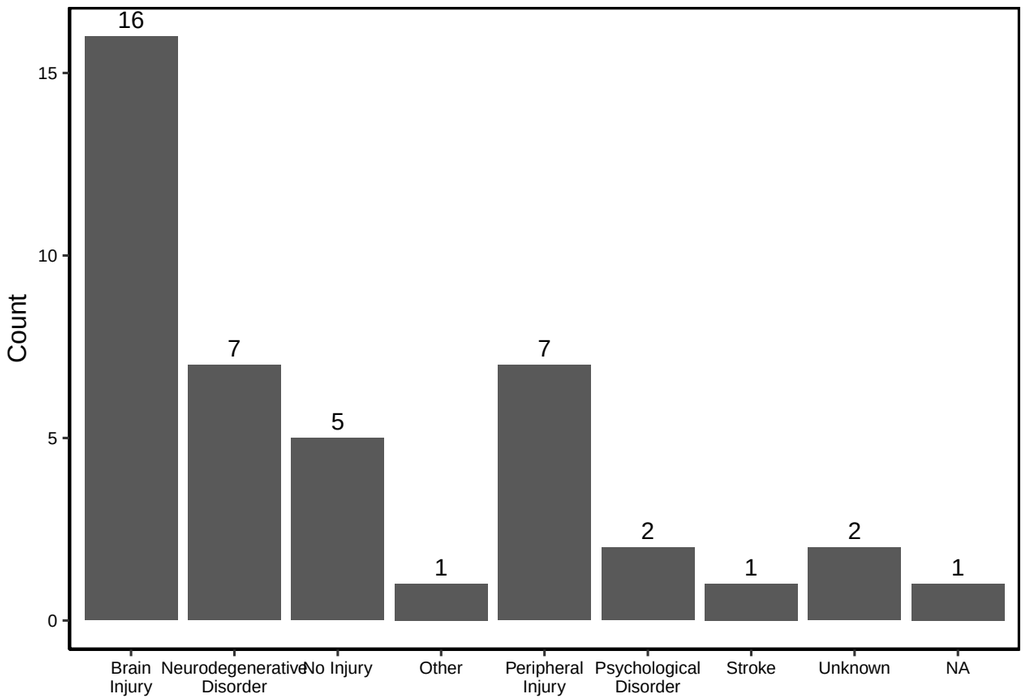
record_id	injury_class	diagnosis_concat	motor_impairment.factor	motor_diagnosis
12	Brain Injury	Stroke	No	
13	Brain Injury	Stroke	Yes	difficulty with entire right body, arms, tongue, legs.
14	No Injury	None	No	
15	No Injury	None	No	
16	Brain Injury	Other, Stroke	Yes	right hand on wrist weak. Right hand dexterity limitations. Not as fluid as left
17	Brain Injury	Other, Traumatic Brain Injury	Yes	asymetric weakness, some nerves that are pissed off,
20	Brain Injury	Stroke	Yes	Arm nearly completely healed. Can walk (walks with dog everyday), but coordination isn't right.
21	Brain Injury	Other, Stroke, Heart Attack	Yes	left arm and hand are pretty much useless, was paralyzed for about a year after stroke. Left leg is coming back. Left shoulder has some function
22	Brain Injury	Stroke	Yes	arm and leg. Partial numbness in both. Leg re-learning how to walk, use cane. Left hand has a bit of trouble with motor control. Low feedback - d
23	Peripheral Injury	Other	Yes	generalized low muscle tone due to pre-mature birth
25	Peripheral Injury	Other	Yes	Left shoulder affected range of motion
28	Brain Injury	Stroke	Yes	gross motor skills with right hand. nothing fine, no more writing with right hand
29	Neurodegenerative Disorder	Multiple Sclerosis	No	
30	Neurodegenerative Disorder	Multiple Sclerosis	No	
31	Neurodegenerative Disorder	Traumatic Brain Injury, Multiple Sclerosis	No	
32	No Injury	None	No	
34	Neurodegenerative Disorder	Parkinsons	Yes	mostly upper body- shoulders and neck. Legs are OK. PD, young onset
35	Neurodegenerative Disorder	Parkinsons	Yes	left side PD is weaker - very mild w/ tremor
36	Psychological Disorder	Other	Yes	autism related motor control
38	Neurodegenerative Disorder	Parkinsons	Yes	tremors, stifness, slowness, off balance - fall, eye spasm, sometimes has mild disconesia
39	Peripheral Injury	Other	Yes	finger amupation and weakness on right arm from accident
40	Neurodegenerative Disorder	Multiple Sclerosis	No	
41	Brain Injury	Stroke, Traumatic Brain Injury	Yes	
42	Psychological Disorder	None	Yes	conversion disorder with some lower limb impairment
43	Brain Injury	Traumatic Brain Injury	Yes	some lower limb weakness
44	Brain Injury	Stroke	Yes	R Hemiparesis
45	Brain Injury	Stroke, Traumatic Brain Injury	Yes	R Hemiparesis
46	Peripheral Injury	Spinal Cord Injury	Yes	paraplegia
48	Unknown	Other	Yes	right hemiparesis
49	Brain Injury	Traumatic Brain Injury	No	
52	Brain Injury	Stroke	Yes	arm more affected than leg. Can point with hand and arm. can crudely throw ball.
54	Peripheral Injury	Spinal Cord Injury	Yes	
55	Brain Injury	Other, Stroke	Yes	low motor control on right side, moderate strength, a little rotator cuff issues.
58	Peripheral Injury	Spinal Cord Injury	Yes	minor hand tremors; leg weakness
59	NA	None	No	
60	No Injury	None	No	
61	No Injury	None	No	
63	Brain Injury	Other, Heart Attack	Yes	deconditioning, reduced motor control
64	Peripheral Injury	Other, Spinal Cord Injury	Yes	paralysis (lower extremities, trunk)
66	Unknown	Other	Yes	Left hemiparesis
68	Stroke	Stroke	Yes	left sided weakness
69	Other	Other	Yes	Lower extremity weakness

I need a second set of eyes to check this

Note, some people with one of the conditions do not actually have an impairment. They just have the condition underlying.

```
ggplot(combined_data, aes(factor(injury_class))) +
  geom_bar(stat = "count") +
  plt_theme +
  geom_text(
    stat = "count",
    aes(y = ..count.., label = ..count..),
    geom = "text",
    vjust = -.5
  ) +
  labs(x = element_blank(), y = "Count") +
  scale_x_discrete(
    labels = function(x) {
      stringr::str_wrap(x, width = 10)
    }
  )
```

```
## Warning: Ignoring unknown parameters: geom
```



Handedness

Dominant Hand - pre injury

```
combined_data %>%
  select(dominant_hand.factor) %>%
  summary()
```

```
##  dominant_hand.factor
##  left : 5
##  right:37
```

Dominant Hand - post injury (current)

```
combined_data %>%
  select(dominant_hand_post.factor) %>%
  summary()
```

```
##  dominant_hand_post.factor
```

```
##  left : 5
##  right:36
##  NA's : 1
```

Educational Level

```
combined_data %>%
  select(years_education) %>%
  psych::describe() %>%
  knitr::kable()
```

	vars	n	mean	sd	median	trimmed	mad	min	max	range	skew	kurtosis	se
X1	1	42	11.69048	6.307131	14	12.08824	5.9304	0	20	20	-0.4518336	-1.148819	0.9732115

Clinical Measures

We are only going to use weak side BBT scores throughout the rest of the analysis, and only the CTT2 scores, so let's look at those.

```
impairment_thickness <- .1
annotation_size <- 2.3
lh <- .8
ctt_bbt_plt <- combined_data %>%
  ggplot(aes(x = color_trails_2_standard, y = bbt.score.weak, color = age)) +
  plt_theme +
  geom_point(aes(shape=ifelse(combined_data$order.factor=='Augmented (Humanoid) First','SRAT First', 'CT First')),size = 2) +
  scale_color_gradientn(limits = c(0, 85), colors = cust_color(100)[10:80], name = "Age") +
  scale_shape_manual(values = c(16,17), name="Randomized Experimental Order:") + # guides(shape=FALSE) +
  xlab("Color Trails Test 2 Z-Score") +
  ylab("Box and Block Test Weak Arm Z-Score") +
  guides(color = guide_colourbar(ticks = FALSE, barheight = 10, label.position = "right", frame.colour = "black")) +
  geom_hline(yintercept = -1, linetype = "solid", color = "black", size = impairment_thickness) +
  geom_hline(yintercept = -2, linetype = "solid", color = "black", size = impairment_thickness) +
  geom_hline(yintercept = -3, linetype = "solid", color = "black", size = impairment_thickness) +
  geom_vline(xintercept = -1, linetype = "solid", color = "black", size = impairment_thickness) +
  geom_vline(xintercept = -2, linetype = "solid", color = "black", size = impairment_thickness) +
  geom_vline(xintercept = -3, linetype = "solid", color = "black", size = impairment_thickness) +
  annotate(geom = "text", x = -Inf, y = -0.5, label = "\\phantom{   }Normal", hjust = 0, size = annotation_size) +
  annotate(geom = "text", x = -Inf, y = -1.5, label = "\\phantom{   }Mild Impairment", hjust = 0, size = annotation_size) +
  annotate(geom = "text", x = -Inf, y = -2.5, label = "\\phantom{   }Moderate Impairment", hjust = 0, size = annotation_size) +
  annotate(geom = "text", x = -Inf, y = -3.5, label = "\\phantom{   }Severe Impairment", hjust = 0, size = annotation_size) +
  annotate(geom = "text", y = -Inf, x = -0.5, label = "Normal\n", hjust = 0.5, vjust = .25, size = annotation_size, lineheight = lh) +
  annotate(geom = "text", y = -Inf, x = -1.5, label = "Mild\nImpairment\n", hjust = 0.5, vjust = .25, size = annotation_size, lineheight = lh) +
  annotate(geom = "text", y = -Inf, x = -2.5, label = "Moderate\nImpairment\n", hjust = 0.5, vjust = .25, size = annotation_size, lineheight = lh) +
  annotate(geom = "text", y = -Inf, x = -3.5, label = "Severe\nImpairment\n", hjust = 0.5, vjust = .25, size = annotation_size, lineheight = lh)

legend <- get_legend(ctt_bbt_plt+ guides(shape=FALSE))
```

```
## Warning: `guides(<scale> = FALSE)` is deprecated. Please use `guides(<scale> = "none")` instead.
```

```
## Warning: Use of `combined_data$order.factor` is discouraged. Use `order.factor` instead.
```

```
## Warning: Removed 3 rows containing missing values (geom_point).
```

```
ctt_bbt_plt <- ctt_bbt_plt + guides(color=FALSE) + theme(legend.position = "bottom",legend.margin=margin(0,0,0,0),legend.box.margin=margin(-10,-10,-10,-10))
```

```
## Warning: `guides(<scale> = FALSE)` is deprecated. Please use `guides(<scale> = "none")` instead.
```

```
ctt_bbt_marginal_plt <- cowplot::plot_grid(ggExtra::ggMarginal(ctt_bbt_plt, type = "histogram"), legend, nrow = 1, rel_widths = c(1, 0.1))
```

```
## Warning: Use of `combined_data$order.factor` is discouraged. Use `order.factor` instead.
```

```
## Warning: Use of `combined_data$order.factor` is discouraged. Use `order.factor` instead.
```

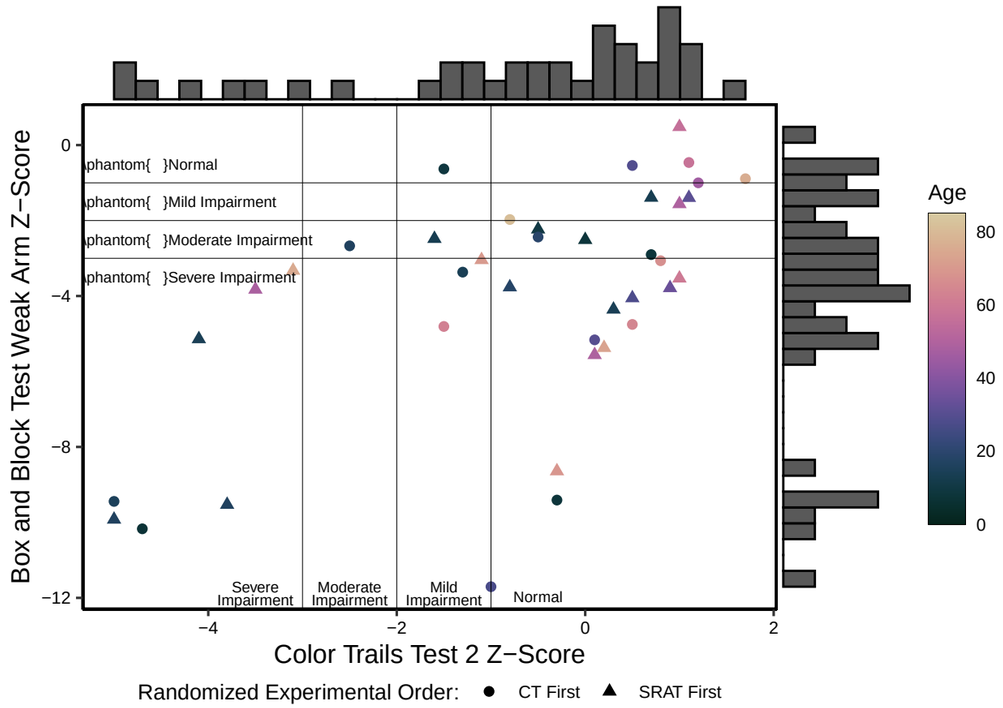
```
## Warning: Removed 3 rows containing missing values (geom_point).
```

```
fn <- file.path(out_dir, "tikz-bbt_ctt.tex")
tikz(
  file = fn,
  width = 5.8,
  height = 3.25,
  sanitize = FALSE
```

```
)
print(ctt_bbt_marginal_plt)
dev.off()
```

```
## pdf
##   2
```

```
strip_tikz_white(fn)
print(ctt_bbt_marginal_plt)
```




```
impairment_thickness <- .1
annotation_size <- 2.8
lh <- .8
eqn_pos<-c(-12,3)
y_limits<-c(-3.5,3)

bbt_gs_plt <- combined_data %>%
  ggplot(aes(y = gs.z.weak, x = bbt.score.weak, color = age)) +
  plt_theme +
  geom_point(size = 2) +
  scale_color_gradientn(limits = c(0, 85), colors = cust_color(100)[10:80], name = "Age") +
  ylab("Grip Strength Weak Arm Z-Score") +
  xlab("Box and Block Test Weak Arm Z-Score") +
  guides(color = guide_colourbar(ticks = FALSE, barheight = 10, label.position = "right", frame.colour = "black"))+
      geom_smooth(
        method = lm,
        color = "black",
        linetype = "dashed",
        size = .5,
        fill = "#d1d1d1"
      )+
      stat_regline_equation(
        label.x = eqn_pos[[1]],
        label.y = eqn_pos[[2]],
        output.type = "expression",
        size = 3
      ) +
      stat_cor(
```

```
        aes(label = ..rr.label..),
        label.x = eqn_pos[[1]],
        label.y = eqn_pos[[2]] - .13 * y_limits[[2]],
        output.type = "expression",
        size = 3
      )

legend <- get_legend(bbt_gs_plt)
```

```
## `geom_smooth()` using formula 'y ~ x'
```

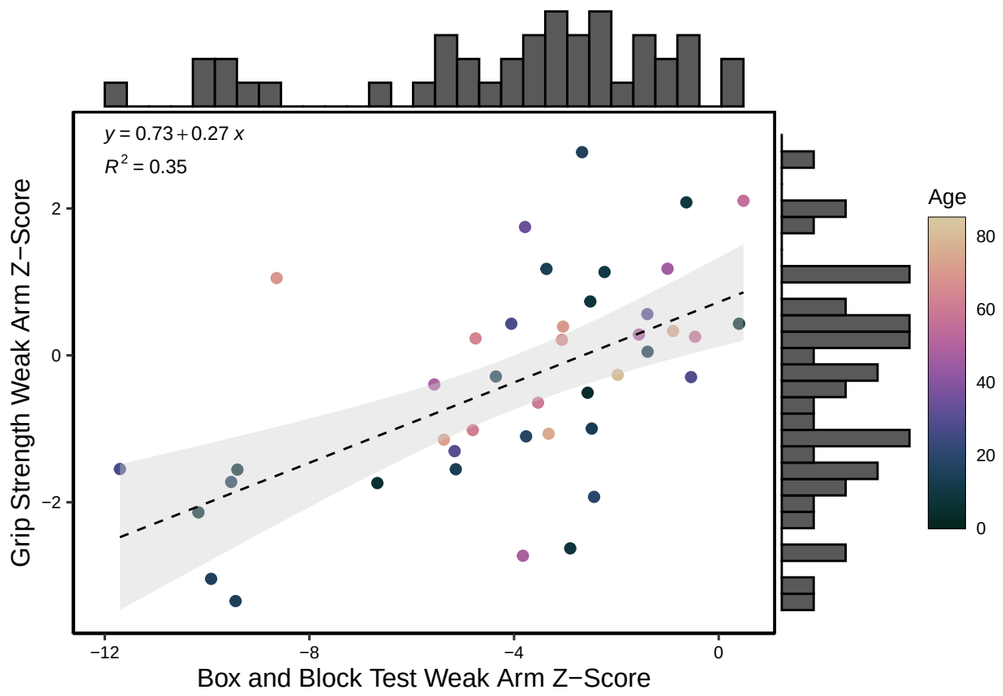
```
bbt_gs_plt <- bbt_gs_plt + theme(legend.position = "none")
bbt_gs_marginal_plt <- cowplot::plot_grid(ggExtra::ggMarginal(bbt_gs_plt, type = "histogram"), legend, nrow = 1, rel_widths = c(1, 0.1))
```

```
## `geom_smooth()` using formula 'y ~ x'
## `geom_smooth()` using formula 'y ~ x'
```

```
fn <- file.path(out_dir, "tikz-gs_bbt.tex")
tikz(
  file = fn,
  width = 5.8,
  height = 3.1,
  sanitize = FALSE
)
print(bbt_gs_marginal_plt)
dev.off()
```

```
## pdf
##   2
```

```
strip_tikz_white(fn)
print(bbt_gs_marginal_plt)
```




```
impairment_thickness <- .1
annotation_size <- 2.8
lh <- .8
eqn_pos<-c(-5,3)
y_limits<-c(-6,4)

ctt1_2_plt <- combined_data %>%
```

```
  ggplot(aes(y = color_trails_1_standard, x = color_trails_2_standard, color = age)) +
  plt_theme +
  geom_point(size = 2) +
  scale_color_gradientn(limits = c(0, 85), colors = cust_color(100)[10:80], name = "Age") +
  ylab("Color Trails Test 1 Z-Score") +
  xlab("Color Trails Test 2 Z-Score") +
  guides(color = guide_colourbar(ticks = FALSE, barheight = 10, label.position = "right", frame.colour = "black"))+
      geom_smooth(
        method = lm,
        color = "black",
        linetype = "dashed",
        size = .5,
        fill = "#d1d1d1"
      )+
      stat_regline_equation(
        label.x = eqn_pos[[1]],
        label.y = eqn_pos[[2]],
        output.type = "expression",
        size = 3
      ) +
      stat_cor(
        aes(label = ..rr.label..),
        label.x = eqn_pos[[1]],
        label.y = eqn_pos[[2]] - .13 * y_limits[[2]],
        output.type = "expression",
        size = 3
      )

legend <- get_legend(ctt1_2_plt)
```

```
## `geom_smooth()` using formula 'y ~ x'
```

```
## Warning: Removed 3 rows containing non-finite values (stat_smooth).
```

```
## Warning: Removed 3 rows containing non-finite values (stat_regline_equation).
```

```
## Warning: Removed 3 rows containing non-finite values (stat_cor).
```

```
## Warning: Removed 3 rows containing missing values (geom_point).
```

```
ctt1_2_plt <- ctt1_2_plt + theme(legend.position = "none")
ctt1_2_marginal_plt <- cowplot::plot_grid(ggExtra::ggMarginal(ctt1_2_plt, type = "histogram"), legend, nrow = 1, rel_widths = c(1, 0.1))
```

```
## `geom_smooth()` using formula 'y ~ x'
```

```
## Warning: Removed 3 rows containing non-finite values (stat_smooth).
```

```
## Warning: Removed 3 rows containing non-finite values (stat_regline_equation).
```

```
## Warning: Removed 3 rows containing non-finite values (stat_cor).
```

```
## `geom_smooth()` using formula 'y ~ x'
```

```
## Warning: Removed 3 rows containing non-finite values (stat_smooth).
```

```
## Warning: Removed 3 rows containing non-finite values (stat_regline_equation).
```

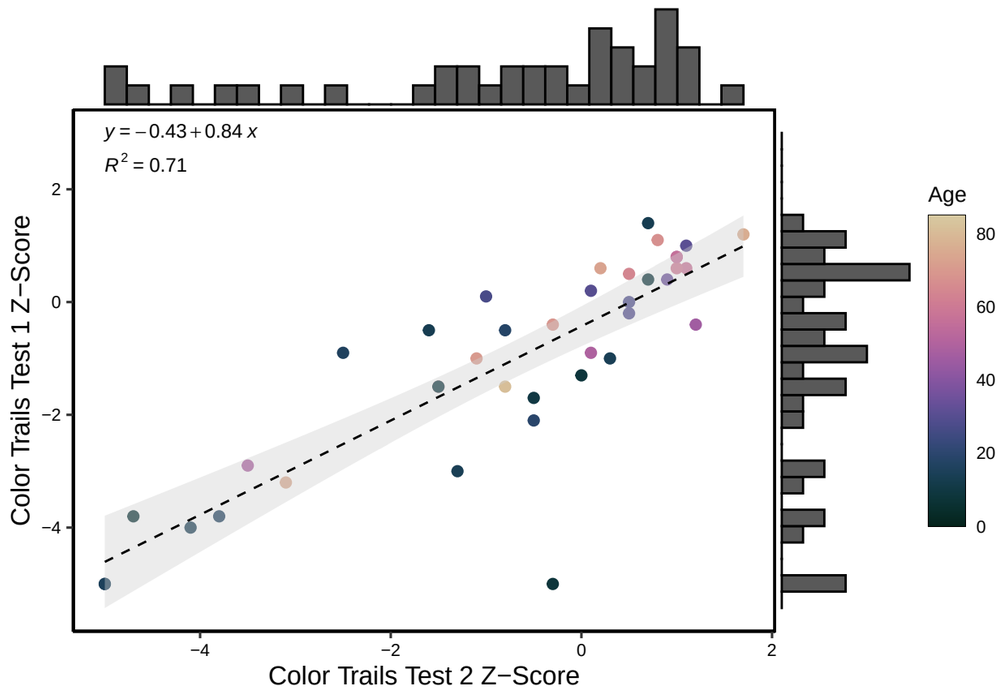
```
## Warning: Removed 3 rows containing non-finite values (stat_cor).
```

```
## Warning: Removed 3 rows containing missing values (geom_point).
```

```
fn <- file.path(out_dir, "tikz-ctt1_2.tex")
tikz(
  file = fn,
  width = 5.8,
  height = 3.1,
  sanitize = FALSE
)
print(ctt1_2_marginal_plt)
dev.off()
```

```
## pdf
##   2
```

```
strip_tikz_white(fn)
print(ctt1_2_marginal_plt)
```



Intake Survey

Note: there is more data from parent's/guardians/caretakers that we are not going through for now. We do include the data where it is needed to respond the questions that subjects with a caretaker do not know the answer to.

Note: many subjects did the experiment in a lab setting in one day, ~2 hours. Some subjects completed the study over two days ~1 hour each day. Some intake questions were repeated for the second day.

Questions

1. How do we want to slice this up? want to see by age group, impairment, etc? What all of this needs to go into the paper? Ex: details on mood/focus altering meds probably does not need to go into paper.
2. What do we want to use as possible factors in later parts of the analysis? I think it is too much to try to use everything and wouldn't make sense to do that. So what questions do we have both the variance to test with and the suspicion of relevance?

Setup

```
rm(list = ls())
source("utility_scripts/setup.r")
```

```
## [1] "Only including subjects with complete consent forms"
## [1] "Excluding subjec # <=10 (pilot trial cohort)"
## [1] "n=44"
## [1] "Excluding Subjects:"
## [1] "    excluding subject 50"
## [1] "    excluding subject 47"
## [1] "Corrected Subject 22 Survey Assignment"
## [1] "Fixing subject 60 post experiment"
## [1] "final number of subjects: 42"
## [1] "Filling in for subjects too young for color trails:"
## [1] "    Subject 15, reported no impairment, marking no impairment"
## [1] "    subject 23, reported motor impairment only, BBT -2.56 z, marking motor impairment"
## [1] "    Subject 66, reported motor impairment only (Left hemiparesis), marking motor impairment"
```

Day 1

SAM

How are you feeling right now?

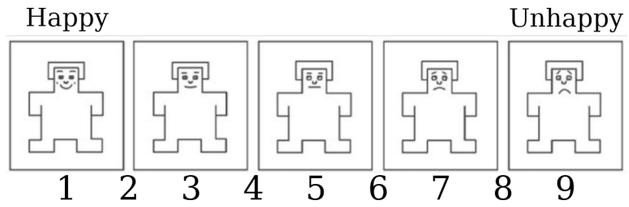


Figure 1: Valence Scale

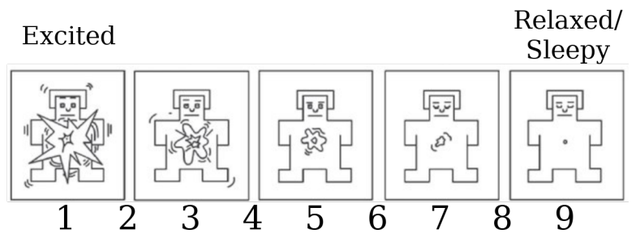


Figure 2: Arrousal Scale

Plot this two ways: 1) the traditional Likert way showing number of responses for each level as a stacked histogram centered on neutral with percent above, below, and at neutral 2) with histograms in a facet.

```
sam_data <- combined_data %>%
  select(intake_sam_valence.factor, intake_sam_arousal.factor, intake_sam_dominance.factor) %>%
  rename(Valence = intake_sam_valence.factor, Arousal = intake_sam_arousal.factor, Dominance = intake_sam_dominance.factor)

plot_likert(sam_data)
```

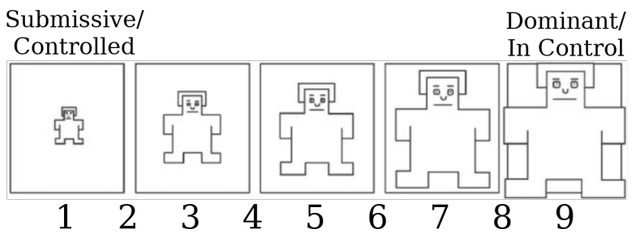
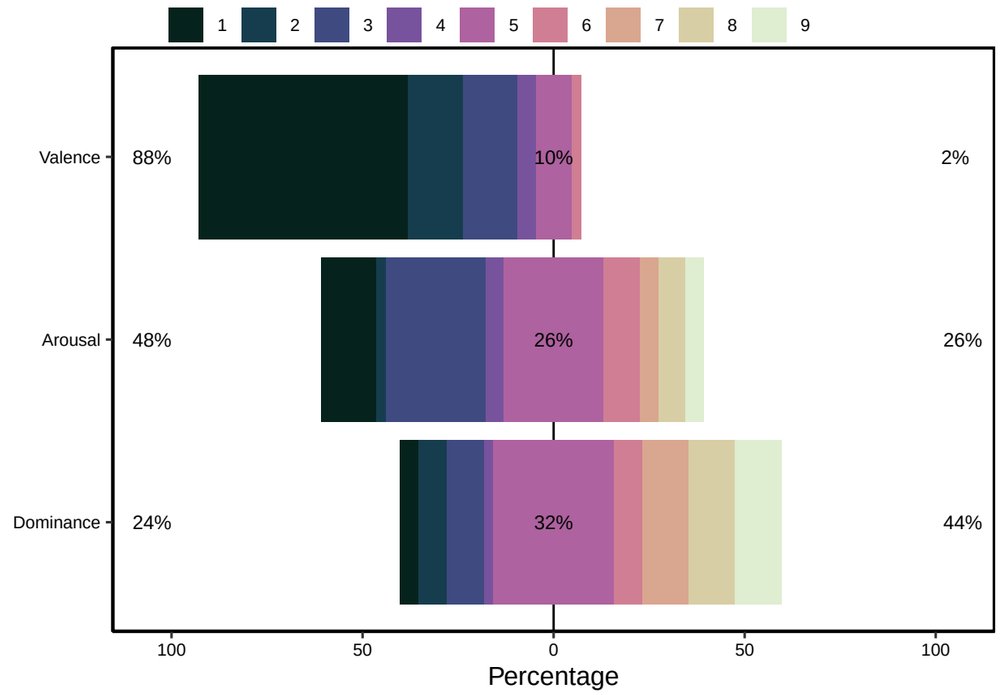


Figure 3: Dominance Scale




```
data_annotate_sam <- data.frame(
  label.low = c("Happy", "Excited", "Submissive/\nControlled"),
  label.high = c("Unhappy", "Relaxed/\nSleepy", "Dominant/\nIn Control"),
  name = c("Valence", "Arousal", "Dominance")
)
```

```
sam_plt <- plot_likert_hist(sam_data) + geom_text(
  data = data_annotate_sam,
  aes(x = 1, y = 25, label = label.low),
  vjust = 1,
  size = 3,
  lineheight = .8
) + geom_text(
  data = data_annotate_sam,
  aes(x = 9, y = 25, label = label.high),
  vjust = 1,
  size = 3,
  lineheight = .8
) +
  scale_y_continuous(limits = c(0, 25)) +
  plt_theme +
  ylab("Count") +
  xlab("Rating")

fn <- file.path(out_dir, "tikz-sam.tex")
tikz(
  file = fn,
  width = 5.8,
  height = 2.5,
  sanitize = TRUE
)
print(sam_plt)
```

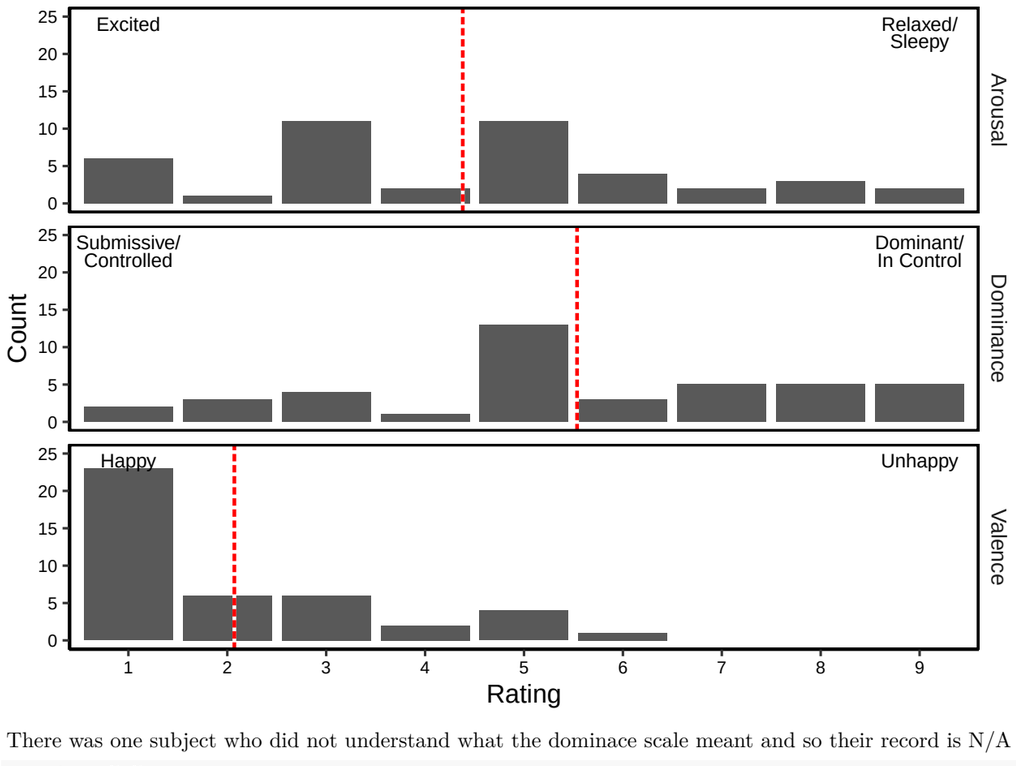
```
## Warning: Removed 1 rows containing non-finite values (stat_count).
```

```
dev.off()
```

```
## pdf
##   2
```

```
strip_tikz_white(fn)
print(sam_plt)
```

```
## Warning: Removed 1 rows containing non-finite values (stat_count).
```



There was one subject who did not understand what the dominace scale meant and so their record is N/A for that.

```
sam_data %>%
  psych::describe() %>%
  knitr::kable()
```

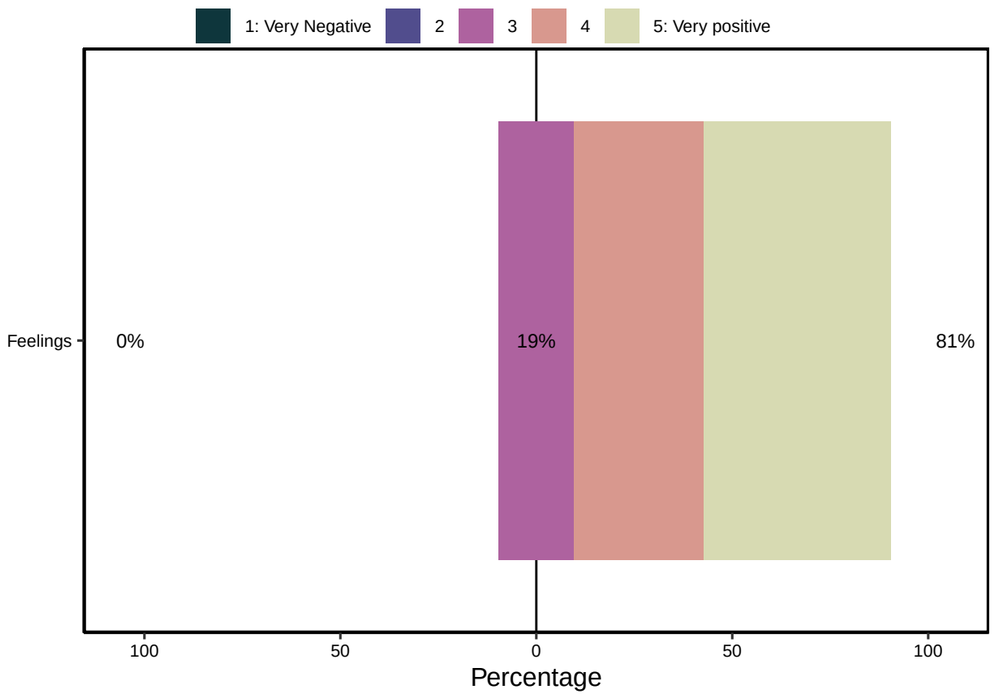
	vars	n	mean	sd	median	trimmed	mad	min	max	range	skew	kurtosis	se
Valence*	1	42	2.071429	1.471566	1	1.823529	0.0000	1	6	5	1.1353736	0.0202992	0.2270675
Arousal*	2	42	4.380952	2.240997	5	4.294118	2.9652	1	9	8	0.2546261	-0.7301551	0.3457933
Dominance*	3	41	5.536585	2.303232	5	5.606061	2.9652	1	9	8	-0.1834837	-0.9066679	0.3597044

Subjects were generally high valence (85%), 12% were neutral and 3% were less than neutral valence (although only slightly). Subjects arousal was spaced more around neutral with a slight bias towards high arousal. Subjects felt generally neutral dominance with a slight bias toward higher dominance.

Feelings about robots

How do you feel about robots?

```
robot_data <- combined_data %>%
  select(intake_robot_feelings) %>%
  rename(Feelings = intake_robot_feelings) %>%
  mutate_all(~ factor(., levels = c("1", "2", "3", "4", "5"), labels = c("1: Very Negative", "2", "3", "4", "5: Very positive")))

plot_likert(robot_data)
```



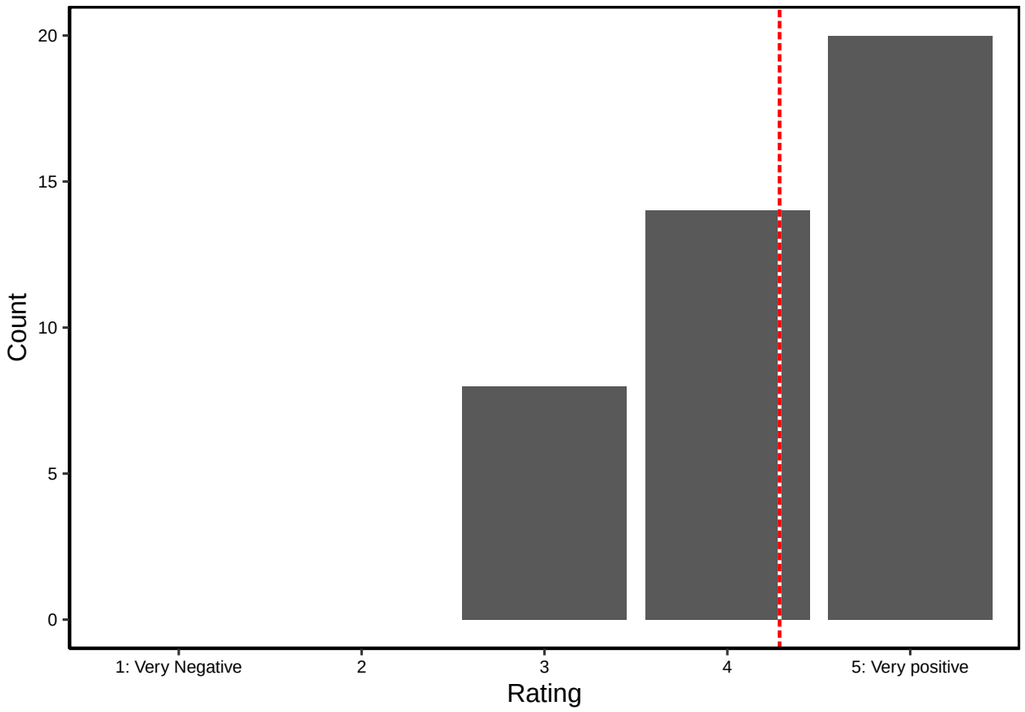

```
robots_plt <- plot_likert_hist(robot_data) + ylab("Count") + xlab("Rating") + theme(strip.text.y = element_blank())

psych::describe(intake %>%
  select(intake_robot_feelings)) %>% knitr::kable()
```

	vars	n	mean	sd	median	trimmed	mad	min	max	range	skew	kurtosis	se
X1	1	37	4.27027	0.8044546	4	4.322581	1.4826	3	5	2	-0.4994316	-1.322612	0.1322515

```
fn <- file.path(out_dir, "tikz-robot_feelings.tex")
tikz(
  file = fn,
  width = 5.8,
  height = .75,
  sanitize = TRUE
)
print(robots_plt)
dev.off()
```

```
## pdf
##   2
```

```
strip_tikz_white(fn)
print(robots_plt)
```

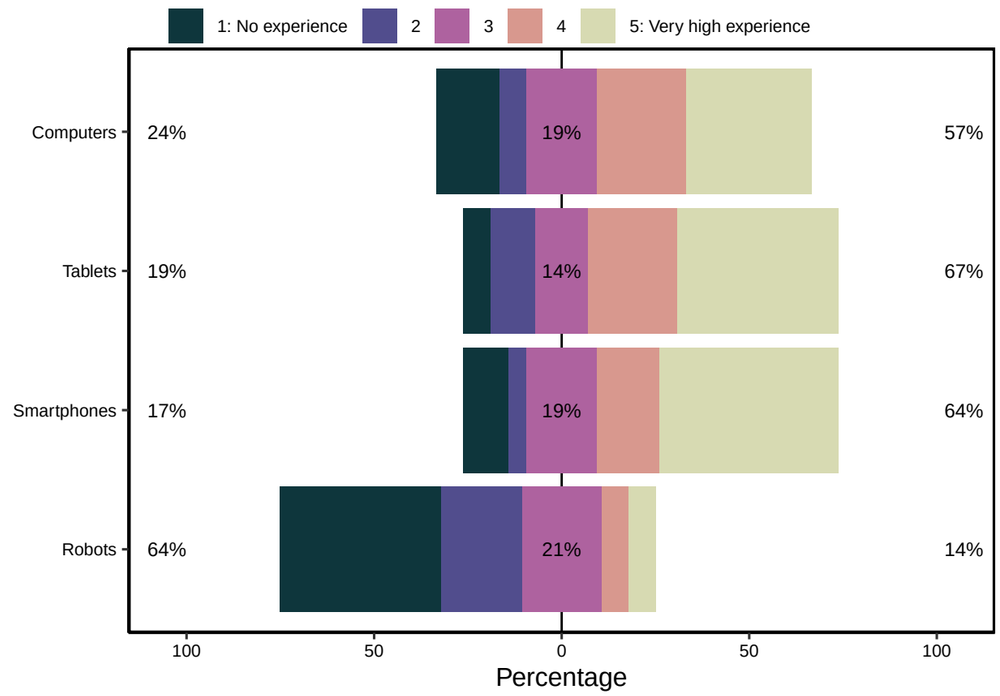


Subjects are neutral to positive on robots

Experience with Technology

Please rate your level of experience with the following:

```
exp_data <- combined_data %>%
  select(intake_comp, intake_tablet, intake_phone, intake_robot_exp) %>%
  rename(Computers = intake_comp, Tablets = intake_tablet, Smartphones = intake_phone, Robots = intake_robot_exp) %>%
  mutate_all(~ factor(., levels = c("1", "2", "3", "4", "5"), labels = c("1: No experience", "2", "3", "4", "5: Very high experience")))

plot_likert(exp_data)
```



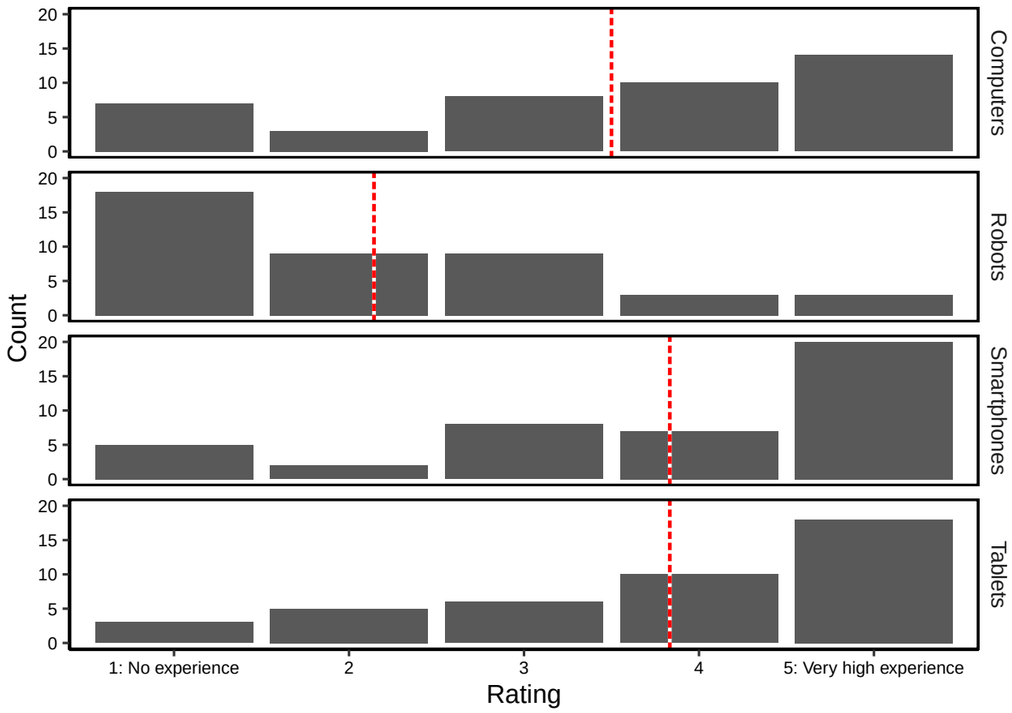

```
tech_exp_plt <- plot_likert_hist(exp_data) + ylab("Count") + xlab("Rating")

psych::describe(intake %>% select(intake_comp, intake_tablet, intake_phone, intake_robot_exp)) %>% knitr::kable()
```

	vars	n	mean	sd	median	trimmed	mad	min	max	range	skew	kurtosis	se
intake_comp	1	37	3.540541	1.386334	4	3.645161	1.4826	1	5	4	-0.5684747	-0.9460155	0.2279119
intake_tablet	2	37	3.810811	1.329951	4	3.967742	1.4826	1	5	4	-0.7652898	-0.7118185	0.2186425
intake_phone	3	37	4.054054	1.268112	5	4.258064	0.0000	1	5	4	-1.1317522	0.1714107	0.2084763
intake_robot_exp	4	37	2.135135	1.272839	2	1.967742	1.4826	1	5	4	0.8553604	-0.3504235	0.2092535

```
fn <- file.path(out_dir, "tikz-tech_exp.tex")
tikz(
  file = fn,
  width = 5.8,
  height = 3,
  sanitize = TRUE
)
print(tech_exp_plt)
dev.off()
```

```
## pdf
##   2
```

```
strip_tikz_white(fn)
print(tech_exp_plt)
```



Most, but not all, subjects have experience with computers, tablets, and smartphones. Most subjects have little to no experience with robots.

Therapy

Do you currently receive therapy?

```
therapy_counts <- combined_data %>%
  select(intake_curr_therapy.factor) %>%
  group_by_all() %>%
  count()
therapy_counts
```

intake_curr_therapy.factor	n
Yes	24
No	18

```
therapy_counts / nrow(intake)
```

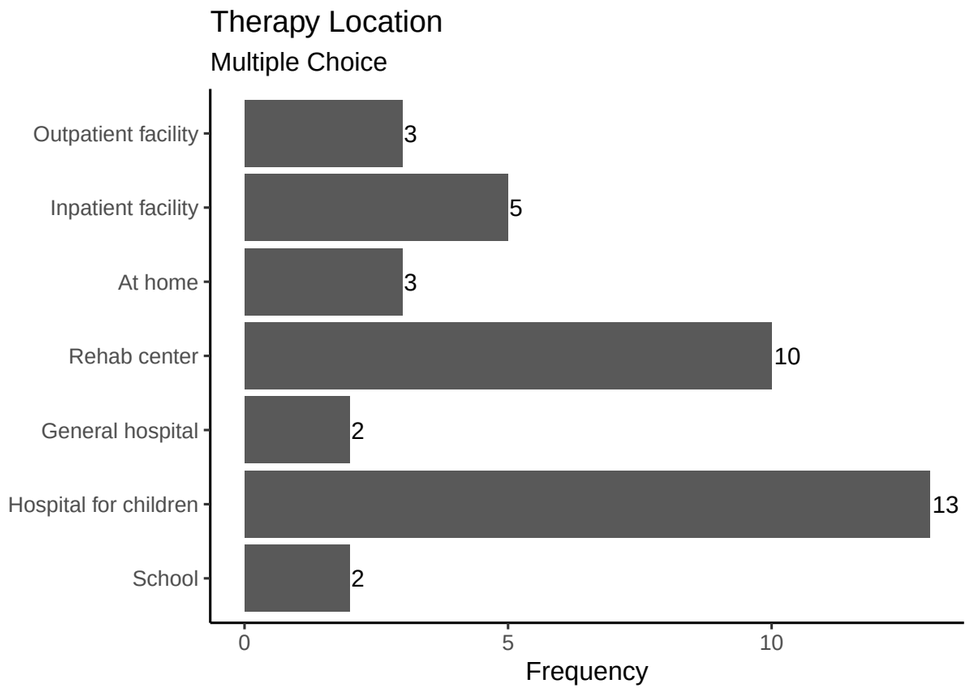
```
## Warning in Ops.factor(left, right): '/' not meaningful for factors
```

intake_curr_therapy.factor	n
NA	0.5714286
NA	0.4285714

For those who are currently getting therapy:

Location Where do you currently receive therapy?

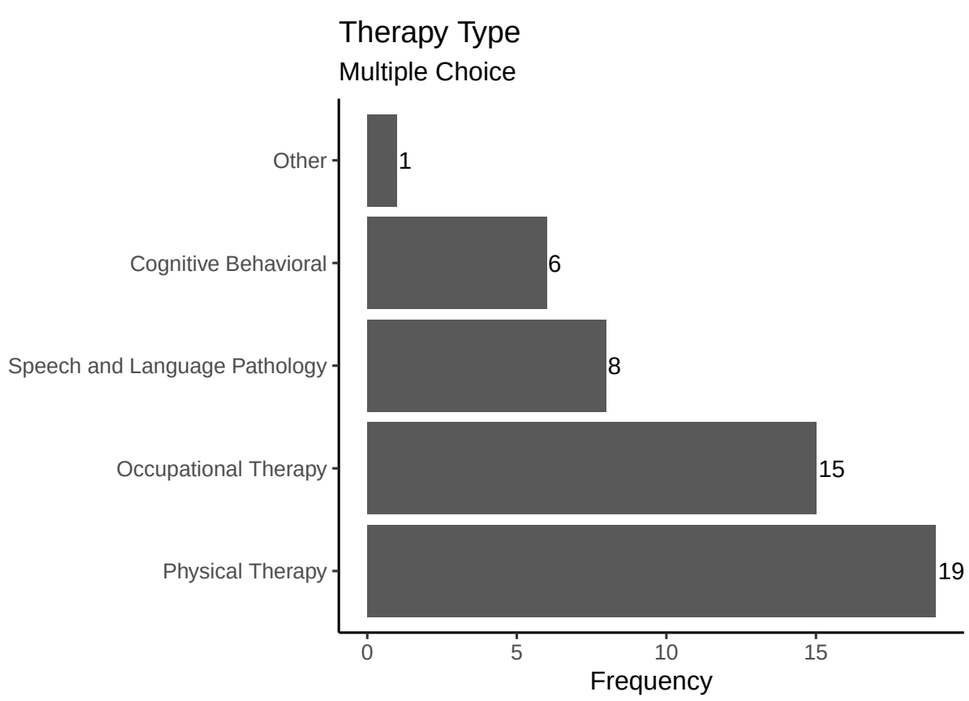
```
plot_multi_choice(combined_data %>% filter(intake_curr_therapy == 1), "intake_therapy_loc", 1:11, "Therapy Location")
```



No other locations. . .

Type of Therapy What kind of therapy do you receive?

```
plot_multi_choice(combined_data %>% filter(intake_curr_therapy == 1), "intake_therapy_type", 1:5, "Therapy Type")
```



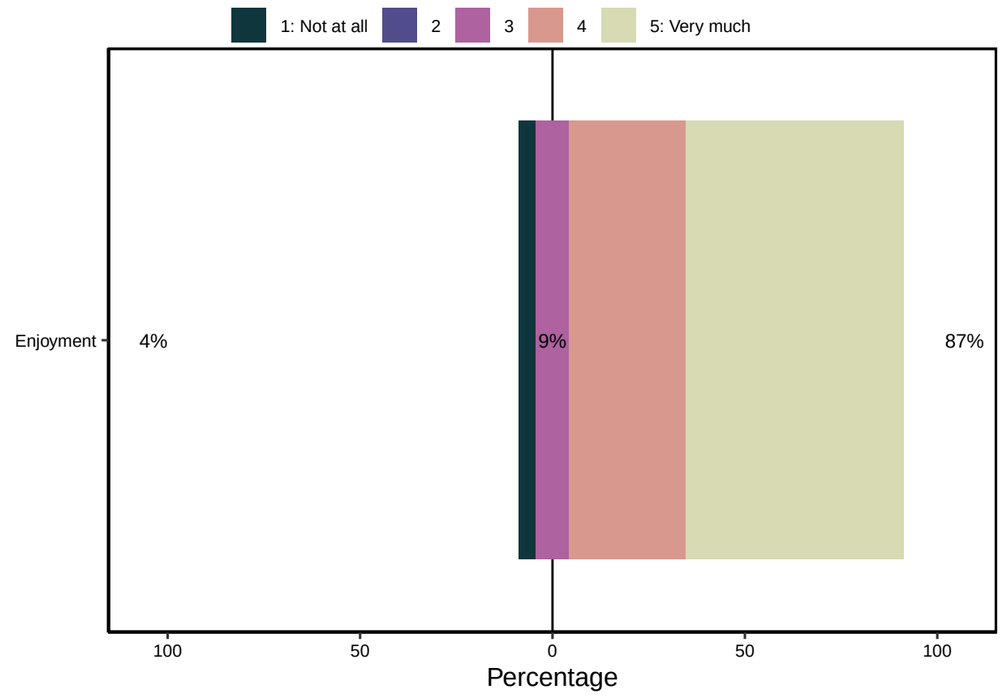
What other types?

```
combined_data %>%
  select(intake_therapy_type_other) %>%
  filter(intake_therapy_type_other != "")
```

intake_therapy_type_other
Cardiac Therapy

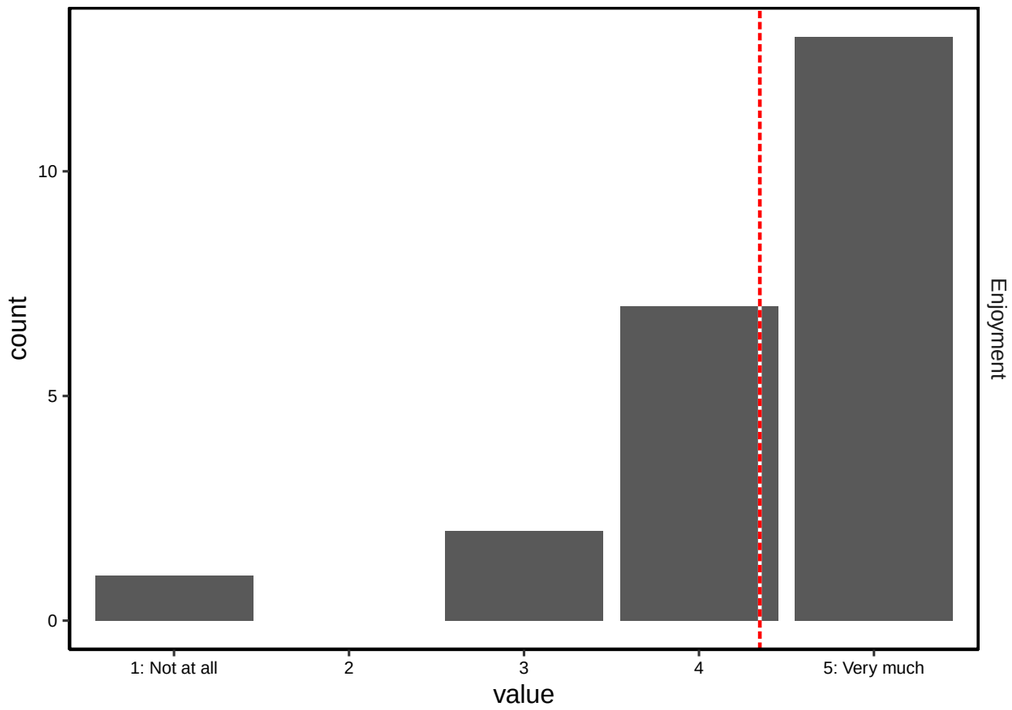
Enjoyment How much do you enjoy your current therapy?

```
therapy_enjoy_data <- combined_data %>%
  filter(intake_curr_therapy == 1) %>%
  select(intake_therapy_enjoy) %>%
  rename(Enjoyment = intake_therapy_enjoy) %>%
  mutate_all(~ factor(., levels = c("1", "2", "3", "4", "5"), labels = c("1: Not at all", "2", "3", "4", "5: Very much")))

plot_likert(therapy_enjoy_data)
```




```
therapy_enjoy_plt <- plot_likert_hist(therapy_enjoy_data)
print(therapy_enjoy_plt)
```

```
## Warning: Removed 1 rows containing non-finite values (stat_count).
```




```
psych::describe(combined_data %>% filter(intake_curr_therapy == 1) %>% select(intake_therapy_enjoy)) %>% knitr::kable()
```

	vars	n	mean	sd	median	trimmed	mad	min	max	range	skew	kurtosis	se
X1	1	23	4.347826	0.9820524	5	4.526316	0	1	5	4	-1.795275	3.295241	0.2047721

Subject 48 did not fill in question

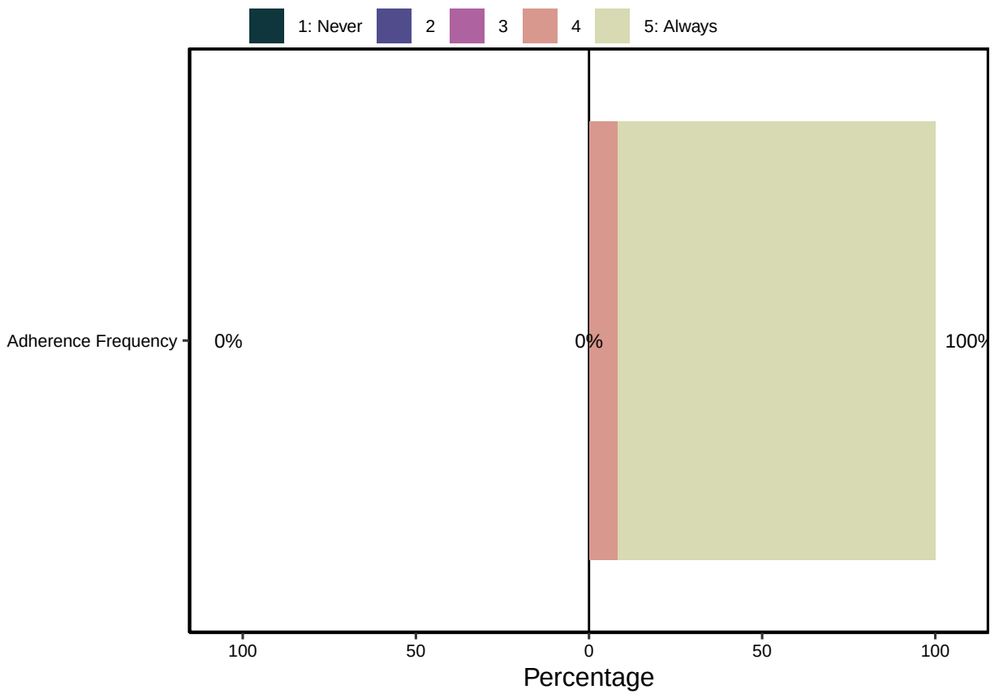
Interesting, subjects enjoy their therapy

Frequency of Adherence to Therapy How often do you do the therapy you are supposed to do?

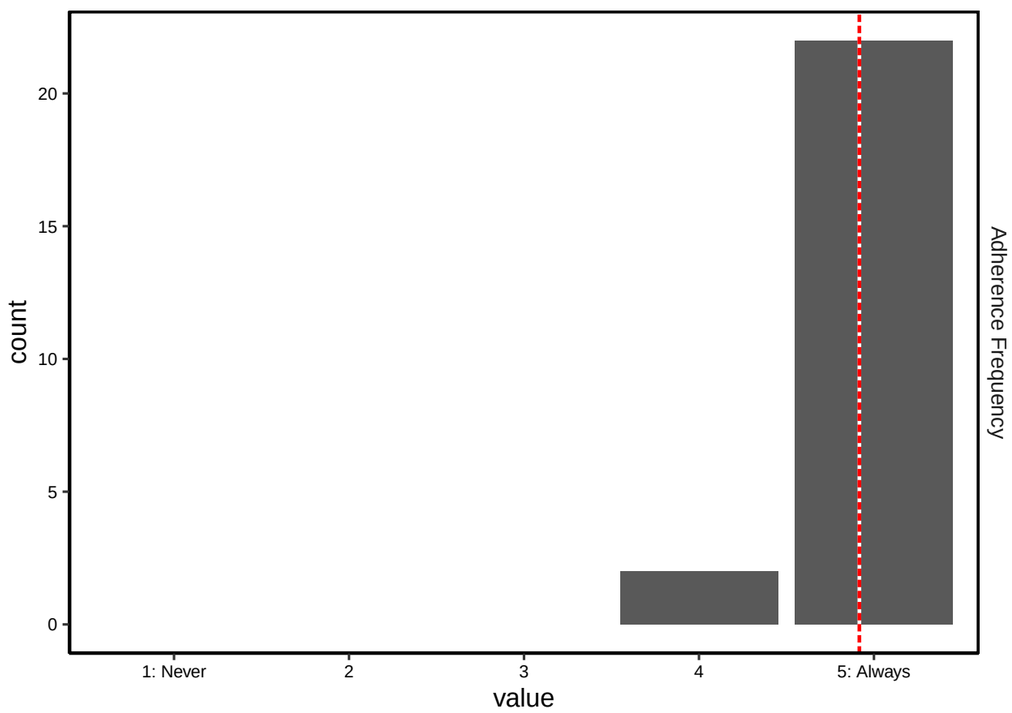
One of the subjects told us that they do all of their therapy because they are in a hospital and so they don't have a choice...

```
therapy_adherence_data <- combined_data %>%
  filter(intake_curr_therapy == 1) %>%
  select(intake_therapy_freq) %>%
  rename(`Adherence Frequency` = intake_therapy_freq) %>%
  mutate_all(~ factor(., levels = c("1", "2", "3", "4", "5"), labels = c("1: Never", "2", "3", "4", "5: Always")))

plot_likert(therapy_adherence_data)
```

```
## Warning: Removed 1 rows containing missing values (position_stack).
## Removed 1 rows containing missing values (position_stack).
```




```
therapy_adherence_plt <- plot_likert_hist(therapy_adherence_data)
print(therapy_adherence_plt)
```




```
psych::describe(combined_data %>% filter(intake_curr_therapy == 1) %>% select(intake_therapy_freq)) %>% knitr::kable()
```

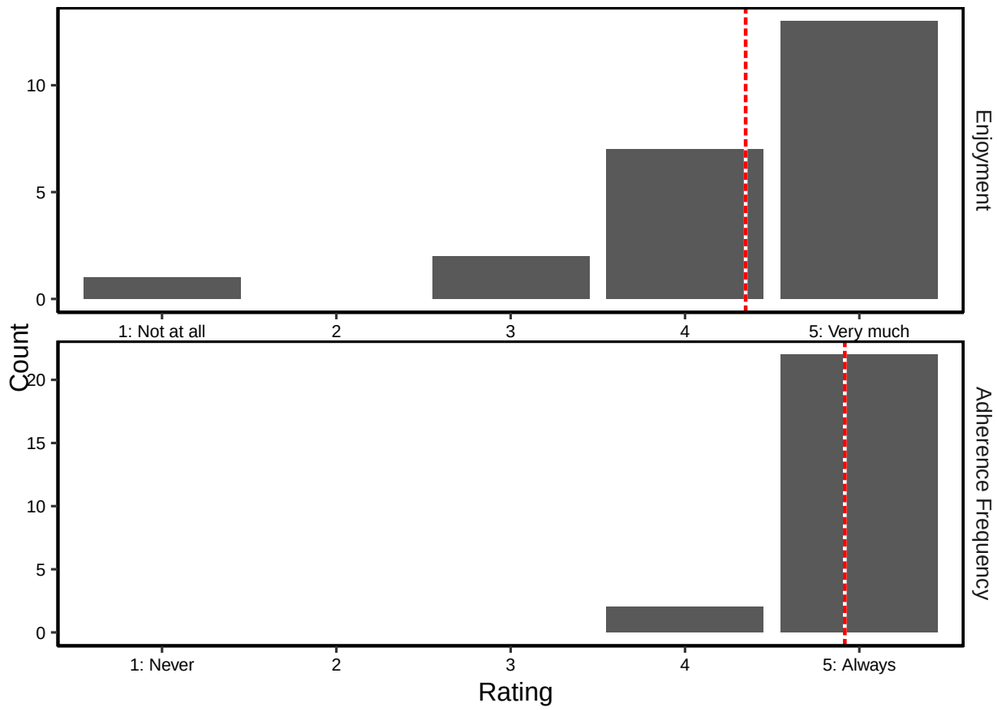
	vars	n	mean	sd	median	trimmed	mad	min	max	range	skew	kurtosis	se
X1	1	24	4.916667	0.2823299	5	5	0	4	5	1	-2.828646	6.267519	0.0576303

In general subjects do their therapy. That is good.

Put plots together

```
therapy_enjoy_adhere_plot <- gridExtra::grid.arrange(
  gridExtra::arrangeGrob(
    therapy_enjoy_plt + theme(axis.title = element_blank()),
    therapy_adherence_plt + theme(axis.title = element_blank()),
    nrow = 2,
    left = grid::textGrob("Count", rot = 90, vjust = 1),
    bottom = grid::textGrob("Rating")
  ),
  nrow = 1
)
```

```
## Warning: Removed 1 rows containing non-finite values (stat_count).
```




```
fn <- file.path(out_dir, "tikz-therapy_enjoy_adhere.tex")
tikz(
  file = fn,
  width = 5.8,
  height = 1.5,
  sanitize = FALSE
)
print(therapy_enjoy_adhere_plot)
```

```
## TableGrob (1 x 1) "arrange": 1 grobs
##   z     cells    name           grob
## 1 1 (1-1,1-1) arrange gtable[arrange]
```

```
dev.off()
```

```
## pdf
##   2
```

```
strip_tikz_white(fn)
print(therapy_enjoy_adhere_plot)
```

```
## TableGrob (1 x 1) "arrange": 1 grobs
##   z     cells    name           grob
## 1 1 (1-1,1-1) arrange gtable[arrange]
```

IDK why, that doesn't want to export

```r
enjoy_adherence_data <- combined_data %>%
  filter(intake_curr_therapy == 1) %>%
  select(intake_therapy_freq, intake_therapy_enjoy) %>%
  mutate_all(~ factor(., levels = c("1", "2", "3", "4", "5"))) %>%
  rename(`Adherence\nFrequency` = intake_therapy_freq, Enjoyment = intake_therapy_enjoy)

data_annotate_ea <- data.frame(
  label.low = c("Not at All", "Never"),
  label.high = c("Very Much", "Always"),
  name = c("Enjoyment", "Adherence\nFrequency")
)
therapy_enjoy_adhere_plot <- plot_likert_hist(enjoy_adherence_data) + geom_text(
  data = data_annotate_ea,
  aes(x = 1, y = 22, label = label.low),
  vjust = 1,
  size = 3,
  lineheight = .8
) + geom_text(
  data = data_annotate_ea,
  aes(x = 5, y = 22, label = label.high),
  vjust = 1,
  size = 3,
  lineheight = .8
) +
  scale_y_continuous(limits = c(0, 22)) +
  plt_theme +
  ylab("Count") +
  xlab("Rating")

fn <- file.path(out_dir, "tikz-therapy_enjoy_adhere.tex")
tikz(
  file = fn,
  width = 5.8,
  height = 1.75,
  sanitize = FALSE
)
print(therapy_enjoy_adhere_plot)
```

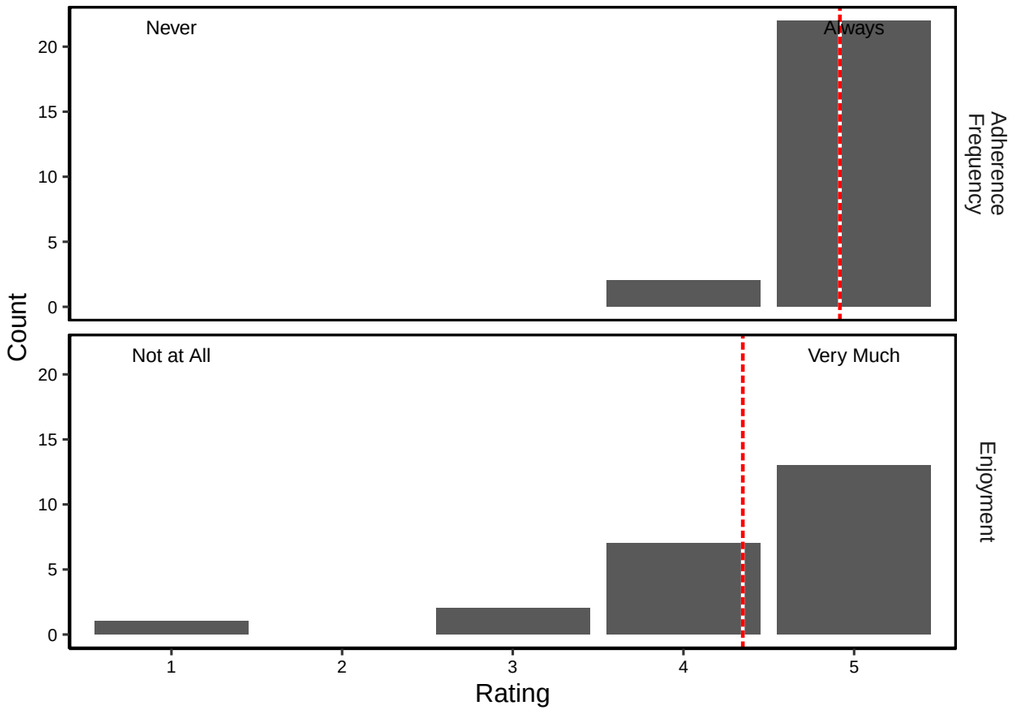
```
## Warning: Removed 1 rows containing non-finite values (stat_count).
```

```r
dev.off()
```

```
## pdf
##   2
```

```r
strip_tikz_white(fn)
print(therapy_enjoy_adhere_plot)
```

```
## Warning: Removed 1 rows containing non-finite values (stat_count).
```



Medication Usage

Do you take any mood or focus-altering medications?

```
combined_data %>%
  select(intake_mood_meds.factor) %>%
  group_by_all() %>%
  count()
```

intake_mood_meds.factor	n
Yes	13
No	22
NA	7

There is one N/A here for a subject who was not sure.

Which mood or focus-altering medications do you take?

```
combined_data %>%
  filter(intake_mood_meds == 1) %>%
  select(intake_mood_medication)
```

intake_mood_medication
Concerta,cymbalta
Venafaxine 150 mg 24 hr capsule, commonly known as effexor XR
Anti-depressant
Zoloft, Azilect, RYTARY ER ,Levodopa Supplement
Zoloft
Trazadone
Medical marijuana, helps to sleep
escitalpram
For anger
Abilify, Buspirone

Anti depressants
Subject said he had but but didn't know what it is.

I don't think there is anything in here that should concern us.

Video Calls

Previous usage of Video Calls Have you ever done a video call?

```
combined_data %>%
  select(intake_videocall.factor) %>%
  group_by_all() %>%
  count()
```

intake_videocall.factor	n
Yes	37
No	4
NA	1

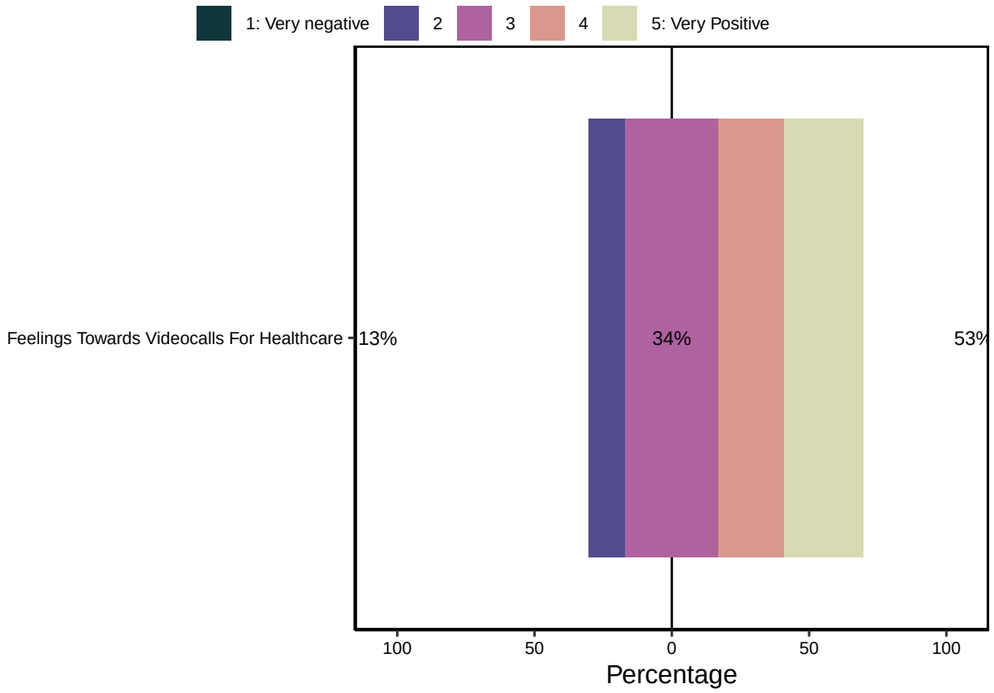
Video Calls for Healthcare Have you ever done a video call for healthcare?

```
combined_data %>%
  select(intake_call_healthcare.factor) %>%
  group_by_all() %>%
  count()
```

intake_call_healthcare.factor	n
Yes	19
No	22
NA	1

How do you feel about using video calls for healthcare?

```
vidcall_healthcare_data <- combined_data %>%
  select(intake_vidcall_healthcare) %>%
  rename(`Feelings Towards Videocalls For Healthcare` = intake_vidcall_healthcare) %>%
  mutate_all(~ factor(., levels = c("1", "2", "3", "4", "5"), labels = c("1: Very negative", "2", "3", "4", "5: Very Positive")))

plot_likert(vidcall_healthcare_data)
```




```
vid_health_feel_plt <- plot_likert_hist(vidcall_healthcare_data) + xlab("Rating") + ylab("Count") + theme(strip.text.y = element_blank())

psych::describe(combined_data %>% select(intake_vidcall_healthcare)) %>% knitr::kable()
```

	vars	n	mean	sd	median	trimmed	mad	min	max	range	skew	kurtosis	se
X1	1	38	3.68421	1.042483	4	3.71875	1.4826	2	5	3	-0.0629276	-1.30349	0.1691131

```
fn <- file.path(out_dir, "tikz-vid_health_feel.tex")
tikz(
  file = fn,
  width = 5.8,
  height = .75,
  sanitize = TRUE
)
print(vid_health_feel_plt)
```

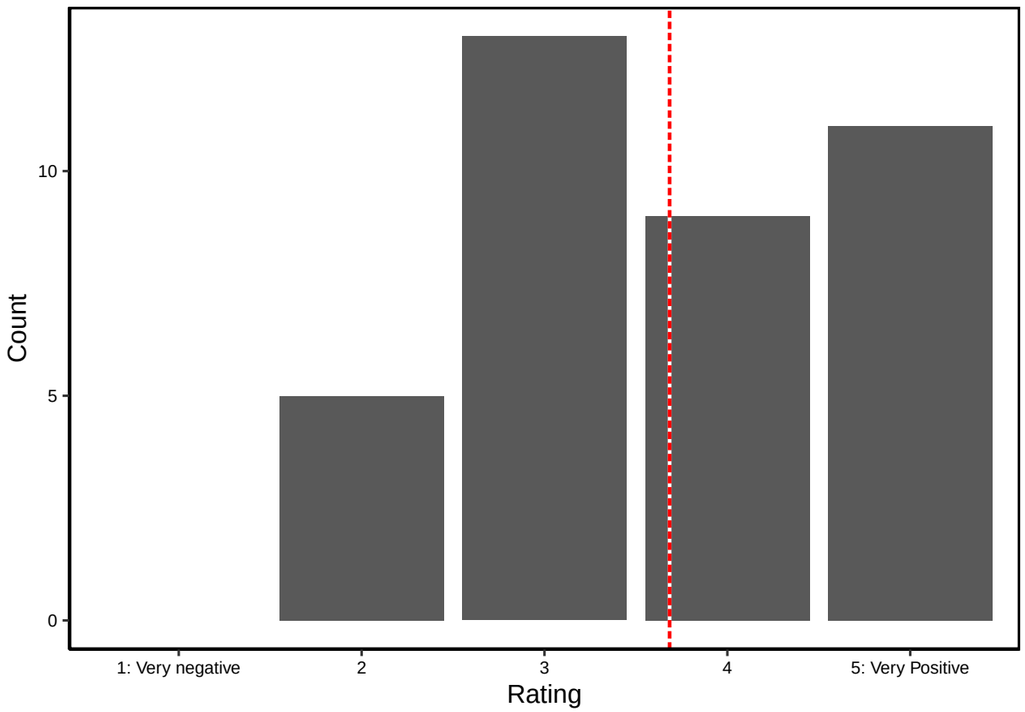
```
## Warning: Removed 4 rows containing non-finite values (stat_count).
```

```
dev.off()
```

```
## pdf
##   2
```

```
strip_tikz_white(fn)
print(vid_health_feel_plt)
```

```
## Warning: Removed 4 rows containing non-finite values (stat_count).
```

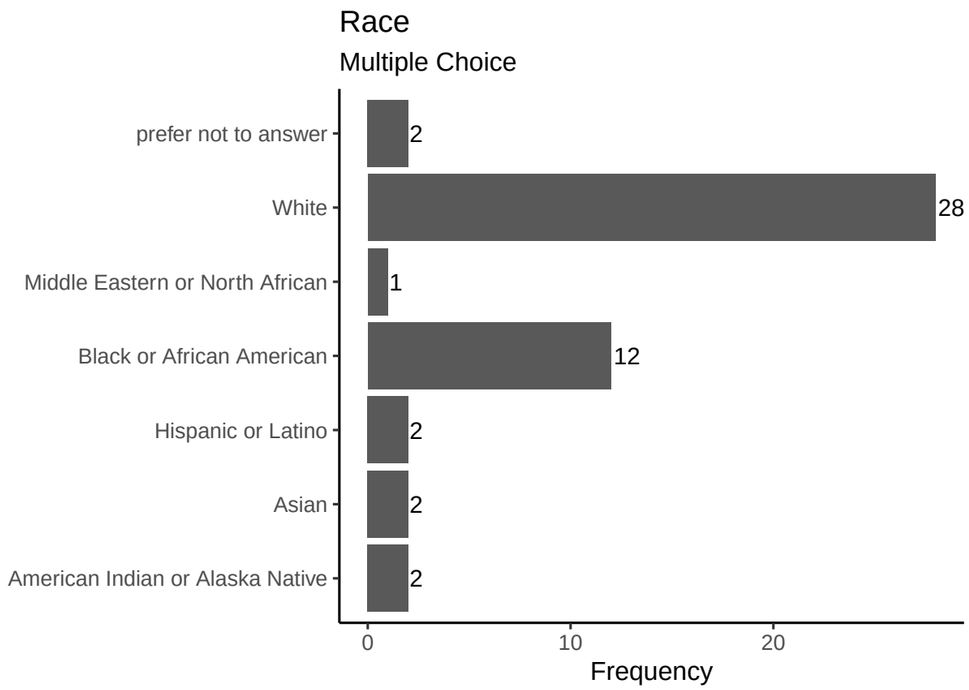


Subjects with N/A values did not have feelings/understanding towards this question

Race

How would you describe yourself? (Select all that apply)

```
plot_multi_choice(combined_data, "intake_race", 1:9, "Race")
```




```
condense_multi_choice(combined_data, "intake_race", 1:9) %>%
  table() %>%
  proportions()
```

```
## field
##           American Indian or Alaska Native                                Asian                 Hispanic or Latino
##                                  0.04081633                       0.04081633                         0.04081633
##                  Black or African American Middle Eastern or North African                              White
##                                  0.24489796                       0.02040816                         0.57142857
## Native Hawaiian or other Pacific Islander                                other           prefer not to answer
##                                  0.00000000                       0.00000000                         0.04081633
```

Need to check if this is representative. Maybe want to do a cross analysis with age groups/impairment to make sure representation holds up?

Day2

SAM

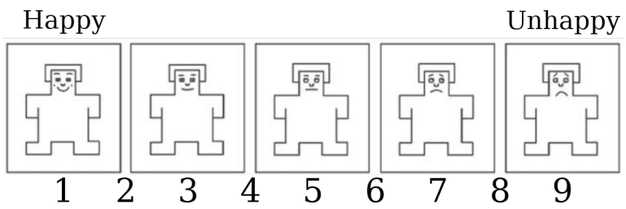


Figure 4: Valence Scale

```
sam_2_data <- combined_data %>%
  select(intake_sam_valence_2.factor, intake_sam_arousal_2.factor, intake_sam_dominance_2.factor) %>%
  rename(Valence = intake_sam_valence_2.factor, Arousal = intake_sam_arousal_2.factor, Dominance = intake_sam_dominance_2.factor)

plot_likert(sam_2_data)
```

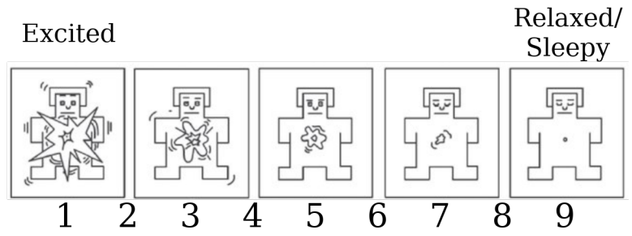


Figure 5: Arrousal Scale

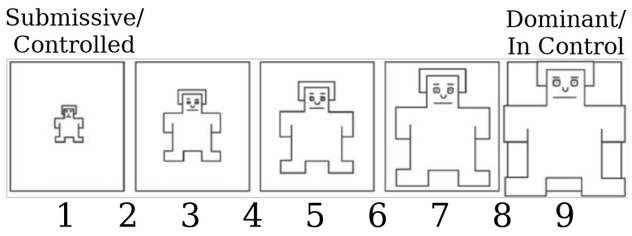
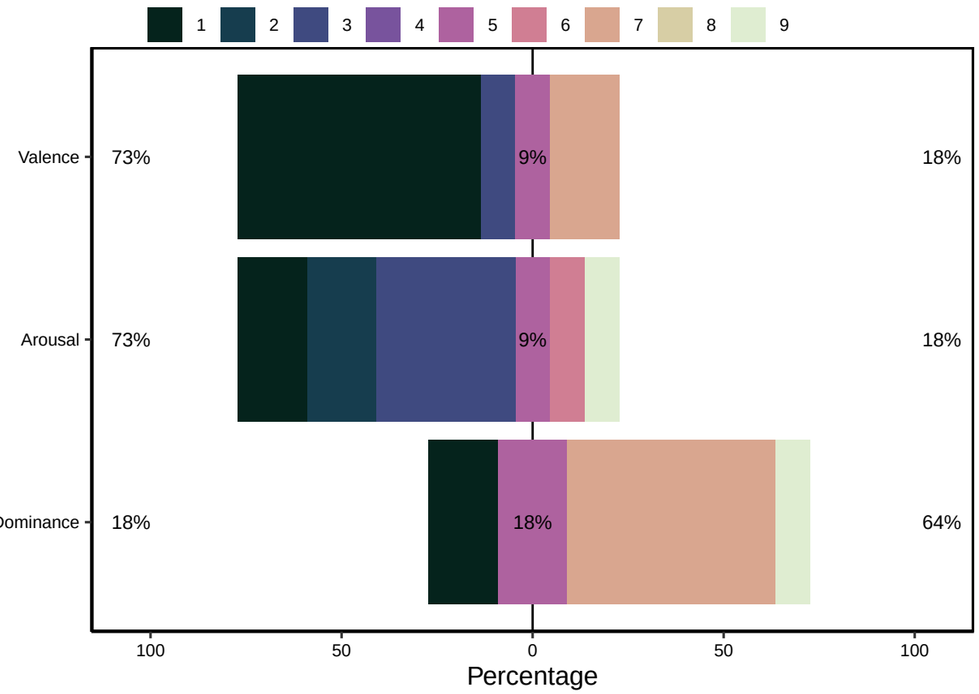
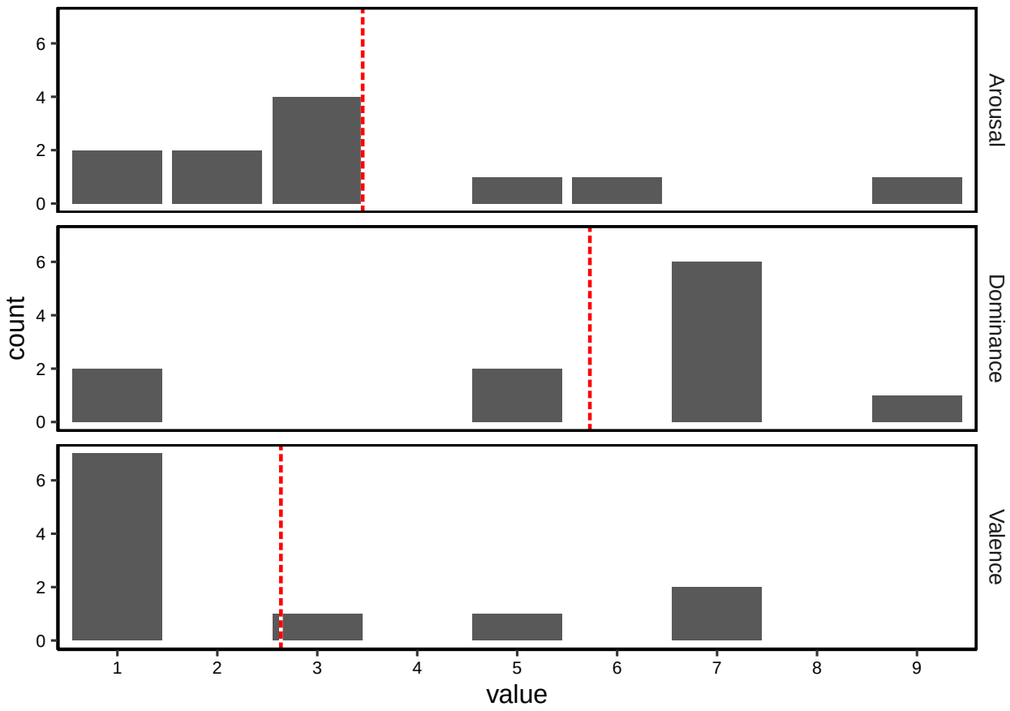


Figure 6: Dominance Scale




```
plot_likert_hist(sam_2_data)
```

```
## Warning: Removed 93 rows containing non-finite values (stat_count).
```



Obviously a lot of na values for the subjects who did not do the second day.

TODO: check if everyone who did a 2-day study is here.

```
sam_2_data %>%
  psych::describe() %>%
  knitr::kable()
```

	vars	n	mean	sd	median	trimmed	mad	min	max	range	skew	kurtosis	se
Valence*	1	11	2.636364	2.500909	1	2.333333	0.0000	1	7	6	0.8645713	-1.1256341	0.7540524
Arousal*	2	11	3.454546	2.381749	3	3.111111	1.4826	1	9	8	1.0403068	0.0371799	0.7181243
Dominance*	3	11	5.727273	2.572583	7	5.888889	0.0000	1	9	8	-0.8790291	-0.6550423	0.7756629

Delta

Did peoples state change day 1 to day 2?

```
sam_2_data_ri <- combined_data %>%
  filter(intake_survey_day_2_complete == 2) %>%
  select(record_id, intake_sam_valence_2.factor, intake_sam_arousal_2.factor, intake_sam_dominance_2.factor) %>%
  rename(Valence = intake_sam_valence_2.factor, Arousal = intake_sam_arousal_2.factor, Dominance = intake_sam_dominance_2.factor, `Record ID` = record_id) %>%
  mutate_at(vars(!`Record ID`), as.integer)

sam_1_data_ri <- combined_data %>%
  filter(record_id %in% unlist(sam_2_data_ri$`Record ID`)) %>%
  select(record_id, intake_sam_valence.factor, intake_sam_arousal.factor, intake_sam_dominance.factor) %>%
  rename(Valence = intake_sam_valence.factor, Arousal = intake_sam_arousal.factor, Dominance = intake_sam_dominance.factor, `Record ID` = record_id) %>%
  mutate_at(vars(!`Record ID`), as.integer)

label(sam_2_data_ri) <- list(`Record ID` = "Record ID", Valence = "Valence", Arousal = "Arousal", Dominance = "Dominance")
label(sam_1_data_ri) <- list(`Record ID` = "Record ID", Valence = "Valence", Arousal = "Arousal", Dominance = "Dominance")
```

How many subjecs?

```
nrow(sam_2_data_ri)
```

```
## [1] 11
```

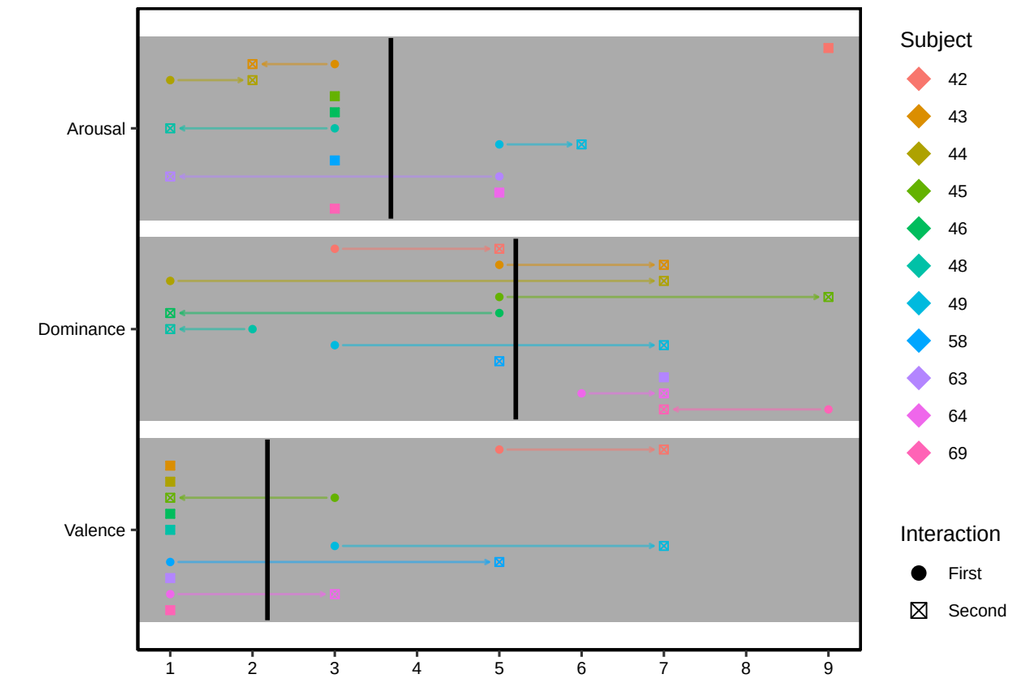
```
plot_change(sam_1_data_ri, sam_2_data_ri, plot_theme(), arrow_scale_adj = 1) +
  scale_y_continuous(
    limits = c(1, 9),
```

```
    breaks = c(1:9)
  )
```

```
## Warning: Removed 1 rows containing non-finite values (stat_summary).
```

```
## Warning: Removed 1 rows containing missing values (geom_point).
```

```
## Warning: Removed 14 rows containing missing values (geom_segment).
```




```
# cust_color(nrow(sam_1_data_ri))

sam_change_plt <- plot_change(sam_1_data_ri, sam_2_data_ri, plot_theme(), arrow_scale_adj = 1) +
  scale_y_continuous(
    limits = c(1, 9),
    breaks = c(1:9)
  ) + guides(color = "none")
# rep("black", nrow(sam_1_data_ri))
fn <- file.path(out_dir, "tikz-sam_delta.tex")
tikz(
  file = fn,
  width = 5.8,
  height = 2.5,
  sanitize = TRUE
)
print(sam_change_plt)
```

```
## Warning: Removed 1 rows containing non-finite values (stat_summary).
```

```
## Warning: Removed 1 rows containing missing values (geom_point).
```

```
## Warning: Removed 14 rows containing missing values (geom_segment).
```

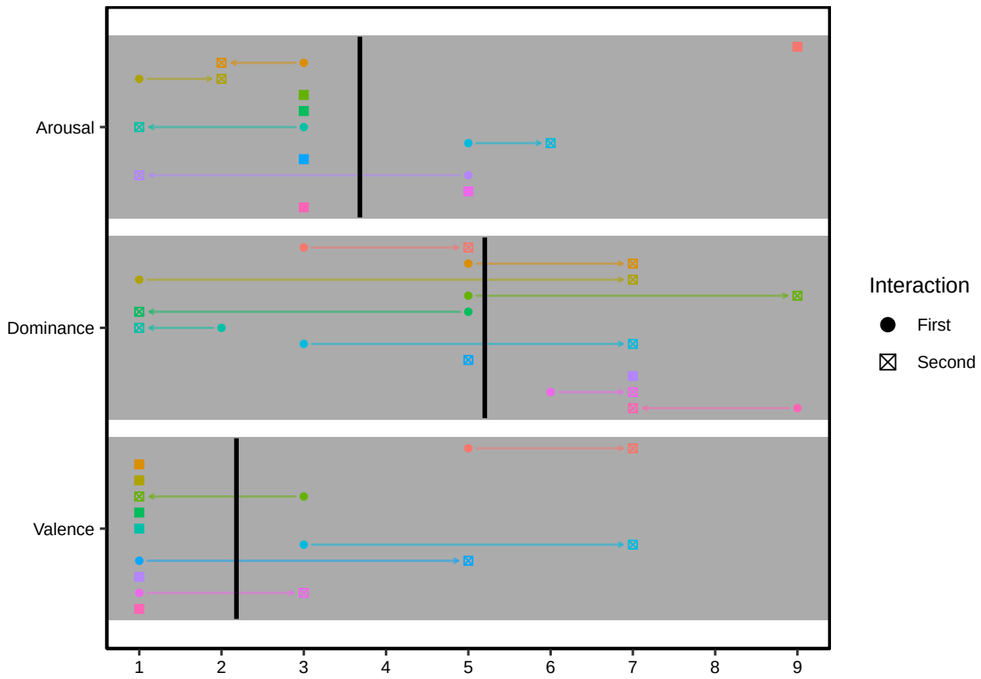
```
dev.off()
```

```
## pdf
##   2
```

```
strip_tikz_white(fn)
print(sam_change_plt)
```

```
## Warning: Removed 1 rows containing non-finite values (stat_summary).
```

```
## Warning: Removed 1 rows containing missing values (geom_point).
## Warning: Removed 14 rows containing missing values (geom_segment).
```



Oof, dominance is all over the place. Arousal doesn't change too much. Valence changes some. How do we handle that?

Post Experiment Survey

Here we will look at the questions asked after each condition.

Goals

Our goal here is to answer:

1. Do subjects find it easier to do the activities with SRAT or CT (NASA TLX; IMI Pressure; IMI competence; post_cust_understanding)
2. Do subjects enjoy activities with SRAT or CT more (post_cust_wouldreapeat, post_enjoyment, ; IMI enjoyment)
3. Do subjects find SRAT or CT to be more valuable? (post_cust_wouldrepeat; IMI value; post_cust2_effective_rehab)
4. Do subjects find that the addition of social robot to SRAT makes it feel less safe? (post_cust_safety)

In the context of these questions, we need to answer:

- Do the variables we can design around (impairment level, age) have an effect?

We also need to control for:

- Experiment ordering (FTF-SRAT-CT vs FTF-CT-SRAT)
- Operator

Setup

```
rm(list = ls())
source("utility_scripts/setup.r")
```

```
## [1] "Only including subjects with complete consent forms"
## [1] "Excluding subjec # <=10 (pilot trial cohort)"
## [1] "n=44"
## [1] "Excluding Subjects:"
## [1] "    excluding subject 50"
## [1] "    excluding subject 47"
## [1] "Corrected Subject 22 Survey Assignment"
```

```
## [1] "Fixing subject 60 post experiment"
## [1] "final number of subjects: 42"
## [1] "Filling in for subjects too young for color trails:"
## [1] "    Subject 15, reported no impairment, marking no impairment"
## [1] "    subject 23, reported motor impairment only, BBT -2.56 z, marking motor impairment"
## [1] "    Subject 66, reported motor impairment only (Left hemiparesis), marking motor impairment"
```

Look at Order

```
post_exp %>%
  filter(redcap_event_name == "after_in_person_arm_1") %>%
  select(order.factor) %>%
  group_by_all() %>%
  count()
```

order.factor	n
Augmented (Humanoid) First	22
Classical (No-Humanoid) First	20

We did a relatively a nice job of balancing ordering. For a more detailed look at how ordering breaks down by age and impairment:

```
ftable(combined_data$impairment.measured, combined_data$age_group, combined_data$order.factor)
```

```
##                                     Augmented (Humanoid) First Classical (No-Humanoid) First
##
## Motor               Young Children                           3                            3
##                     Teens-Young Adults                       3                            2
##                     Adults                                   4                            4
##                     Older Adults                             3                            1
## Motor and Cognitive Young Children                           0                            1
##                     Teens-Young Adults                       3                            2
##                     Adults                                   1                            0
##                     Older Adults                             1                            0
## None                Young Children                           0                            2
##                     Teens-Young Adults                       1                            0
##                     Adults                                   3                            3
##                     Older Adults                             0                            2
```

There are a few groups that aren't filled. We will be using continuous variables to help address this.

TLX

Please answer the following questions based on the interaction you just had using the sliders.

For the TLX, we skipped the weighting step (a normal thing to do). So all we have to do is either add up or average the scores (we will average). There is good information about working with the TLX here: https://measuringu.com/nasa-tlx/

Note: we did not ask the temporal demand question. It doesn't make sense for the tasks we are doing, which are not done independently, and we found in our pilot study that it was poorly understood.

For the TLX, lower values are better.

The way the questions were presented, we need to reverse performance

```
post_exp <-
  post_exp %>% mutate(
    post_tlx_avg = (
      post_tlx_mentaldemand + post_tlx_physicaldemand + (100 - post_tlx_performance) +
        post_tlx_effort + post_tlx_frustration
    ) / 5
  )
```

Look for any N/A:

```
tlx_vals <-
  post_exp %>% select(
    post_tlx_mentaldemand,
    post_tlx_physicaldemand,
    post_tlx_performance,
    post_tlx_effort,
    post_tlx_frustration
  )
post_exp[apply(tlx_vals, 1, function(x) {
```

```
  any(is.na(x))
}), ] %>% select(record_id, redcap_event_name)
```

	record_id	redcap_event_name
85	48	after_in_person_arm_1
86	48	after_augmented_arm_1
87	48	after_classical_arm_1
122	68	after_augmented_arm_1

Subject 48 was severely impaired. They had a hard time with many survey questions. They were able to understand the final survey questions, but the post experiment questions, not so much. We should exclude them from the post experiment analysis. Subject 66 was excluded due to exhaustion.

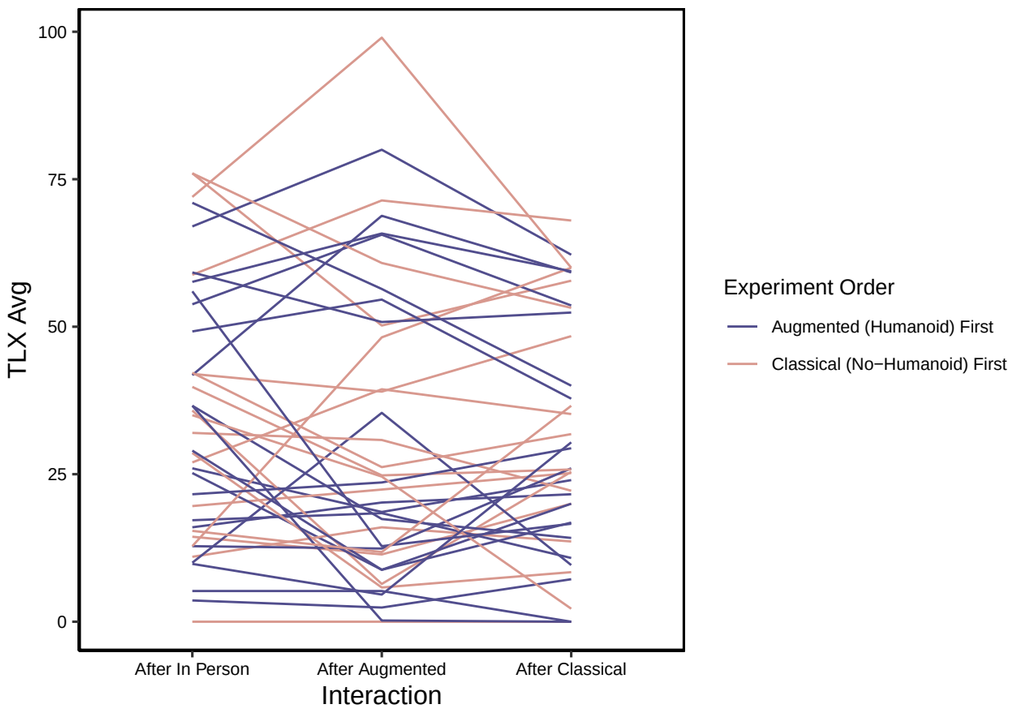
```
post_exp <- post_exp %>% filter(record_id != 48 & record_id != 66  )
unique(post_exp$record_id)
```

```
##  [1] 12 13 14 15 16 17 20 21 22 23 25 28 29 30 31 32 34 35 36 38 39 40 41 42 43 44 45 46 49 52 54 55 58 59 60 61 63 64 68 69
```

Explore data:

```
post_exp %>%
  ggplot(
    aes(
      y = post_tlx_avg,
      x = redcap_event_name.factor,
      color = order.factor,
      shape = order.factor,
      group = record_id
    )
  ) +
  geom_line() +
  ylab("TLX Avg") +
  xlab("Interaction") +
  plt_theme +
  scale_color_manual(values = cust_color(5)[c(2, 4)]) +
  theme(legend.position = "right") +
  labs(color = "Experiment Order")
```

```
## Don't know how to automatically pick scale for object of type labelled/integer. Defaulting to continuous.
```

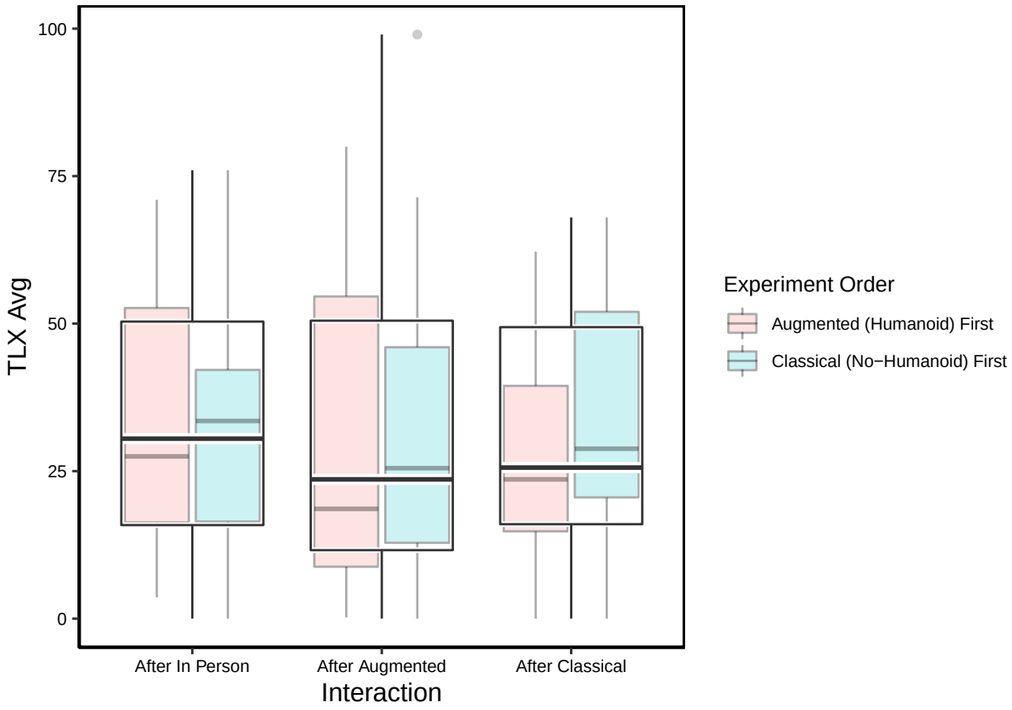


This is why we use a within subjects design, there is no standard response here.

Look at aggregate:

```
tlx_plt <- post_exp %>% ggplot(aes(
  y = post_tlx_avg, x = redcap_event_name.factor,
)) +
  ylab("TLX Avg") +
  xlab("Interaction") +
  plt_theme +
  scale_color_manual(values = cust_color(5)[c(2, 4)]) +
  theme(legend.position = "right") +
  geom_boxplot(aes(
    fill =
      order.factor
  ), alpha = .2, color = ("#00000055")) +
  labs(fill = "Experiment Order")
tlx_plt + geom_boxplot(color = "white", size = 1.2, fill = "#00000000") + geom_boxplot(fill = "#00000000")
```

```
## Warning: Removed 1 rows containing non-finite values (stat_boxplot).
## Removed 1 rows containing non-finite values (stat_boxplot).
## Removed 1 rows containing non-finite values (stat_boxplot).
```

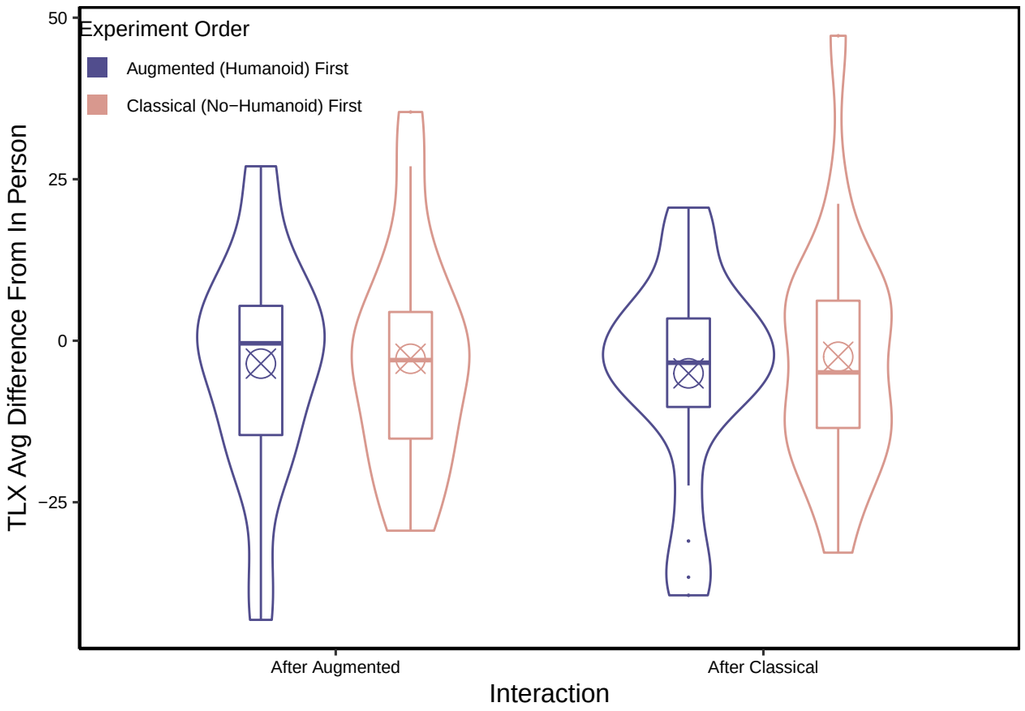


To exploit the within subjects nature of the test, while still viewing aggregate data, we can subtract the after in person data from the other two conditions on a subject by subject basis.

```
dodge <- .7
width <- 2
tlx_diff_plot_data <- post_exp %>%
  group_by(record_id) %>%
  mutate(post_tlx_avg = post_tlx_avg - post_tlx_avg[redcap_event_name.factor ==
    "After In Person"]) %>%
  filter(redcap_event_name.factor != "After In Person") %>%
  ungroup()

tlx_diff_plot_data %>%
  ggplot(aes(y = post_tlx_avg, x = redcap_event_name.factor, color = order.factor)) +
  plt_theme +
  ylab("TLX Avg Difference From In Person") +
  xlab("Interaction") +
  scale_color_manual(name = "Experiment Order", values = cust_color(5)[c(2, 4)]) +
  theme(legend.position = "right") +
```

```
  geom_violin(width = .8, position = position_dodge(dodge)) +
  geom_boxplot(
    width = .1 * width,
    position = position_dodge(dodge),
    outlier.size = 0.1
  ) +
  stat_summary(
    fun = "mean",
    geom = "point",
    size = 6,
    shape = 13,
    # https://ggplot2.tidyverse.org/articles/ggplot2-specs.html#sec:shape-spec
    position = position_dodge(dodge)
  ) +
  guides(colour = guide_legend(override.aes = list(
    shape = 15,
    size = 4,
    linetype = integer(2)
  ))) +
  theme(legend.position = c(.15, .9))
```

```
## Warning: Removed 1 rows containing non-finite values (stat_ydensity).
## Warning: Removed 1 rows containing non-finite values (stat_boxplot).
## Warning: Removed 1 rows containing non-finite values (stat_summary).
```



There doesn't appear to be anything significant here at the large scale. What we will need to dive into is whether this plot changes at all when we partition by demographics.

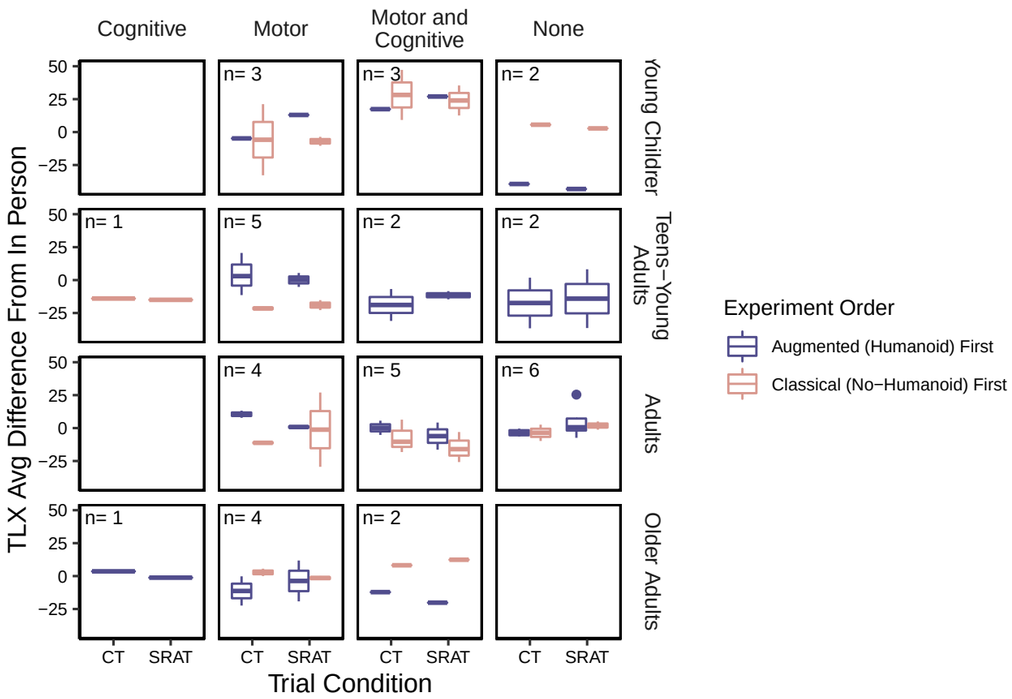
As a preview, let's look at age:

```
tlx_diff_plot_data %>%
  mutate(event_short = ifelse(redcap_event_name.factor == "After Augmented", "SRAT", "CT")) %>%
  ggplot(aes(y = post_tlx_avg, x = event_short, color = order.factor)) +
  plt_theme +
  facet_grid(
    rows = vars(age_group),
    cols = vars(impairment),
    labeller = label_wrap_gen(width = 15, multi_line = TRUE)
  ) +
```

```
  geom_boxplot() +
  scale_color_manual(name = "Experiment Order", values = cust_color(5)[c(2, 4)]) +
  geom_text(
    data = tlx_diff_plot_data %>%
      group_by(record_id) %>%
      filter(row_number() == 1) %>%
      ungroup() %>%
      count(age_group, impairment),
    aes(
      label = paste("n=", n),
      y = 50,
      x = .5,
      order.factor = "Augmented (Humanoid) First"
    ),
    vjust = 1,
    hjust = 0,
    color = "black",
    size = 3
  ) +
  xlab("Trial Condition") +
  ylab("TLX Avg Difference From In Person")
```

```
## Warning: Ignoring unknown aesthetics: order.factor
```

```
## Warning: Removed 1 rows containing non-finite values (stat_boxplot).
```



When we test this, we will use age, CTT, and BBT as continuous variables, to get away from this small groups problem and prevent boundary effects. But this plot provides a nice way of showing that age and impairment do interact with these ratings.

```
knitr::kable(skimr::skim_without_charts(post_exp %>% select(post_tlx_avg, redcap_event_name.factor) %>% group_by(redcap_event_name.factor)))
```

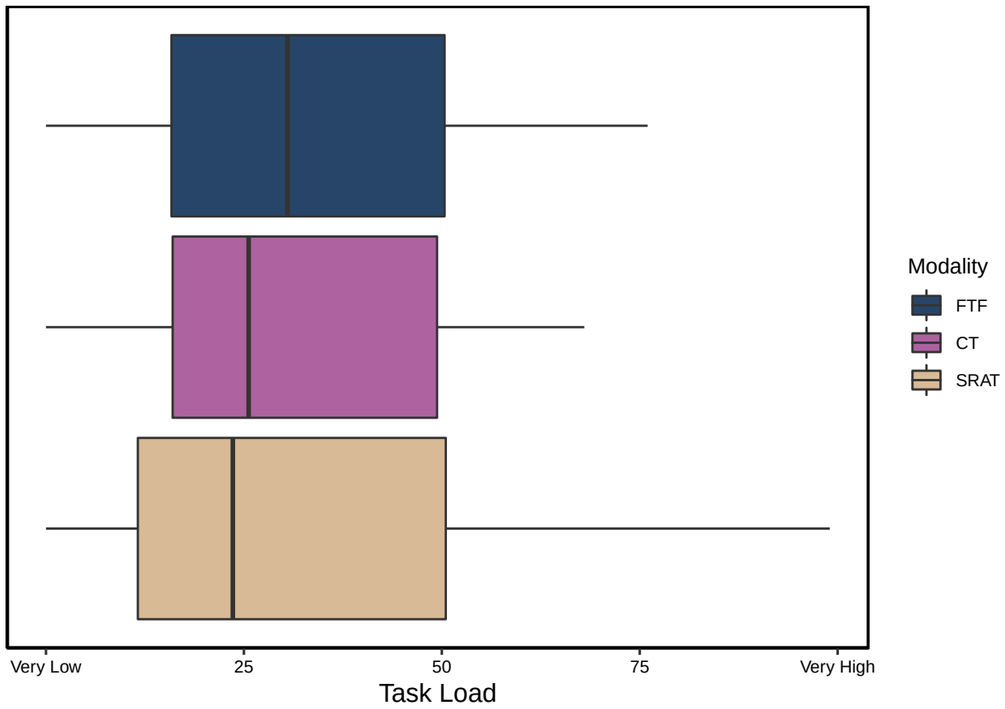
skim_type	skim_variable	redcap_event_name.factor	n_missing	complete_rate	numeric.mean	numeric.sd	numeric.p0	numeric.p25	numeric.p50	numeric.p75	numeric.p100
numeric	post_tlx_avg	After In Person	0	1.000	34.09500	21.61604	0	15.85	30.5	50.35	76
numeric	post_tlx_avg	After Augmented	1	0.975	31.25641	25.44790	0	11.60	23.6	50.50	99
numeric	post_tlx_avg	After Classical	0	1.000	30.20500	19.96641	0	16.00	25.6	49.40	68

Let's actually make a nice plot:

```
tlx_plot <- post_exp %>%
  ggplot(aes(post_tlx_avg, fill = redcap_event_name)) +
  geom_boxplot() +
```

```
  plt_theme +
  scale_fill_manual(
    values = cust_color(7)[c(2, 4, 6)],
    name = "Modality",
    breaks = c("after_in_person_arm_1", "after_classical_arm_1", "after_augmented_arm_1"),
    labels = c("FTF", "CT", "SRAT")
  ) +
  xlab("Task Load") +
  theme(axis.text.y = element_blank(), axis.ticks.y = element_blank()) +
  scale_x_continuous(breaks = c(0, 25, 50, 75, 100), labels = c("Very Low", 25, 50, 75, "Very High"))

print(tlx_plot)
```

```
## Warning: Removed 1 rows containing non-finite values (stat_boxplot).
```




```
fn <- file.path(out_dir, "tikz-tlx_boxplot.tex")
tikz(
  file = fn,
  width = 5.8,
  height = 1.25,
  sanitize = TRUE
)
print(tlx_plot)
```

```
## Warning: Removed 1 rows containing non-finite values (stat_boxplot).
```

```
dev.off()
```

```
## pdf
##   2
```

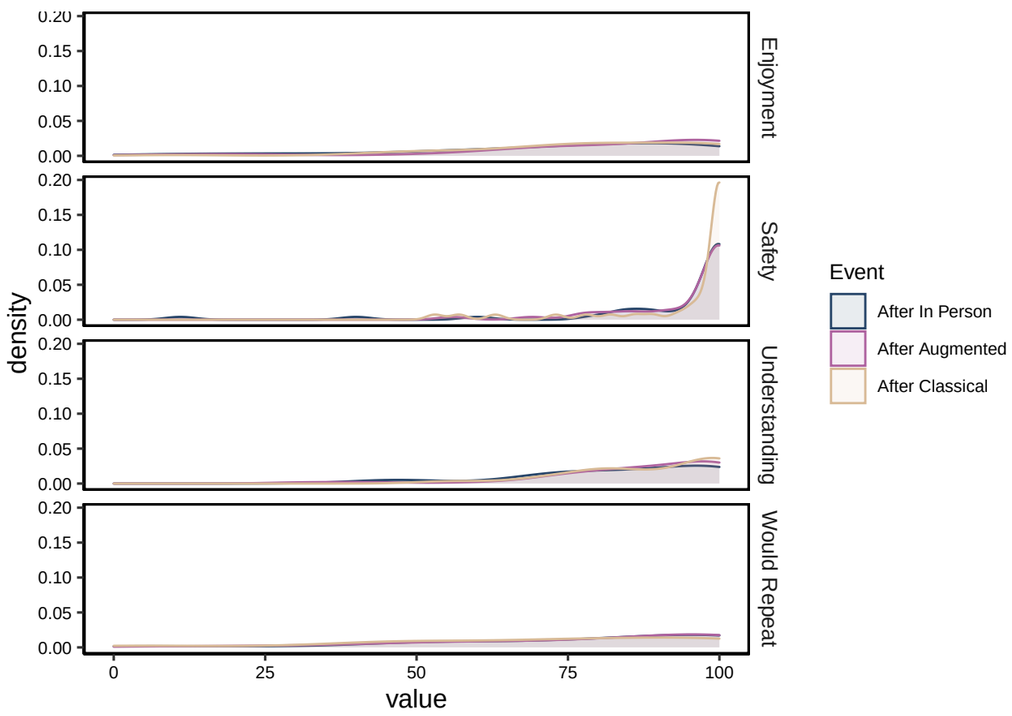
```
strip_tikz_white(fn)
```

Custom Questions

Please answer the following questions based on the interaction you just had using the sliders.

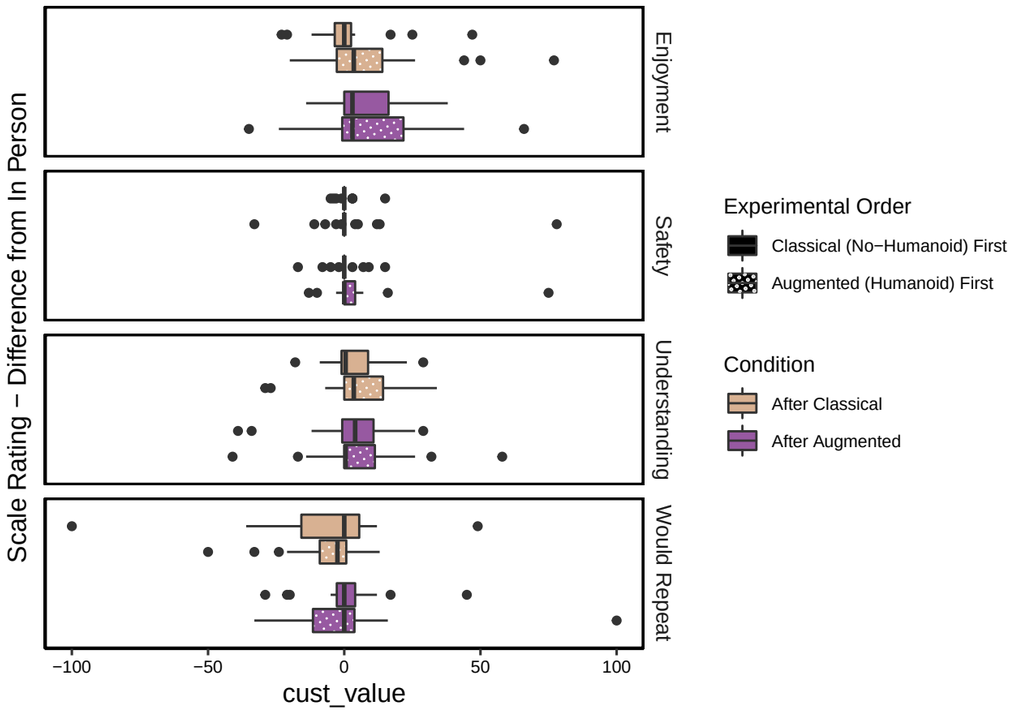
We created a series of custom questions, in the style of the TLX. These measure different scales and can not be combined.

```r
post_cust_data <- post_exp %>%
  select(
    starts_with("post_cust_") &
      !(ends_with("_p")),
    post_enjoyment,
    order.factor,
    redcap_event_name.factor
  ) %>%
  mutate_at(vars(starts_with("post_cust_"), post_enjoyment), as.integer) %>%
  rename(
    Understanding = post_cust_understanding,
    Safety = post_cust_safety,
    `Would Repeat` = post_cust_wouldrepeat,
    Enjoyment = post_enjoyment
  ) %>%
  tidyr::pivot_longer(!(order.factor | redcap_event_name.factor))

post_cust_data %>% ggplot(aes(x = value, color = redcap_event_name.factor, fill = redcap_event_name.factor)) +
  geom_density() +
  facet_grid(rows = "name") +
  plt_theme +
  scale_fill_manual(values = alpha(cust_color(3), .1), name = "Event") +
  scale_color_manual(values = cust_color(3), name = "Event")
```



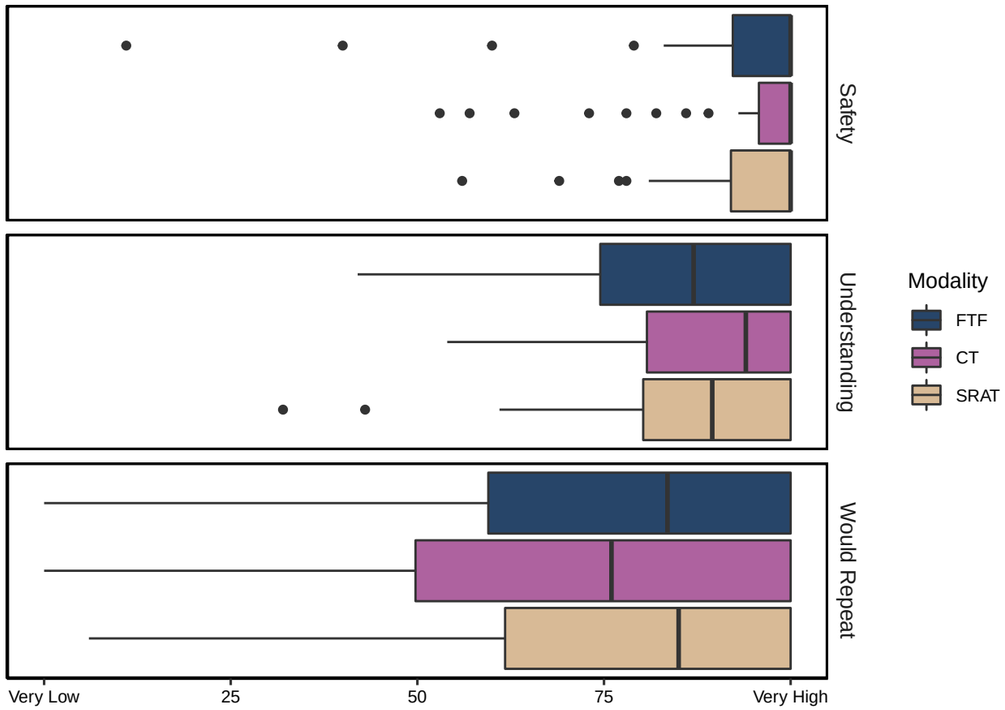

```r
cust_diff_plot_data <- post_exp %>%
  group_by(record_id) %>%
  mutate(Understanding = as.numeric(post_cust_understanding - post_cust_understanding[redcap_event_name.factor ==
    "After In Person"])) %>%
  mutate(Safety = as.numeric(post_cust_safety - post_cust_safety[redcap_event_name.factor ==
    "After In Person"])) %>%
  mutate(`Would Repeat` = as.numeric(post_cust_wouldrepeat - post_cust_wouldrepeat[redcap_event_name.factor ==
    "After In Person"])) %>%
  mutate(Enjoyment = as.numeric(post_enjoyment - post_enjoyment[redcap_event_name.factor ==
    "After In Person"])) %>%
  filter(redcap_event_name.factor != "After In Person") %>%
  ungroup()
```

```r
cust_diff_plot_data %>%
  tidyr::pivot_longer(
    c(Understanding, Safety, `Would Repeat`, Enjoyment),
    names_to = "cust_category",
    values_to = "cust_value"
  ) %>%
  ggplot(
    aes(
      y = cust_value,
      x = redcap_event_name.factor,
      fill = redcap_event_name.factor,
      pattern = order.factor
    )
  ) +
  geom_boxplot_pattern(pattern_color = "white", pattern_density = .01) +
  facet_grid(rows = "cust_category") +
  plt_theme +
  scale_fill_manual(
    values = cust_color(10)[c(5, 8)],
    name = "Condition",
    guide = guide_legend(
      override.aes = list(pattern = "none"),
      reverse = T
    ),
  ) +
  scale_pattern_discrete(
    choices = c("circle", "none"),
    name = "Experimental Order",
    guide = guide_legend(
      override.aes = list(
        pattern_density = .5,
        pattern_size = .005,
        pattern_spacing = .01,
        fill = "black"
      ),
      reverse = T
    )
  )
) +
theme(axis.text.y = element_blank(), axis.ticks.y = element_blank()) +
xlab("Scale Rating - Difference from In Person") +
coord_flip()
```



- These questions aren't actually validated, when I designed the surveys, these were things that I wanted to know. But given that they are individual questions, not scales, I think maybe we should just throw them away. In the future we should be more careful to only use validated scales.

```
cust_plt <- post_cust_data %>%
  filter(name != "Enjoyment") %>%
  ggplot(aes(value, fill = forcats::fct_relevel(redcap_event_name.factor, "After Augmented", "After Classical", "After In Person"))) +
  plt_theme +
  facet_grid(rows = vars(name)) +
  geom_boxplot() +
  scale_fill_manual(
    values = cust_color(7)[c(2, 4, 6)],
    name = "Modality",
    breaks = c("After In Person", "After Classical", "After Augmented"),
    labels = c("FTF", "CT", "SRAT")
  ) +
  theme(axis.text.y = element_blank(), axis.ticks.y = element_blank(), axis.title.x = element_blank()) +
  scale_x_continuous(breaks = c(0, 25, 50, 75, 100), labels = c("Very Low", 25, 50, 75, "Very High"))

print(cust_plt)
```




```
fn <- file.path(out_dir, "tikz-cust_boxplot.tex")
tikz(
  file = fn,
  width = 5.8,
  height = 3,
  sanitize = TRUE
)
print(cust_plt)
dev.off()
```

```
## pdf
##   2
```

```
strip_tikz_white(fn)
```

IMI

Determine Consistent Measures in Sample

To determine whether the scales work, the authors of the IMI recommend doing a factor analysis. Their guidelines for inclusion of a question are that it has a factor loading of at least 0.6 on the appropriate sub scale and no cross loading above 0.4. Any questions which meet these criteria are then used in the scale as an equal weighted average.

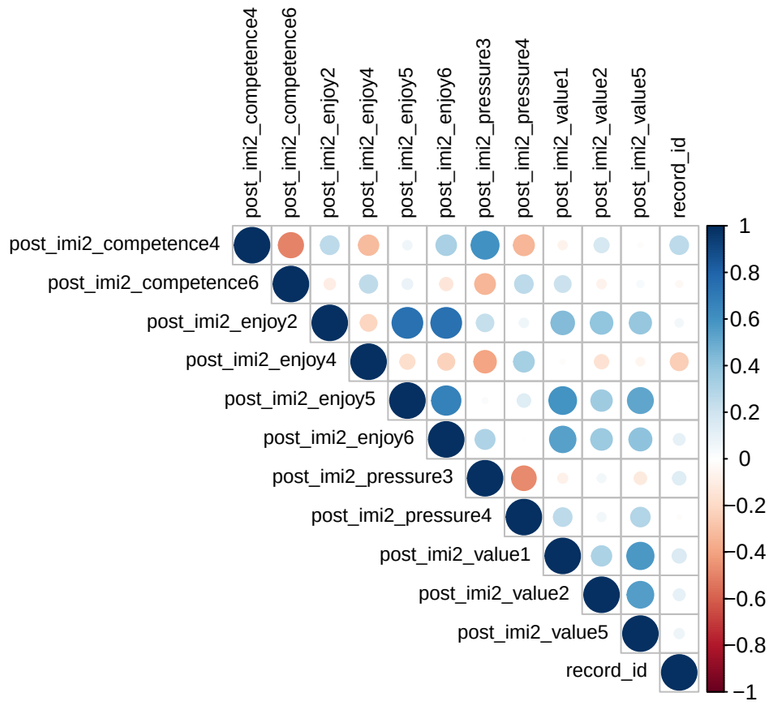
A difference from the original design is that we use 5 element Likert scales instead of 7. During the pilot study we found that 7 overwhelms subjects.

```
imi_data <-
  post_exp %>% select(
    starts_with("post_imi2") &
      !(ends_with("factor") | ends_with("_p")),
    record_id
  )
var.labels <- label(imi_data)
imi_data <- imi_data %>%
  mutate_at(vars(-record_id), as.numeric)
label(imi_data) <-
  as.list(var.labels[match(names(imi_data), names(var.labels))])
imi_data <- imi_data %>%
  select(sort(current_vars()))
```

```
## Warning: `current_vars()` was deprecated in dplyr 0.8.4.
## Please use `tidyselect::peek_vars()` instead.
```

```
## This warning is displayed once every 8 hours.
## Call `lifecycle::last_lifecycle_warnings()` to see where this warning was generated.
```

```
corrplot::corrplot(
  cor(imi_data),
  order = "alphabet",
  tl.col = "black",
  tl.cex = .75,
  type = "upper",
)
```




```
key_def <- list(
  Competence = c(1, -2),
  Enjoyment = c(3, -4, 5, 6),
  Pressure = c(-7, 8),
  Value = c(9, 10, 11)
)
# To make sure the definition is right:
keys_labelled <-
  psych::make.keys(nvars = 12, key_def, item.labels = label(imi_data))
knitr::kable(keys_labelled)
```

	Competence	Enjoyment	Pressure	Value
I am satisfied with my performance at these tasks	1	0	0	0
This was an activity that I couldnt do very well	-1	0	0	0
The activities were fun to do	0	1	0	0
The activities did not hold my attention at all	0	-1	0	0
I would describe the activities as very interesting	0	1	0	0
I thought the activities were quite enjoyable	0	1	0	0
I was very relaxed in doing the activities	0	0	-1	0
I was anxious while doing the activities	0	0	1	0
I believe the activities could be of some value to me	0	0	0	1
I think that doing these activities is useful for rehab	0	0	0	1
I think doing these activities could help me to improve my arm function	0	0	0	1
Study ID	0	0	0	0

```
keys <-
  psych::make.keys(nvars = 12, key_def, item.labels = colnames(imi_data))
```

```r
scores <- psych::scoreItems(keys = keys, items = imi_data)
scores
```

```
## Call: psych::scoreItems(keys = keys, items = imi_data)
##
## (Unstandardized) Alpha:
##       Competence Enjoyment Pressure Value
## alpha       0.66      0.76     0.63  0.73
##
## Standard errors of unstandardized Alpha:
##       Competence Enjoyment Pressure Value
## ASE         0.14     0.069     0.14 0.089
##
## Average item correlation:
##           Competence Enjoyment Pressure Value
## average.r       0.49      0.44     0.46  0.48
##
## Median item correlation:
## Competence  Enjoyment   Pressure      Value
##       0.49       0.45       0.47       0.56
##
##  Guttman 6* reliability:
##          Competence Enjoyment Pressure Value
## Lambda.6        0.6      0.81      0.6  0.75
##
## Signal/Noise based upon av.r :
##              Competence Enjoyment Pressure Value
## Signal/Noise        1.9       3.2      1.7   2.8
##
## Scale intercorrelations corrected for attenuation
##  raw correlations below the diagonal, alpha on the diagonal
##  corrected correlations above the diagonal:
##            Competence Enjoyment Pressure Value
## Competence      0.660      0.36    -0.78 -0.06
## Enjoyment       0.253      0.76    -0.28  0.75
## Pressure       -0.507     -0.19     0.63  0.31
## Value          -0.042      0.56     0.21  0.73
##
##  In order to see the item by scale loadings and frequency counts of the data
##  print with the short option = FALSE
```

```r
scores$item.corrected
```

```
##                         Competence   Enjoyment    Pressure       Value
## post_imi2_competence4  0.73998205  0.34794354 -0.69186386  0.02394110
## post_imi2_competence6 -0.60256792 -0.14030359  0.44353376  0.10471974
## post_imi2_enjoy2       0.26985031  0.85382659 -0.10610169  0.57056504
## post_imi2_enjoy4      -0.42579597 -0.30740922  0.53740502 -0.09437484
## post_imi2_enjoy5      -0.01767701  0.81345129  0.09824986  0.71467138
## post_imi2_enjoy6       0.33928167  0.82365549 -0.21141254  0.63053974
## post_imi2_pressure3    0.69855169  0.34136016 -0.73690660 -0.07877003
## post_imi2_pressure4   -0.44958525 -0.05349172  0.60755979  0.31269454
## post_imi2_value1      -0.20933855  0.56833489  0.26959190  0.70211690
## post_imi2_value2       0.17739392  0.45197049  0.01095323  0.59579434
## post_imi2_value5      -0.03944358  0.49183568  0.32228010  0.79441949
```

enjoy4 (The activities did not hold my attention at all) is poorly coorelated, so should be removed. We have observed this in the past, with some populations, the negative questions are just all over the place.

value2 (I think that doing these activities is useful for rehab) is also slightly low, but is close enough.

```r
key_def_2 <- list(
  Competence = c(1, -2),
  Enjoyment = c(3, 5, 6),
  Pressure = c(-7, 8),
  Value = c(9, 10, 11)
)
# To make sure the definition is right:
keys_2 <-
```

```
  psych::make.keys(
    nvars = 12,
    key_def_2,
    item.labels = colnames(imi_data)
  )
keys_2
```

```
##                       Competence Enjoyment Pressure Value
## post_imi2_competence4          1         0        0     0
## post_imi2_competence6         -1         0        0     0
## post_imi2_enjoy2               0         1        0     0
## post_imi2_enjoy4               0         0        0     0
## post_imi2_enjoy5               0         1        0     0
## post_imi2_enjoy6               0         1        0     0
## post_imi2_pressure3            0         0       -1     0
## post_imi2_pressure4            0         0        1     0
## post_imi2_value1               0         0        0     1
## post_imi2_value2               0         0        0     1
## post_imi2_value5               0         0        0     1
## record_id                      0         0        0     0
```

```
scores_2 <- psych::scoreItems(keys = keys_2, items = imi_data)
scores_2
```

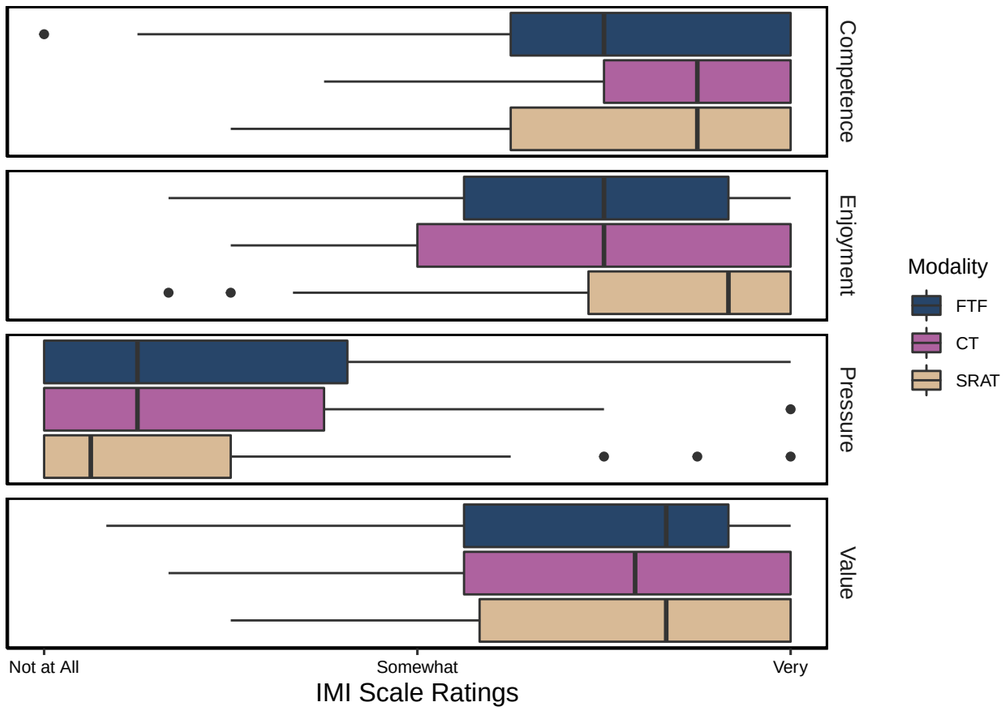
```
## Call: psych::scoreItems(keys = keys_2, items = imi_data)
##
## (Unstandardized) Alpha:
##       Competence Enjoyment Pressure Value
## alpha       0.66      0.88     0.63  0.73
##
## Standard errors of unstandardized Alpha:
##       Competence Enjoyment Pressure Value
## ASE         0.14     0.071     0.14 0.089
##
## Average item correlation:
##           Competence Enjoyment Pressure Value
## average.r       0.49      0.71     0.46  0.48
##
## Median item correlation:
## Competence  Enjoyment   Pressure      Value
##       0.49       0.74       0.47       0.56
##
##  Guttman 6* reliability:
##          Competence Enjoyment Pressure Value
## Lambda.6        0.6      0.87     0.58  0.75
##
## Signal/Noise based upon av.r :
##              Competence Enjoyment Pressure Value
## Signal/Noise        1.9       7.4      1.7   2.8
##
## Scale intercorrelations corrected for attenuation
##  raw correlations below the diagonal, alpha on the diagonal
##  corrected correlations above the diagonal:
##            Competence Enjoyment Pressure Value
## Competence      0.660     0.209   -0.785 -0.06
## Enjoyment       0.159     0.880   -0.073  0.77
## Pressure       -0.507    -0.055    0.633  0.31
## Value          -0.042     0.619    0.209  0.73
##
##  In order to see the item by scale loadings and frequency counts of the data
##  print with the short option = FALSE
```

```
scores_2$item.corrected
```

```
##                        Competence   Enjoyment    Pressure       Value
## post_imi2_competence4  0.74163511  0.25143112 -0.70109952  0.02394693
## post_imi2_competence6 -0.59763586 -0.04769172  0.44945447  0.10474522
```

```
## post_imi2_enjoy2       0.27053821  0.86353134 -0.10751804  0.57070383
## post_imi2_enjoy5      -0.01772207  0.83327098  0.09956139  0.71484522
## post_imi2_enjoy6       0.34014656  0.82633658 -0.21423468  0.63069312
## post_imi2_pressure3    0.70033243  0.21264974 -0.73371613 -0.07878919
## post_imi2_pressure4   -0.45073133  0.08302546  0.59420207  0.31277060
## post_imi2_value1      -0.20987219  0.62875475  0.27319068  0.70223127
## post_imi2_value2       0.17784613  0.43928839  0.01109944  0.59486871
## post_imi2_value5      -0.03954413  0.52797014  0.32658220  0.79450656
```

```r
imi_scores <- cbind(post_exp, data.frame(psych::scoreItems(keys = keys_2, items = imi_data)$scores))
imi.agg_plot <- imi_scores %>%
  tidyr::pivot_longer(
    c(Competence, Enjoyment, Pressure, Value),
    names_to = "imi_category",
    values_to = "imi_value"
  ) %>%
  ggplot(aes(imi_value, fill = redcap_event_name)) +
  geom_boxplot() +
  facet_grid(rows = "imi_category") +
  plt_theme +
  scale_fill_manual(
    values = cust_color(7)[c(2, 4, 6)],
    name = "Modality",
    breaks = c("after_in_person_arm_1", "after_classical_arm_1", "after_augmented_arm_1"),
    labels = c("FTF", "CT", "SRAT")
  ) +
  xlab("IMI Scale Ratings") +
  theme(axis.text.y = element_blank(), axis.ticks.y = element_blank()) +
  scale_x_continuous(limits = c(1, 5), breaks = c(1, 3, 5), labels = c("Not at All", "Somewhat", "Very"))

print(imi.agg_plot)
```




```r
fn <- file.path(out_dir, "tikz-imi_agg.tex")
tikz(
  file = fn,
  width = 5.8,
  height = 3.5,
  sanitize = TRUE
```

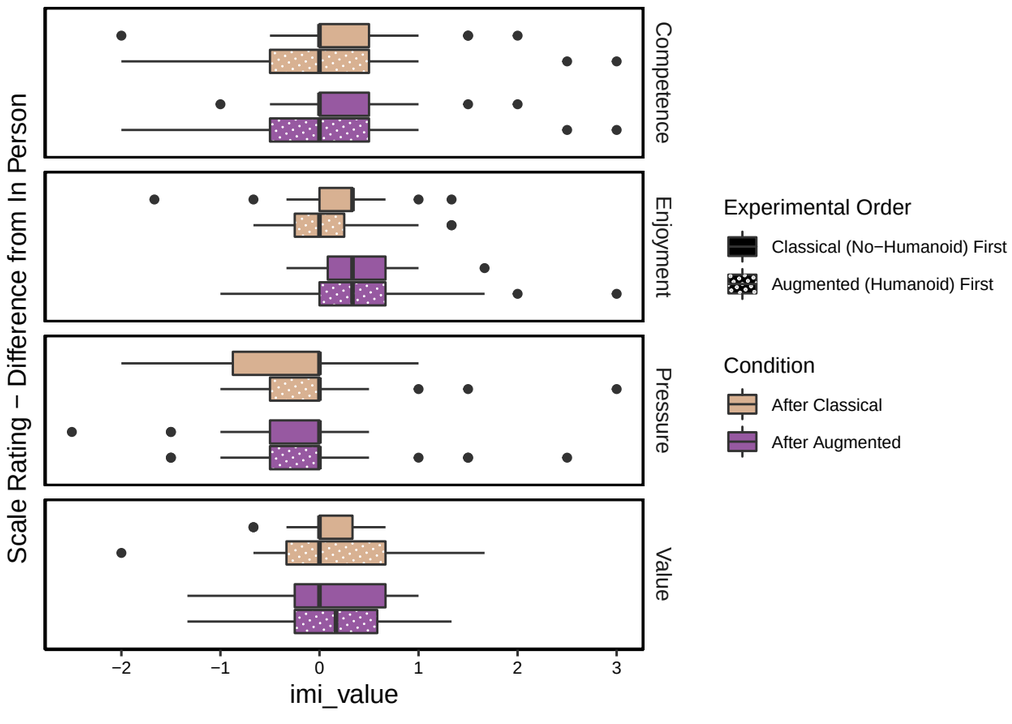
```
)
print(imi.agg_plot)
dev.off()
```

```
## pdf
##   2
```

```
strip_tikz_white(fn)
```

Let's take the same approach as above where we subtract out in person condition

```
imi_diff_plot_data <-
  cbind(post_exp, data.frame(psych::scoreItems(keys = keys_2, items = imi_data)$scores)) %>%
  group_by(record_id) %>%
  mutate(Competence = Competence - Competence[redcap_event_name.factor ==
    "After In Person"]) %>%
  mutate(Enjoyment = Enjoyment - Enjoyment[redcap_event_name.factor == "After In Person"]) %>%
  mutate(Pressure = Pressure - Pressure[redcap_event_name.factor == "After In Person"]) %>%
  mutate(Value = Value - Value[redcap_event_name.factor == "After In Person"]) %>%
  filter(redcap_event_name.factor != "After In Person") %>%
  ungroup()

imi_diff_plot_data %>%
  tidyr::pivot_longer(
    c(Competence, Enjoyment, Pressure, Value),
    names_to = "imi_category",
    values_to = "imi_value"
  ) %>%
  ggplot(
    aes(
      y = imi_value,
      x = redcap_event_name.factor,
      fill = redcap_event_name.factor,
      pattern = order.factor
    )
  ) +
  geom_boxplot_pattern(pattern_color = "white", pattern_density = .01) +
  facet_grid(rows = "imi_category") +
  plt_theme +
  scale_fill_manual(
    values = cust_color(10)[c(5, 8)],
    name = "Condition",
    guide = guide_legend(
      override.aes = list(pattern = "none"),
      reverse = T
    ),
  ) +
  scale_pattern_discrete(
    choices = c("circle", "none"),
    name = "Experimental Order",
    guide = guide_legend(
      override.aes = list(
        pattern_density = .5,
        pattern_size = .005,
        pattern_spacing = .01,
        fill = "black"
      ),
      reverse = T
    )
  ) +
  theme(axis.text.y = element_blank(), axis.ticks.y = element_blank()) +
  xlab("Scale Rating - Difference from In Person") +
  coord_flip()
```



Looks like the medians for most things here line up pretty close to the in person for all measures but enjoyment. For enjoyment, it looks like the values are a bit higher. There does appear to be an impact from ordering on enjoyment, when rating the classical condition (those who did classical first enjoyed it more than those who did SRAT first).

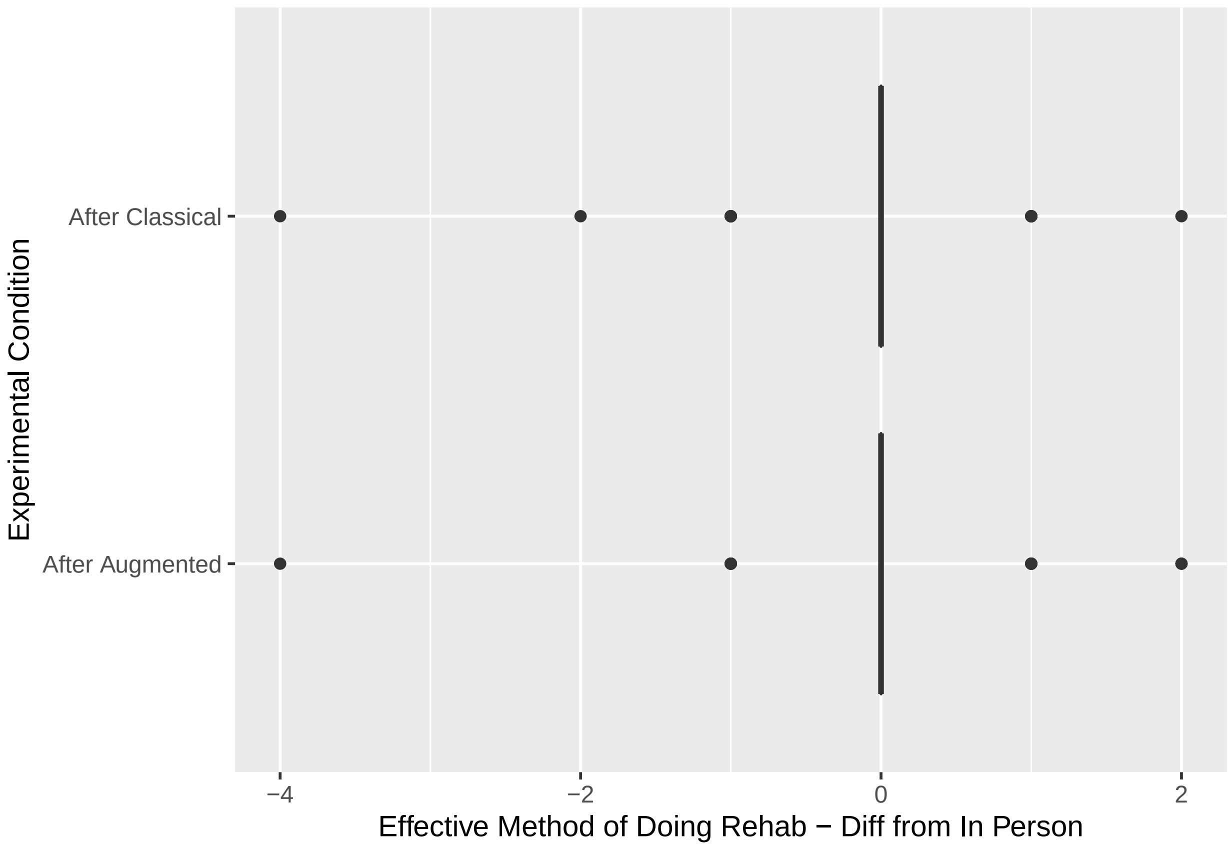
```
knitr::kable(skimr::skim_without_charts(imi_scores %>% select(Competence, Enjoyment, Pressure, Value, redcap_event_name.factor) %>% group_by(redcap_event_name.factor)))
```

skim_type	skim_variable	redcap_event_name.factor	n_missing	complete_rate	numeric.mean	numeric.sd	numeric.p0	numeric.p25	numeric.p50	numeric.p75	numeric.p100
numeric	Competence	After In Person	0	1	4.012500	1.0711095	1.000000	3.500000	4.000000	5.000000	5
numeric	Competence	After Augmented	0	1	4.162500	0.9014767	2.000000	3.500000	4.500000	5.000000	5
numeric	Competence	After Classical	0	1	4.187500	0.7653347	2.500000	4.000000	4.500000	5.000000	5
numeric	Enjoyment	After In Person	0	1	3.800000	1.0289264	1.666667	3.250000	4.000000	4.666667	5
numeric	Enjoyment	After Augmented	0	1	4.233333	0.9554164	1.666667	3.916667	4.666667	5.000000	5
numeric	Enjoyment	After Classical	0	1	3.925000	0.9562733	2.000000	3.000000	4.000000	5.000000	5
numeric	Pressure	After In Person	0	1	1.950000	1.1024448	1.000000	1.000000	1.500000	2.625000	5
numeric	Pressure	After Augmented	0	1	1.775000	1.0916349	1.000000	1.000000	1.250000	2.000000	5
numeric	Pressure	After Classical	0	1	1.837500	1.0462846	1.000000	1.000000	1.500000	2.500000	5
numeric	Value	After In Person	0	1	3.908333	0.9151697	1.333333	3.250000	4.333333	4.666667	5
numeric	Value	After Augmented	0	1	4.058333	0.9086087	2.000000	3.333333	4.333333	5.000000	5
numeric	Value	After Classical	0	1	4.008333	0.9651698	1.666667	3.250000	4.166667	5.000000	5

Custom IMI like question

This was an effective method of doing rehab

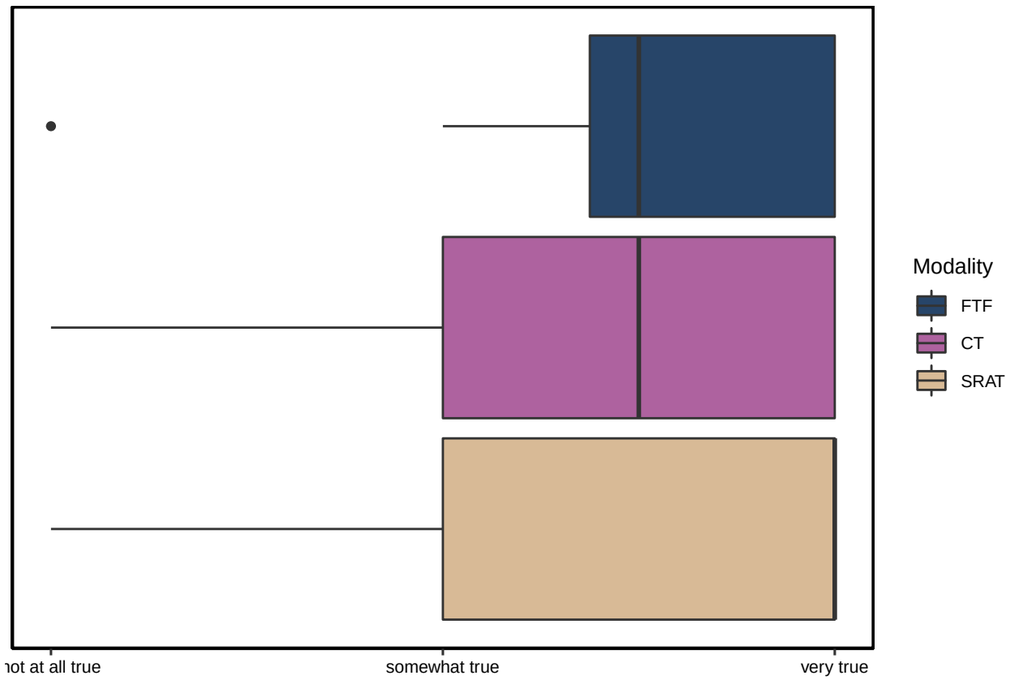
```
cust_er_diff_plot_data <- post_exp %>%
  group_by(record_id) %>%
  mutate(`Effective for Rehab` = as.numeric(post_cust2_effective_rehab -
    post_cust2_effective_rehab[redcap_event_name.factor == "After In Person"])) %>%
  filter(redcap_event_name.factor != "After In Person") %>%
  ungroup()

cust_er_diff_plot_data %>% ggplot(aes(y = `Effective for Rehab`, x = redcap_event_name.factor)) +
  geom_boxplot() +
  coord_flip() +
  xlab("Experimental Condition") +
  ylab("Effective Method of Doing Rehab - Diff from In Person")
```



Mostly nothing there. And this another non-validated question. I think we should just drop it.

```
eff_rehab_plt <- post_exp %>%
  ggplot(aes(post_cust2_effective_rehab, fill = forcats::fct_relevel(redcap_event_name.factor, "After Augmented", "After Classical", "After In Person"))) +
  plt_theme +
  geom_boxplot() +
  scale_fill_manual(
    values = cust_color(7)[c(2, 4, 6)],
    name = "Modality",
    breaks = c("After In Person", "After Classical", "After Augmented"),
    labels = c("FTF", "CT", "SRAT")
  ) +
  theme(axis.text.y = element_blank(), axis.ticks.y = element_blank()) +
  xlab("This was an effective method of doing rehab ") +
  scale_x_continuous(breaks = c(1, 3, 5), labels = c("not at all true", "somewhat true", "very true"))

print(eff_rehab_plt)
```

```
## Warning in grid.Call(C_textBounds, as.graphicsAnnot(x$label), x$x, x$y, : font width unknown for character 0x9

## Warning in grid.Call(C_textBounds, as.graphicsAnnot(x$label), x$x, x$y, : font width unknown for character 0x9

## Warning in grid.Call(C_textBounds, as.graphicsAnnot(x$label), x$x, x$y, : font width unknown for character 0x9

## Warning in grid.Call(C_textBounds, as.graphicsAnnot(x$label), x$x, x$y, : font width unknown for character 0x9

## Warning in grid.Call(C_textBounds, as.graphicsAnnot(x$label), x$x, x$y, : font width unknown for character 0x9

## Warning in grid.Call(C_textBounds, as.graphicsAnnot(x$label), x$x, x$y, : font width unknown for character 0x9

## Warning in grid.Call(C_textBounds, as.graphicsAnnot(x$label), x$x, x$y, : font width unknown for character 0x9
## Warning in grid.Call.graphics(C_text, as.graphicsAnnot(x$label), x$x, x$y, : font width unknown for character 0x9
```




```
fn <- file.path(out_dir, "tikz-eff_rehab.tex")
tikz(
  file = fn,
  width = 5.8,
  height = 1.25,
  sanitize = TRUE
)
print(eff_rehab_plt)
dev.off()
```

```
## pdf
##   2
```

```
strip_tikz_white(fn)
```

Mixed Model with Repeated Measures

There is a good guide on designing mixed effect models here: https://lme4.r-forge.r-project.org/book/Ch2.pdf

- dependent: survey answers (IMI and TLX)
- treatment: interaction with robot (`interaction.modality`)
- Random Variables: subject, robot.operator
- Factors: age, color trails 2, bbt (weak side max score), order

Random effect (understand here: https://youtu.be/FCcVPsq8VcA): - Record ID; to avoid pseudo replication and handle repeated measures - operator; we use three of the many thousands of possible operators

Although `robot.operator` should be a random effect, we don't have enough samples of different robot operators (only 3). So we must treat it as a fixed effect. It is reasonable to think that different operators perform differently in different conditions. It might be the case that different operators interact differently with various age groups/impairment groups, but that is a stretch, will not test that.

A good argument could be made that `experimental.order` is a random effect, but we only have 2 experimental orders, so not possible to do that.

For understanding how the random effects are specified: https://stats.stackexchange.com/a/61466/192527

This leads to equations of the form: `<dependent>~interaction.modality*((Age*BBT*CTT2)+experimental.order+robot.operator)+(1|subject)`

It would be prefered if BBT and CTT2 were independent, we know that they are not. But we also know that they aren't completely coorelated (we would collapse them). This is a common situation in these types of analyses, and it is customary to move forward.

This is the data we are going to work with:

```
all_data <-
  cbind(post_exp, data.frame(psych::scoreItems(keys = keys_2, items = imi_data)$scores)) %>%
  mutate(
    subject = record_id,
```

```
    interaction.modality = redcap_event_name.factor,
    experimental.order = order.factor,
    robot.operator = team_operator.factor,
    CTT2 = color_trails_2_standard,
    BBT = bbt.score.weak,
    TLX = post_tlx_avg,
    Age = age
  ) %>%
  mutate(
    interaction.modality = forcats::fct_recode(interaction.modality, "FTF" = "After In Person", "CT" = "After Classical", "SRAT" = "After Augmented"),
    experimental.order = forcats::fct_recode(experimental.order, "SRAT First" = "Augmented (Humanoid) First", "CT First" = "Classical (No-Humanoid) First"),
    robot.operator = forcats::fct_recode(robot.operator, "MS" = "Michael Sobrepera", "AA" = "Ajay Anand", "TA" = "Tuan Anh Nguyen")
  )
all_data$interaction.modality <- droplevels(all_data$interaction.modality)
target.data <-
  all_data %>% select(
    subject,
    interaction.modality,
    experimental.order,
    robot.operator,
    Age,
    CTT2,
    BBT,
    Competence,
    Enjoyment,
    Pressure,
    Value,
    TLX
  )
str(target.data)
```

```
## 'data.frame':    120 obs. of  12 variables:
##  $ subject             : 'labelled' int  12 12 12 13 13 13 14 14 14 15 ...
##   ..- attr(*, "label")= chr "Study ID"
##  $ interaction.modality: Factor w/ 3 levels "FTF","SRAT","CT": 1 2 3 1 2 3 1 2 3 1 ...
##  $ experimental.order  : Factor w/ 2 levels "SRAT First","CT First": 1 1 1 2 2 2 1 1 1 2 ...
##  $ robot.operator      : Factor w/ 3 levels "MS","AA","TA": 1 1 1 1 1 1 1 1 1 1 ...
##  $ Age                 : 'labelled' num  75 75 75 62 62 62 31 31 31 5 ...
##   ..- attr(*, "label")= chr "Age (years)"
##  $ CTT2                : 'labelled' num  -3.1 -3.1 -3.1 -1.5 -1.5 -1.5 1.1 1.1 1.1 NA ...
##   ..- attr(*, "label")= chr "Color Trails 2 T-Score"
##  $ BBT                 : 'labelled' num  -3.32 -3.32 -3.32 -4.81 -4.81 ...
##   ..- attr(*, "label")= chr "Box and Block 1 - Left Arm"
##  $ Competence          : num  5 4.5 4.5 2.5 2.5 2.5 3.5 3.5 4 4 ...
##  $ Enjoyment           : num  3.67 4 4 3.67 4 ...
##  $ Pressure            : num  2 2 1.5 4.5 4.5 3 1 1 1.5 1.5 ...
##  $ Value               : num  2.67 3 3.33 5 4.67 ...
##  $ TLX                 : 'labelled' num  3.6 2.4 7.2 76 50.2 57.8 26 18.6 24 19.6 ...
##   ..- attr(*, "label")= chr "Mental Demand: How mentally demanding was the interaction?"
```

```
summary(target.data)
```

```
##     subject      interaction.modality  experimental.order robot.operator      Age             CTT2              BBT        
##  Min.   :12.00   FTF :40              SRAT First:66       MS:78          Min.   : 4.00   Min.   :-5.0000   Min.   :-11.7042  
##  1st Qu.:24.50   SRAT:40              CT First  :54       AA:21          1st Qu.:13.75   1st Qu.:-1.5000   1st Qu.: -4.8899  
##  Median :38.50   CT  :40                                 TA:21          Median :28.50   Median :-0.1500   Median : -3.1944  
##  Mean   :38.58                                                          Mean   :34.83   Mean   :-0.6447   Mean   : -3.8261  
##  3rd Qu.:52.50                                                          3rd Qu.:57.75   3rd Qu.: 0.7000   3rd Qu.: -1.8697  
##  Max.   :69.00                                                          Max.   :81.00   Max.   : 1.7000   Max.   :  0.4831  
##                                                                                         NA's   :6                           
##    Competence      Enjoyment        Pressure         Value            TLX        
##  Min.   :1.000   Min.   :1.667   Min.   :1.000   Min.   :1.333   Min.   : 0.00  
##  1st Qu.:3.500   1st Qu.:3.333   1st Qu.:1.000   1st Qu.:3.333   1st Qu.:13.90  
##  Median :4.500   Median :4.000   Median :1.500   Median :4.333   Median :26.00  
##  Mean   :4.121   Mean   :3.986   Mean   :1.854   Mean   :3.992   Mean   :31.86  
##  3rd Qu.:5.000   3rd Qu.:5.000   3rd Qu.:2.500   3rd Qu.:5.000   3rd Qu.:50.50
```

```
##  Max.   :5.000   Max.   :5.000   Max.   :5.000   Max.   :5.000   Max.   :99.00
##                                                                 NA's   :1
```

Levels to plot in interaction plots

Based on realistic scores on these tests, won't affect analysis, just for visualization:

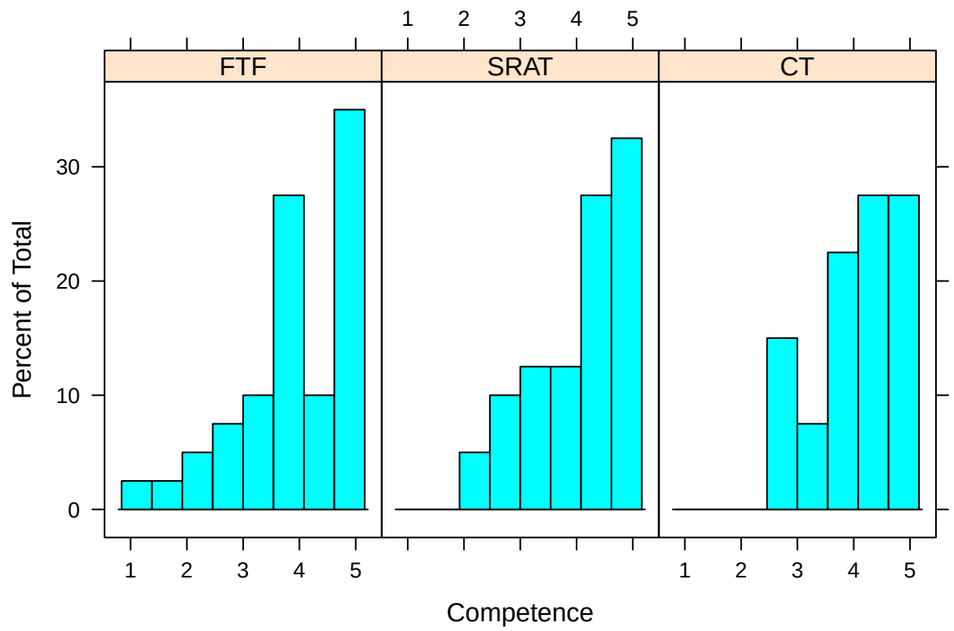
```
interaction.levels <- list(
  BBT = -5:0,
  CTT2 = -4:1,
  Age = 6:80
)
```

Check data

We don't expect to see anything here without considering interactions, but we do want to make sure none of our data looks wrong.

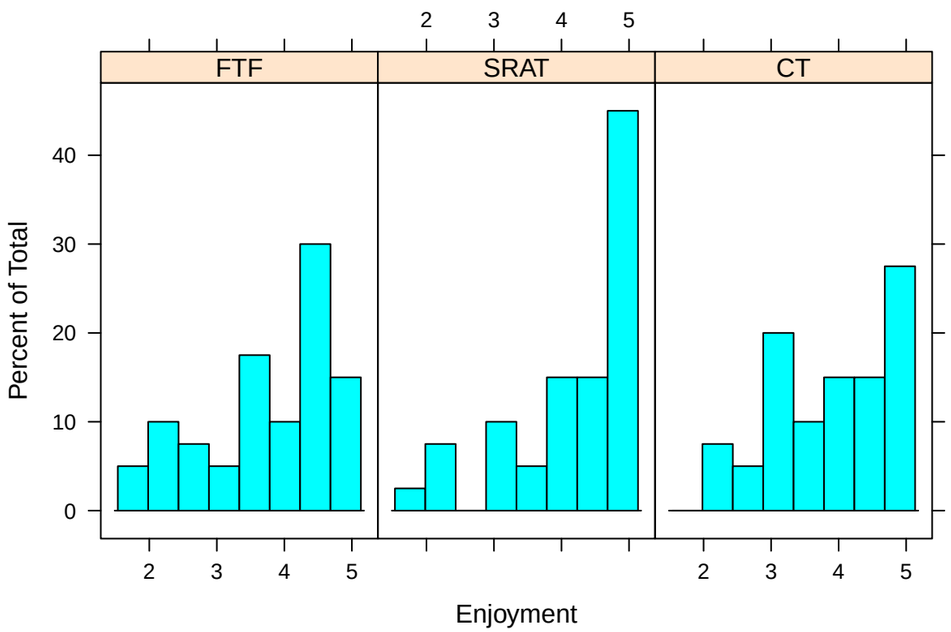
We want random effects and residuals to have normal distributions. But it is OK if the residuals aren't actually meeting assumptions: https://besjournals.onlinelibrary.wiley.com/doi/full/10.1111/2041-210X.13434 That will be checked after we run each model.

```
histogram(~ Competence | interaction.modality, data = all_data)
```

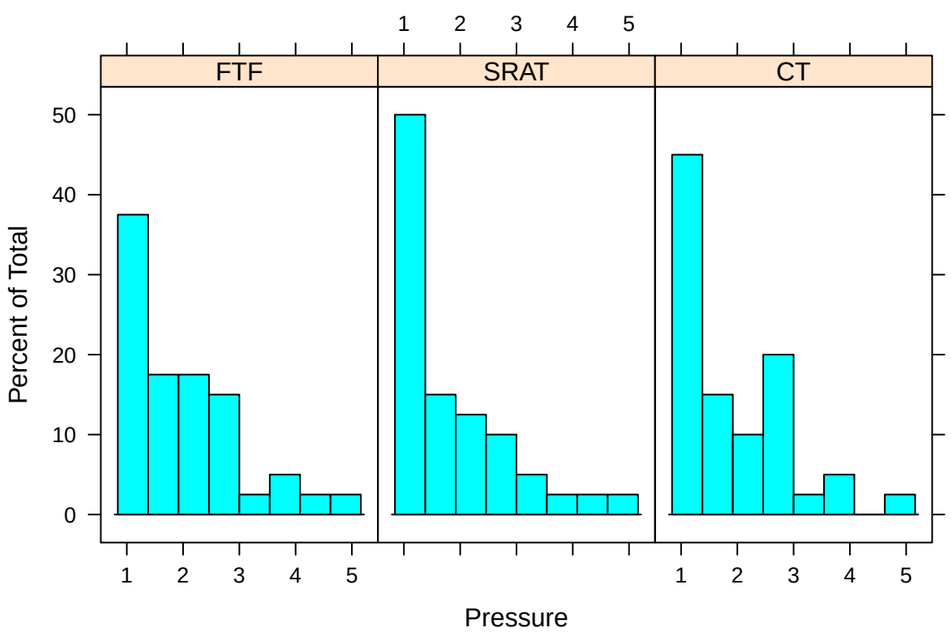


Modality

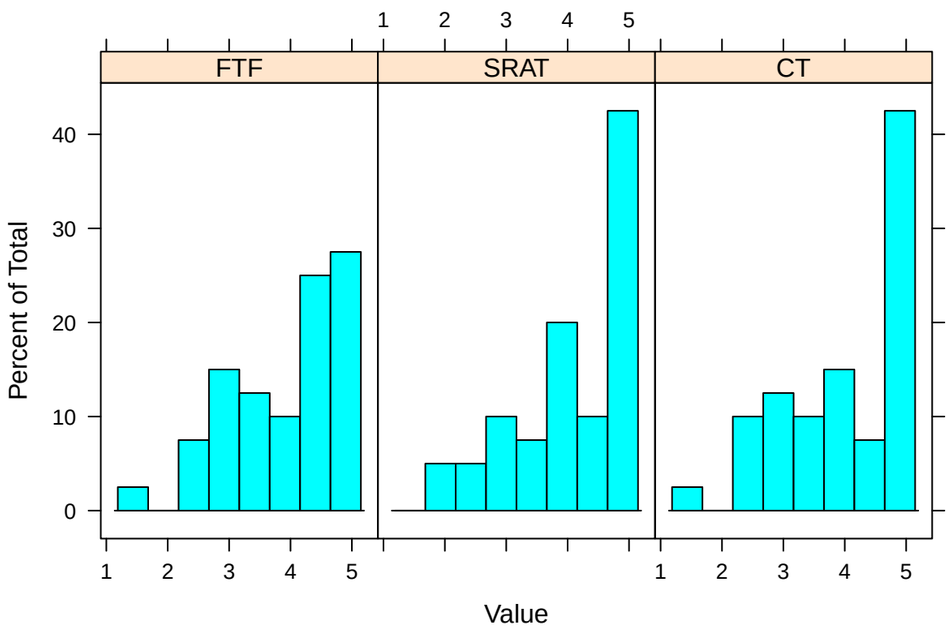
```
histogram(~ Enjoyment | interaction.modality, data = all_data)
```



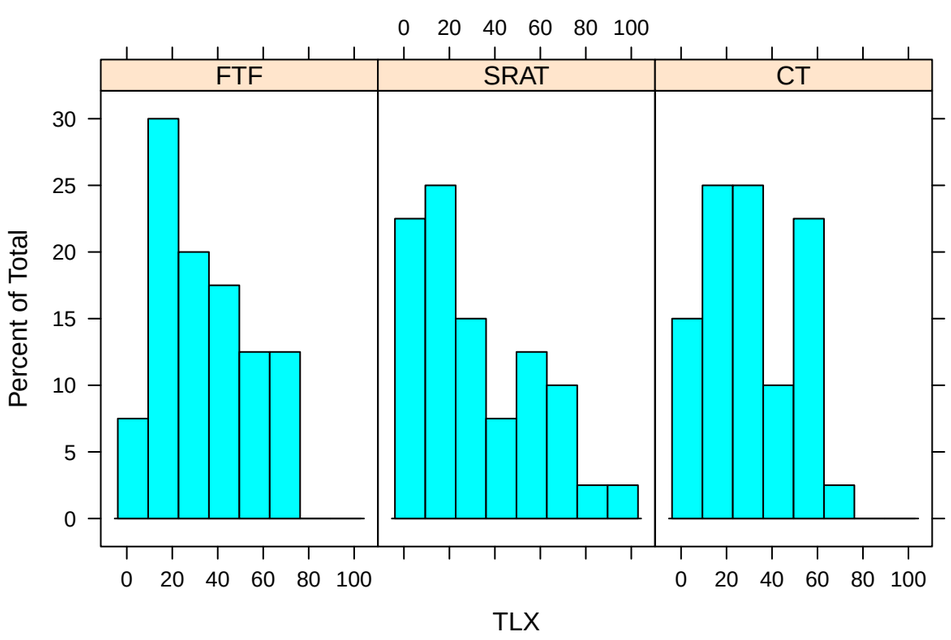

```
histogram(~ Pressure | interaction.modality, data = all_data)
```



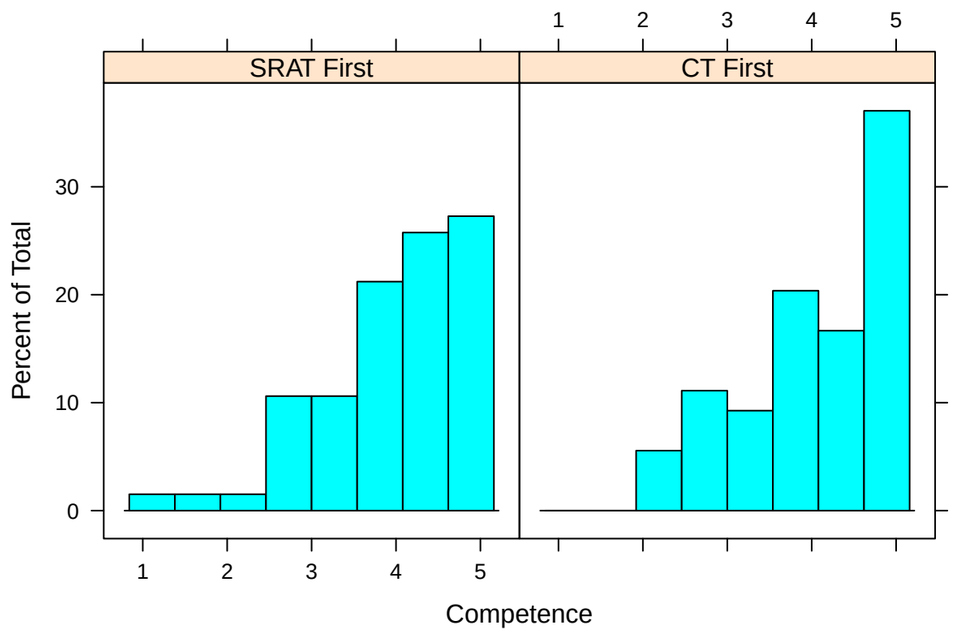

```
histogram(~ Value | interaction.modality, data = all_data)
```




```
histogram(~ TLX | interaction.modality, data = all_data)
```

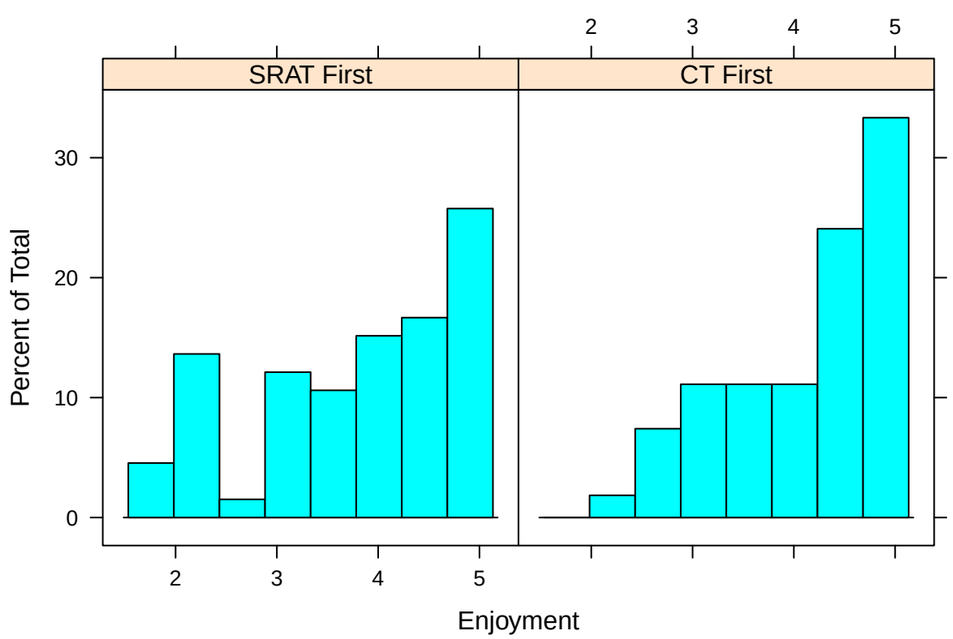



```
histogram(~ Competence | experimental.order, data = all_data)
```

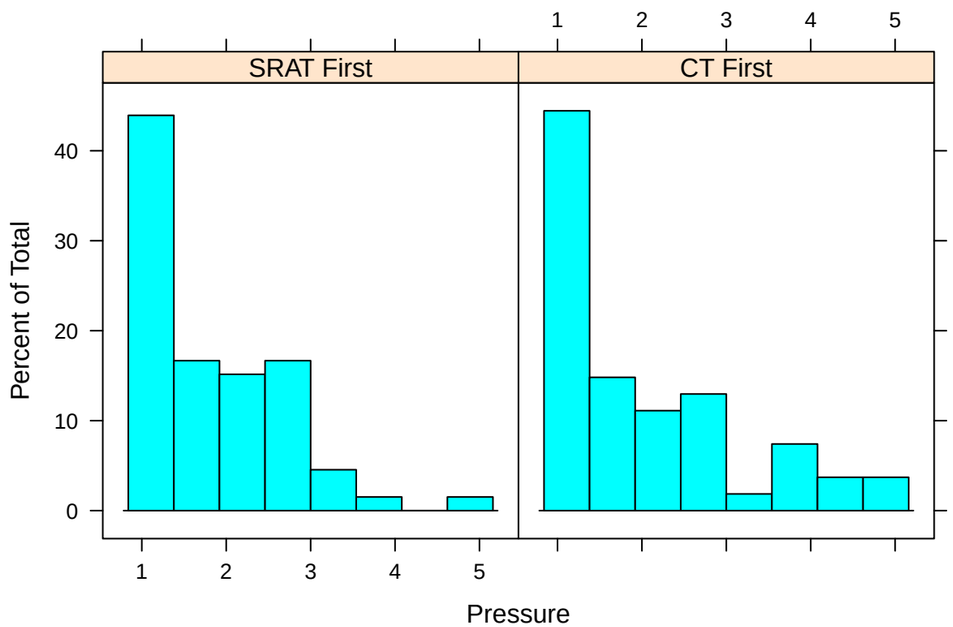


Experimental Order

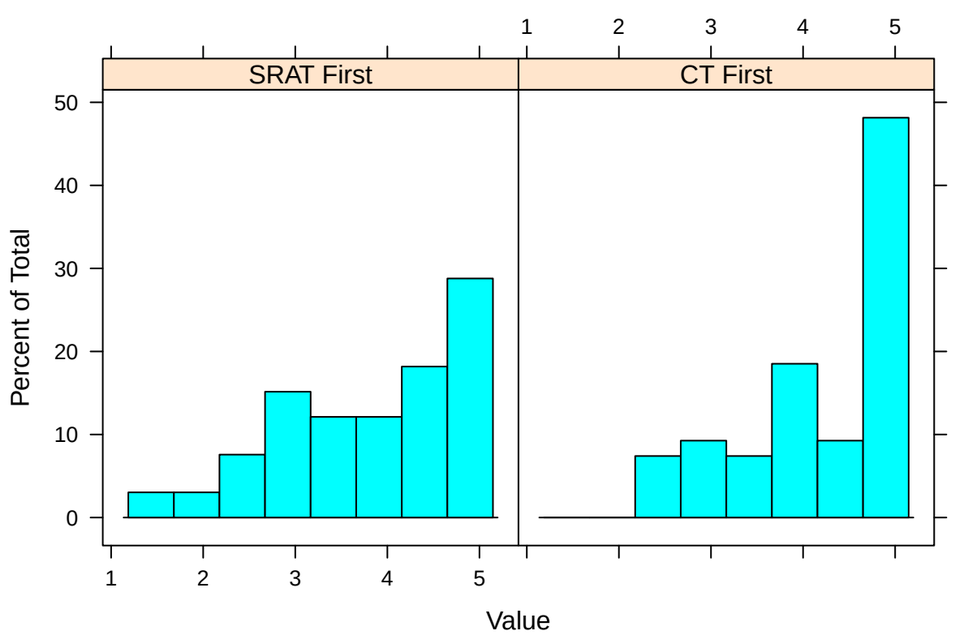
```
histogram(~ Enjoyment | experimental.order, data = all_data)
```



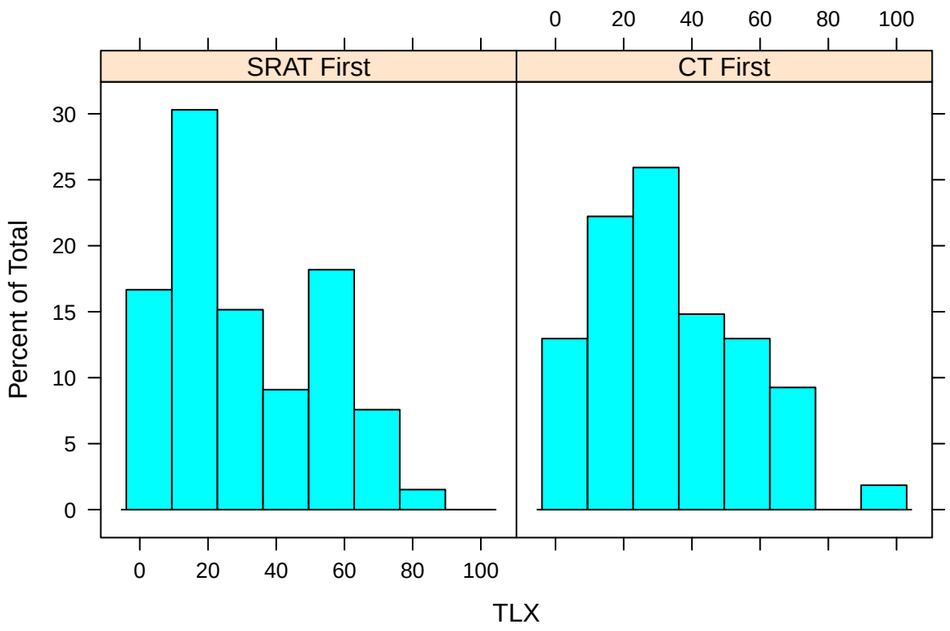

```
histogram(~ Pressure | experimental.order, data = all_data)
```



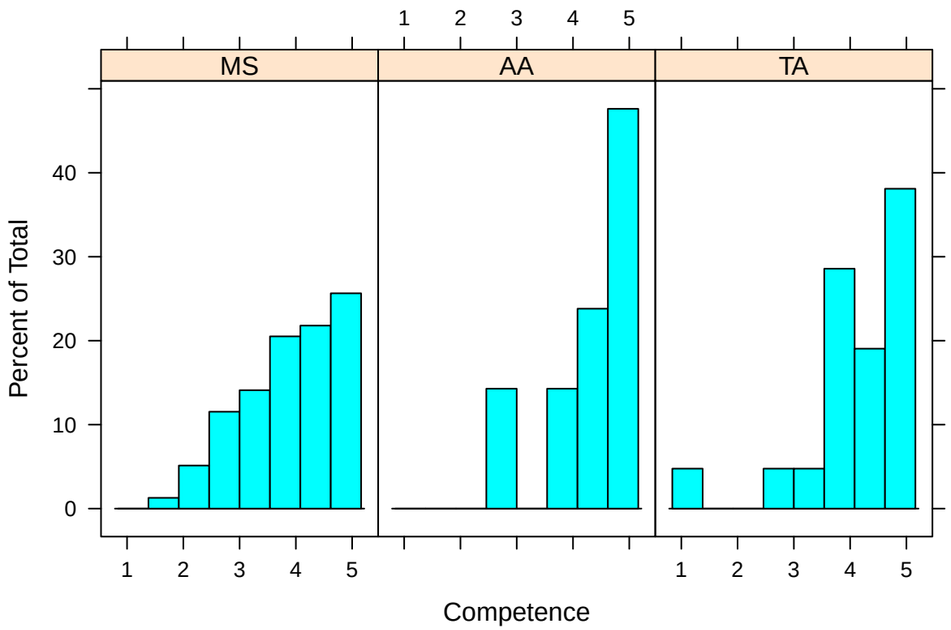

```
histogram(~ Value | experimental.order, data = all_data)
```




```
histogram(~ TLX | experimental.order, data = all_data)
```

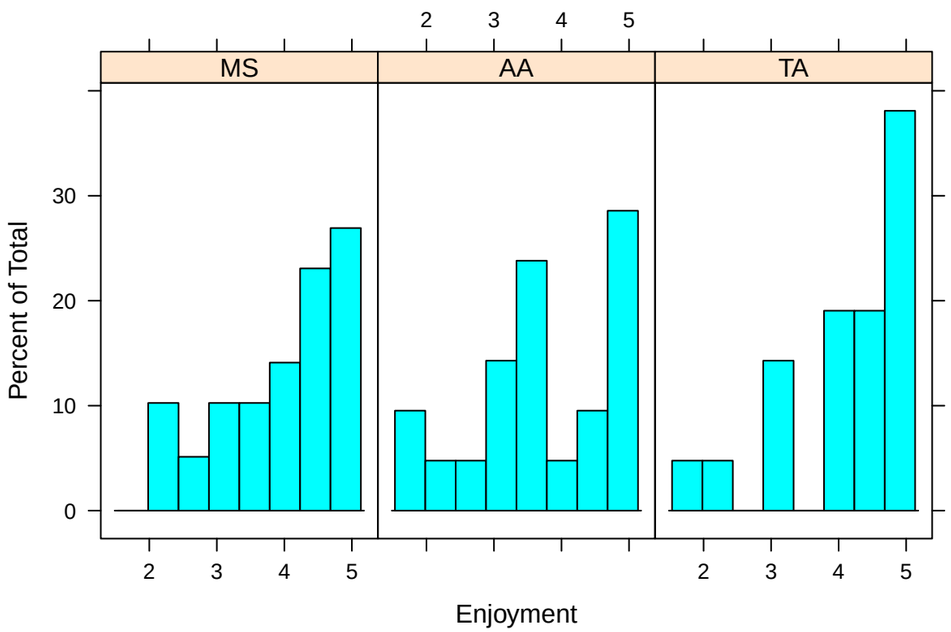



```
histogram(~ Competence | robot.operator, data = all_data)
```

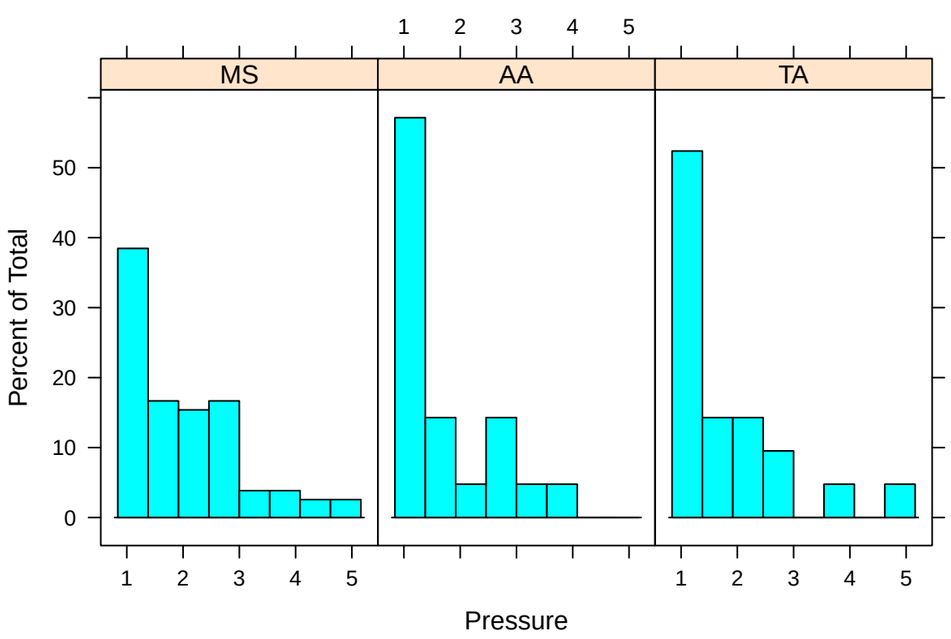


Robot Operator

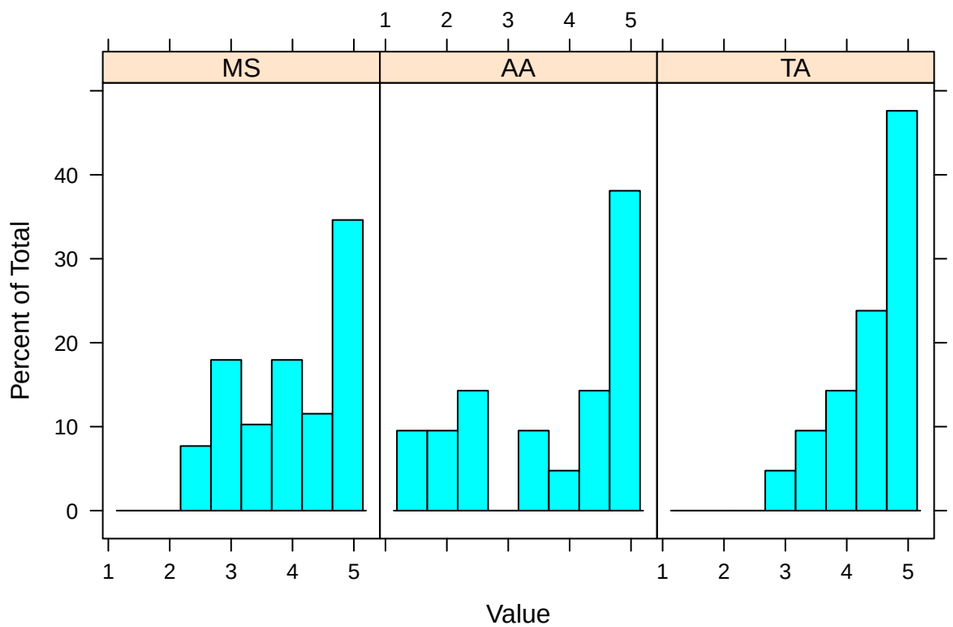
```
histogram(~ Enjoyment | robot.operator, data = all_data)
```



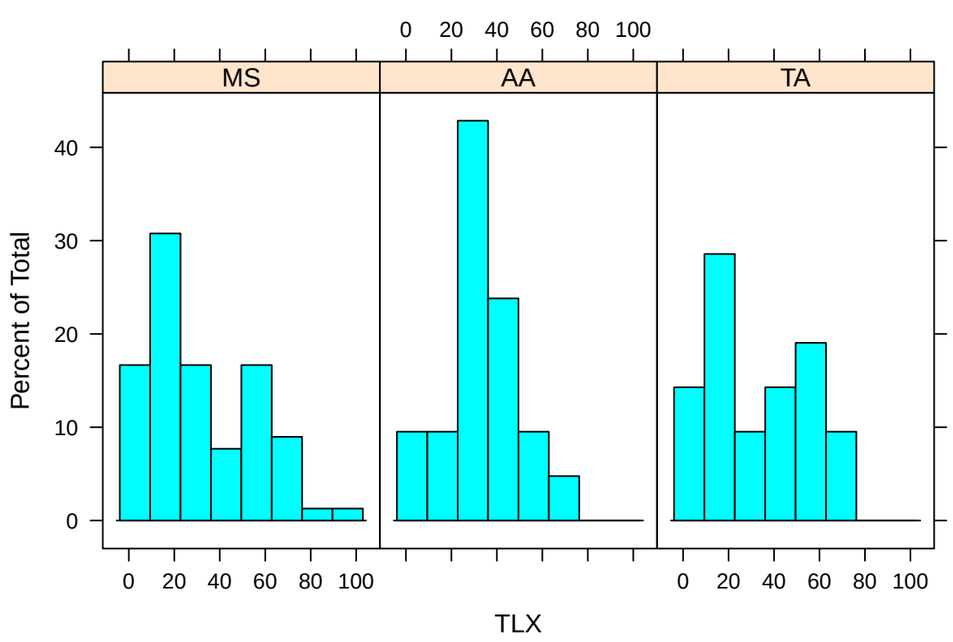

```
histogram(~ Pressure | robot.operator, data = all_data)
```



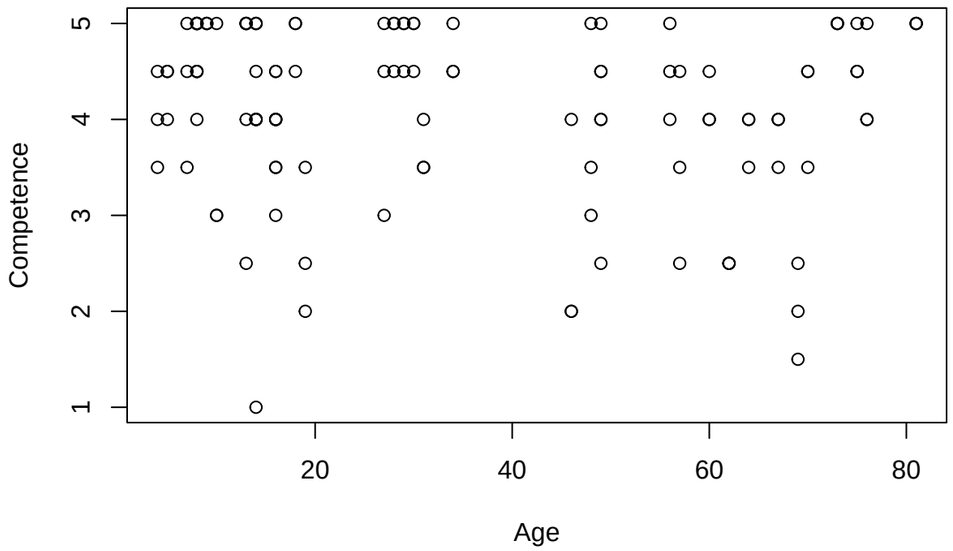

```
histogram(~ Value | robot.operator, data = all_data)
```




```
histogram(~ TLX | robot.operator, data = all_data)
```

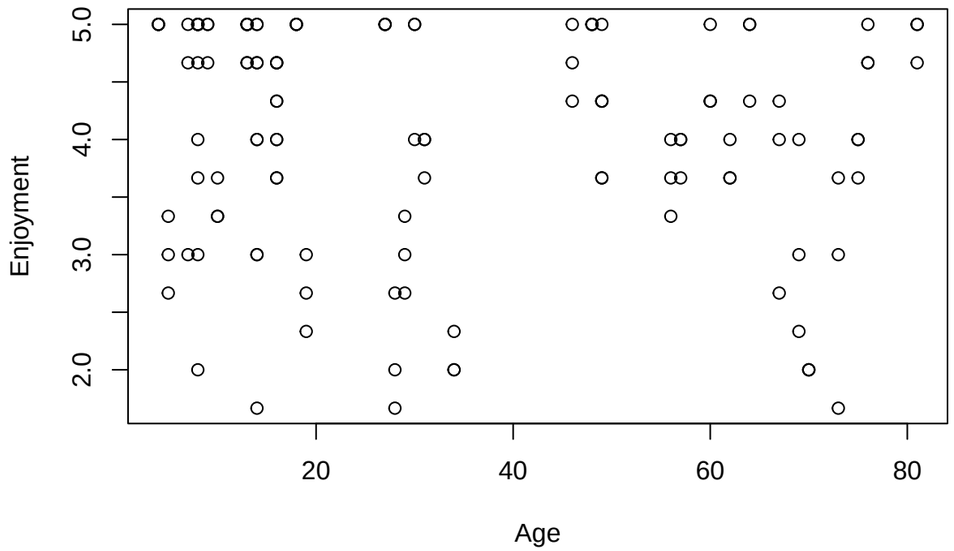



```
plot(Competence ~ Age, data = all_data)
```

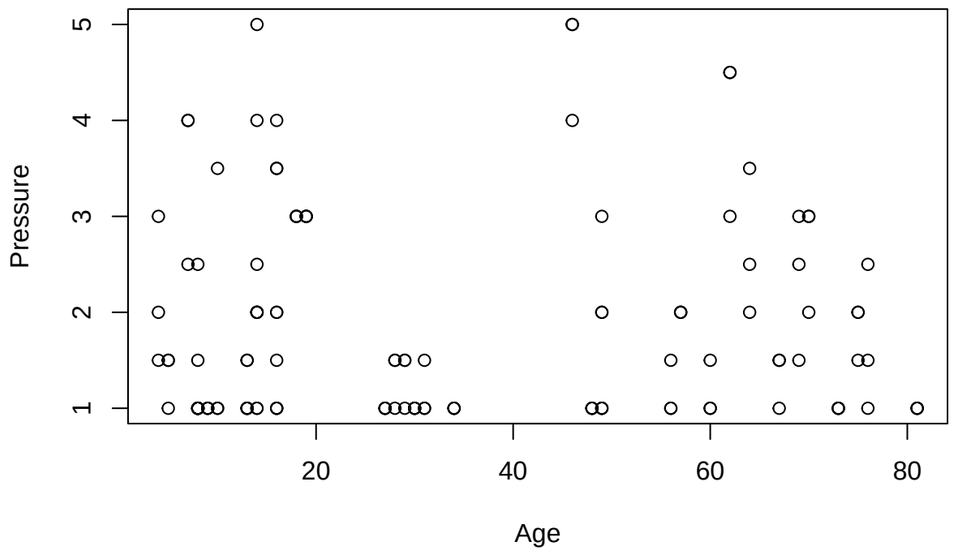


Age

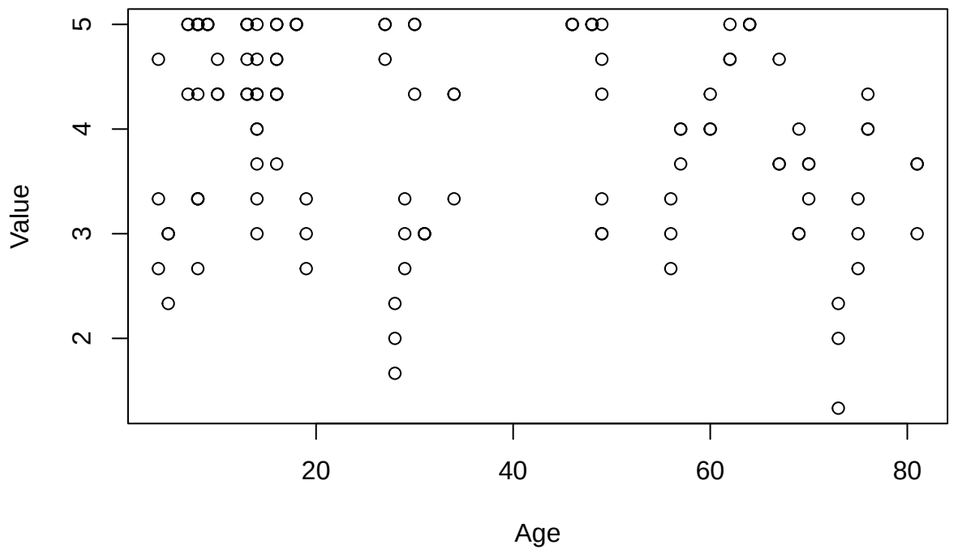
```
plot(Enjoyment ~ Age, data = all_data)
```



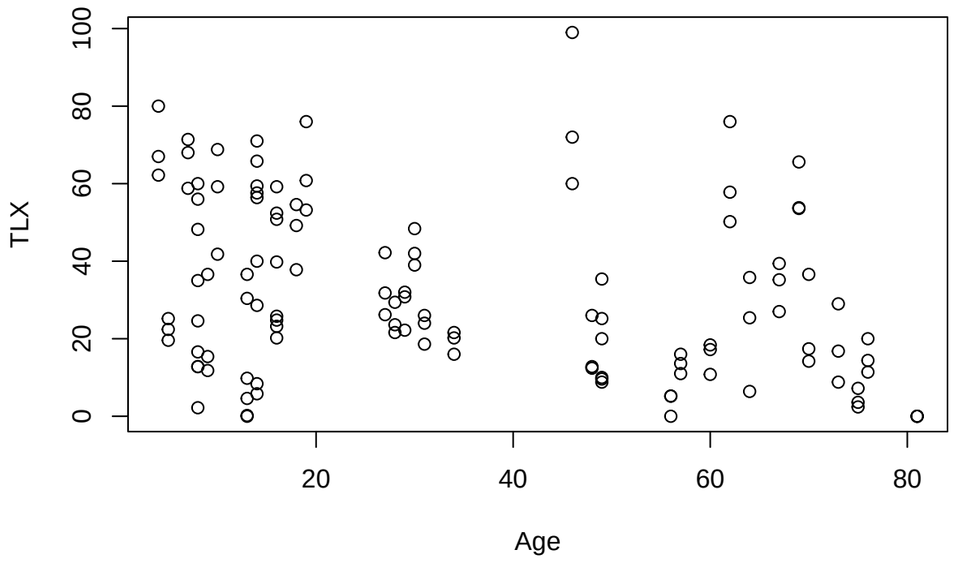

```
plot(Pressure ~ Age, data = all_data)
```




```
plot(Value ~ Age, data = all_data)
```



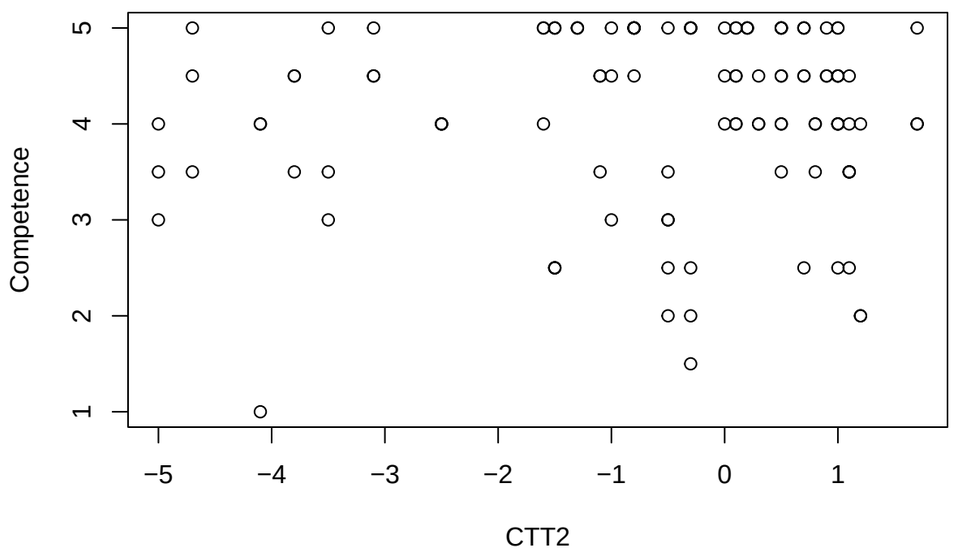

```
plot(TLX ~ Age, data = all_data)
```



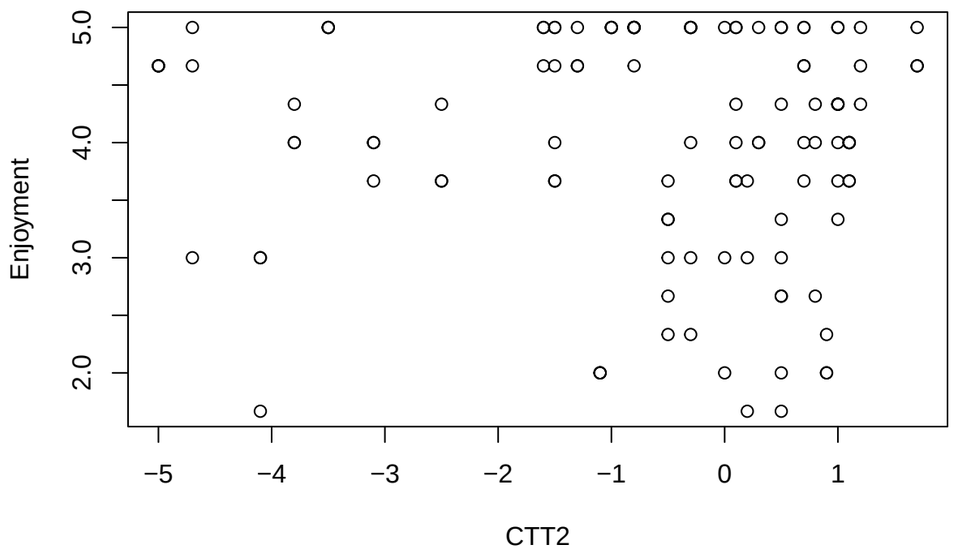
CTT Recall:

- Mild impairment is -1 to -2
- Moderate impairment is -2 to -3
- Severe impairment less than -3

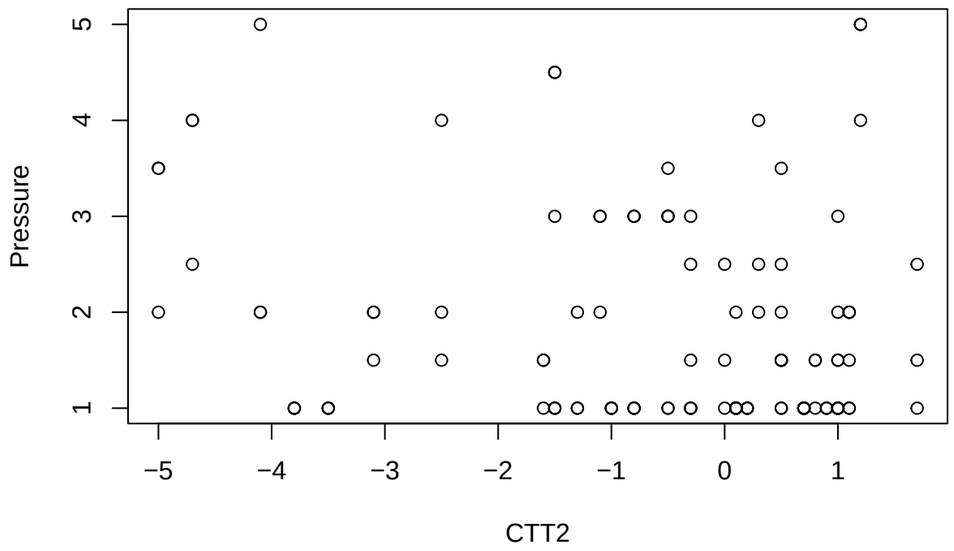
```
plot(Competence ~ CTT2, data = all_data)
```



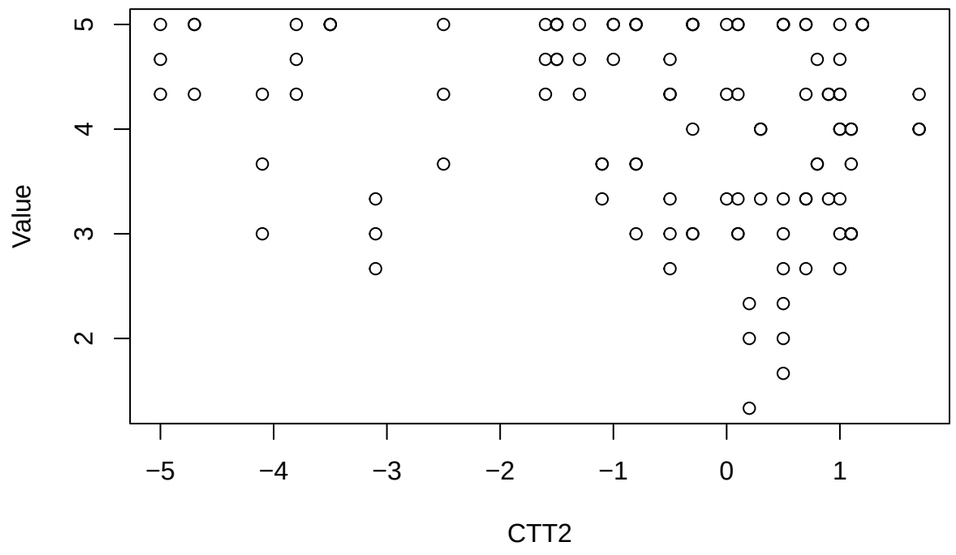

```
plot(Enjoyment ~ CTT2, data = all_data)
```



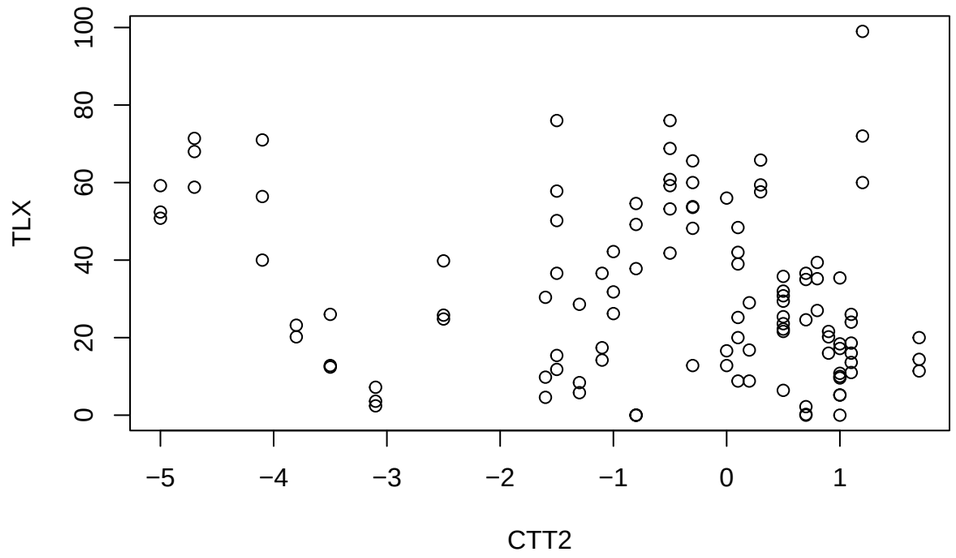

```
plot(Pressure ~ CTT2, data = all_data)
```




```
plot(Value ~ CTT2, data = all_data)
```



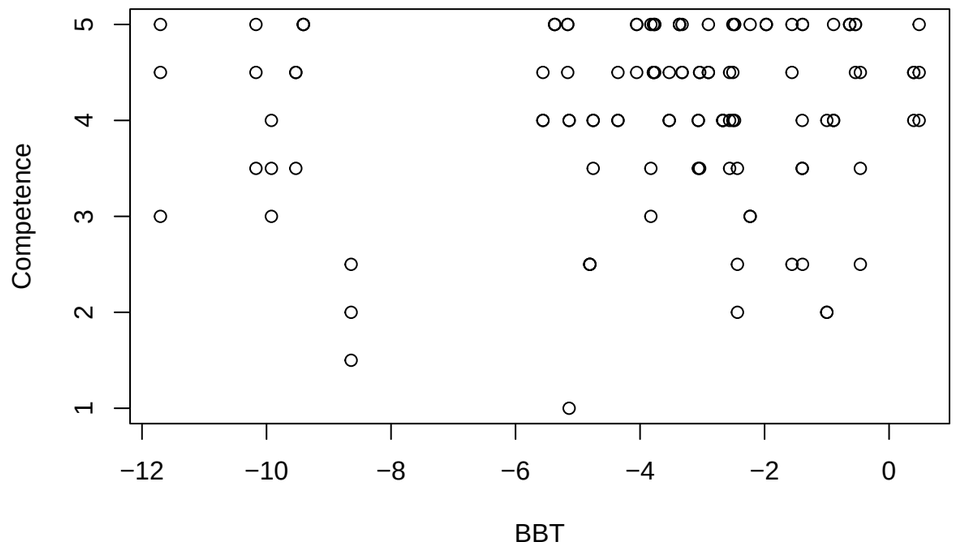

```
plot(TLX ~ CTT2, data = all_data)
```



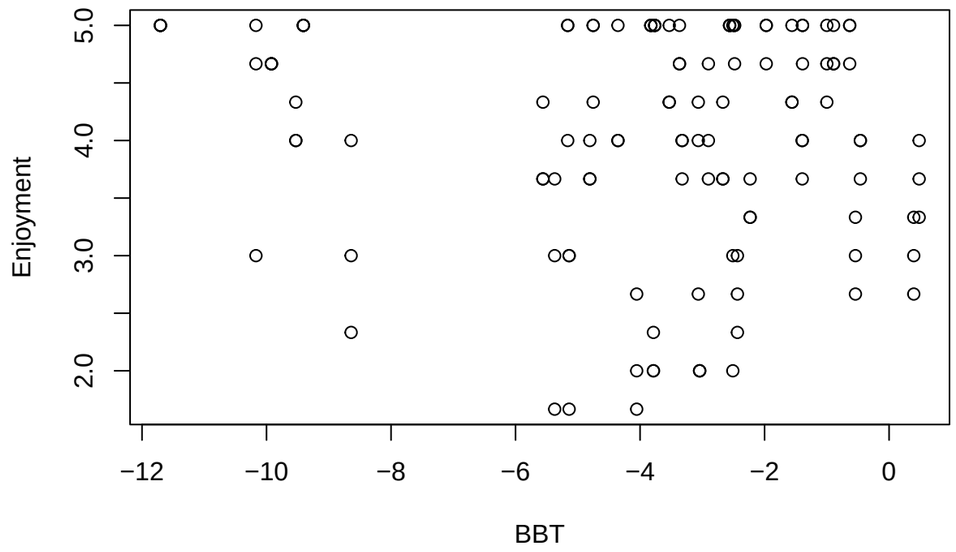
BBT Recall:

- Mild impairment is -1 to -2
- Moderate impairment is -2 to -3
- Severe impairment less than -3

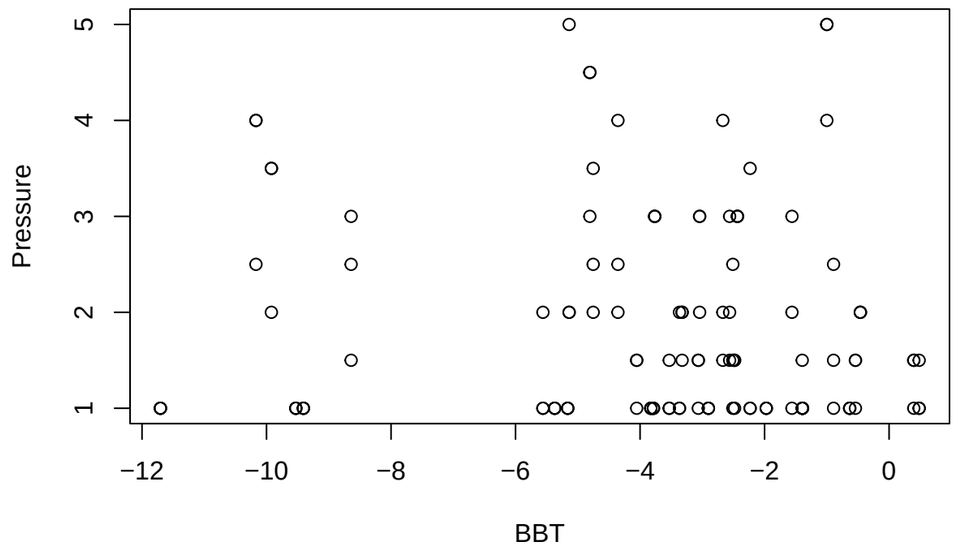
```
plot(Competence ~ BBT, data = all_data)
```



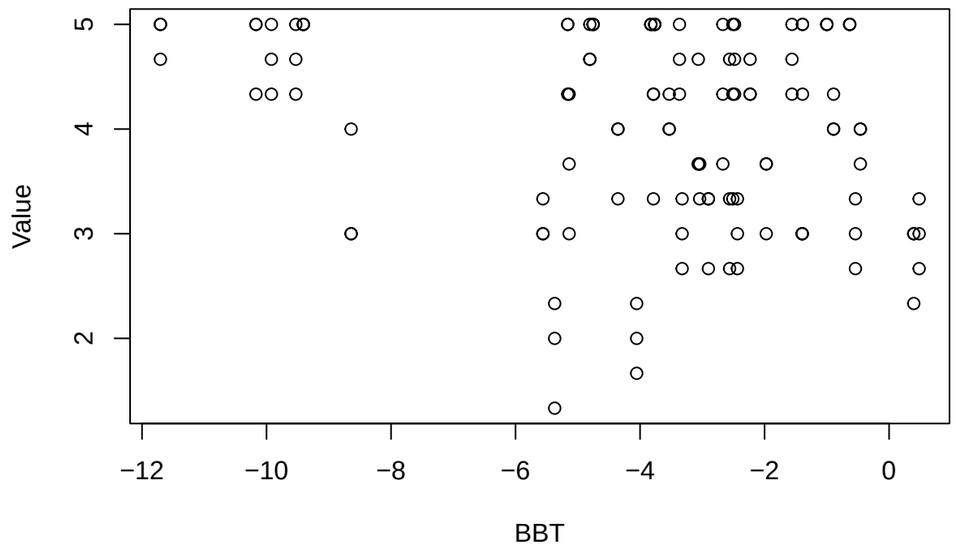

```
plot(Enjoyment ~ BBT, data = all_data)
```



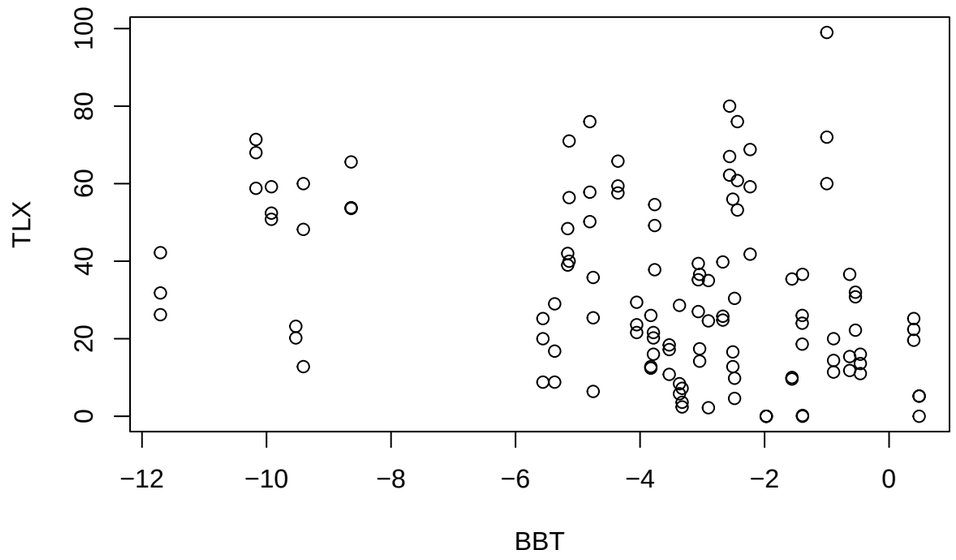

```
plot(Pressure ~ BBT, data = all_data)
```



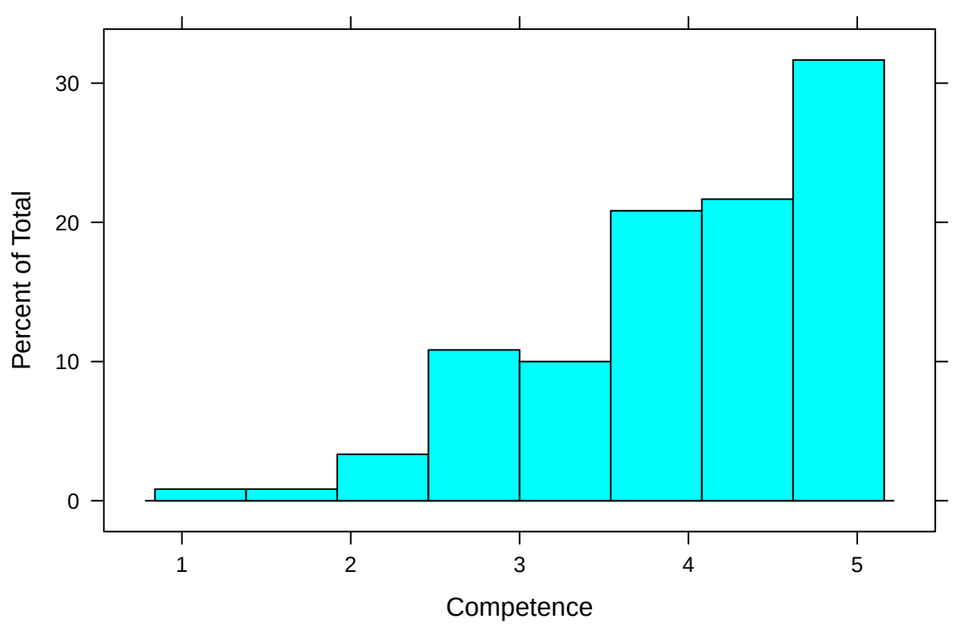

```
plot(Value ~ BBT, data = all_data)
```




```
plot(TLX ~ BBT, data = all_data)
```

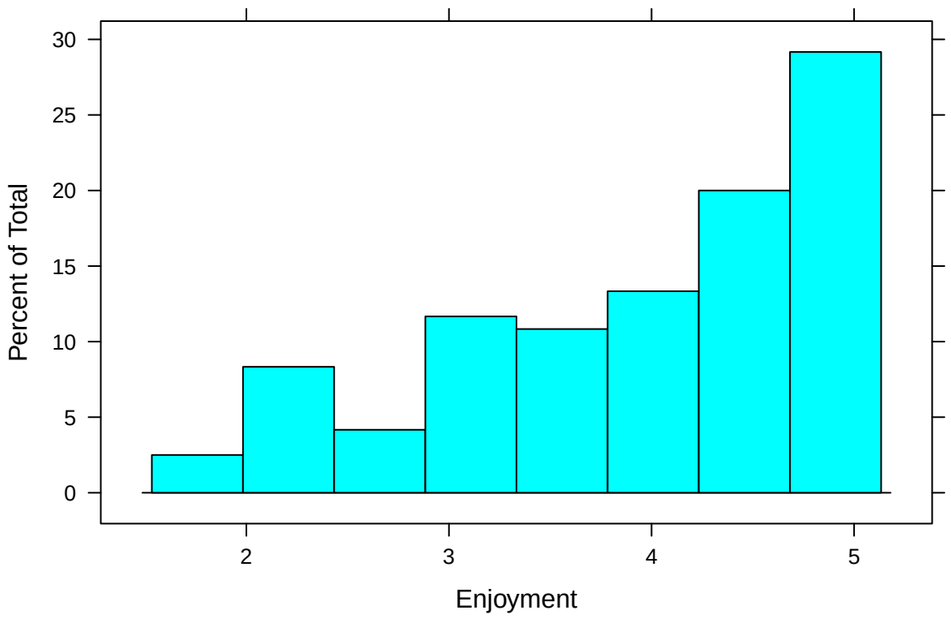



```
histogram(~Competence, data = all_data)
```

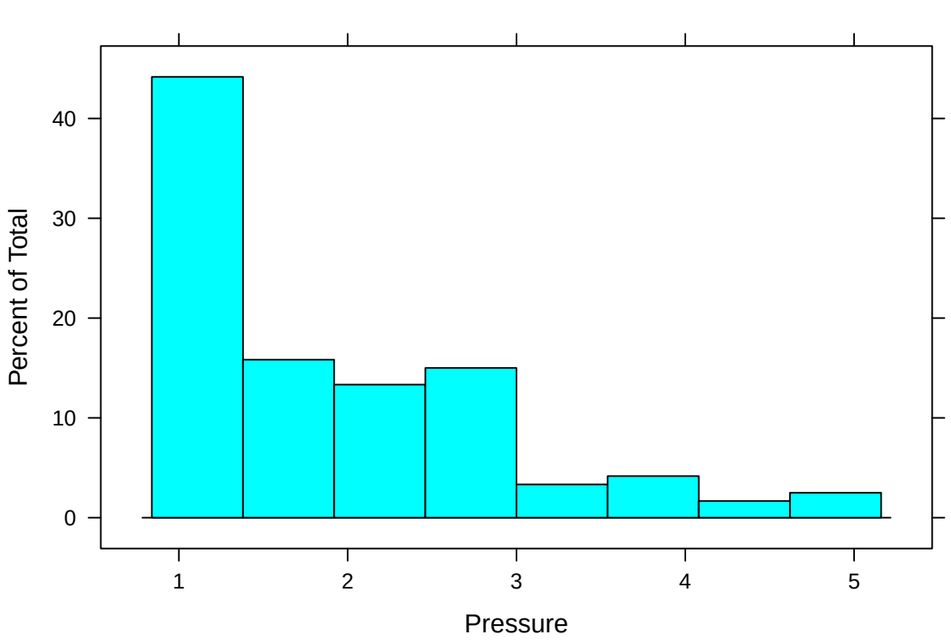


Aggregate

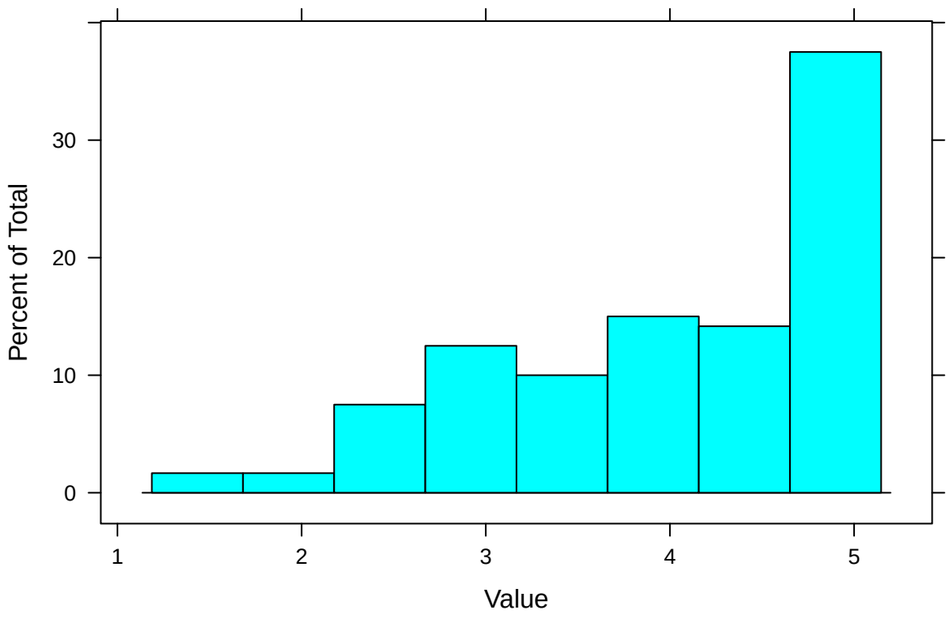
```
histogram(~Enjoyment, data = all_data)
```



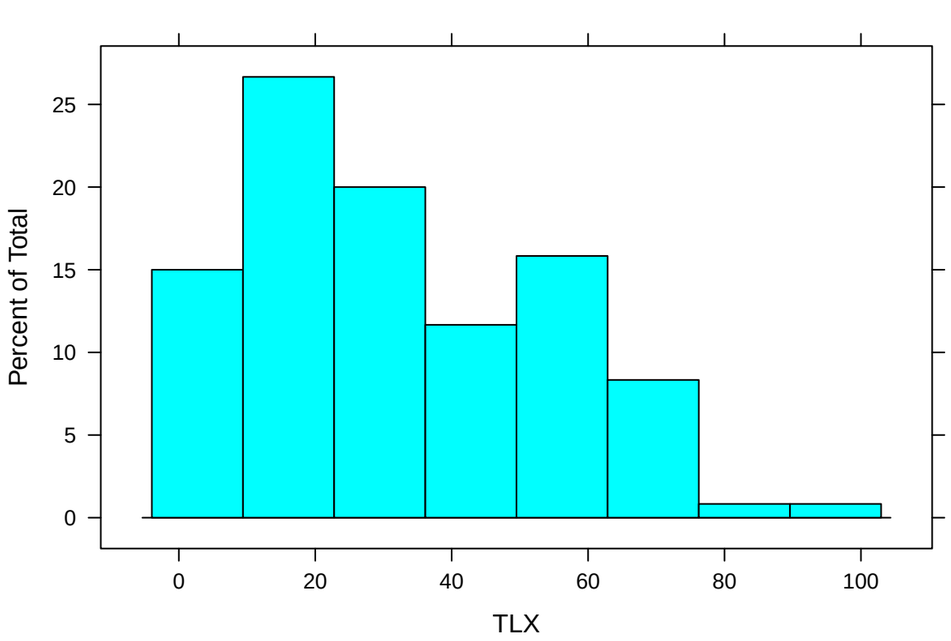

```
histogram(~Pressure, data = all_data)
```




```
histogram(~Value, data = all_data)
```

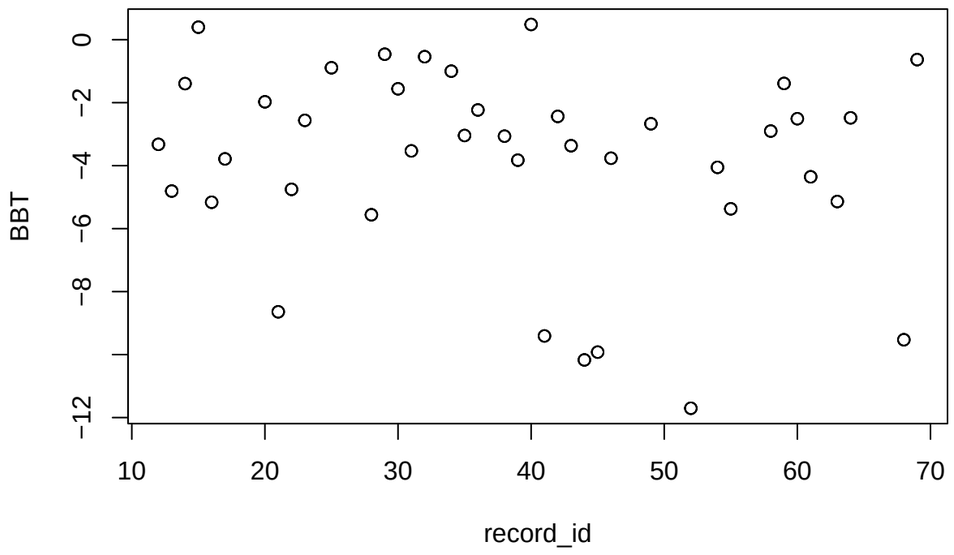



```
histogram(~TLX, data = all_data)
```

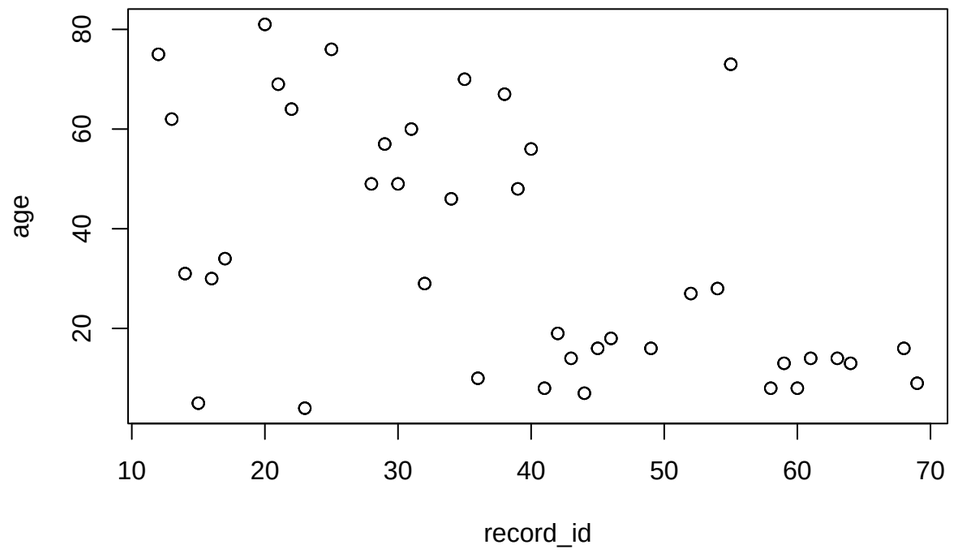


check outlier for subj 69

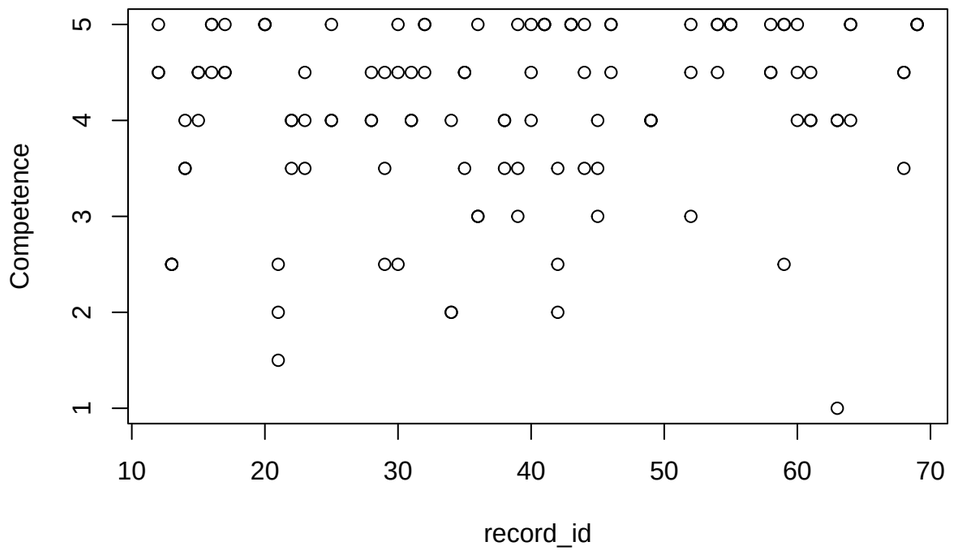
```
#pdf(file.path(out_dir, "check_69_outlier.pdf"))
plot(BBT~record_id , data = all_data)
```



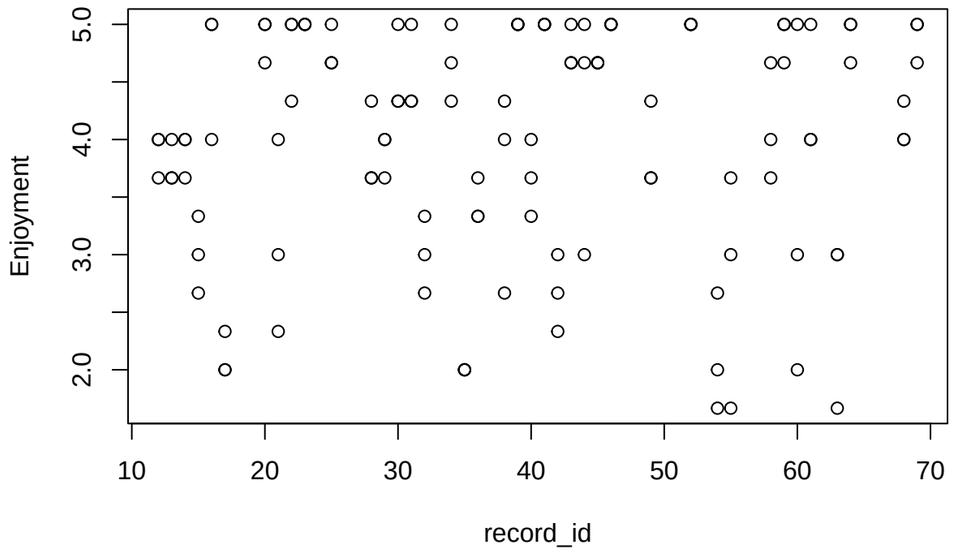

```
plot(age~record_id, data = all_data)
```



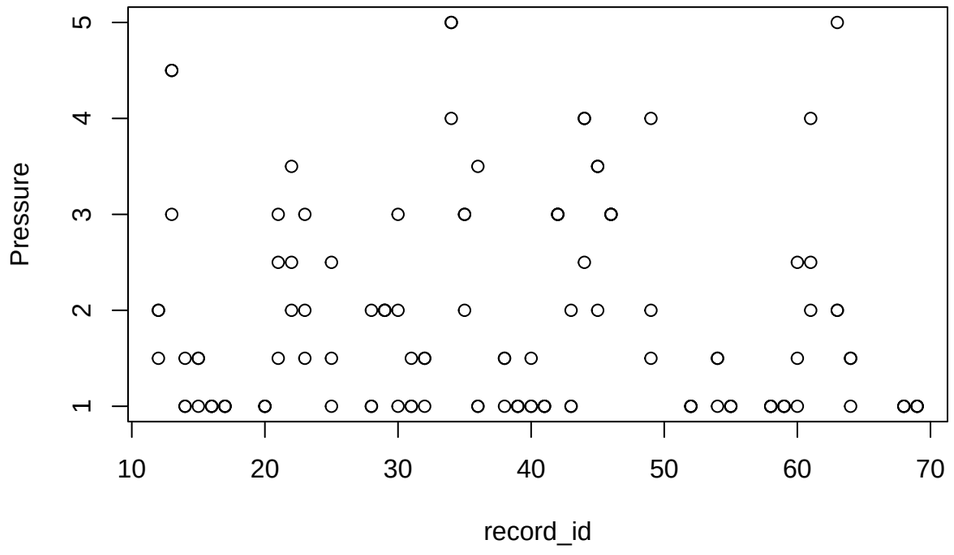

```
plot(Competence ~ record_id, data = all_data)
```



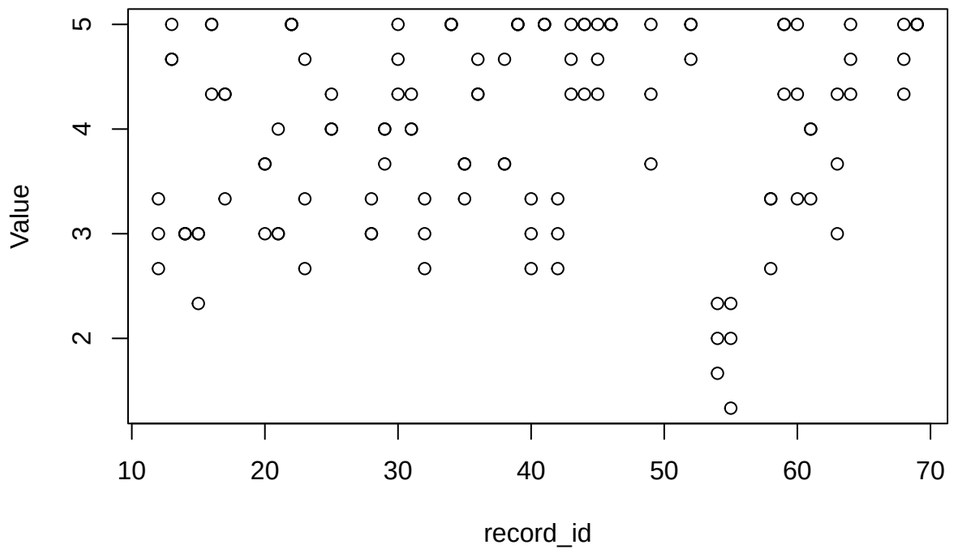

```
plot(Enjoyment ~ record_id, data = all_data)
```



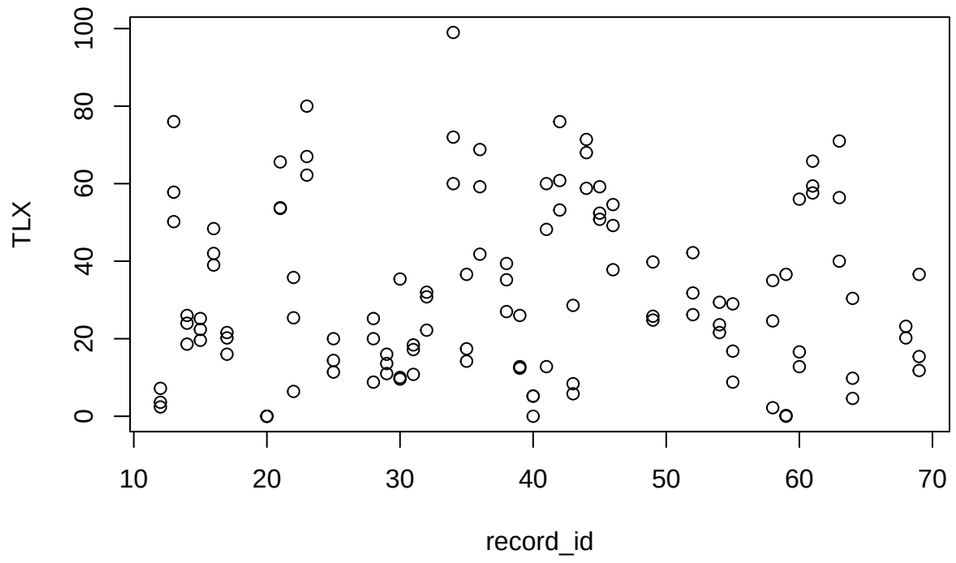

```
plot(Pressure ~ record_id, data = all_data)
```




```
plot(Value ~ record_id, data = all_data)
```




```
plot(TLX~record_id , data = all_data)
```



Run Models

We will run a model for each question to ease modeling (multiple outputs are not natural in lme4, which we are using) and interpretation.

We will visualize some diagnostics for each model. Good guide here: https://lmudge13.github.io/sample_code/mixed_effects.html which also explains how to make formatted tables.

There is a good article on how to determine whether the model meets assumptions: https://www.ssc.wisc.edu/sscc/pubs/MM/MM_DiagInfer.html

```
length(unique(all_data$record_id))
```

TLX

```
## [1] 40
```

```
model.tlx <- lme4::lmer(TLX ~ interaction.modality * ((Age * BBT * CTT2) + experimental.order + robot.operator) + (1 | subject), data = all_data)
summary(model.tlx)
```

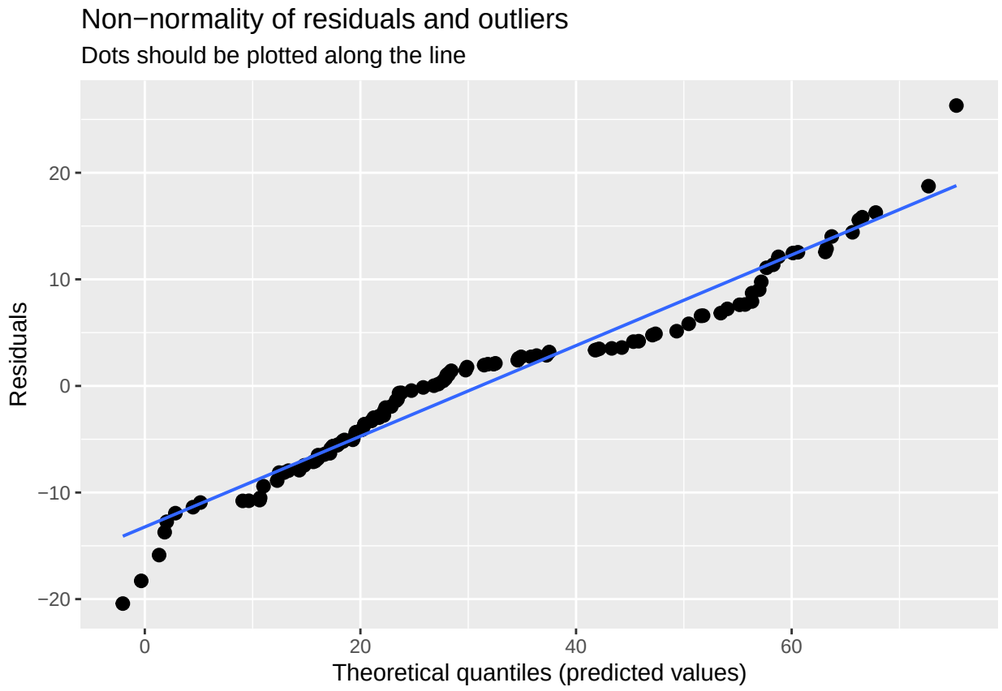
```
## Linear mixed model fit by REML ['lmerMod']
## Formula: TLX ~ interaction.modality * ((Age * BBT * CTT2) + experimental.order +      robot.operator) + (1 | subject)
##    Data: all_data
##
## REML criterion at convergence: 883.9
##
## Scaled residuals:
##      Min       1Q   Median       3Q      Max
## -1.75965 -0.48624 -0.01214  0.36152  2.26691
##
## Random effects:
##  Groups   Name        Variance Std.Dev.
##  subject  (Intercept) 324.1    18.0
##  Residual             134.7    11.6
## Number of obs: 113, groups:  subject, 38
##
## Fixed effects:
##                                              Estimate Std. Error t value
## (Intercept)                                 56.844354  16.170489   3.515
## interaction.modalitySRAT                    -6.207579  12.663679  -0.490
## interaction.modalityCT                     -19.314733  12.389126  -1.559
## Age                                         -0.917201   0.340674  -2.692
```

```
## BBT                                                5.834985   3.199892   1.823
## CTT2                                               4.555431   8.867590   0.514
## experimental.orderCT First                        10.766027   8.102154   1.329
## robot.operatorAA                                  -1.259651  10.851161  -0.116
## robot.operatorTA                                  -1.673129  12.774433  -0.131
## Age:BBT                                           -0.189839   0.073831  -2.571
## Age:CTT2                                           0.029279   0.213555   0.137
## BBT:CTT2                                           1.246394   1.298025   0.960
## interaction.modalitySRAT:Age                       0.250185   0.263197   0.951
## interaction.modalityCT:Age                         0.403188   0.261010   1.545
## interaction.modalitySRAT:BBT                      -4.325947   2.466759  -1.754
## interaction.modalityCT:BBT                        -6.694035   2.451618  -2.730
## interaction.modalitySRAT:CTT2                     -4.257870   6.831755  -0.623
## interaction.modalityCT:CTT2                      -11.348850   6.793962  -1.670
## interaction.modalitySRAT:experimental.orderCT First  -7.572722   6.208086  -1.220
## interaction.modalityCT:experimental.orderCT First    -5.377884   6.207518  -0.866
## interaction.modalitySRAT:robot.operatorAA          -5.739338   8.369895  -0.686
## interaction.modalityCT:robot.operatorAA           -10.365525   8.313688  -1.247
## interaction.modalitySRAT:robot.operatorTA         -18.455077  10.445182  -1.767
## interaction.modalityCT:robot.operatorTA           -10.657362   9.787215  -1.089
## Age:BBT:CTT2                                       0.008501   0.053184   0.160
## interaction.modalitySRAT:Age:BBT                   0.107216   0.056716   1.890
## interaction.modalityCT:Age:BBT                     0.128652   0.056566   2.274
## interaction.modalitySRAT:Age:CTT2                  0.085027   0.163696   0.519
## interaction.modalityCT:Age:CTT2                    0.140966   0.163617   0.862
## interaction.modalitySRAT:BBT:CTT2                 -0.818391   0.998674  -0.819
## interaction.modalityCT:BBT:CTT2                   -1.893069   0.994490  -1.904
## interaction.modalitySRAT:Age:BBT:CTT2              0.004940   0.040974   0.121
## interaction.modalityCT:Age:BBT:CTT2                0.012708   0.040747   0.312
##
## Correlation matrix not shown by default, as p = 33 > 12.
## Use print(x, correlation=TRUE)  or
##     vcov(x)        if you need it
```

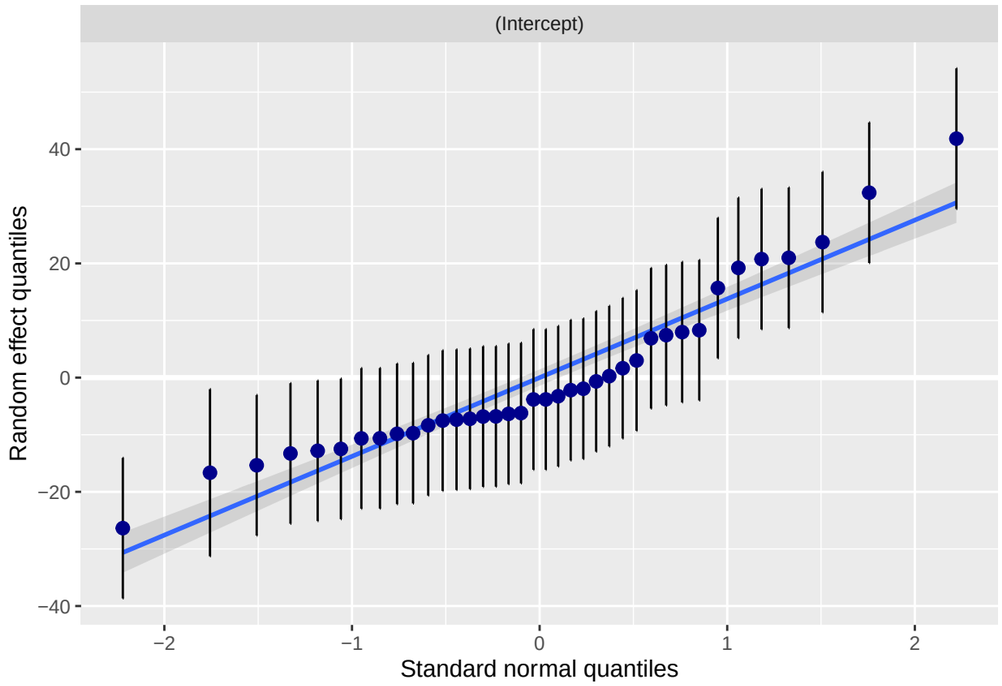
```
sjPlot::plot_model(model.tlx, type = "diag")
```

Diagnostics on model

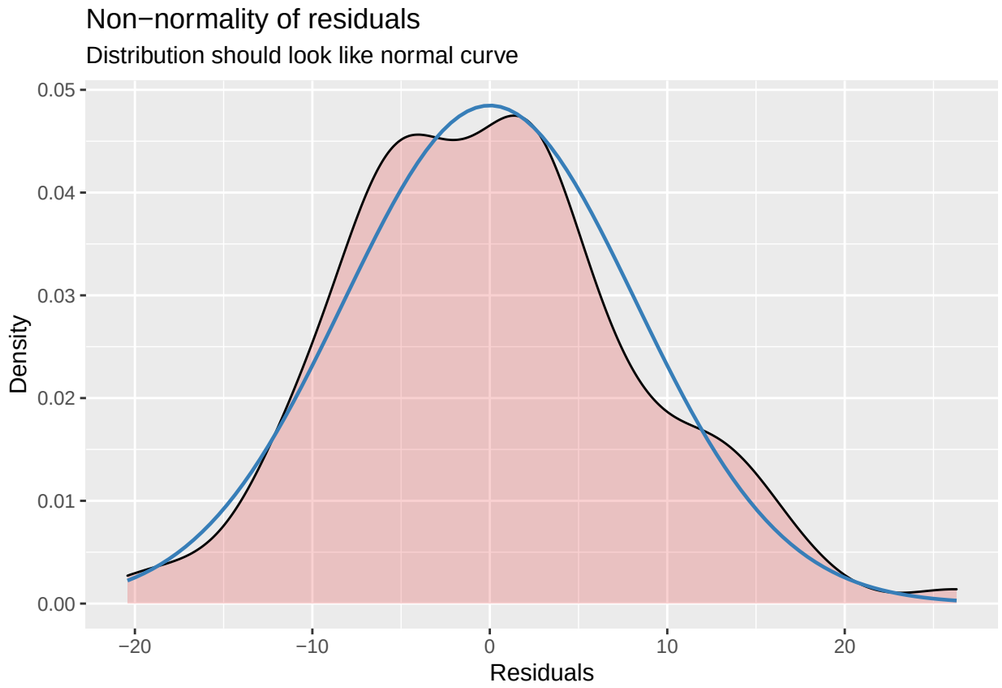
```
## [[1]]
## `geom_smooth()` using formula 'y ~ x'
```




```
##
## [[2]]
## [[2]]$subject

## `geom_smooth()` using formula 'y ~ x'
```

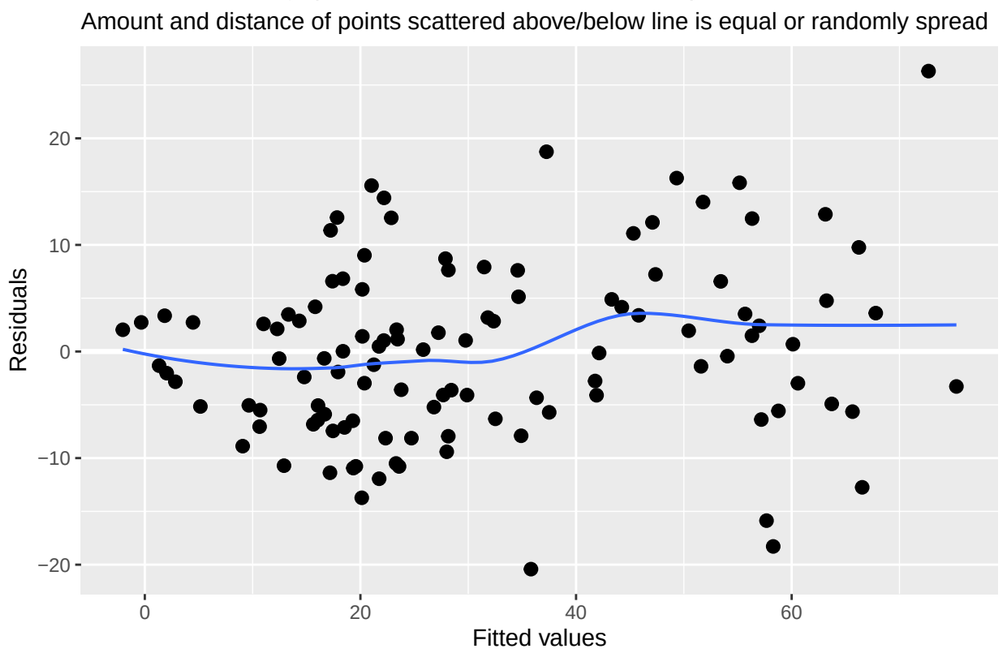



```
##
##
## [[3]]
```




```
##
## [[4]]
```

```
## `geom_smooth()` using formula 'y ~ x'
```



Residuals look ok

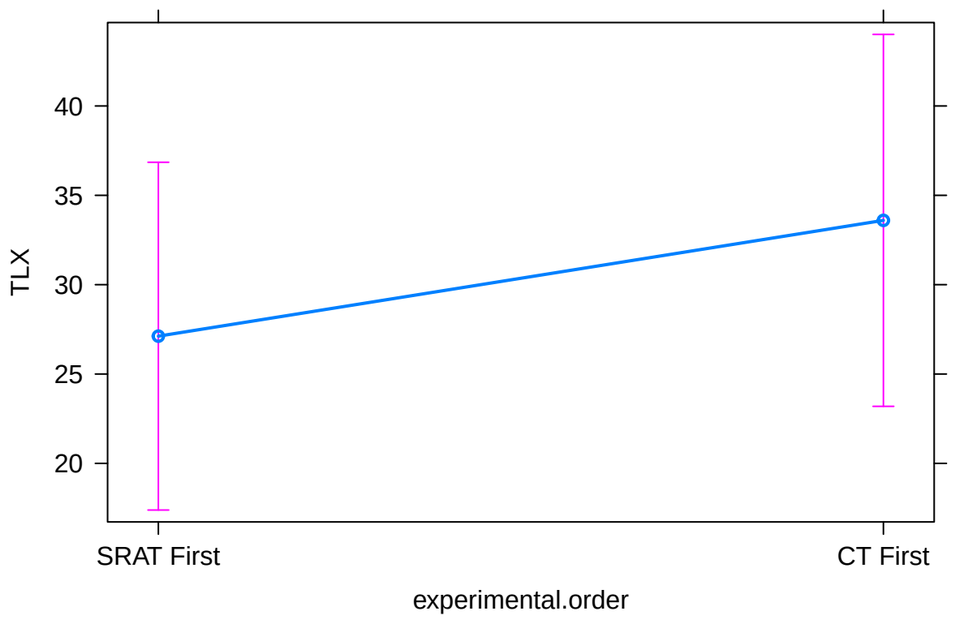
```
car::Anova(model.tlx, type = "III")
```

ANOVA

```
## Analysis of Deviance Table (Type III Wald chisquare tests)
##
## Response: TLX
##                                          Chisq Df Pr(>Chisq)
## (Intercept)                            12.3574  1  0.0004392 ***
## interaction.modality                    2.5281  2  0.2825139
## Age                                     7.2486  1  0.0070958 **
## BBT                                     3.3251  1  0.0682286 .
## CTT2                                    0.2639  1  0.6074499
## experimental.order                      1.7657  1  0.1839187
## robot.operator                          0.0213  2  0.9894207
## Age:BBT                                 6.6113  1  0.0101333 *
## Age:CTT2                                0.0188  1  0.8909507
## BBT:CTT2                                0.9220  1  0.3369425
## interaction.modality:Age                2.4314  2  0.2965065
## interaction.modality:BBT                7.6645  2  0.0216606 *
## interaction.modality:CTT2               2.8475  2  0.2408145
## interaction.modality:experimental.order 1.5757  2  0.4548291
## interaction.modality:robot.operator     4.3550  4  0.3600894
## Age:BBT:CTT2                            0.0255  1  0.8730109
## interaction.modality:Age:BBT            5.9339  2  0.0514603 .
## interaction.modality:Age:CTT2           0.7528  2  0.6863249
## interaction.modality:BBT:CTT2           3.6454  2  0.1615870
## interaction.modality:Age:BBT:CTT2       0.0988  2  0.9517796
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Experimental Order

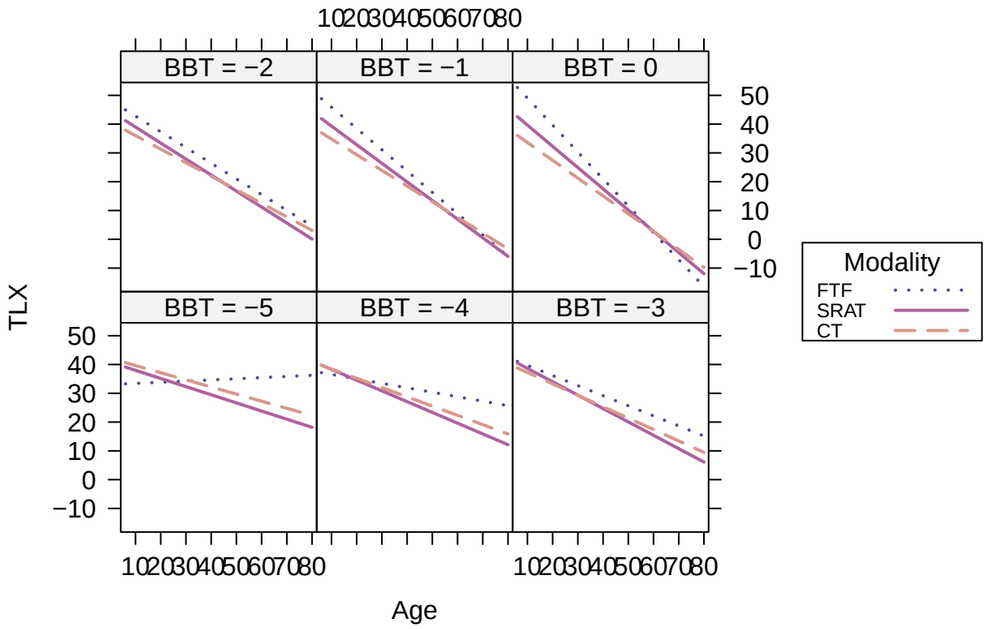
```
lattice::trellis.par.set(effects::effectsTheme())
plot(
  effects::Effect(c("experimental.order"), model.tlx),
  main = NULL, lattice = list(strip = list(factor.names = FALSE))
)
```



There is some effect due to experimental order, luckily, this term handles that variance.

BBT : Age : Interaction Modality

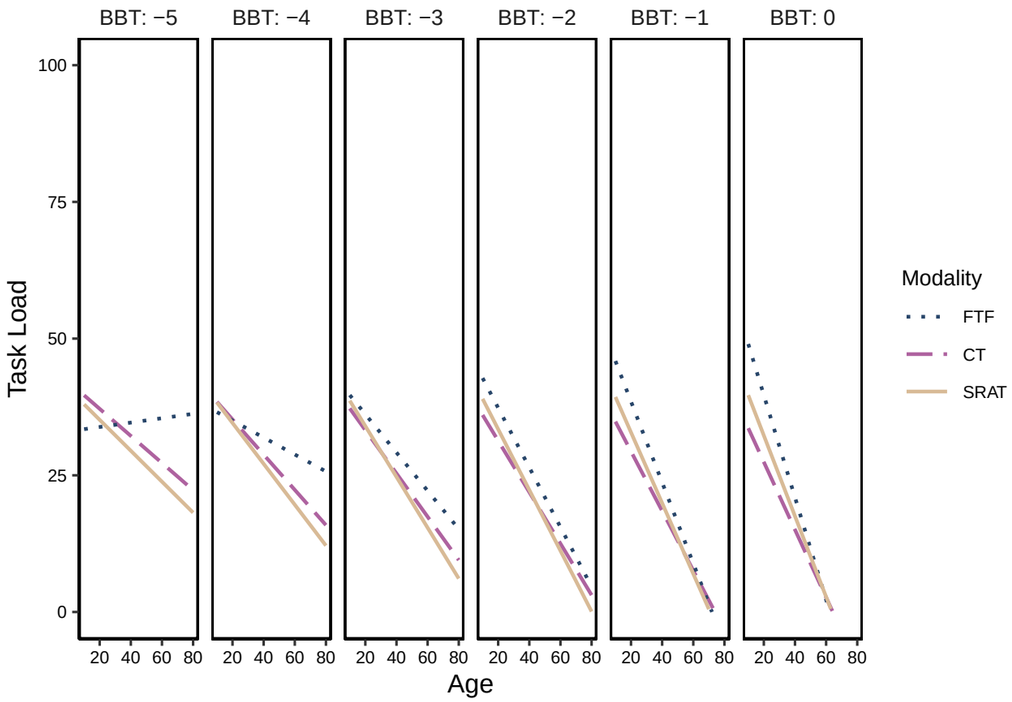
```
lattice::trellis.par.set(effects::effectsTheme())
plot(
  effects::Effect(c("BBT", "Age", "interaction.modality"), model.tlx,
    xlevels =
      interaction.levels[c("Age", "BBT")]
  ),
  axes = list(x = list(rug = FALSE)),
  lines = list(
    multiline = TRUE,
    z.var = "interaction.modality",
    col = cust_color(5)[2:4],
    lty = c(3, 1, 5)
  ),
  lattice = list(key.args = list(space = "right", border = TRUE, title = "Modality")),
  main = NULL
)
```




```
effects.tlx <-
  effects::Effect(c("BBT", "Age", "interaction.modality"), model.tlx,
    xlevels =
      interaction.levels[c("Age", "BBT")]
  )

tlx.model.plot <- cbind(effects.tlx[["x"]], effects.tlx[["fit"]]) %>%
  ggplot(aes(x = Age, y = `effects.tlx[["fit"]]`, color = interaction.modality, linetype = interaction.modality)) +
  geom_line(size = .8) +
  facet_wrap(vars(BBT), nrow = 1, labeller = label_both) +
  plt_theme +
  ylab("Task Load") +
  scale_color_manual(
    values = cust_color(7)[c(2, 4, 6)],
    breaks = c("FTF", "CT", "SRAT")
  ) +
  scale_linetype_manual(
    values = c(3, 5, 1),
    breaks = c("FTF", "CT", "SRAT")
  ) +
  labs(color = "Modality", linetype = "Modality") +
```

```
  xlim(c(10, 80)) +
  ylim(c(0, 100)) +
  theme(legend.key.width = unit(.05, "npc"), legend.position = "right")

print(tlx.model.plot)
```

```
## Warning: Removed 63 row(s) containing missing values (geom_path).
```




```
fn <- file.path(out_dir, "tikz-tlx_model.tex")
tikz(
  file = fn,
  width = 5.8,
  height = 1.25,
  sanitize = TRUE
)
print(tlx.model.plot)
```

```
## Warning: Removed 63 row(s) containing missing values (geom_path).
```

```
dev.off()
```

```
## pdf
##   2
```

```
strip_tikz_white(fn)
```

We need to keep focus on the question we designed this to answer, looking at SRAT and CT

- At mid-age and up (~50+), there is no separation.
- For younger subjects CT has lower task load than SRAT, this difference narrows as impairment gets worse, past severe motor impairment (z<-3), they are nearly identical

```
model.value <- lme4::lmer(Value ~ interaction.modality * ((Age * BBT * CTT2) + experimental.order + robot.operator) + (1 | subject), data = all_data)
summary(model.value)
```

Value

```
## Linear mixed model fit by REML ['lmerMod']
## Formula: Value ~ interaction.modality * ((Age * BBT * CTT2) + experimental.order +      robot.operator) + (1 | subject)
##    Data: all_data
##
```

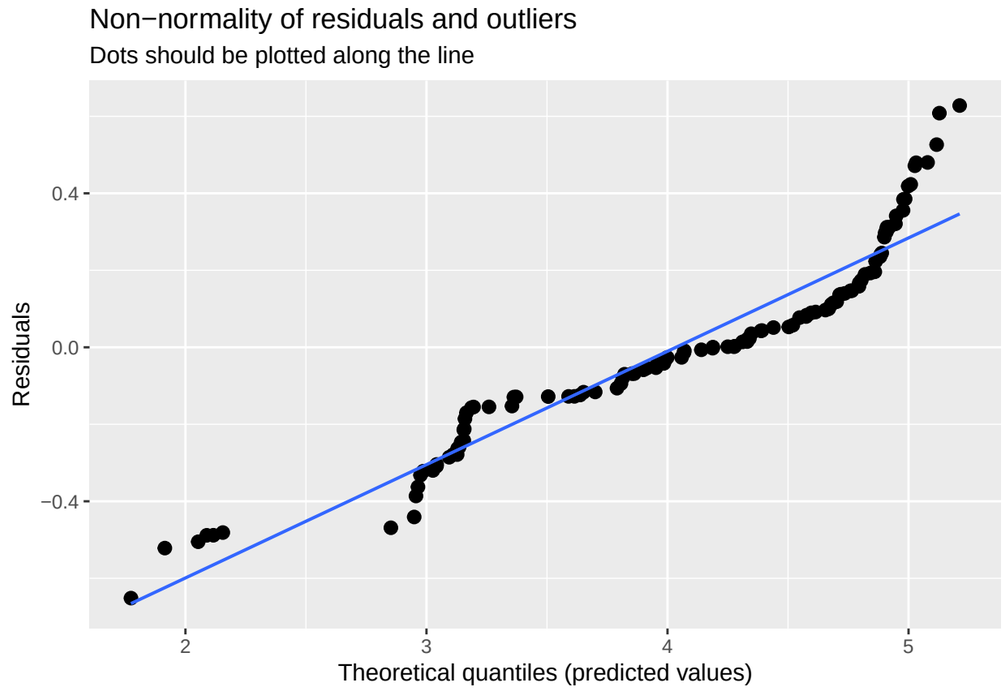
```
## REML criterion at convergence: 350
##
## Scaled residuals:
##      Min       1Q   Median       3Q      Max
## -1.76587 -0.41807  0.00254  0.39803  1.70195
##
## Random effects:
##  Groups   Name        Variance Std.Dev.
##  subject  (Intercept) 0.6330   0.7956
##  Residual             0.1361   0.3690
## Number of obs: 114, groups:  subject, 38
##
## Fixed effects:
##                                                  Estimate Std. Error t value
## (Intercept)                                     3.8284841  0.6620836   5.782
## interaction.modalitySRAT                        0.1022726  0.3939230   0.260
## interaction.modalityCT                          0.0322110  0.3939230   0.082
## Age                                            -0.0075067  0.0139485  -0.538
## BBT                                            -0.1158412  0.1310162  -0.884
## CTT2                                           -0.6057096  0.3630741  -1.668
## experimental.orderCT First                      0.3825491  0.3317341   1.153
## robot.operatorAA                               -0.4936190  0.4442893  -1.111
## robot.operatorTA                               -0.3040938  0.5230357  -0.581
## Age:BBT                                         0.0018377  0.0030229   0.608
## Age:CTT2                                        0.0172681  0.0087438   1.975
## BBT:CTT2                                       -0.0973411  0.0531462  -1.832
## interaction.modalitySRAT:Age                   -0.0004202  0.0082990  -0.051
## interaction.modalityCT:Age                      0.0018830  0.0082990   0.227
## interaction.modalitySRAT:BBT                    0.0111609  0.0779513   0.143
## interaction.modalityCT:BBT                      0.0022270  0.0779513   0.029
## interaction.modalitySRAT:CTT2                   0.2687919  0.2160199   1.244
## interaction.modalityCT:CTT2                     0.2447027  0.2160199   1.133
## interaction.modalitySRAT:experimental.orderCT First  0.0501831  0.1973734   0.254
## interaction.modalityCT:experimental.orderCT First    0.0386444  0.1973734   0.196
## interaction.modalitySRAT:robot.operatorAA      -0.2285209  0.2643409  -0.864
## interaction.modalityCT:robot.operatorAA        -0.1736273  0.2643409  -0.657
## interaction.modalitySRAT:robot.operatorTA       0.5268482  0.3111930   1.693
## interaction.modalityCT:robot.operatorTA         0.5298639  0.3111930   1.703
## Age:BBT:CTT2                                    0.0041619  0.0021776   1.911
## interaction.modalitySRAT:Age:BBT               -0.0013567  0.0017986  -0.754
## interaction.modalityCT:Age:BBT                 -0.0002826  0.0017986  -0.157
## interaction.modalitySRAT:Age:CTT2              -0.0088308  0.0052023  -1.697
## interaction.modalityCT:Age:CTT2                -0.0095382  0.0052023  -1.833
## interaction.modalitySRAT:BBT:CTT2               0.0448579  0.0316207   1.419
## interaction.modalityCT:BBT:CTT2                 0.0456606  0.0316207   1.444
## interaction.modalitySRAT:Age:BBT:CTT2          -0.0024126  0.0012956  -1.862
## interaction.modalityCT:Age:BBT:CTT2            -0.0023587  0.0012956  -1.821
##
## Correlation matrix not shown by default, as p = 33 > 12.
## Use print(x, correlation=TRUE)  or
##     vcov(x)        if you need it
```

```
sjPlot::plot_model(model.value, type = "diag")
```

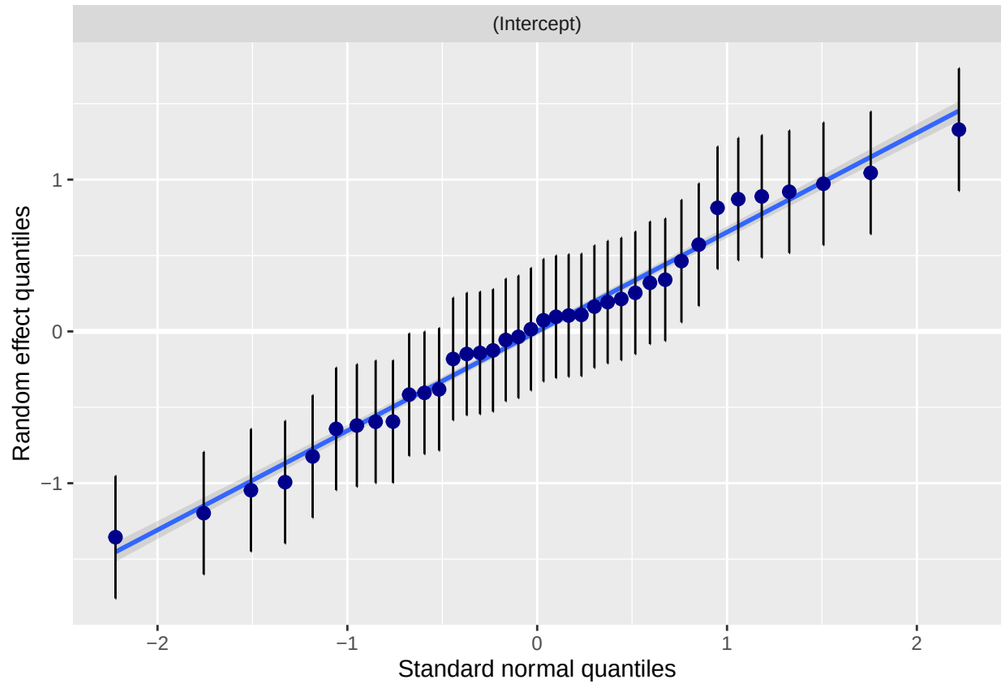
Diagnostics on model

```
## [[1]]
```

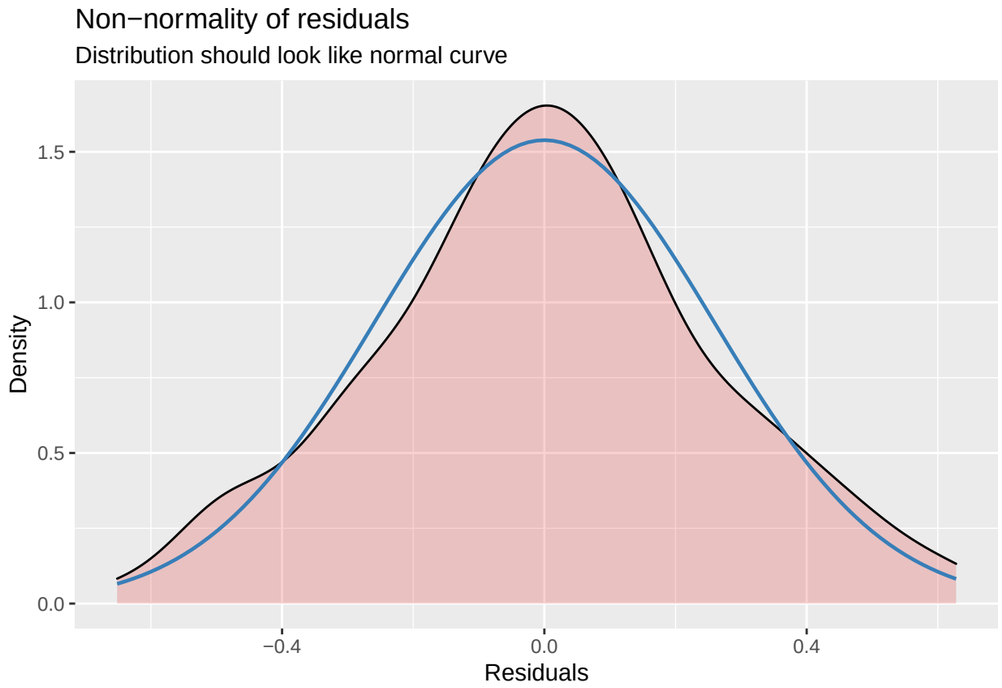
```
## `geom_smooth()` using formula 'y ~ x'
```




```
##
## [[2]]
## [[2]]$subject

## `geom_smooth()` using formula 'y ~ x'
```

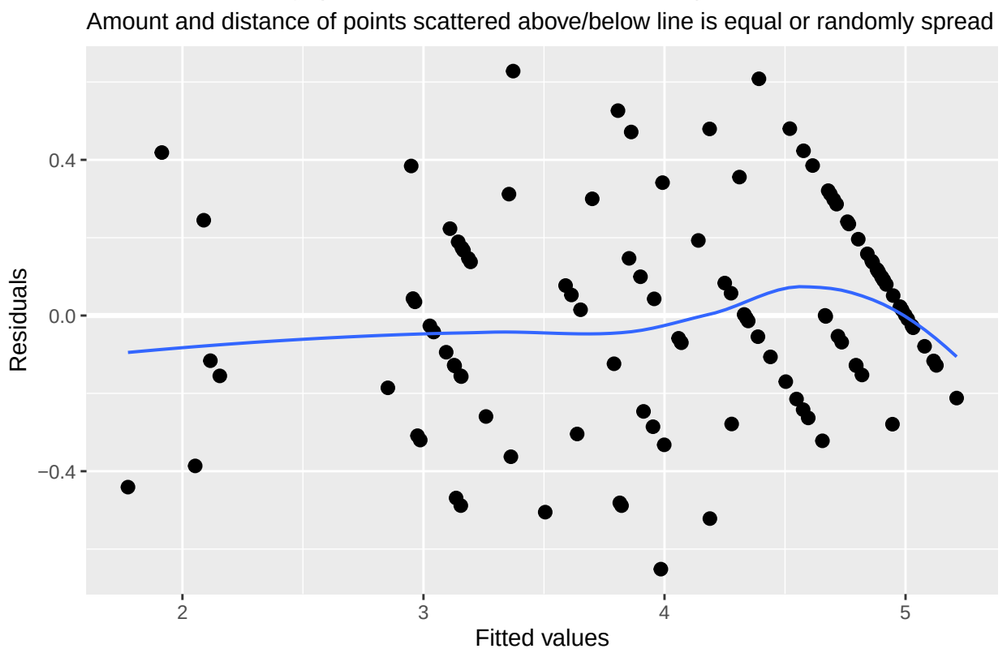



```
##
##
## [[3]]
```




```
##
## [[4]]
```

```
## `geom_smooth()` using formula 'y ~ x'
```



The residuals are not perfectly normal, but should be good enough.

```
car::Anova(model.value, type = "III")
```

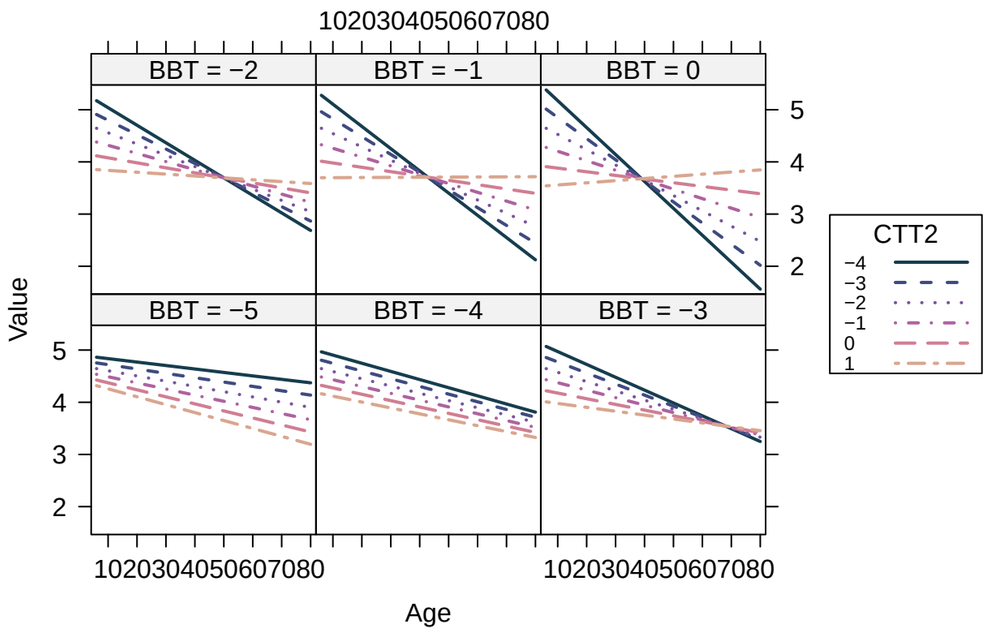
ANOVA

```
## Analysis of Deviance Table (Type III Wald chisquare tests)
##
## Response: Value
##                                          Chisq Df Pr(>Chisq)
## (Intercept)                            33.4371  1  7.361e-09 ***
## interaction.modality                    0.0705  2    0.96537
## Age                                     0.2896  1    0.59046
## BBT                                     0.7818  1    0.37660
## CTT2                                    2.7832  1    0.09526 .
## experimental.order                      1.3298  1    0.24884
## robot.operator                          1.2430  2    0.53713
## Age:BBT                                 0.3696  1    0.54324
## Age:CTT2                                3.9002  1    0.04828 *
## BBT:CTT2                                3.3546  1    0.06702 .
## interaction.modality:Age                0.0874  2    0.95725
## interaction.modality:BBT                0.0230  2    0.98858
## interaction.modality:CTT2               1.8959  2    0.38753
## interaction.modality:experimental.order 0.0709  2    0.96516
## interaction.modality:robot.operator     7.7617  4    0.10071
## Age:BBT:CTT2                            3.6530  1    0.05597 .
## interaction.modality:Age:BBT            0.6336  2    0.72848
## interaction.modality:Age:CTT2           4.1743  2    0.12404
## interaction.modality:BBT:CTT2           2.7322  2    0.25510
## interaction.modality:Age:BBT:CTT2       4.5224  2    0.10422
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Age : BBT : CTT2

This higher order term actually isn't significant (just barely), but the combined cross terms are.

```
lattice::trellis.par.set(effects::effectsTheme())
plot(
  effects::Effect(c("BBT", "Age", "CTT2"), model.value,
    xlevels =
      interaction.levels[c("Age", "BBT", "CTT2")]
  ),
  axes = list(x = list(rug = FALSE)),
  lines = list(
    multiline = TRUE,
    z.var = "CTT2",
    col = cust_color(9)[2:8],
    lty = 1:7
  ),
  lattice = list(key.args = list(space = "right", border = TRUE, title = "CTT2")),
  main = NULL
)
```



We aren't saying anything about interaction modality here. But we do see that These things interact with how valuable subjects found the experience in general. But there isn't much internal control across this, so not much to say.

```
model.pressure <- lme4::lmer(Pressure ~ interaction.modality * ((Age * BBT * CTT2) + experimental.order + robot.operator) + (1 | subject), data = all_data)
summary(model.pressure)
```

Pressure

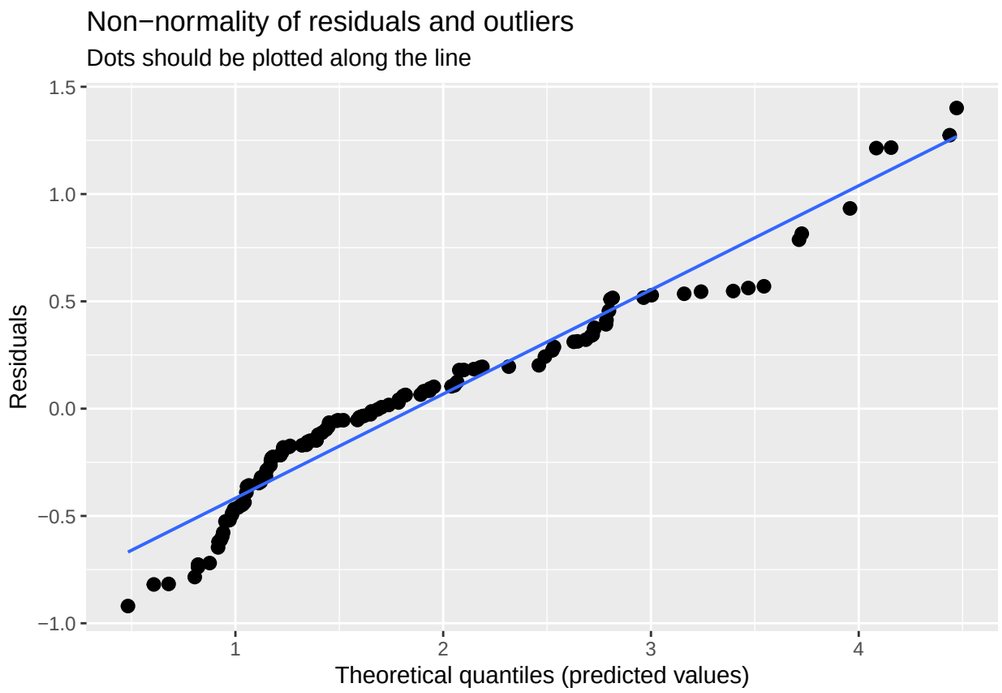
```
## Linear mixed model fit by REML ['lmerMod']
## Formula: Pressure ~ interaction.modality * ((Age * BBT * CTT2) + experimental.order +      robot.operator) + (1 | subject)
##    Data: all_data
##
## REML criterion at convergence: 420.2
##
## Scaled residuals:
##      Min       1Q   Median       3Q      Max
## -1.45038 -0.44254 -0.05381  0.36626  2.20891
##
## Random effects:
##  Groups   Name        Variance Std.Dev.
##  subject  (Intercept) 0.9140   0.9560
##  Residual             0.4022   0.6342
## Number of obs: 114, groups:  subject, 38
##
## Fixed effects:
##                                                Estimate Std. Error t value
## (Intercept)                                   2.4502037  0.8661378   2.829
## interaction.modalitySRAT                      0.1500306  0.6771052   0.222
## interaction.modalityCT                       -0.6178531  0.6771052  -0.912
## Age                                          -0.0158901  0.0182475  -0.871
## BBT                                           0.2539545  0.1713954   1.482
## CTT2                                         -0.1419312  0.4749736  -0.299
## experimental.orderCT First                    0.5874612  0.4339746   1.354
## robot.operatorAA                             -0.3407455  0.5812193  -0.586
## robot.operatorTA                             -0.6334205  0.6842353  -0.926
## Age:BBT                                      -0.0058806  0.0039546  -1.487
## Age:CTT2                                      0.0006099  0.0114386   0.053
## BBT:CTT2                                      0.0421767  0.0695259   0.607
```

```
## interaction.modalitySRAT:Age                          -0.0010086  0.0142650  -0.071
## interaction.modalityCT:Age                              0.0129940  0.0142650   0.911
## interaction.modalitySRAT:BBT                           -0.0489641  0.1339887  -0.365
## interaction.modalityCT:BBT                             -0.1126913  0.1339887  -0.841
## interaction.modalitySRAT:CTT2                           0.4878985  0.3713116   1.314
## interaction.modalityCT:CTT2                            -0.2453943  0.3713116  -0.661
## interaction.modalitySRAT:experimental.orderCT First -0.4048715  0.3392606  -1.193
## interaction.modalityCT:experimental.orderCT First   -0.4211562  0.3392606  -1.241
## interaction.modalitySRAT:robot.operatorAA               0.3678476  0.4543695   0.810
## interaction.modalityCT:robot.operatorAA                 0.1033794  0.4543695   0.228
## interaction.modalitySRAT:robot.operatorTA               0.2101049  0.5349025   0.393
## interaction.modalityCT:robot.operatorTA                 0.5816620  0.5349025   1.087
## Age:BBT:CTT2                                           -0.0008826  0.0028487  -0.310
## interaction.modalitySRAT:Age:BBT                        0.0028046  0.0030915   0.907
## interaction.modalityCT:Age:BBT                          0.0031989  0.0030915   1.035
## interaction.modalitySRAT:Age:CTT2                      -0.0019136  0.0089422  -0.214
## interaction.modalityCT:Age:CTT2                         0.0075017  0.0089422   0.839
## interaction.modalitySRAT:BBT:CTT2                       0.0164042  0.0543520   0.302
## interaction.modalityCT:BBT:CTT2                        -0.0159824  0.0543520  -0.294
## interaction.modalitySRAT:Age:BBT:CTT2                   0.0020365  0.0022270   0.914
## interaction.modalityCT:Age:BBT:CTT2                     0.0009010  0.0022270   0.405
##
## Correlation matrix not shown by default, as p = 33 > 12.
## Use print(x, correlation=TRUE)  or
##     vcov(x)        if you need it
```

```
sjPlot::plot_model(model.pressure, type = "diag")
```

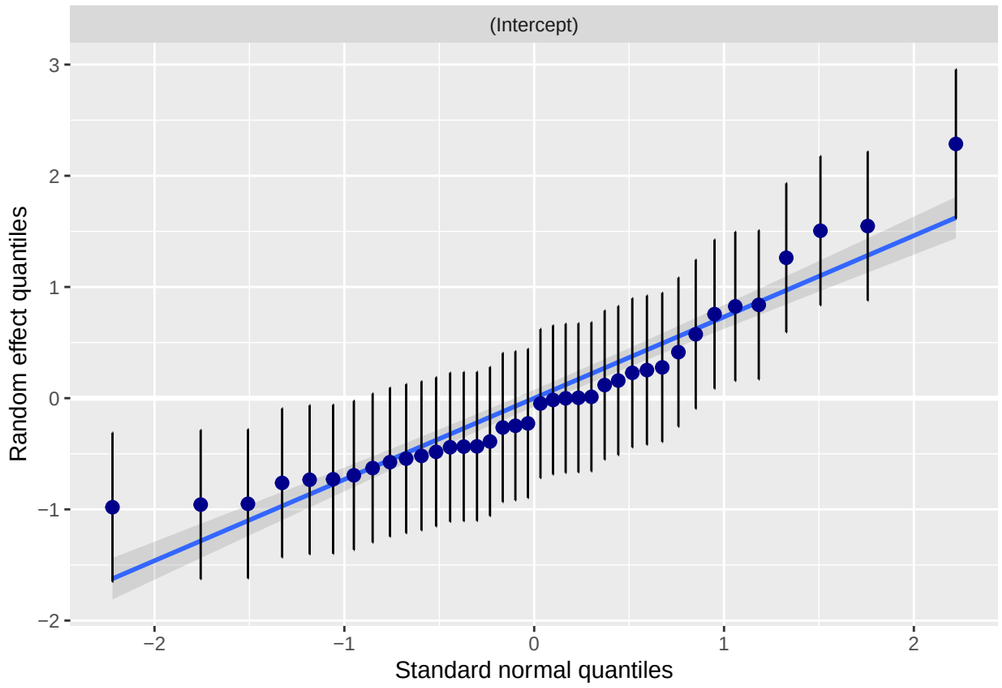
Diagnostics on model

```
## [[1]]
## `geom_smooth()` using formula 'y ~ x'
```

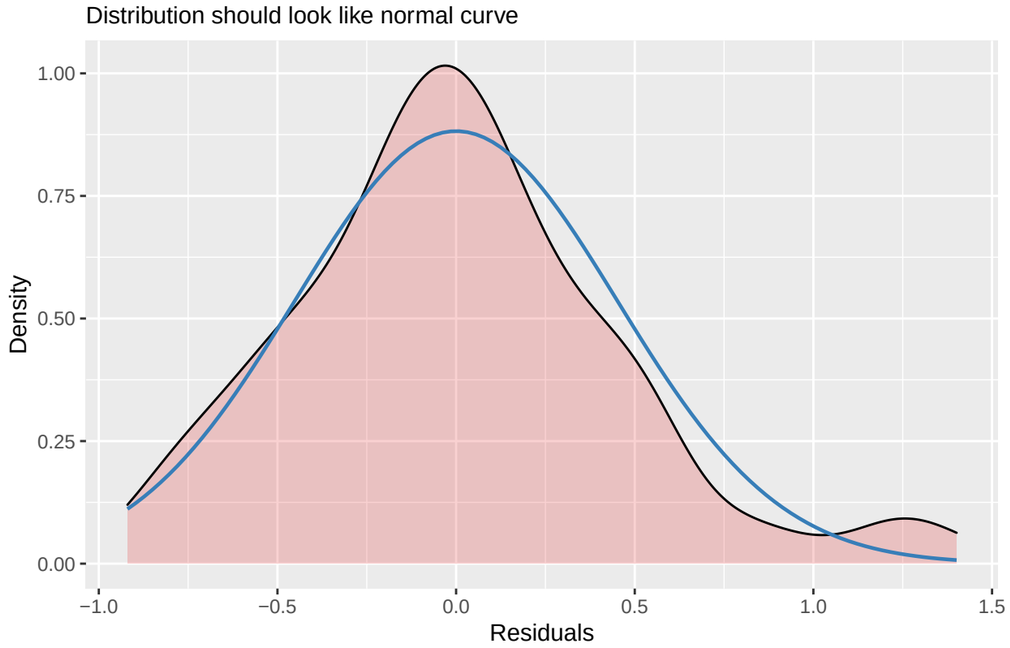



```
##
## [[2]]
## [[2]]$subject
```

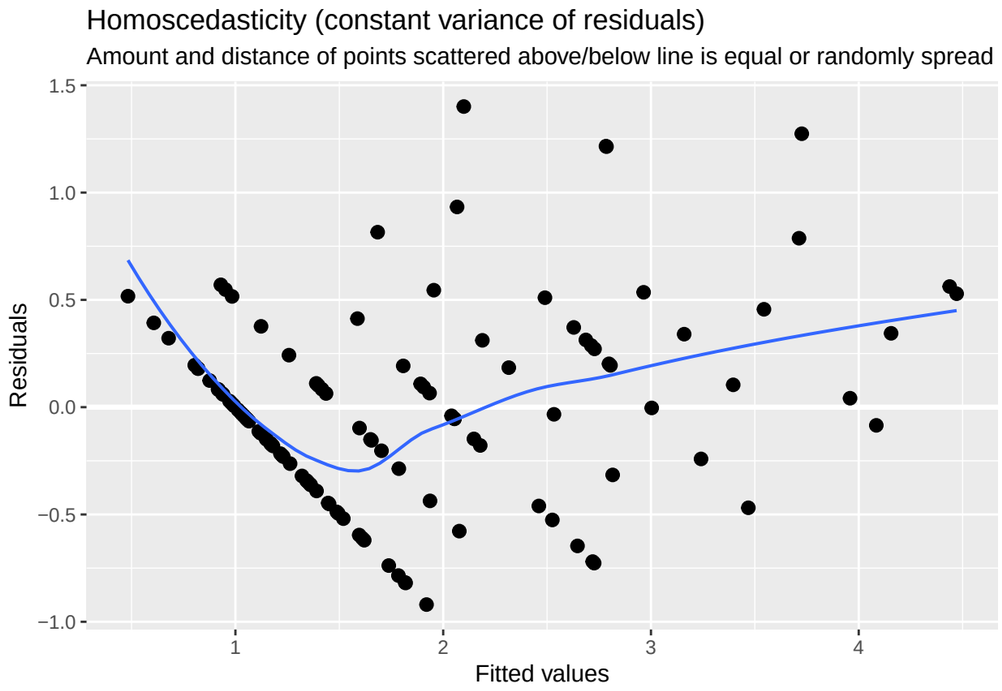
```
## `geom_smooth()` using formula 'y ~ x'
```




```
##
##
## [[3]]
```




```
##
## [[4]]
## `geom_smooth()` using formula 'y ~ x'
```



The lack of levels in the "continuous" measure of pressure causes a bit of a mess here, leading to the residuals being not quite normal and not independent from Pressure. Interpret with caution.

```
all_data %>%
  select(Pressure) %>%
  unique() %>%
  unlist()
```

```
## Pressure1 Pressure2 Pressure3 Pressure4 Pressure5 Pressure6 Pressure7 Pressure8 Pressure9
##       2.0       1.5       4.5       3.0       1.0       2.5       3.5       5.0       4.0
```

```
car::Anova(model.pressure, type = "III")
```

ANOVA

```
## Analysis of Deviance Table (Type III Wald chisquare tests)
##
## Response: Pressure
##                                          Chisq Df Pr(>Chisq)
## (Intercept)                             8.0026  1   0.004671 **
## interaction.modality                    1.4452  2   0.485480
## Age                                     0.7583  1   0.383858
## BBT                                     2.1954  1   0.138423
## CTT2                                    0.0893  1   0.765078
## experimental.order                      1.8324  1   0.175840
## robot.operator                          0.8936  2   0.639659
## Age:BBT                                 2.2112  1   0.137009
## Age:CTT2                                0.0028  1   0.957480
## BBT:CTT2                                0.3680  1   0.544095
## interaction.modality:Age                1.1989  2   0.549124
## interaction.modality:BBT                0.7114  2   0.700678
## interaction.modality:CTT2               4.0423  2   0.132503
## interaction.modality:experimental.order 1.9784  2   0.371880
## interaction.modality:robot.operator     2.2704  4   0.686161
## Age:BBT:CTT2                            0.0960  1   0.756688
## interaction.modality:Age:BBT            1.2733  2   0.529069
## interaction.modality:Age:CTT2           1.2388  2   0.538272
## interaction.modality:BBT:CTT2           0.3551  2   0.837328
## interaction.modality:Age:BBT:CTT2       0.8400  2   0.657053
```

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

- Pressure shows no significant Effects

```
model.enjoyment <- lme4::lmer(Enjoyment ~ interaction.modality * ((Age * BBT * CTT2) + experimental.order + robot.operator) + (1 | subject), data = all_data)
summary(model.enjoyment)
```

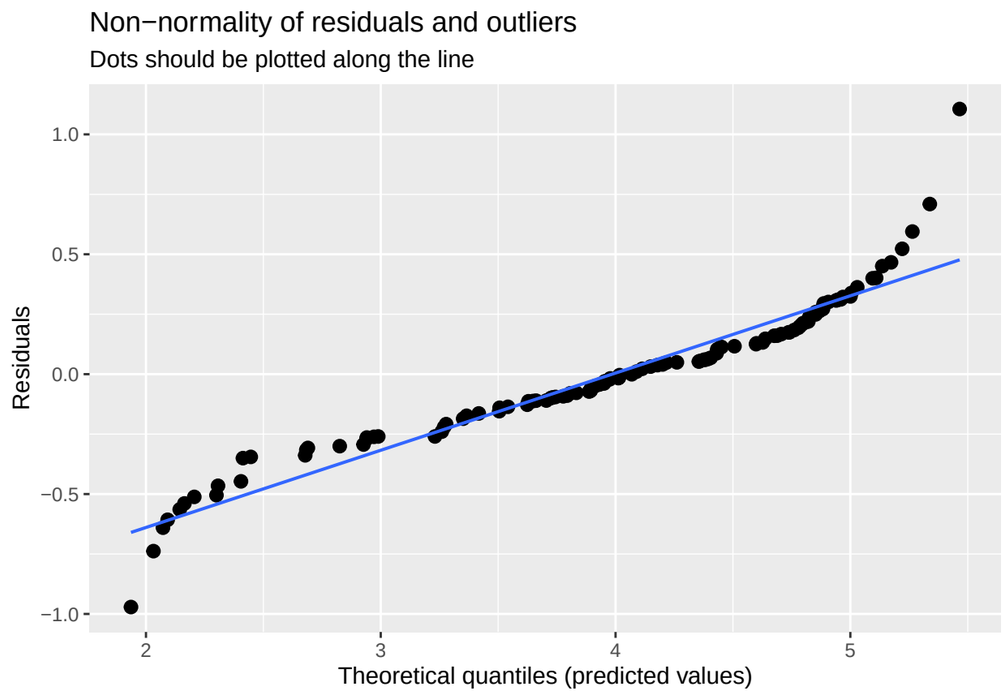
Enjoyment

```
## Linear mixed model fit by REML ['lmerMod']
## Formula: Enjoyment ~ interaction.modality * ((Age * BBT * CTT2) + experimental.order +      robot.operator) + (1 | subject)
##    Data: all_data
##
## REML criterion at convergence: 374.1
##
## Scaled residuals:
##      Min       1Q   Median       3Q      Max
## -2.26136 -0.35129  0.01186  0.42299  2.57465
##
## Random effects:
##  Groups   Name        Variance Std.Dev.
##  subject  (Intercept) 0.8404   0.9167
##  Residual             0.1845   0.4295
## Number of obs: 114, groups:  subject, 38
##
## Fixed effects:
##                                                  Estimate Std. Error t value
## (Intercept)                                      3.323318   0.764288   4.348
## interaction.modalitySRAT                         0.158819   0.458547   0.346
## interaction.modalityCT                          -0.414427   0.458547  -0.904
## Age                                              0.007024   0.016102   0.436
## BBT                                             -0.198600   0.151241  -1.313
## CTT2                                            -0.090870   0.419121  -0.217
## experimental.orderCT First                       0.361109   0.382943   0.943
## robot.operatorAA                                -0.244270   0.512874  -0.476
## robot.operatorTA                                -0.184267   0.603776  -0.305
## Age:BBT                                          0.005289   0.003490   1.516
## Age:CTT2                                         0.004951   0.010094   0.491
## BBT:CTT2                                        -0.043712   0.061350  -0.712
## interaction.modalitySRAT:Age                    -0.002343   0.009661  -0.243
## interaction.modalityCT:Age                       0.004319   0.009661   0.447
## interaction.modalitySRAT:BBT                     0.111510   0.090740   1.229
## interaction.modalityCT:BBT                       0.025432   0.090740   0.280
## interaction.modalitySRAT:CTT2                    0.205412   0.251459   0.817
## interaction.modalityCT:CTT2                     -0.186367   0.251459  -0.741
## interaction.modalitySRAT:experimental.orderCT First  0.273577   0.229753   1.191
## interaction.modalityCT:experimental.orderCT First    0.276459   0.229753   1.203
## interaction.modalitySRAT:robot.operatorAA        0.108065   0.307707   0.351
## interaction.modalityCT:robot.operatorAA          0.119006   0.307707   0.387
## interaction.modalitySRAT:robot.operatorTA        0.981102   0.362245   2.708
## interaction.modalityCT:robot.operatorTA          0.704171   0.362245   1.944
## Age:BBT:CTT2                                     0.002429   0.002514   0.966
## interaction.modalitySRAT:Age:BBT                -0.004069   0.002094  -1.944
## interaction.modalityCT:Age:BBT                  -0.001899   0.002094  -0.907
## interaction.modalitySRAT:Age:CTT2               -0.004191   0.006056  -0.692
## interaction.modalityCT:Age:CTT2                  0.005185   0.006056   0.856
## interaction.modalitySRAT:BBT:CTT2                0.046169   0.036808   1.254
## interaction.modalityCT:BBT:CTT2                 -0.036201   0.036808  -0.984
## interaction.modalitySRAT:Age:BBT:CTT2           -0.001748   0.001508  -1.159
## interaction.modalityCT:Age:BBT:CTT2              0.001095   0.001508   0.726
##
## Correlation matrix not shown by default, as p = 33 > 12.
## Use print(x, correlation=TRUE)  or
##     vcov(x)        if you need it
```

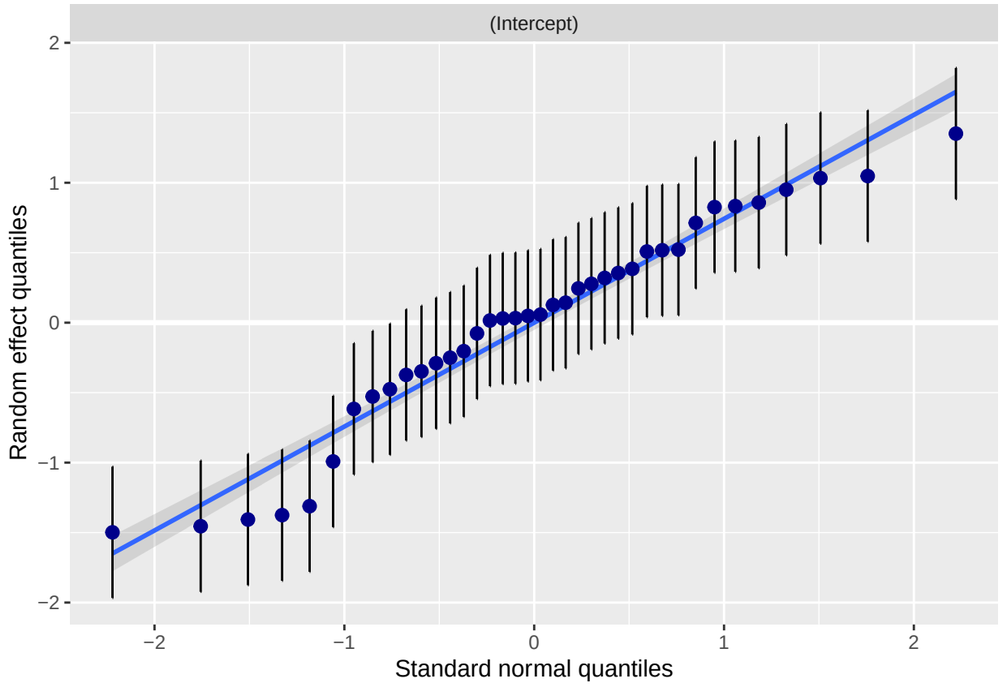
```
sjPlot::plot_model(model.enjoyment, type = "diag")
```

Diagnostics on model

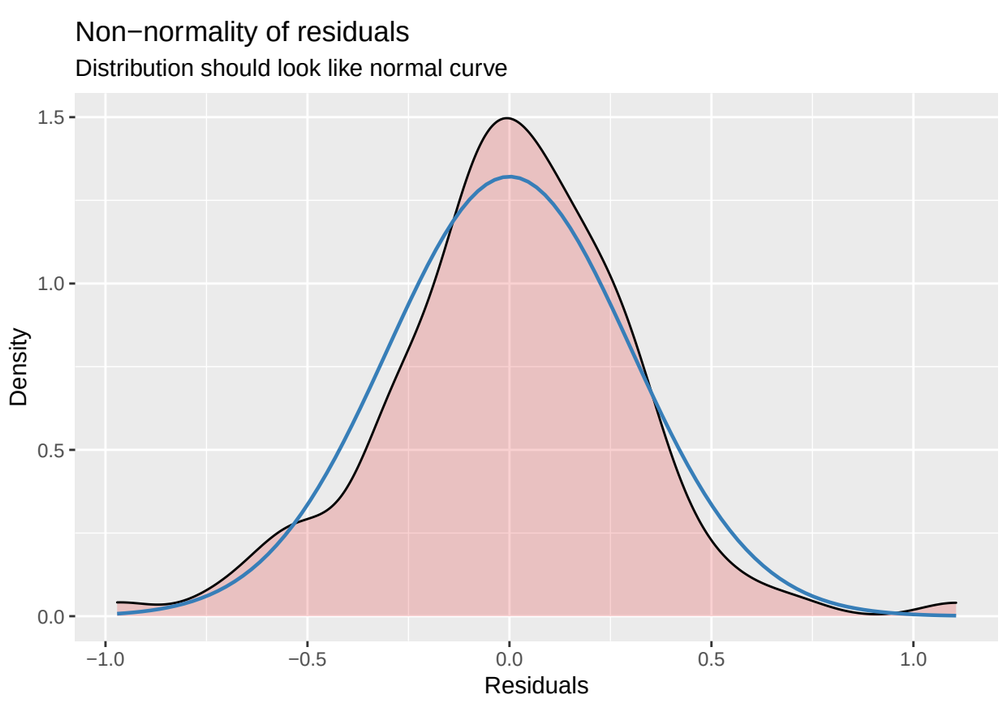
```
## [[1]]
## `geom_smooth()` using formula 'y ~ x'
```



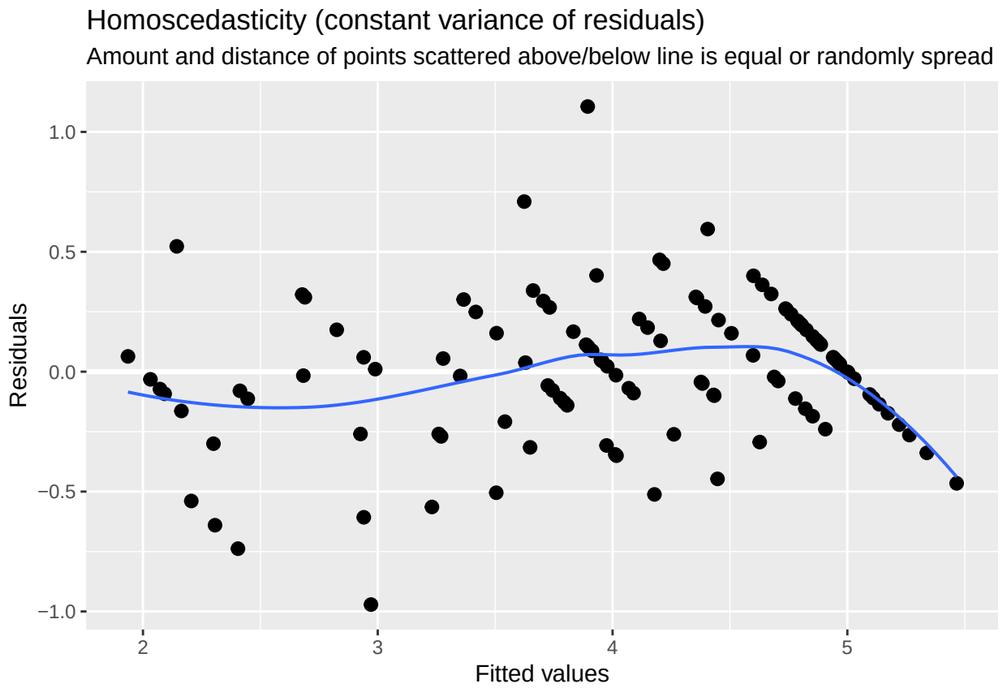

```
##
## [[2]]
## [[2]]$subject
## `geom_smooth()` using formula 'y ~ x'
```




```
##
##
## [[3]]
```




```
##
## [[4]]
## `geom_smooth()` using formula 'y ~ x'
```



Again, lack of levels in the continuous output causes some problems. Still going to push through, but again, a bit of caution is warranted...

```
car::Anova(model.enjoyment, type = "III")
```

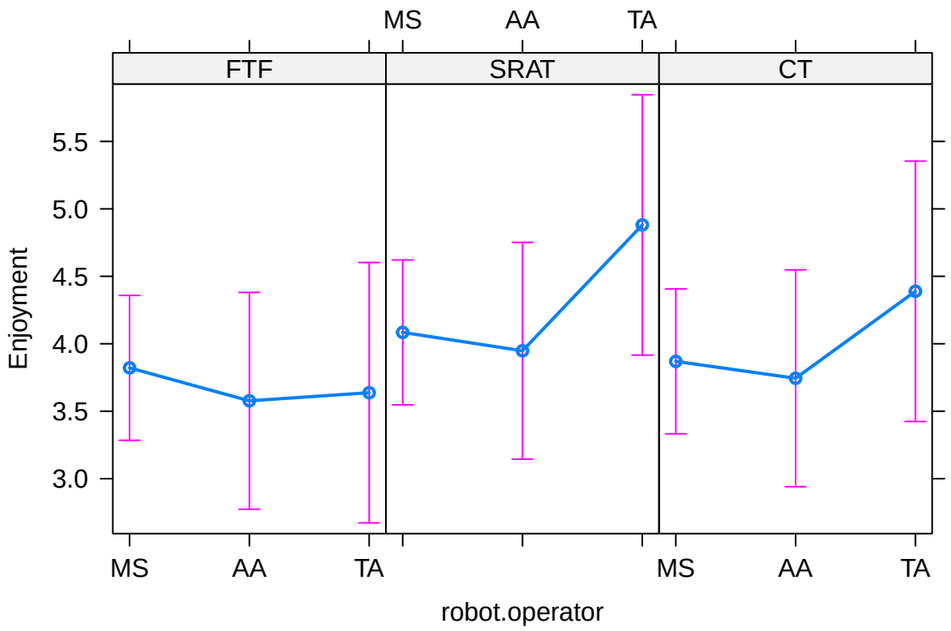
ANOVA

```
## Analysis of Deviance Table (Type III Wald chisquare tests)
##
## Response: Enjoyment
##                                          Chisq Df Pr(>Chisq)
## (Intercept)                            18.9073  1  1.372e-05 ***
## interaction.modality                    1.6664  2    0.43465
## Age                                     0.1903  1    0.66267
## BBT                                     1.7243  1    0.18914
## CTT2                                    0.0470  1    0.82836
## experimental.order                      0.8892  1    0.34569
## robot.operator                          0.2373  2    0.88810
## Age:BBT                                 2.2970  1    0.12962
## Age:CTT2                                0.2406  1    0.62375
## BBT:CTT2                                0.5076  1    0.47616
## interaction.modality:Age                0.4896  2    0.78285
## interaction.modality:BBT                1.6591  2    0.43625
## interaction.modality:CTT2               2.4293  2    0.29681
## interaction.modality:experimental.order 1.9106  2    0.38469
## interaction.modality:robot.operator     8.7368  4    0.06803 .
## Age:BBT:CTT2                            0.9339  1    0.33386
## interaction.modality:Age:BBT            3.7834  2    0.15082
## interaction.modality:Age:CTT2           2.4062  2    0.30026
## interaction.modality:BBT:CTT2           5.0323  2    0.08077 .
## interaction.modality:Age:BBT:CTT2       3.6149  2    0.16408
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Robot Operator : Interaction Modality

```
lattice::trellis.par.set(effects::effectsTheme())
plot(
  effects::Effect(c("robot.operator", "interaction.modality"), model.enjoyment),
```

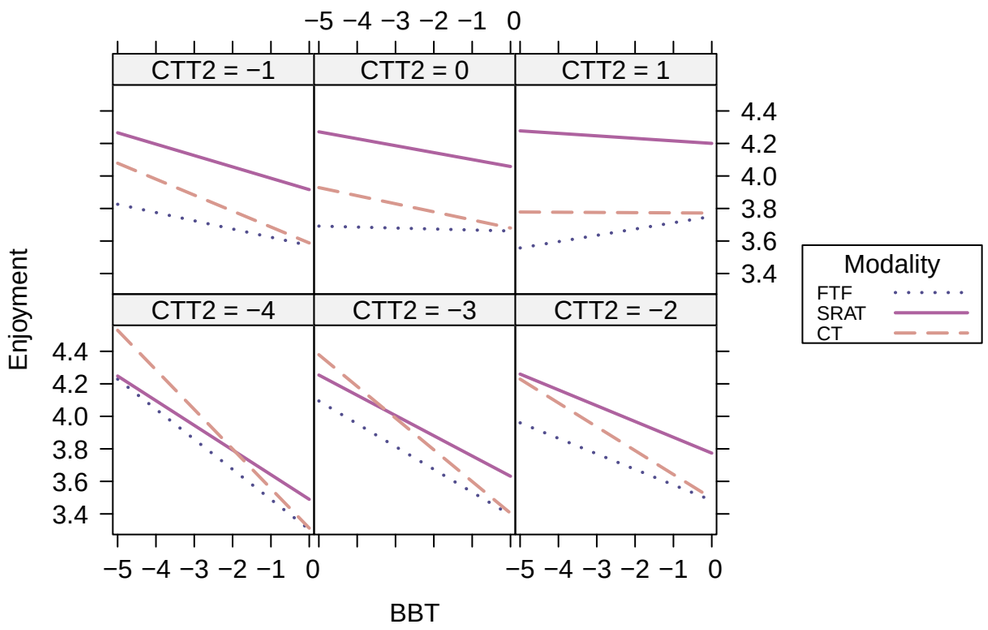
```
  main = NULL,
  lattice = list(strip = list(factor.names = FALSE))
)
```



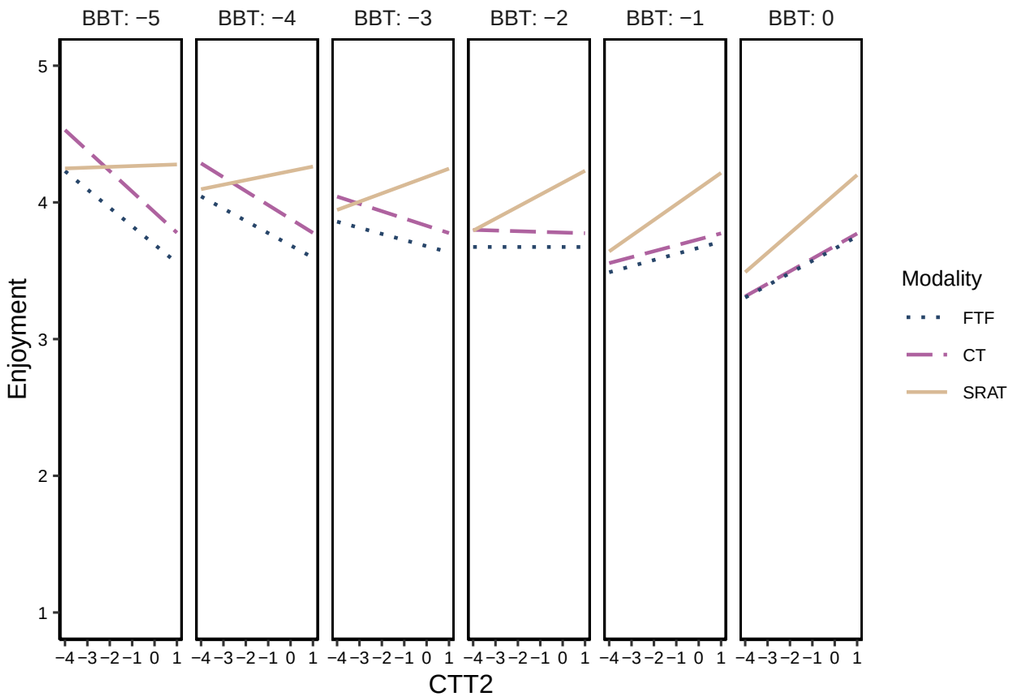
- TA generates more enjoyment in SRAT condition and less in FTF.

BBT : Interaction Modality : CTT2

```
lattice::trellis.par.set(effects::effectsTheme())
plot(
  effects::Effect(c("BBT", "CTT2", "interaction.modality"), model.enjoyment,
    xlevels =
      interaction.levels[c("CTT2", "BBT")]
  ),
  axes = list(x = list(rug = FALSE)),
  lines = list(
    multiline = TRUE,
    z.var = "interaction.modality",
    col = cust_color(5)[2:4],
    lty = c(3, 1, 5)
  ),
  lattice = list(key.args = list(space = "right", border = TRUE, title = "Modality")),
  main = NULL
)
```




```
effects.enjoyment.bbt_ctt <-
  effects::Effect(c("BBT", "CTT2", "interaction.modality"), model.enjoyment,
    xlevels =
      interaction.levels[c("CTT2", "BBT")]
  )

enjoyment.model.bbt_ctt.plot <- cbind(effects.enjoyment.bbt_ctt[["x"]], effects.enjoyment.bbt_ctt[["fit"]]) %>%
  ggplot(aes(x = CTT2, y = `effects.enjoyment.bbt_ctt[["fit"]]`, color = interaction.modality, linetype = interaction.modality)) +
  geom_line(size = .8) +
  facet_grid(cols = vars(BBT), labeller = label_both) +
  plt_theme +
  ylab("Enjoyment") +
  scale_color_manual(
    values = cust_color(7)[c(2, 4, 6)],
    breaks = c("FTF", "CT", "SRAT")
  ) +
  scale_linetype_manual(
    values = c(3, 5, 1),
    breaks = c("FTF", "CT", "SRAT")
  ) +
  labs(color = "Modality", linetype = "Modality") +
  xlim(c(-4, 1)) +
  ylim(c(1, 5)) +
  theme(legend.key.width = unit(.05, "npc"), legend.position = "right")

print(enjoyment.model.bbt_ctt.plot)
```




```
fn <- file.path(out_dir, "tikz-enjoyment_bbt_ctt_model.tex")
tikz(
  file = fn,
  width = 5.8,
  height = 1.25,
  sanitize = TRUE
)
print(enjoyment.model.bbt_ctt.plot)
dev.off()
```

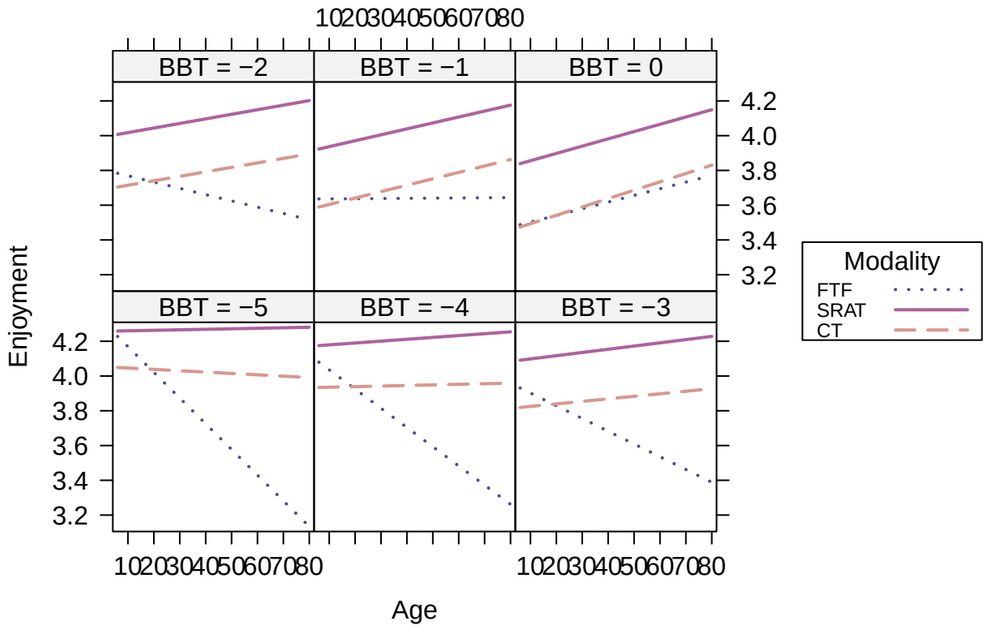
```
## pdf
##   2
```

```
strip_tikz_white(fn)
```

- Among all levels of motor impairment, at normal cog function, SRAT is more enjoyable than CT.
- At and beyond severe cognitive impairment (z<-3), but at all levels of motor function, CT is more enjoyable.
- Between moderate (z=-2) and severe (z=-3) cognitive impairment, at all levels of motor function, enjoyment is equivalent between conditions.

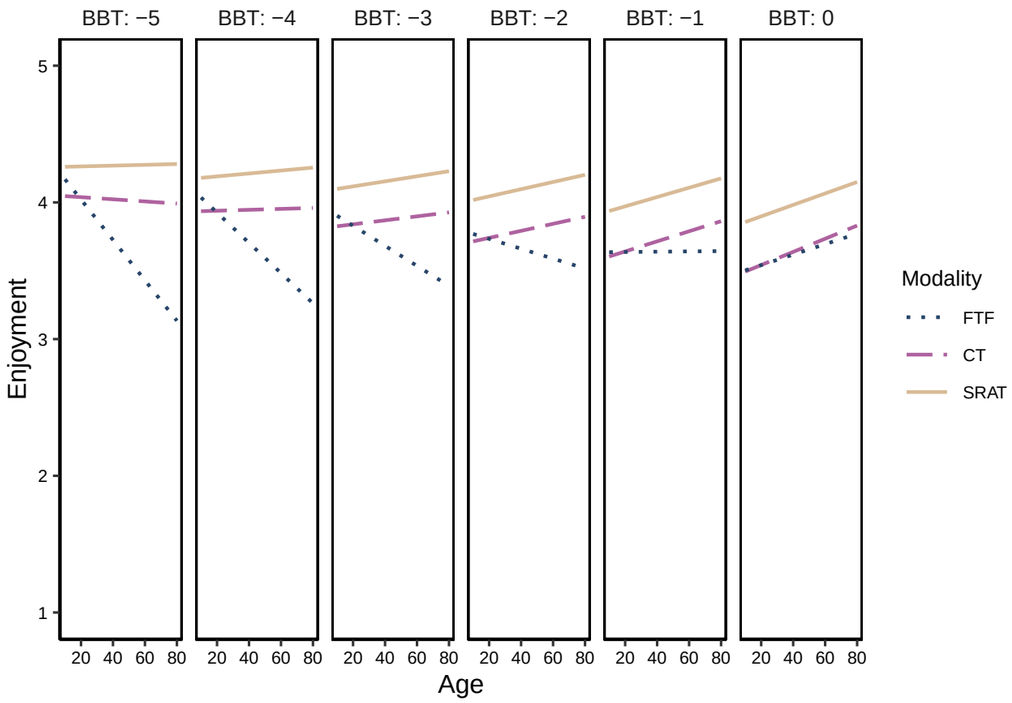
Age : Interaction Modality : CTT2

```
lattice::trellis.par.set(effects::effectsTheme())
plot(
  effects::Effect(c("BBT", "Age", "interaction.modality"), model.enjoyment,
    xlevels =
      interaction.levels[c("Age", "BBT")]
  ),
  axes = list(x = list(rug = FALSE)),
  lines = list(
    multiline = TRUE,
    z.var = "interaction.modality",
    col = cust_color(5)[2:4],
    lty = c(3, 1, 5)
  ),
  lattice = list(key.args = list(space = "right", border = TRUE, title = "Modality")),
  main = NULL
)
```




```
effects.enjoyment.bbt_age <-
  effects::Effect(c("BBT", "Age", "interaction.modality"), model.enjoyment,
    xlevels =
      interaction.levels[c("Age", "BBT")]
  )

enjoyment.model.bbt_age.plot <- cbind(effects.enjoyment.bbt_age[["x"]], effects.enjoyment.bbt_age[["fit"]]) %>%
  ggplot(aes(x = Age, y = `effects.enjoyment.bbt_age[["fit"]]`, color = interaction.modality, linetype = interaction.modality)) +
  geom_line(size = .8) +
  facet_wrap(~BBT, nrow = 1, labeller = label_both) +
  plt_theme +
  ylab("Enjoyment") +
  scale_color_manual(
    values = cust_color(7)[c(2, 4, 6)],
    breaks = c("FTF", "CT", "SRAT")
  ) +
  scale_linetype_manual(
    values = c(3, 5, 1),
    breaks = c("FTF", "CT", "SRAT")
  ) +
  labs(color = "Modality", linetype = "Modality") +
  xlim(c(10, 80)) +
  ylim(c(1, 5)) +
  theme(legend.key.width = unit(.05, "npc"), legend.position = "right")

print(enjoyment.model.bbt_age.plot)
```

```
## Warning: Removed 12 row(s) containing missing values (geom_path).
```




```
fn <- file.path(out_dir, "tikz-enjoyment_bbt_age_model.tex")
tikz(
  file = fn,
  width = 5.8,
  height = 1.25,
  sanitize = TRUE
)
print(enjoyment.model.bbt_age.plot)
```

```
## Warning: Removed 12 row(s) containing missing values (geom_path).
```

```
dev.off()
```

```
## pdf
##   2
```

```
strip_tikz_white(fn)
```

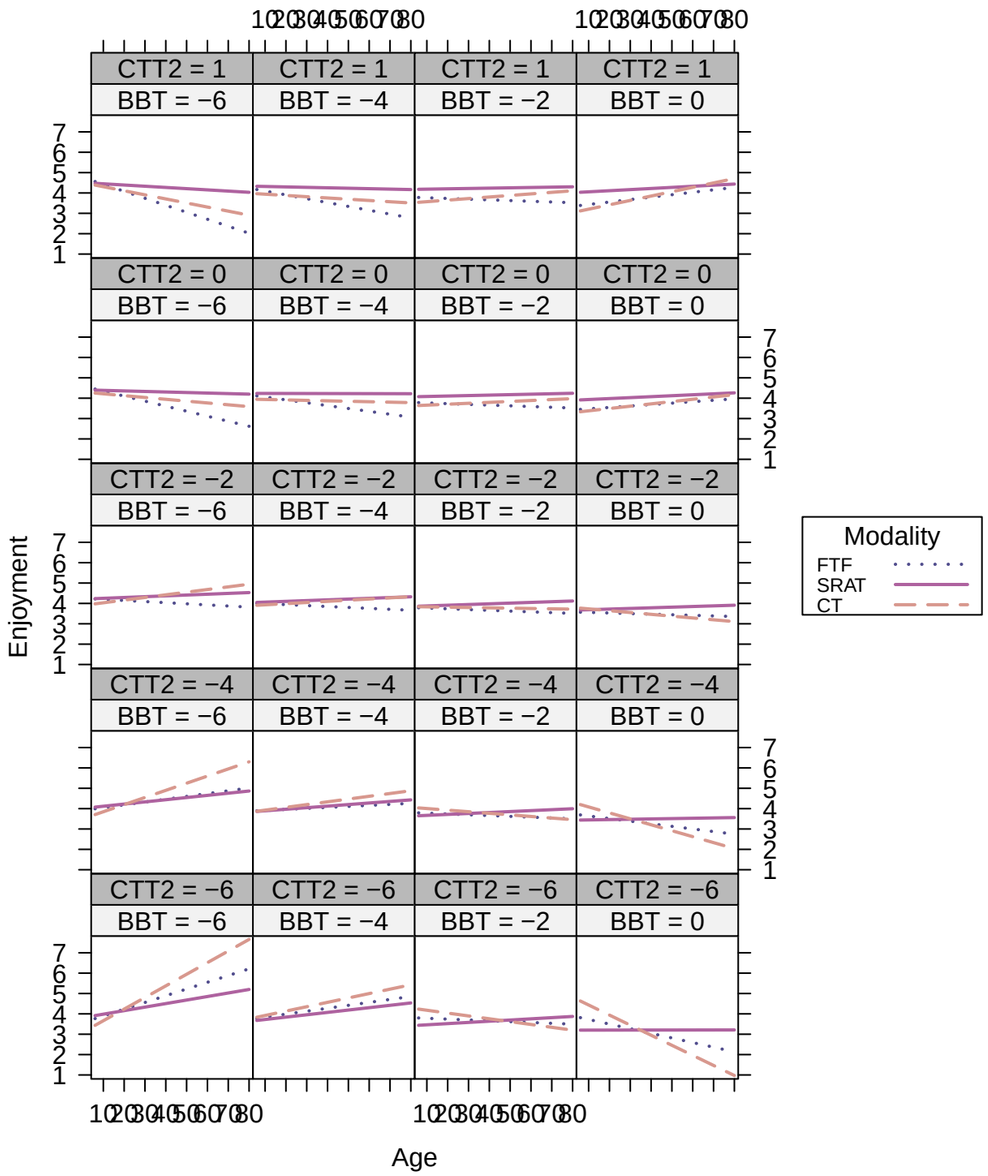
- Among all ages, SRAT is more enjoyable than CT. For older people, there is a greater difference at lower motor function levels. Among younger people, there is a greater difference at higher motor function levels.
- Essentially the age:motor function interaction is acting as a multiplier on the cog function:motor function interaction

Age : Interaction Modality : CTT2 : BBT

This higher order term is not itself significant, but it may be helpful to visualize the two prior sets of graphs together.

```
lattice::trellis.par.set(effects::effectsTheme())
plot(
  effects::Effect(c("BBT", "Age", "interaction.modality", "CTT2"), model.enjoyment,
    xlevels =
      list(
        BBT = c(-6, -4, -2, 0),
        CTT2 = c(-6, -4, -2, 0, 1),
        Age = 6:80
      )
  ),
  axes = list(x = list(rug = FALSE)),
  lines = list(
    multiline = TRUE,
    z.var = "interaction.modality",
    col = cust_color(5)[2:4],
    lty = c(3, 1, 5)
```

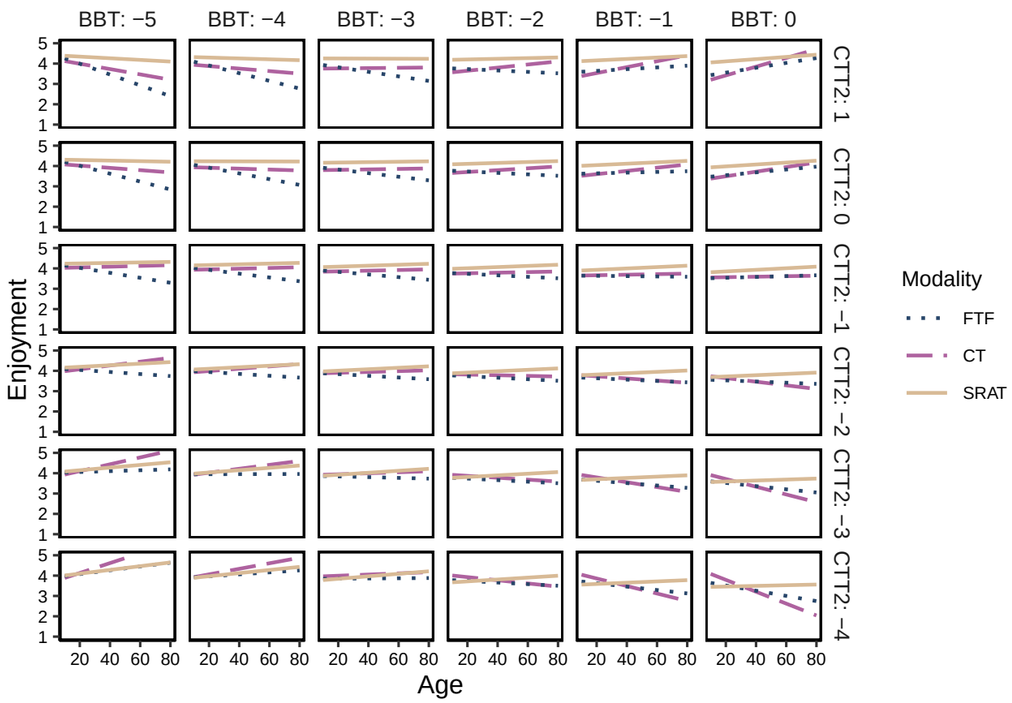
```
  ),
  main = NULL,
  lattice = list(key.args = list(space = "right", border = TRUE, title = "Modality"), layout = c(4, 5))
)
```




```
effects.enjoyment <-
  effects::Effect(c("BBT", "Age", "CTT2", "interaction.modality"), model.enjoyment,
    xlevels =
      interaction.levels[c("Age", "BBT", "CTT2")]
  )

enjoyment.model.plot <- cbind(effects.enjoyment[["x"]], effects.enjoyment[["fit"]]) %>%
  mutate(
    CTT2 = forcats::fct_rev(factor(CTT2))
  ) %>%
  ggplot(aes(x = Age, y = `effects.enjoyment[["fit"]]`, color = interaction.modality, linetype = interaction.modality)) +
```

```
  geom_line(size = .8) +
  facet_grid(rows = vars(CTT2), cols = vars(BBT), labeller = label_both) +
  plt_theme +
  ylab("Enjoyment") +
  scale_color_manual(
    values = cust_color(7)[c(2, 4, 6)],
    breaks = c("FTF", "CT", "SRAT")
  ) +
  scale_linetype_manual(
    values = c(3, 5, 1),
    breaks = c("FTF", "CT", "SRAT")
  ) +
  labs(color = "Modality", linetype = "Modality") +
  xlim(c(10, 80)) +
  ylim(c(1, 5)) +
  theme(legend.key.width = unit(.05, "npc"), legend.position = "right")

print(enjoyment.model.plot)
```

```
## Warning: Removed 12 row(s) containing missing values (geom_path).
```




```
fn <- file.path(out_dir, "tikz-enjoyment_bbt_ctt_age_model.tex")
tikz(
  file = fn,
  width = 5.8,
  height = 5,
  sanitize = TRUE
)
print(enjoyment.model.plot)
```

```
## Warning: Removed 12 row(s) containing missing values (geom_path).
```

```
dev.off()
```

```
## pdf
##   2
```

```
strip_tikz_white(fn)
```

- At high cog ability (z>0) and very severe motor impairment (z<-5), adults enjoy SRAT more than CT and children show no difference; at severe motor impairment (-4<z<-3), both adults and children enjoy SRAT more than CT; at normal motor function

(z>-1), children enjoy SRAT more than CT and adults show little difference. This pattern holds until mild cognitive impairmen (z=-1).
- At moderate cog impairment (z=-2), across ages and motor function levels, enjoyment of SRAT and CT are nearly identical.
- With very severe motor function (z<-5), children show no difference in their enjoyment of SRAT and CT
- With very severe motor function (z<-5) and sever cognitive function (z<-3) adults enjoy CT more than SRAT
- At moderate or better motor function (z>-3) and severe cog impairment (z<-3), persons under around 50 years old enjoy CT more than SRAT and persons over ~70 years old enjoy SRAT more than CT

These are very complex interactions. Not sure how to communicate best.

```
model.competence <- lme4::lmer(Competence ~ interaction.modality * ((Age * BBT * CTT2) + experimental.order + robot.operator) + (1 | subject), data = all_data)
summary(model.competence)
```

Competence

```
## Linear mixed model fit by REML ['lmerMod']
## Formula: Competence ~ interaction.modality * ((Age * BBT * CTT2) + experimental.order +      robot.operator) + (1 | subject)
##    Data: all_data
##
## REML criterion at convergence: 408.6
##
## Scaled residuals:
##      Min       1Q   Median       3Q      Max
## -2.84744 -0.36180  0.06956  0.46403  1.55891
##
## Random effects:
##  Groups   Name        Variance Std.Dev.
##  subject  (Intercept) 0.3017   0.5492
##  Residual             0.4877   0.6984
## Number of obs: 114, groups:  subject, 38
##
## Fixed effects:
##                                                          Estimate Std. Error t value
## (Intercept)                                             3.6874825  0.6707628   5.497
## interaction.modalitySRAT                               -1.1929585  0.7456362  -1.600
## interaction.modalityCT                                  0.0003142  0.7456362   0.000
## Age                                                     0.0240781  0.0141314   1.704
## BBT                                                    -0.2119335  0.1327337  -1.597
## CTT2                                                    0.0442051  0.3678336   0.120
## experimental.orderCT First                             -0.3525713  0.3360828  -1.049
## robot.operatorAA                                        0.5719747  0.4501135   1.271
## robot.operatorTA                                       -0.3614812  0.5298921  -0.682
## Age:BBT                                                 0.0081757  0.0030626   2.670
## Age:CTT2                                               -0.0118966  0.0088584  -1.343
## BBT:CTT2                                               -0.0088562  0.0538429  -0.164
## interaction.modalitySRAT:Age                            0.0129581  0.0157088   0.825
## interaction.modalityCT:Age                             -0.0054021  0.0157088  -0.344
## interaction.modalitySRAT:BBT                           -0.1201377  0.1475500  -0.814
## interaction.modalityCT:BBT                              0.0345923  0.1475500   0.234
## interaction.modalitySRAT:CTT2                           0.0377910  0.4088928   0.092
## interaction.modalityCT:CTT2                             0.3371419  0.4088928   0.825
## interaction.modalitySRAT:experimental.orderCT First     0.4112676  0.3735978   1.101
## interaction.modalityCT:experimental.orderCT First       0.3378577  0.3735978   0.904
## interaction.modalitySRAT:robot.operatorAA               0.1073998  0.5003571   0.215
## interaction.modalityCT:robot.operatorAA                -0.1442121  0.5003571  -0.288
## interaction.modalitySRAT:robot.operatorTA               1.5013945  0.5890409   2.549
## interaction.modalityCT:robot.operatorTA                 0.8574460  0.5890409   1.456
## Age:BBT:CTT2                                           -0.0025126  0.0022061  -1.139
## interaction.modalitySRAT:Age:BBT                        0.0002016  0.0034044   0.059
## interaction.modalityCT:Age:BBT                         -0.0022761  0.0034044  -0.669
## interaction.modalitySRAT:Age:CTT2                      -0.0014797  0.0098472  -0.150
## interaction.modalityCT:Age:CTT2                        -0.0059693  0.0098472  -0.606
## interaction.modalitySRAT:BBT:CTT2                       0.0236188  0.0598531   0.395
## interaction.modalityCT:BBT:CTT2                         0.0520116  0.0598531   0.869
## interaction.modalitySRAT:Age:BBT:CTT2                  -0.0016560  0.0024524  -0.675
## interaction.modalityCT:Age:BBT:CTT2                    -0.0020700  0.0024524  -0.844

##
```

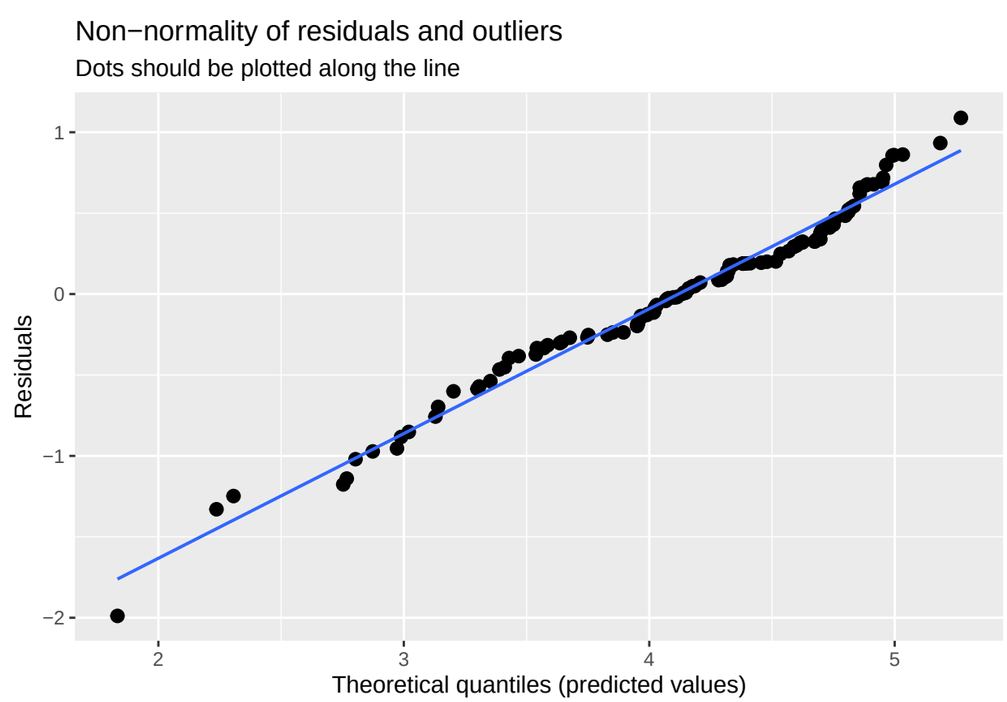
```
## Correlation matrix not shown by default, as p = 33 > 12.
## Use print(x, correlation=TRUE)  or
##     vcov(x)        if you need it
```

```
sjPlot::plot_model(model.competence, type = "diag")
```

Diagnostics on model

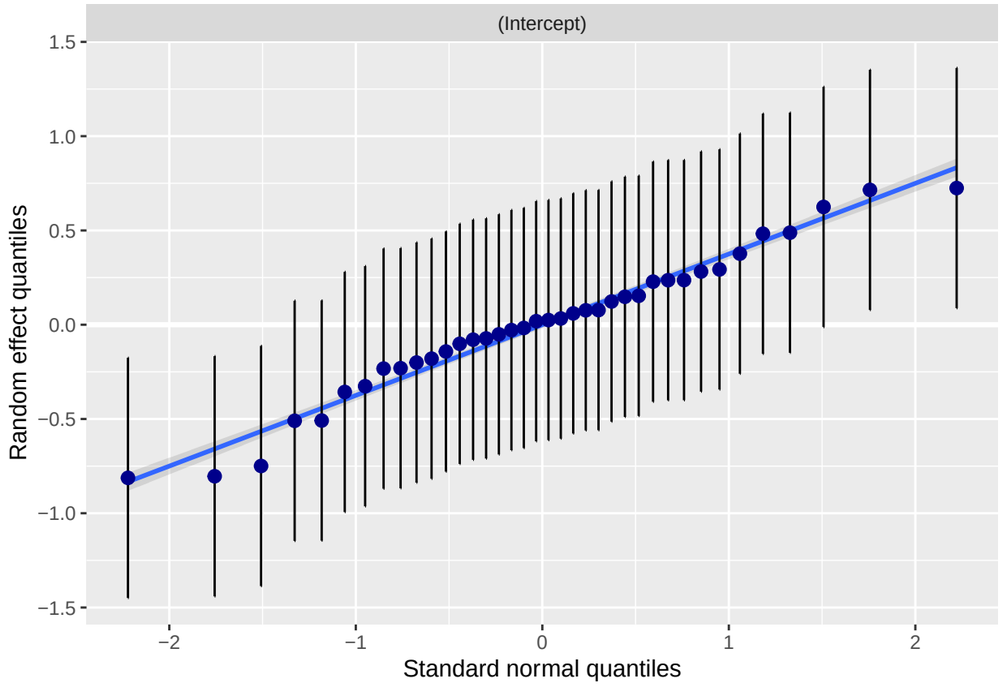
```
## [[1]]
```

```
## `geom_smooth()` using formula 'y ~ x'
```

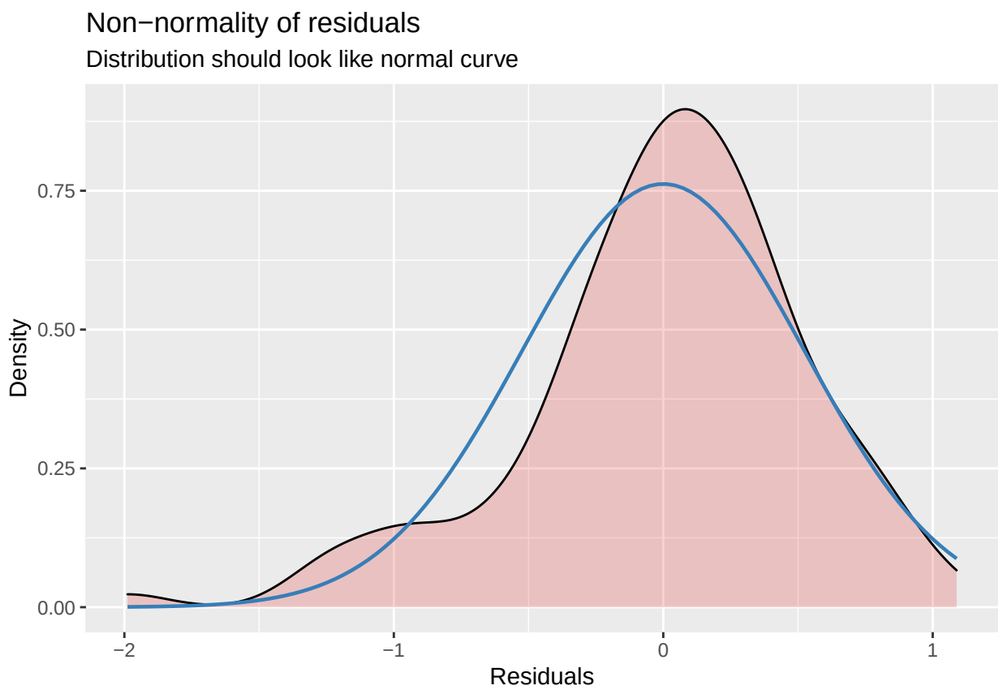



```
##
## [[2]]
## [[2]]$subject
```

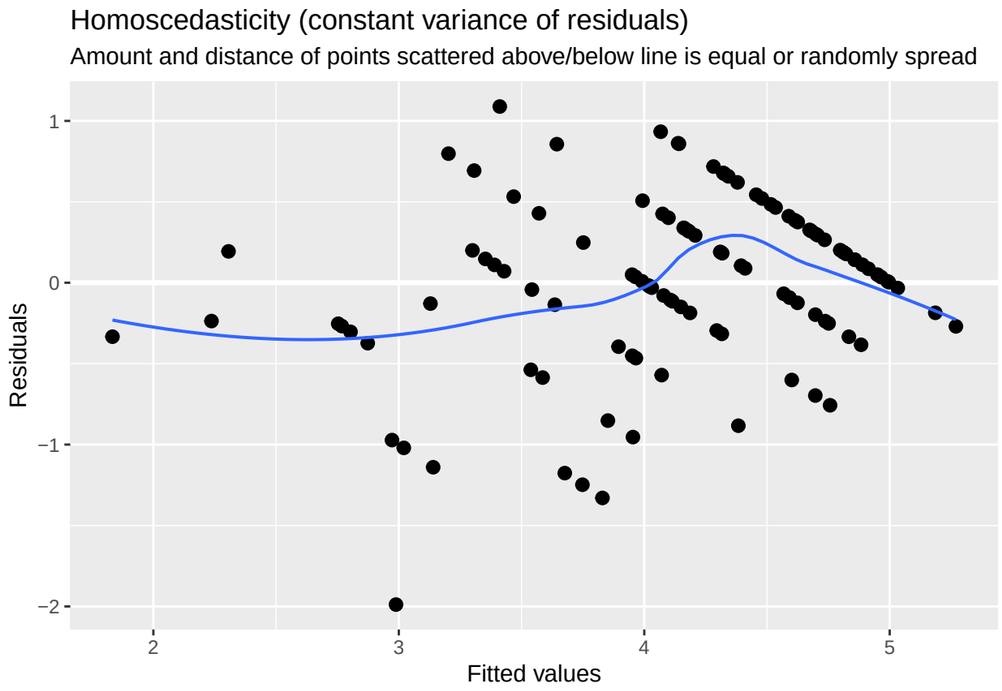
```
## `geom_smooth()` using formula 'y ~ x'
```




```
##
##
## [[3]]
```




```
##
## [[4]]
## `geom_smooth()` using formula 'y ~ x'
```



Normality looks meh, and homoscedasticity is not great. Need to be careful using/ interpreting this on. I think one of the challenges is that there are not a lot of unique levels in the competence scale:

```
all_data %>%
  select(Competence) %>%
  unique() %>%
  unlist()
```

```
## Competence1 Competence2 Competence3 Competence4 Competence5 Competence6 Competence7 Competence8 Competence9
##         5.0         4.5         2.5         3.5         4.0         1.5         2.0         3.0         1.0
```

So the idea of the output being continous is not really true here.

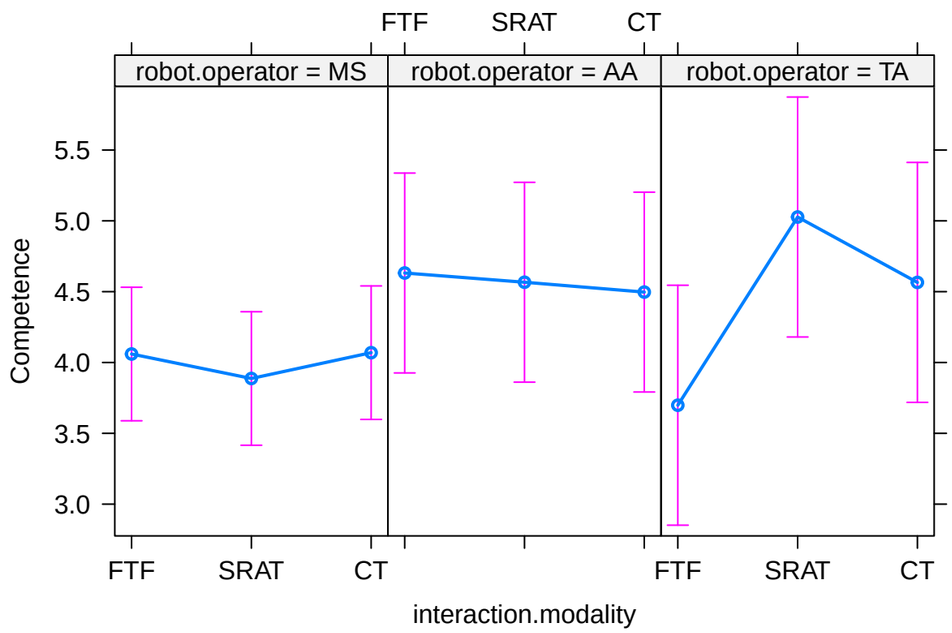
```
car::Anova(model.competence, type = "III")
```

ANOVA

```
## Analysis of Deviance Table (Type III Wald chisquare tests)
##
## Response: Competence
##                                          Chisq Df Pr(>Chisq)
## (Intercept)                            30.2219  1  3.853e-08 ***
## interaction.modality                    3.4139  2   0.181419
## Age                                     2.9032  1   0.088405 .
## BBT                                     2.5494  1   0.110337
## CTT2                                    0.0144  1   0.904343
## experimental.order                      1.1005  1   0.294150
## robot.operator                          3.5769  2   0.167216
## Age:BBT                                 7.1266  1   0.007595 **
## Age:CTT2                                1.8036  1   0.179280
## BBT:CTT2                                0.0271  1   0.869352
## interaction.modality:Age                1.4432  2   0.485981
## interaction.modality:BBT                1.2117  2   0.545601
## interaction.modality:CTT2               0.8162  2   0.664900
## interaction.modality:experimental.order 1.3788  2   0.501867
## interaction.modality:robot.operator     7.9989  4   0.091620 .
## Age:BBT:CTT2                            1.2972  1   0.254734
## interaction.modality:Age:BBT            0.6535  2   0.721273
## interaction.modality:Age:CTT2           0.3986  2   0.819302
## interaction.modality:BBT:CTT2           0.7573  2   0.684799
```

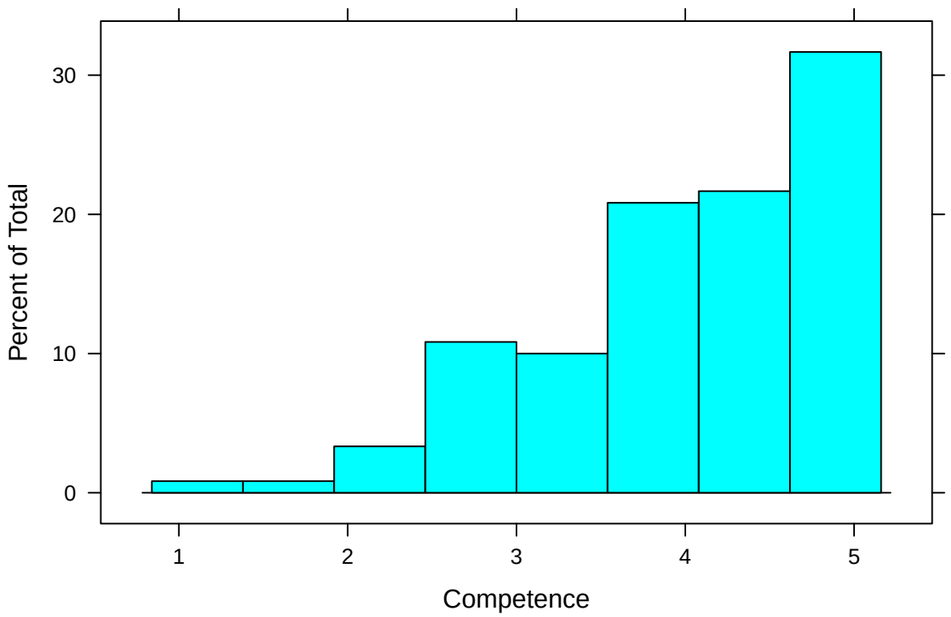
```
## interaction.modality:Age:BBT:CTT2        0.7980  2   0.670989
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
lattice::trellis.par.set(effects::effectsTheme())
plot(
  effects::Effect(c("interaction.modality", "robot.operator"), model.competence),
  axes = list(x = list(rug = FALSE)),
  main = NULL
)
```



- interaction.modality is not significant, so will just report aggregate:

```
histogram(~Competence, all_data)
```



Conclusion

We have identified that SRAT is better than CT for certain populations as measured by decreased task load and higher enjoyment compared to CT:

- For persons <~40 years old of normal, mildly impaired motor function, SRAT has higher task load than CT, although by only a small margin (max: 12/100 at 7 years old, BBT z=0.5). For others, task load is nearly identical.
- In general, task load is low,
- For people less than 50 years old, of normal cog function, and no more than mild impairment, SRAT is more enjoyable. This stops being true for persons with moderate and severe cog impairment.
- For people with moderate to severe cognitive function, and less than severe motor function, SRAT is more enjoyable.
- In all modalities:
  - task load was low, averaging between 31 and 35 / 100 on the NASA TLX.
  - Competence was high, averaging greater than 4/5 using the IMI
  - Pressure was low, averaging between 1.8 and 2 / 5 (note: scale 1-5)
  - Value was moderately high, averaging between 3.9 and 4 / 5
- Enjoyment was high in the SRAT condition (avg 4.2/5) and moderately high (>=3.75/5) for the FTF and CT condition

Limitations

- Some of the assumptions of the mixed model GLMs are being pushed
- We do not have a post-hoc test to run on the linear interactions, we are judging based on the graphs (many statisticians recommend this over relying too much on tests, others prefer tests) (I don't know how to do tests on this and am out of time)
- We are using linear models. It is very likely that some of the outputs are not linear in the factors.
- I don't think these models are stabilized (adding more data will likely change some results)

Final Survey - Interaction Mode Preference

Setup

```
rm(list = ls())
source("utility_scripts/setup.r")
```

```
## [1] "Only including subjects with complete consent forms"
## [1] "Excluding subjec # <=10 (pilot trial cohort)"
## [1] "n=44"
## [1] "Excluding Subjects:"
## [1] "    excluding subject 50"
## [1] "    excluding subject 47"
## [1] "Corrected Subject 22 Survey Assignment"
## [1] "Fixing subject 60 post experiment"
```

```
## [1] "final number of subjects: 42"
## [1] "Filling in for subjects too young for color trails:"
## [1] "    Subject 15, reported no impairment, marking no impairment"
## [1] "    subject 23, reported motor impairment only, BBT -2.56 z, marking motor impairment"
## [1] "    Subject 66, reported motor impairment only (Left hemiparesis), marking motor impairment"
```

```
options(width = 600)
```

There are two subjects who did not complete the questions in this part of the analysis because they are too young: Also filter out subject 66 as he didnt complete exit survey:

```
combined_data <- combined_data %>%  filter(!is.na(preference)) #!record_id==66)
combined_data %>%
  filter(is.na(color_trails_2_standard)) %>%
  select(record_id, age)
```

```
##   record_id age
## 1        15   5
## 2        23   4
```

We could keep them around for anywhere that we are using reported cog/motor impairment, but then they will have to be dropped later in the analysis. It is probably best to just drop them now:

Best Interaction

We are trying to answer two questions here:

1. Do people prefer Social Robot Augmented Telepresence (SRAT) or Classical Telepresence (CT) for rehab interactions?
2. Do the order of experiment, robot/telepresence operator, and/or the cross interaction among patient age, cognitivie abilities, and motor abilities affect responses

Note: We collected a bunch of other variables. We are testing the two major risk variables (order, operator), and the things which are both expected to have an influence and able to be used as design parameters. For example, we would not design systems around someones previous usage of telepresence (that is not inherent to the person and will change after one telepresence interaction). But we would design around age, since that is a durable defining feature of the patient, as is impairment level.

Please rank which interaction you thought was best, second best, and worst:

Three types of interactions:

- Face to face (FTF)
- Social robot augmented telepresence (SRAT)
- Classic telepresence (CT)

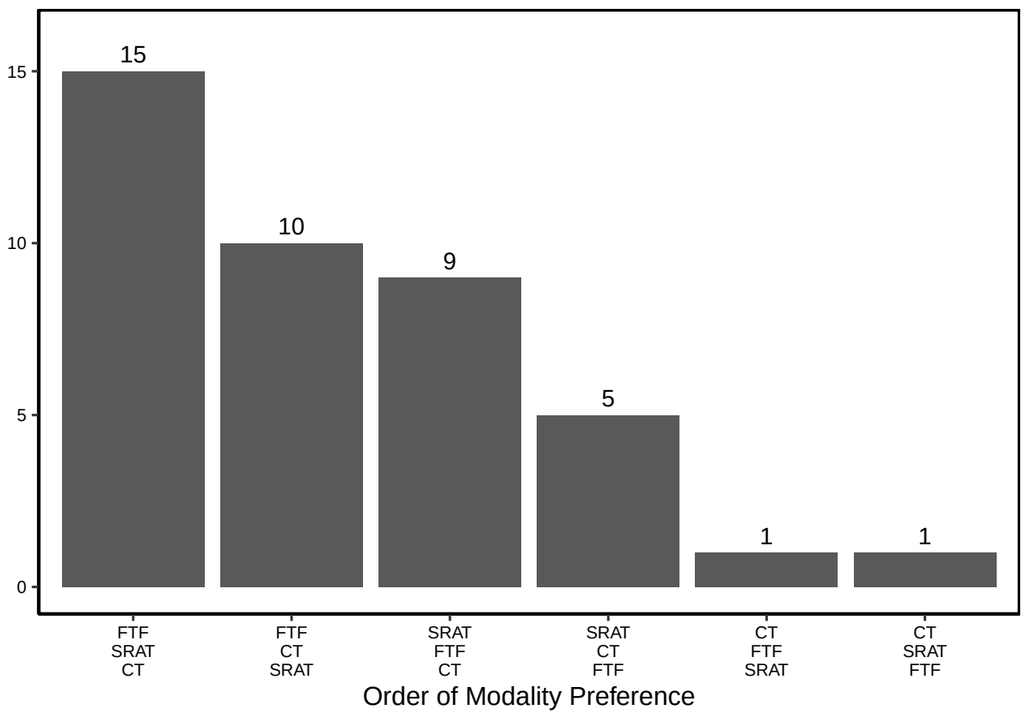
To keep us from being deceived by shifting scales, let's look at tables with row wise percentages. We are going to end up doing a multivariate analysis looking only at whether SRAT is better than CT, but to just probe the data and make sure we are thinking about it correctly, we can start with looking at how the independent variables/cofactors (grouped, non-continous) interact with rating overall, using Fisher's Exact Test.

```
order_tbl <-
  combined_data %>%
  select(preference, age_group, impairment.measured, order.factor, team_operator) %>%
  gtsummary::tbl_summary(
    by = preference,
    missing = "no",
    label = c(
      age_group ~ "Age",
      impairment.measured ~ "Impairment",
      order.factor ~ "Experiment Order",
      team_operator ~ "Operator"
    ),
    percent = "row"
  ) %>%
  gtsummary::add_overall(
    last = TRUE,
    statistic = ~"{n}"
  ) %>%
  gtsummary::add_p() %>%
  gtsummary::modify_header(label = "") %>% # update the column header
  gtsummary::bold_labels()
order_tbl
```

```
## Table printed with `knitr::kable()`, not {gt}. Learn why at
## https://www.danieldsjoberg.com/gtsummary/articles/rmarkdown.html
## To suppress this message, include `message = FALSE` in code chunk header.
```

	FTF-SRAT-CT, N = 15	**FTF-CT-SRAT**, N = 10	**SRAT-FTF-CT**, N = 9	**SRAT-CT-FTF**, N = 5	**CT-FTF-SRAT**, N = 1	**CT-SRAT-FTF**, N = 1	**Overall**, N = 41	**p-value**
___Age___								0.007
Young Children	0 (0%)	0 (0%)	5 (62%)	3 (38%)	0 (0%)	0 (0%)	8	
Teens-Young Adults	5 (45%)	2 (18%)	2 (18%)	1 (9.1%)	0 (0%)	1 (9.1%)	11	
Adults	8 (53%)	5 (33%)	1 (6.7%)	0 (0%)	1 (6.7%)	0 (0%)	15	
Older Adults	2 (29%)	3 (43%)	1 (14%)	1 (14%)	0 (0%)	0 (0%)	7	
___Impairment___								0.4
Motor	6 (27%)	7 (32%)	5 (23%)	3 (14%)	1 (4.5%)	0 (0%)	22	
Motor and Cognitive	2 (25%)	1 (12%)	2 (25%)	2 (25%)	0 (0%)	1 (12%)	8	
None	7 (64%)	2 (18%)	2 (18%)	0 (0%)	0 (0%)	0 (0%)	11	
___Experiment Order___								0.5
Augmented (Humanoid) First	6 (27%)	6 (27%)	5 (23%)	4 (18%)	0 (0%)	1 (4.5%)	22	
Classical (No-Humanoid) First	9 (47%)	4 (21%)	4 (21%)	1 (5.3%)	1 (5.3%)	0 (0%)	19	
___Operator___								0.10
1	12 (46%)	7 (27%)	5 (19%)	2 (7.7%)	0 (0%)	0 (0%)	26	
2	1 (12%)	3 (38%)	2 (25%)	1 (12%)	1 (12%)	0 (0%)	8	
3	2 (29%)	0 (0%)	2 (29%)	2 (29%)	0 (0%)	1 (14%)	7	

```
pref_all_plt <- combined_data%>%
  mutate(preference=factor(stringr::str_replace_all(preference,"-","\n"), levels=c("FTF\nSRAT\nCT", "FTF\nCT\nSRAT", "SRAT\nFTF\nCT", "SRAT\nCT\nFTF","CT\nFTF\nSRAT","CT\nSRAT\nFTF"))) %>%
  select(preference) %>%
  ggplot(aes(preference)) +
  geom_bar() +
  #   aes(fill = srat_betterthan_ct),
  #   color = "black",
  #   size = 1
  # ) +
  plt_theme +
  theme(axis.title.y = element_blank()) +
  xlab("Order of Modality Preference") +
  stat_count(aes(y = ..count.., label = ..count..),
    geom = "text",
    vjust = -.5
  ) +
  ylim(c(0, 16))

print(pref_all_plt)
```



```
fn <- file.path(out_dir, "tikz-pref_all.tex")
tikz(
  file = fn,
  width = 5.8,
  height = 1.25,
  sanitize = TRUE
)
print(pref_all_plt)
dev.off()
```

```
## pdf
##   2
```

```
strip_tikz_white(fn)
```

A bit of commentary:

- First and foremost, we don't actually care about this, we aren't interested in comparing face to face (FTF) to the other modalities.
- Age is a significant factor in this form.
- Operator is significant, so we need to make sure to account for that in our final analysis.

SRAT vs CT

What we really care about isn't face to face interactions, it is just SRAT vs CT. So let's take a look, with fisher's exact test for each variable:

```
combined_data <- combined_data %>%
  mutate(srat_betterthan_ct = (exit_best_interaction_sr < exit_best_interaction_ct)) %>%
  mutate(
    BBT = bbt.score.weak,
    CTT2 = color_trails_2_standard,
    Age = age,
    srat.better.than.ct = srat_betterthan_ct,
    experimental.order = order.factor,
    robot.operator = team_operator.factor
  ) %>%
  mutate(Age = as.numeric(Age))
label(combined_data$BBT) <- "Box and Block Test - Weak Arm"
```

```
order_tbl <-
  combined_data %>%
  mutate(srat_betterthan_ct_str = ifelse(srat_betterthan_ct, "SRAT", "CT")) %>%
  select(srat_betterthan_ct_str, age_group, impairment.measured, order.factor, team_operator) %>%
  gtsummary::tbl_summary(
    by = srat_betterthan_ct_str,
    missing = "no",
    label = c(
      age_group ~ "Age",
      impairment.measured ~ "Impairment",
      order.factor ~ "Experiment Order",
      team_operator ~ "Operator"
    ),
    percent = "row"
  ) %>%
  gtsummary::add_overall(
    last = TRUE,
    statistic = ~"{n}"
  ) %>%
  gtsummary::add_p(test = everything() ~ "fisher.test") %>%
  gtsummary::modify_header(label = "Preference (Ignoring FTF):") %>% # update the column header
  gtsummary::bold_labels()
order_tbl
```

```
## Table printed with `knitr::kable()`, not {gt}. Learn why at
## https://www.danieldsjoberg.com/gtsummary/articles/rmarkdown.html
## To suppress this message, include `message = FALSE` in code chunk header.
```

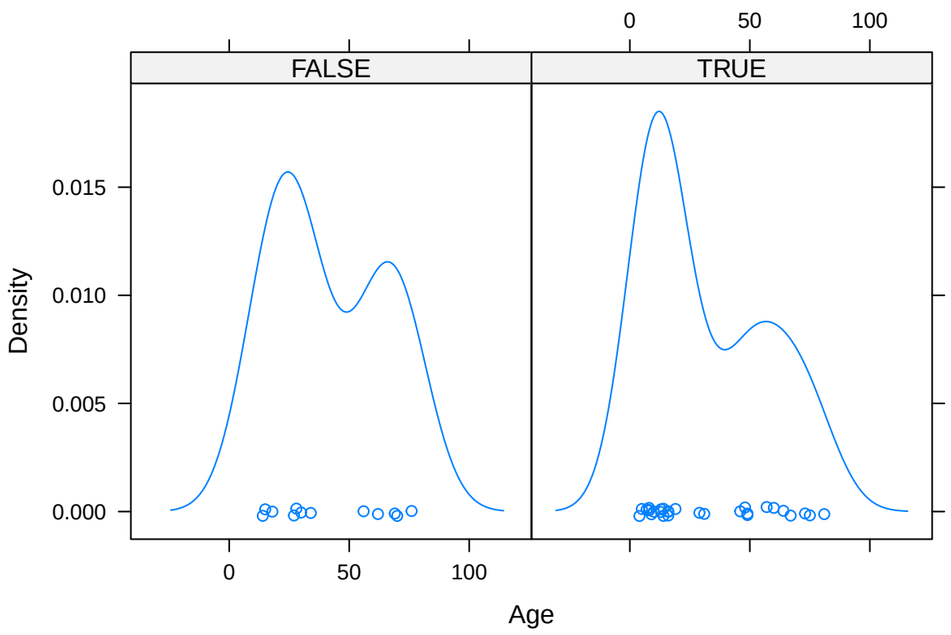
Preference (Ignoring FTF):	**CT**, N = 12	**SRAT**, N = 29	**Overall**, N = 41	**p-value**
___Age___				0.15
Young Children	0 (0%)	8 (100%)	8	
Teens-Young Adults	3 (27%)	8 (73%)	11	
Adults	6 (40%)	9 (60%)	15	
Older Adults	3 (43%)	4 (57%)	7	
___Impairment___				0.7
Motor	8 (36%)	14 (64%)	22	
Motor and Cognitive	2 (25%)	6 (75%)	8	
None	2 (18%)	9 (82%)	11	
___Experiment Order___				0.7
Augmented (Humanoid) First	7 (32%)	15 (68%)	22	
Classical (No-Humanoid) First	5 (26%)	14 (74%)	19	
___Operator___				0.3
1	7 (27%)	19 (73%)	26	
2	4 (50%)	4 (50%)	8	
3	1 (14%)	6 (86%)	7	

- No significance here
- Even though it isn't even close to significance, there is a clear trend among operators. That might be a result of experience operating the robot. But experience was gained beyond just this study, so we can't really quantify that and test with it. We could proxy by which interaction # each test is for each operator, but I think that gets too far into the weeds.

Of course, impairment and age are actually continuous variables that we measure, so let's do them justice:

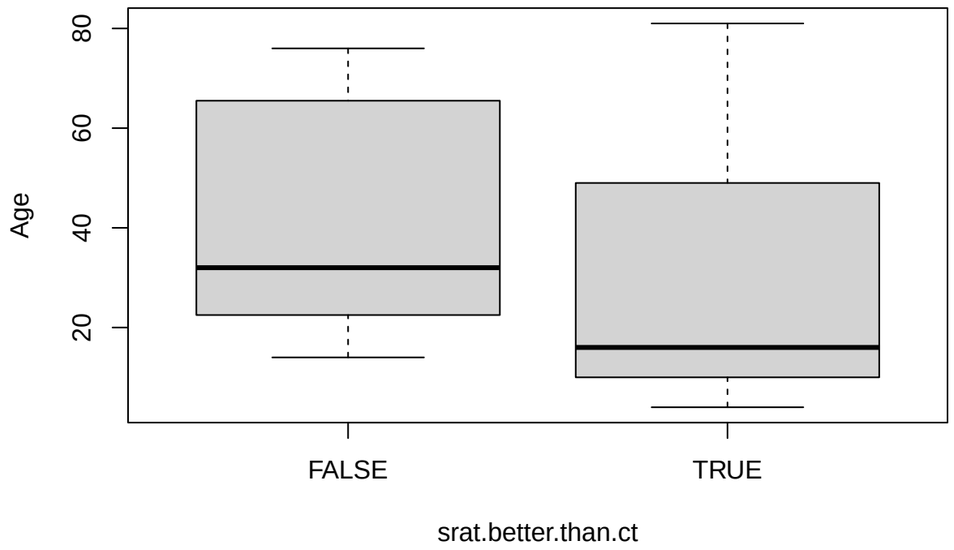
Age

```
densityplot(~ Age | srat.better.than.ct, data = combined_data)
```



Not normal, so use a Wilcoxon rank sum test to see if the group that prefers SRAT over CT is a different age group than those that do not:

```
boxplot(Age ~ srat.better.than.ct, data = combined_data)
```




```
wilcox.test(Age ~ srat.better.than.ct, data = combined_data)
```

```
## Warning in wilcox.test.default(x = DATA[[1L]], y = DATA[[2L]], ...): cannot compute exact p-value with ties
```

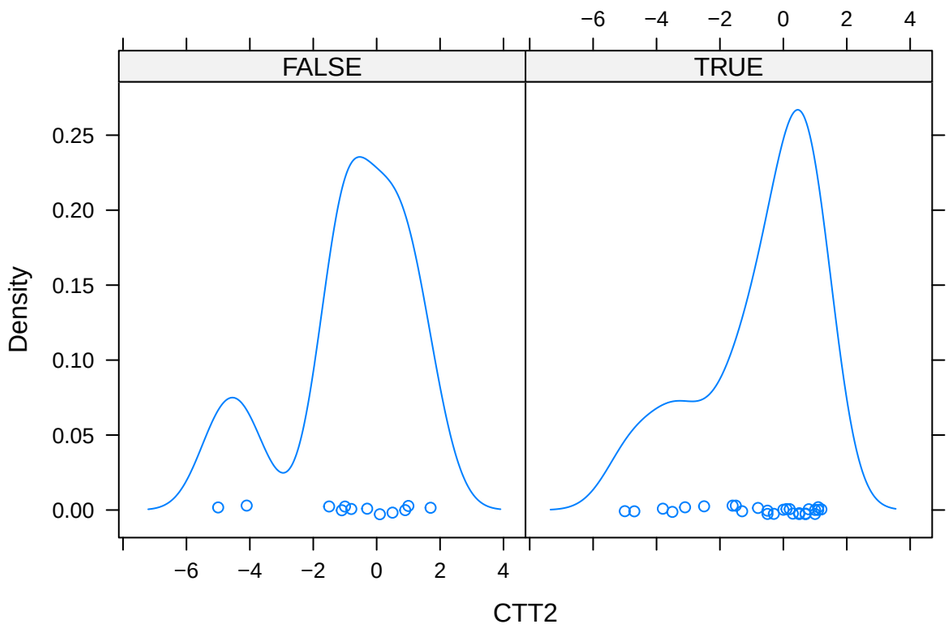
```
##
##  Wilcoxon rank sum test with continuity correction
##
## data:  Age by srat.better.than.ct
## W = 231, p-value = 0.1053
## alternative hypothesis: true location shift is not equal to 0
```

No difference

Cog Impairment

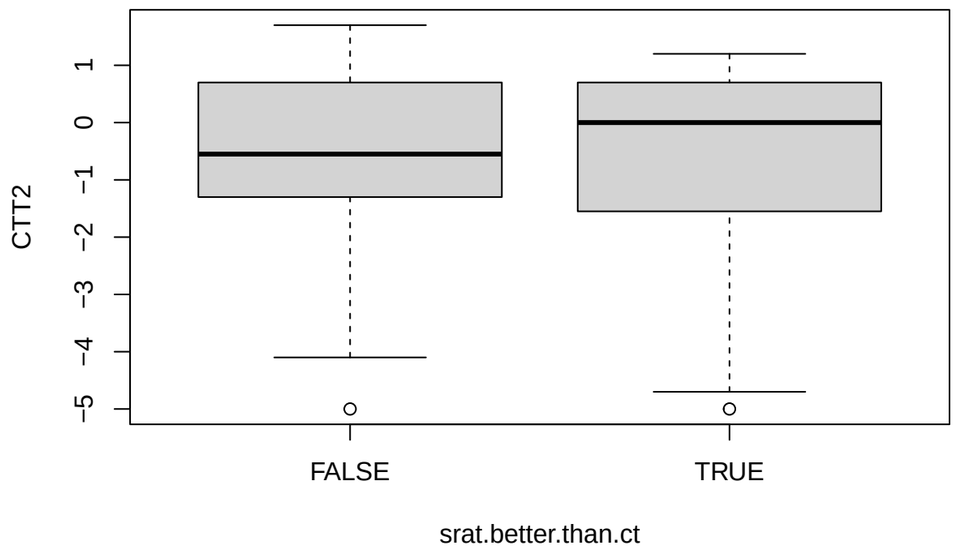
Same sort of think for cognition

```
densityplot(~ CTT2 | srat.better.than.ct, data = combined_data)
```



Not normal, so use a Wilcoxon rank sum test to see if the group that prefers SRAT over CT is a different cognitive group than those that do not:

```
boxplot(CTT2 ~ srat.better.than.ct, data = combined_data)
```




```
wilcox.test(CTT2 ~ srat.better.than.ct, data = combined_data)
```

```
## Warning in wilcox.test.default(x = DATA[[1L]], y = DATA[[2L]], ...): cannot compute exact p-value with ties
```

```
##
##  Wilcoxon rank sum test with continuity correction
##
```

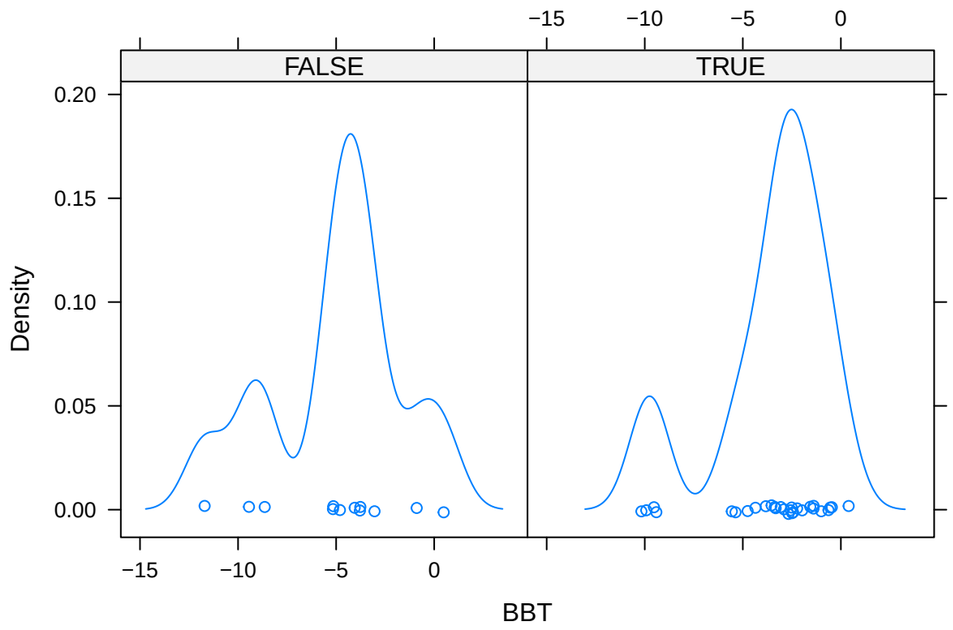
```
## data:  CTT2 by srat.better.than.ct
## W = 154.5, p-value = 0.8312
## alternative hypothesis: true location shift is not equal to 0
```

No difference

Motor Impairment

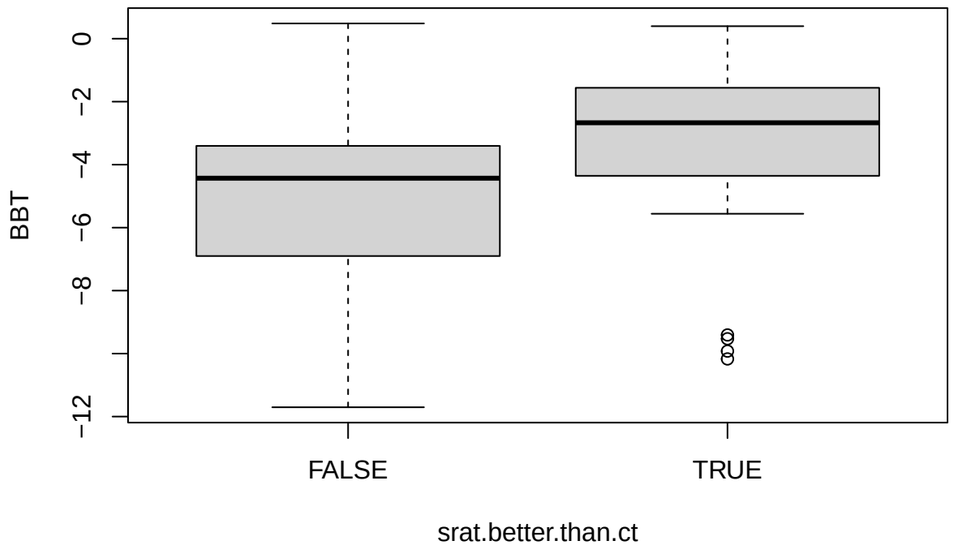
And for motor function

```
densityplot(~ BBT | srat.better.than.ct, data = combined_data)
```



Not normal, so use a Wilcoxon rank sum test to see if the group that prefers SRAT over CT is a different cognitive group than those that do not:

```
boxplot(BBT ~ srat.better.than.ct, data = combined_data)
```




```
wilcox.test(BBT ~ srat.better.than.ct, data = combined_data)
```

```
##
##  Wilcoxon rank sum exact test
##
## data:  BBT by srat.better.than.ct
## W = 118, p-value = 0.1126
## alternative hypothesis: true location shift is not equal to 0
```

Visually, looks like the people that prefer SRAT have higher BBT z-scores (better motor function). Not quite significant.

Compare CT to SRAT using logistic regression (GLM w/ binomial(logit link))

Here we are looking at a single measure, T/F on whether SRAT is greater than CT. We are going to use a GLM, keeping our variables of interest that are continuous as continuous factors. We could instead group everything (age groups, impairment levels) and use a Fisher's exact test to see if different groups/sub groups perform differently.

Lower number is higher rank:

- 1 Best
- 2 Second best
- 3 Third best

It is very important that for the categorical variables, we use the factor form to keep them from being treated as continuous. Note that the first factor will not be shown, because it is consumed by the intercept.

GLM Model

This method uses iteratively reweighted least squares (IWLS)

```
model <- glm(
  srat.better.than.ct ~
  Age * CTT2 * BBT +
    experimental.order + robot.operator,
  data = combined_data,
  family = binomial(link = "logit")
)
summary(model)
```

```
##
## Call:
## glm(formula = srat.better.than.ct ~ Age * CTT2 * BBT + experimental.order +
##     robot.operator, family = binomial(link = "logit"), data = combined_data)
```

```
##
## Deviance Residuals:
##     Min       1Q   Median       3Q      Max
## -2.0003  -0.4530   0.4488   0.7839   1.4403
##
## Coefficients:
##                                              Estimate Std. Error z value Pr(>|z|)
## (Intercept)                                  3.758508   2.433110   1.545   0.1224
## Age                                         -0.029677   0.050413  -0.589   0.5561
## CTT2                                         2.079922   1.286520   1.617   0.1059
## BBT                                          0.528233   0.424621   1.244   0.2135
## experimental.orderClassical (No-Humanoid) First  0.981802   0.981620   1.000   0.3172
## robot.operatorAjay Anand                    -1.458372   1.233253  -1.183   0.2370
## robot.operatorTuan Anh Nguyen                0.683368   1.710873   0.399   0.6896
## Age:CTT2                                    -0.079640   0.038987  -2.043   0.0411 *
## Age:BBT                                     -0.004330   0.009595  -0.451   0.6518
## CTT2:BBT                                     0.444615   0.224815   1.978   0.0480 *
## Age:CTT2:BBT                                -0.020792   0.010496  -1.981   0.0476 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## (Dispersion parameter for binomial family taken to be 1)
##
##     Null deviance: 48.145  on 38  degrees of freedom
## Residual deviance: 35.160  on 28  degrees of freedom
##   (2 observations deleted due to missingness)
## AIC: 57.16
##
## Number of Fisher Scoring iterations: 5
```

Remember, using logit function here, so none of this is linear.

Odds Ratio We can directly interpret these as telling you how the variables change outcome. These values tell you how the output will change as a multiple of the input.

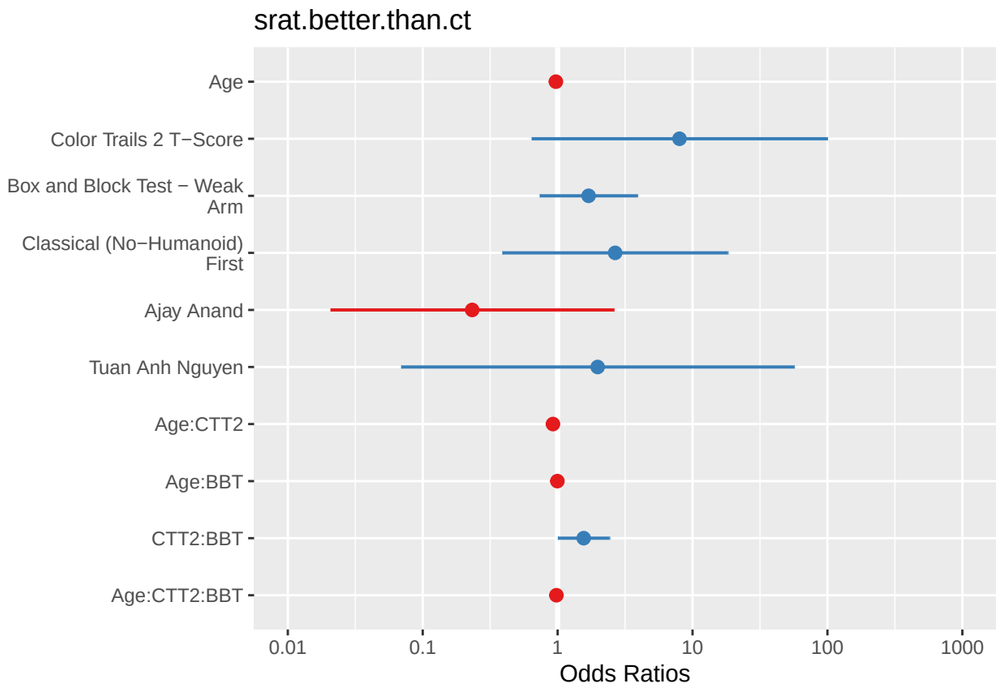
https://stats.oarc.ucla.edu/other/mult-pkg/faq/general/faq-how-do-i-interpret-odds-ratios-in-logistic-regression/

```
exp(cbind(OR = coef(model), confint(model)))
```

```
## Waiting for profiling to be done...
```

```
##                                                    OR      2.5 %       97.5 %
## (Intercept)                                 42.8844007 0.54339999 1.152017e+04
## Age                                          0.9707592 0.87342624 1.079422e+00
## CTT2                                         8.0038451 0.74175514 1.428854e+02
## BBT                                          1.6959336 0.72293597 4.403376e+00
## experimental.orderClassical (No-Humanoid) First  2.6692620 0.41735537 2.191451e+01
## robot.operatorAjay Anand                     0.2326147 0.01608679 2.386128e+00
## robot.operatorTuan Anh Nguyen                1.9805366 0.07421155 9.136637e+01
## Age:CTT2                                     0.9234484 0.83845155 9.841328e-01
## Age:BBT                                      0.9956795 0.97682255 1.017357e+00
## CTT2:BBT                                     1.5598902 1.06192392 2.620230e+00
## Age:CTT2:BBT                                 0.9794228 0.95487317 9.960465e-01
```

```
sjPlot::plot_model(model)
```



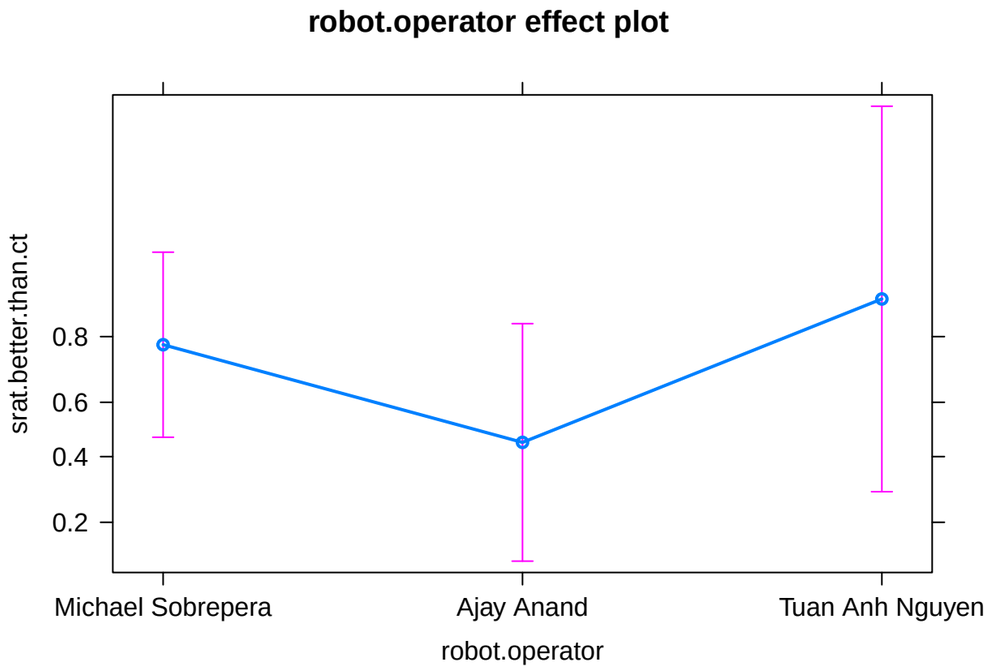
ANOVA Let's see if these factors capture a significant amount of variability when added to the model. For a very nice discussion of what a type III Anova is doing, see: https://stats.stackexchange.com/a/20455/192527

```
car::Anova(model, type = c("III"))
```

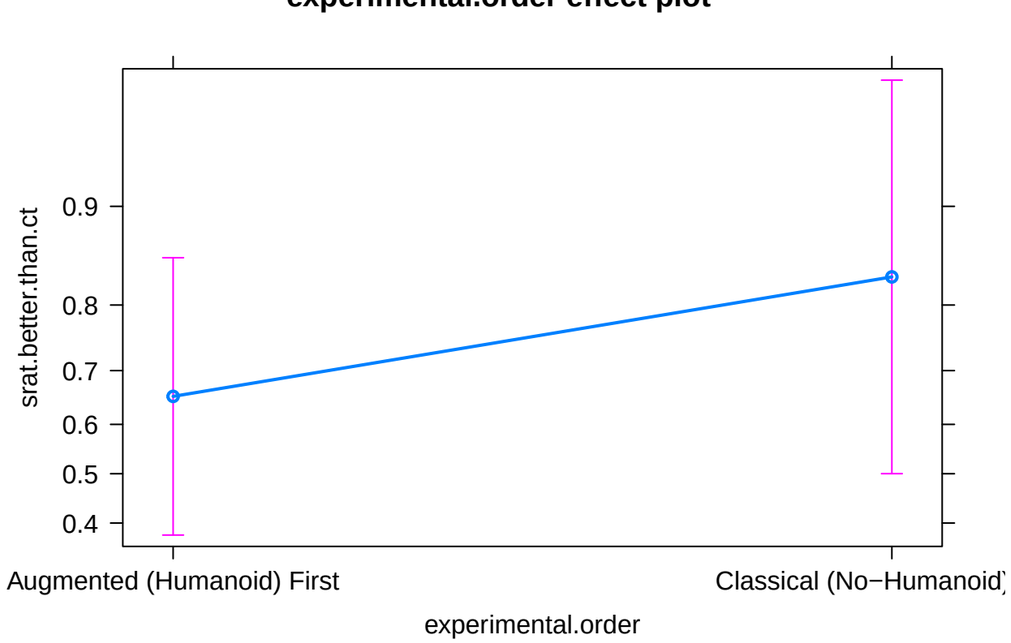
```
## Analysis of Deviance Table (Type III tests)
##
## Response: srat.better.than.ct
##                     LR Chisq Df Pr(>Chisq)
## Age                   0.3422  1    0.55859
## CTT2                  2.9294  1    0.08698 .
## BBT                   1.5629  1    0.21124
## experimental.order    1.0534  1    0.30473
## robot.operator        2.8160  2    0.24463
## Age:CTT2              6.5353  1    0.01058 *
## Age:BBT               0.1956  1    0.65826
## CTT2:BBT              5.3385  1    0.02086 *
## Age:CTT2:BBT          6.5671  1    0.01039 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Plots Let's plot the effects: https://cran.r-project.org/web/packages/effects/vignettes/predictor-effects-gallery.pdf

```
eff <- effects::allEffects(model, xlevels = list(
  BBT = -5:0,
  CTT2 = -3:1,
  Age = 6:80
))
plot(effects::effect("robot.operator", model))
```

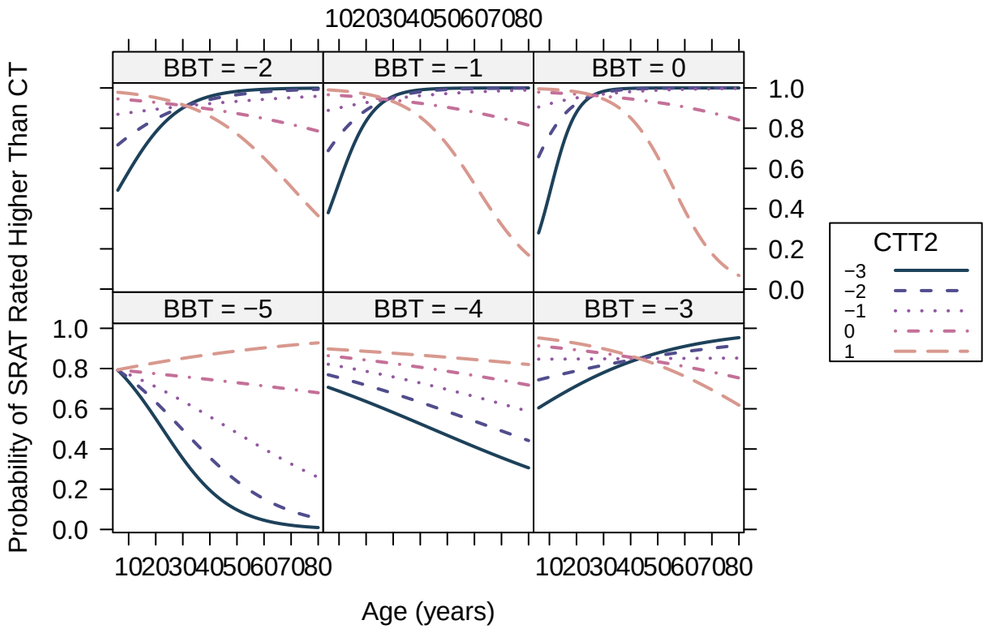



```
plot(effects::effect("experimental.order", model))
```



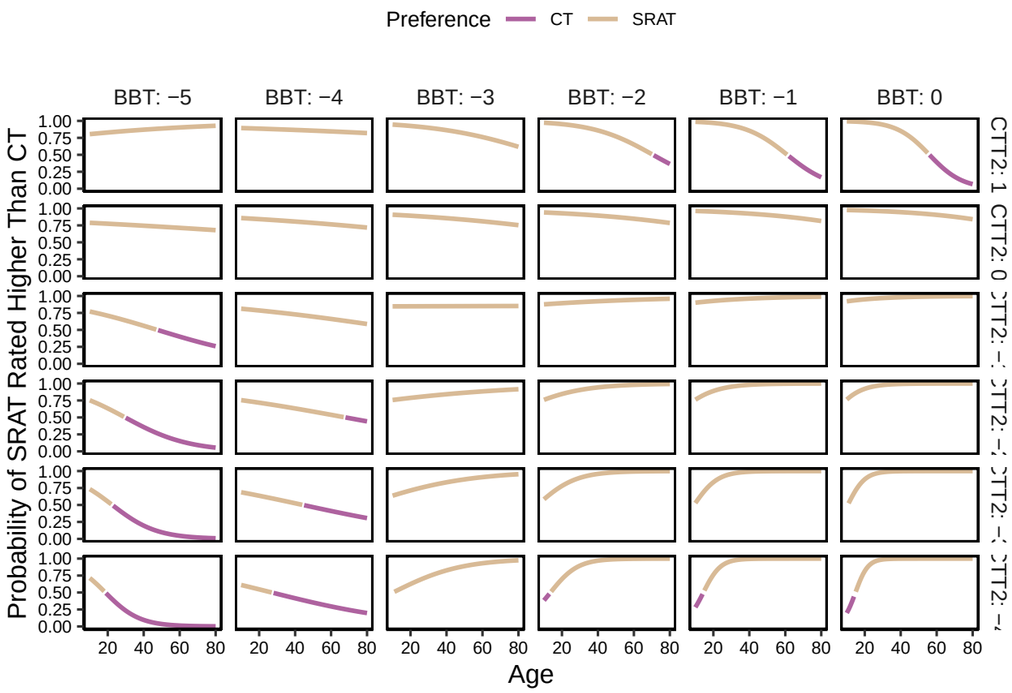

```
lattice::trellis.par.set(effects::effectsTheme())
plot(
  eff,
  "Age:CTT2:BBT",
  axes = list(
    y = list(type = "response", lab = "Probability of SRAT Rated Higher Than CT"),
    x = list(rug = FALSE, Age = list(lab = "Age (years)"))
  ),
```

```
  lines = list(multiline = TRUE, z.var = "CTT2", col = cust_color(8)[2:7], lty = 1:5),
  lattice = list(key.args = list(space = "right", border = TRUE, lab = "CTT")),
  main = NULL
)
```




```
effects.pref <- effects::Effect(c("BBT", "Age", "CTT2"), model, xlevels = list(
  BBT = -5:0,
  CTT2 = -4:1,
  Age = 6:80
))

preference.model.plt <- cbind(effects.pref[["x"]], effects.pref[["fit"]]) %>%
  mutate(
    CTT2 = forcats::fct_rev(factor(CTT2)),
    prob = boot::inv.logit(`effects.pref[["fit"]]`)
  ) %>%
  ggplot(aes(x = Age, y = prob, color = prob > 0.5)) +
  geom_line(size = 1) +
  facet_grid(rows = vars(CTT2), cols = vars(BBT), labeller = label_both) +
  plt_theme +
  ylab("Probability of SRAT Rated Higher Than CT") +
  scale_color_manual(
    values = cust_color(7)[c(4, 6)],
    name = "Preference",
    labels = c("CT", "SRAT")
  ) +
  xlim(c(10, 80)) +
  ylim(c(0, 1)) +
  theme(legend.position="top")

print(preference.model.plt)
```

```
## Warning: Removed 4 row(s) containing missing values (geom_path).
```




```
fn <- file.path(out_dir, "tikz-preference_model.tex")
tikz(
  file = fn,
  width = 5.8,
  height = 6,
  sanitize = TRUE
)
print(preference.model.plt)
```

```
## Warning: Removed 4 row(s) containing missing values (geom_path).
```

```
dev.off()
```

```
## pdf
##   2
```

```
strip_tikz_white(fn)
```

Interpretation

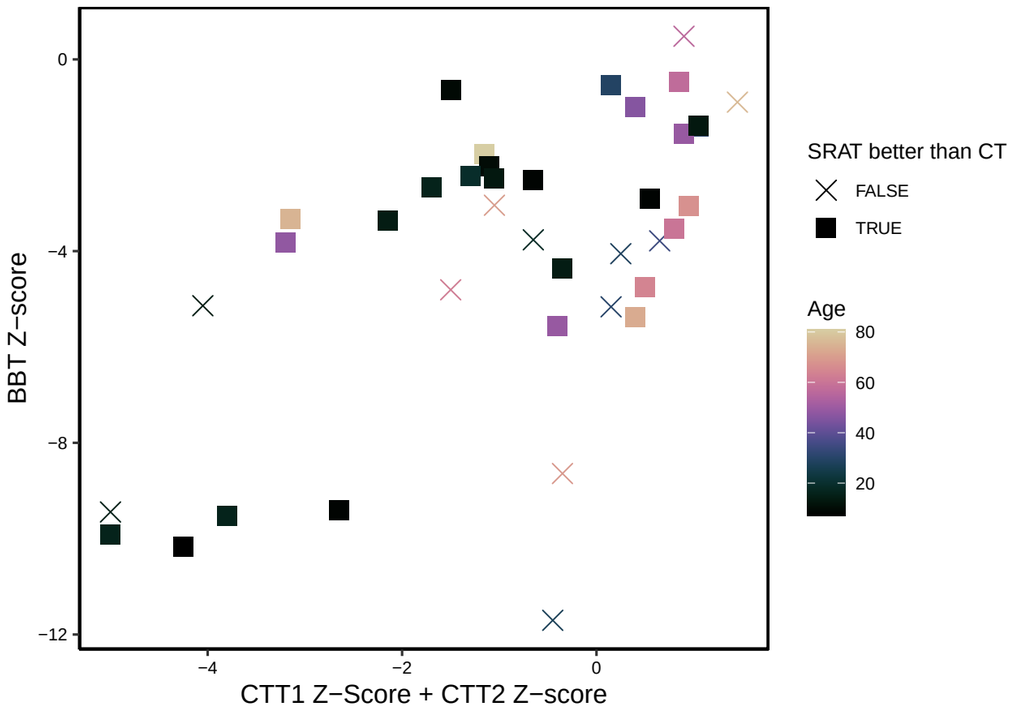
- Normal motor function, <20 years old
  - significant cognitive impairment -> neutral
  - no to mild cognitive impairment -> prefer SRAT
- 20 – 40 years old, severe or better motor impairment, any cog function, prefer SRAT
- Normal motor function, >40 years old
  - normal or less cog function (z<0) -> prefer SRAT
  - high cog function (z>0) -> prefer CT
- Severe motor impairment:
  - older and cog -> prefers SRAT
- Beyond severe motor impairment (z<-3), young (<20 yrs old) -> prefer SRAT
- Beyond severe motor impairment (z<-3), >20 yrs old
  - low executive function -> prefer CT
  - high executive function -> prefer SRAT

Output Plots

So now let's try to plot these interacting components:

```
new_combined_data <- combined_data %>%  filter(!is.na(color_trails_2_standard))
ggplot(
```

```
  new_combined_data,
  aes(
    x = (color_trails_1_standard + color_trails_2_standard) / 2,
    y = bbt.score.weak,
    color = age,
    shape = srat_betterthan_ct
  )
) +
  geom_point(size = 4) +
  plt_theme +
  scale_color_gradientn(name = "Age", colors = cust_color(1000)[0:800]) +
  scale_shape_manual(name = "SRAT better than CT", values = c("cross", "square")) +
  scale_x_continuous(name = "CTT1 Z-Score + CTT2 Z-score") +
  scale_y_continuous(name = "BBT Z-score")
```



That isn't very clear, let's plot over a multi-plot. note, we could add color and annotation to show the order and operator. I don't see a reason to do that (https://cran.r-project.org/web/packages/scatterplot3d/vignettes/s3d.pdf, pg 19)

```
for (run in c(0, 1)) {
  if (run == 1) {
    fn <- file.path(out_dir, "tikz-preference.tex")
    tikz(
      file = fn,
      width = 5.8,
      height = 3.314286,
      sanitize = TRUE
    )
  }
  grid::grid.newpage()
  # par(mfrow=c(2,2), mar=c(0,0,0,0), oma=c(0,0,0,0))
  # plot.new()
  col1 <- 1.2
  col2 <- 1.2
  col3 <- .5
  sum_cols <- col1 + col2 + col3
  layout(
    mat = matrix(c(0, 0, 1, 0, 0, 0), nrow = 2, ncol = 3),
    # tweaking these values to make 3d plot decent:
    height = c(1.2, .8),
```

```
  widths = c(col1 - .5, col2 + 1.2, col3 - .1)
)

plot3D::scatter3D(
  y = (
    (
      combined_data$color_trails_1_standard + combined_data$color_trails_2_standard
    ) / 2
  ),
  ylab = "CTT",
  x = combined_data$bbt.score.weak,
  xlab = "BBT",
  z = combined_data$age,
  zlab = "Age",
  colvar = NULL,
  # colvar = ifelse(combined_data$srat_betterthan_ct, 0, 1),
  pch = ifelse(combined_data$srat_betterthan_ct, 1, 19),
  ticktype = "detailed",
  bty = "b2",
  phi = 20,
  theta = 40,
  cex.axis = .5,
  cex.lab = .8,
  type = "h",
  col = NULL
  # col = cust_color(10)[c(7, 3)],
  # clim = c(0, 1),
  # colkey = c(plot = FALSE)
)


vp_ul <-
  grid::viewport(
    height = unit(.5, "npc"),
    width = unit(col1 / sum_cols, "npc"),
    just = c("left", "top"),
    y = 1,
    x = 0
  )
vp_ll <-
  grid::viewport(
    height = unit(.5, "npc"),
    width = unit(col1 / sum_cols, "npc"),
    just = c("left", "top"),
    y = 0.5,
    x = 0
  )
vp_lr <-
  grid::viewport(
    height = unit(.5, "npc"),
    width = unit(col2 / sum_cols, "npc"),
    just = c("left", "top"),
    y = .5,
    x = col1 / sum_cols
  )
vp_3 <-
  grid::viewport(
    height = unit(.7, "npc"),
    width = unit(col3 / sum_cols, "npc"),
    just = c("left", "bottom"),
    y = 0,
    x = (col1 + col2) / sum_cols
  )
vp_bbt <- grid::viewport(
  height = unit(.3, "npc"),
```

```
  # adjusting values for appearance:
  width = unit(.32, "npc"),
  just = c("right", "top"),
  y = 1,
  x = 1
)
vp_legend <-
  grid::viewport(
    height = unit(.1, "npc"),
    # adjusting values for appearance:
    width = unit((col3 / sum_cols) - .05, "npc"),
    just = c("right", "top"),
    y = .65,
    x = (col1 + col2) / sum_cols - .01
  )

shapes <- c(1, 19)
p1 <-
  combined_data %>%
  ggplot(aes(x = bbt.score.weak, y = age, shape = srat_betterthan_ct)) +
  geom_point() +
  plt_theme +
  xlab("BBT") +
  ylab("Age") +
  scale_shape_manual(values = shapes, guide = "none")
p2 <-
  combined_data %>% ggplot(aes(
    x = bbt.score.weak,
    y = (color_trails_1_standard + color_trails_2_standard) / 2,
    shape = srat_betterthan_ct
  )) +
  geom_point() +
  plt_theme +
  xlab("BBT") +
  ylab("CTT") +
  scale_shape_manual(values = shapes, guide = "none")
p3 <-
  combined_data %>% ggplot(aes(
    x = age,
    y = (color_trails_1_standard + color_trails_2_standard) / 2,
    shape = srat_betterthan_ct
  )) +
  geom_point() +
  plt_theme +
  xlab("Age") +
  ylab("CTT") +
  scale_shape_manual(values = shapes, guide = "none")
p4 <-
  combined_data %>% ggplot(aes(ifelse(srat_betterthan_ct, "SRAT", "CT"))) +
  geom_bar(aes(fill = srat_betterthan_ct),
    color = "black",
    size = 1
  ) +
  plt_theme +
  theme(axis.title.y = element_blank()) +
  xlab("Preference") +
  stat_count(aes(y = ..count.., label = ..count..),
    geom = "text",
    vjust = -.5
  ) +
  ylim(c(0, 30)) +
  scale_fill_manual(
    values = c("#00000000", "#000000FF"),
    guide = "none"
  )
```

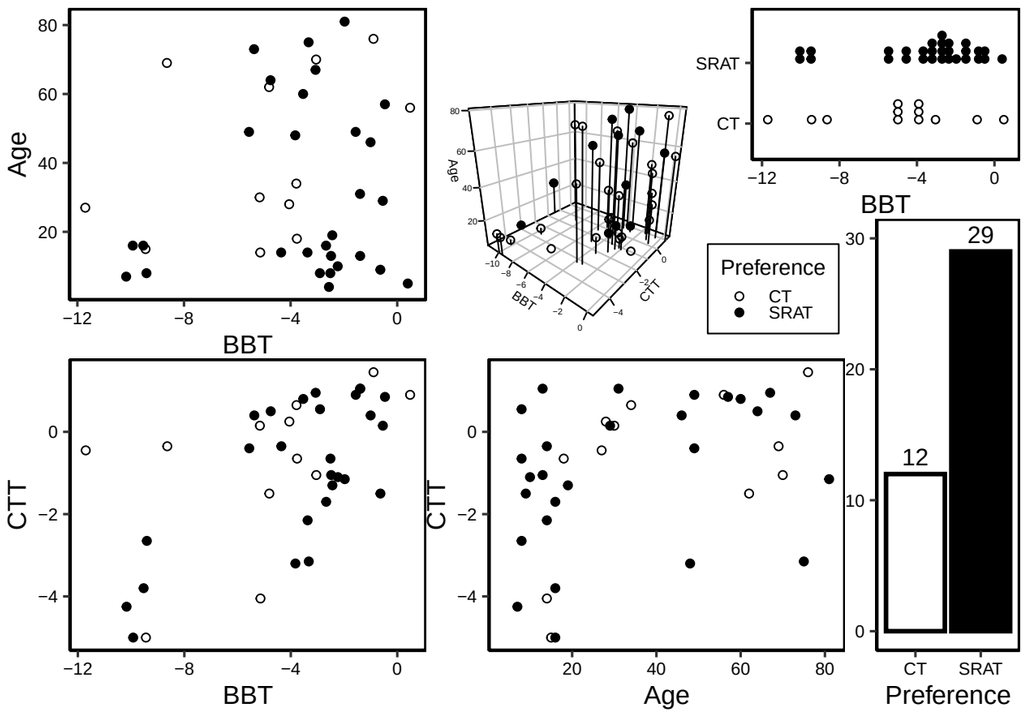
```
p_legend <- as_ggplot(
  ggpubr::get_legend(
    combined_data %>% ggplot(aes(
      x = age,
      y = (color_trails_1_standard + color_trails_2_standard) / 2,
      shape = ifelse(srat_betterthan_ct, "SRAT", "CT")
    )) +
      geom_point() +
      plt_theme +
      xlab("Age") +
      ylab("CTT") +
      scale_shape_manual(values = shapes, name = "Preference") +
      theme(legend.box.background = element_rect(colour = "black")) +
      guides(shape = guide_legend(keyheight = .1))
  )
)

p_bbt <- combined_data %>% ggplot(aes(
  y = bbt.score.weak,
  x = ifelse(srat_betterthan_ct, "SRAT", "CT"),
  fill = srat_betterthan_ct
)) +
  geom_dotplot(binaxis = "y") +
  coord_flip() +
  plt_theme +
  ylab("BBT") +
  theme(axis.title.y = element_blank()) +
  scale_fill_manual(
    values = c("#00000000", "#000000FF"),
    guide = "none"
  )

  print(p1, vp = vp_ul)
  print(p2, vp = vp_ll)
  print(p3, vp = vp_lr)
  print(p4, vp = vp_3)
  print(p_legend, vp = vp_legend)
  print(p_bbt, vp = vp_bbt)
  if (run == 1) {
    dev.off()
    strip_tikz_white(fn)
  }
}
```

```
## Warning: Removed 2 rows containing missing values (geom_point).
## Removed 2 rows containing missing values (geom_point).
## Removed 2 rows containing missing values (geom_point).
```

```
## Bin width defaults to 1/30 of the range of the data. Pick better value with `binwidth`.
```

```
## Warning: Removed 2 rows containing missing values (geom_point).
## Removed 2 rows containing missing values (geom_point).
## Removed 2 rows containing missing values (geom_point).
```

```
## Bin width defaults to 1/30 of the range of the data. Pick better value with `binwidth`.
```



That is a pretty solid plot showing the data with the added bonus of showing the interaction among Age, BBT, and CTT... But seeing the patterns individually is hard

We might be able to make something easier to understand:

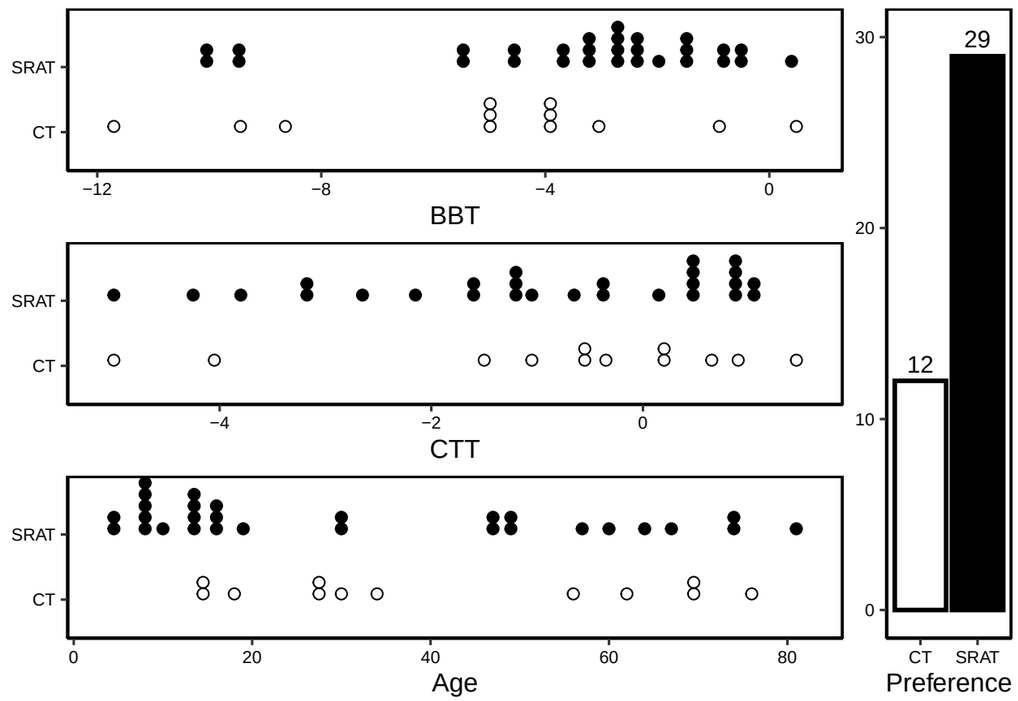
```
ds <- .5
p_base <- combined_data %>% ggplot(aes(
  x = ifelse(srat_betterthan_ct, "SRAT", "CT"),
  fill = srat_betterthan_ct
)) +
  coord_flip() +
  plt_theme +
  theme(axis.title.y = element_blank()) +
  scale_fill_manual(
    values = c("#00000000", "#000000FF"),
    guide = "none"
  )
p_age <-
  p_base + geom_dotplot(aes(y = age), binaxis = "y", dotsize = ds) + ylab("Age")
p_bbt <-
  p_base + geom_dotplot(aes(y = bbt.score.weak),
    binaxis = "y",
    dotsize = ds
  ) + ylab("BBT")
p_ctt <-
  p_base + geom_dotplot(aes(y = (
    color_trails_1_standard + color_trails_2_standard
  ) / 2), binaxis = "y", dotsize = ds) + ylab("CTT")
```

```
left_side <-
  cowplot::plot_grid(
    p_bbt + theme(plot.margin = unit(integer(4) + 1, "mm")),
    p_ctt + theme(plot.margin = unit(integer(4) +
      1, "mm")),
    p_age + theme(plot.margin = unit(integer(4) +
      1, "mm")),
    ncol = 1
  )
```

```
## Bin width defaults to 1/30 of the range of the data. Pick better value with `binwidth`.
```

```
## Bin width defaults to 1/30 of the range of the data. Pick better value with `binwidth`.
## Warning: Removed 2 rows containing non-finite values (stat_bindot).
## Bin width defaults to 1/30 of the range of the data. Pick better value with `binwidth`.
```

```
simple_preference_plot <-
  cowplot::plot_grid(
    left_side,
    p4 + theme(plot.margin = unit(integer(4) + 1, "mm")),
    nrow = 1,
    rel_widths = c(1, .2)
  )
print(simple_preference_plot)
```




```
fn <- file.path(out_dir, "tikz-preference-simple.tex")
tikz(
  file = fn,
  width = 5.8,
  height = 2.5,
  sanitize = TRUE
)
print(simple_preference_plot)
dev.off()
```

```
## pdf
##   2
```

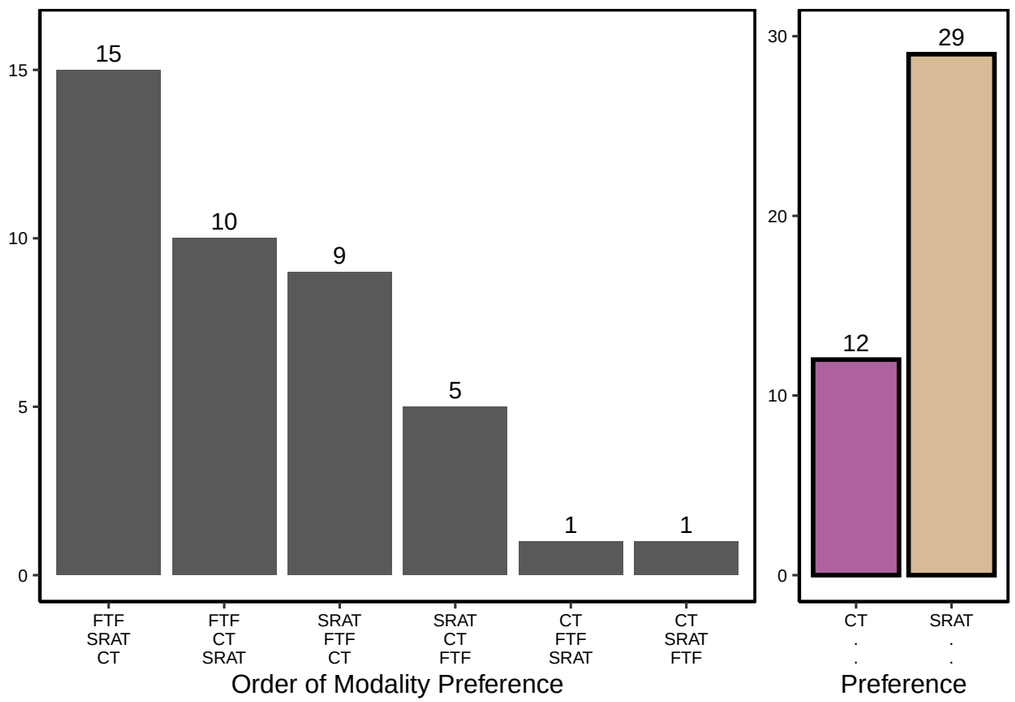
```
strip_tikz_white(fn)
```

```
p4_color <-
  combined_data  %>% ggplot(aes(ifelse(srat_betterthan_ct, "SRAT\n.\n.", "CT\n.\n."))) +
  geom_bar(aes(fill = srat_betterthan_ct),
    color = "black",
    size = 1
  ) +
  plt_theme +
  theme(axis.title.y = element_blank()) +
  xlab("Preference") +
  stat_count(aes(y = ..count.., label = ..count..),
    geom = "text",
```

```
    vjust = -.5
  ) +
  scale_fill_manual(
    values = cust_color(7)[c(4, 6)],
    guide = "none"
  ) +
  ylim(c(0, 30))

agg_pref_plt <- cowplot::plot_grid(pref_all_plt + theme(plot.margin = unit(integer(4) + 1, "mm")), p4_color + theme(plot.margin = unit(integer(4) + 1, "mm")), rows = 1, rel_widths = c(6, 2))
```

```
## Warning in cowplot::plot_grid(pref_all_plt + theme(plot.margin = unit(integer(4) + : Argument 'rows' is deprecated. Use 'nrow' instead.
```

```
print(agg_pref_plt)
```




```
fn <- file.path(out_dir, "tikz-agg_preference.tex")
tikz(
  file = fn,
  width = 5.8,
  height = 3,
  sanitize = TRUE
)
print(agg_pref_plt)
dev.off()
```

```
## pdf
##   2
```

```
strip_tikz_white(fn)
```

Conclusion

SRAT was preferred by a ratio of 24:12 by the totality of subjects. Certain groups of subjects are more likely to prefer SRAT or CT:

- Young people (<20) with mild or more severe motor impairment
- Young people (<20) with no motor impairment and no more than moderate cognitive impairment
- People 20-40 years old with no more than moderate motor impairment
- People 40+ years old with normal cognitive function or lower (z<1) and no worse than severe motor impairment (z>-4)

Final Survey - General Questions

Setup

```
rm(list = ls())
source("utility_scripts/setup.r")
```

```
## [1] "Only including subjects with complete consent forms"
## [1] "Excluding subjec # <=10 (pilot trial cohort)"
## [1] "n=44"
## [1] "Excluding Subjects:"
## [1] "    excluding subject 50"
## [1] "    excluding subject 47"
## [1] "Corrected Subject 22 Survey Assignment"
## [1] "Fixing subject 60 post experiment"
## [1] "final number of subjects: 42"
## [1] "Filling in for subjects too young for color trails:"
## [1] "    Subject 15, reported no impairment, marking no impairment"
## [1] "    subject 23, reported motor impairment only, BBT -2.56 z, marking motor impairment"
## [1] "    Subject 66, reported motor impairment only (Left hemiparesis), marking motor impairment"
```

Data Analysis

Best Interaction

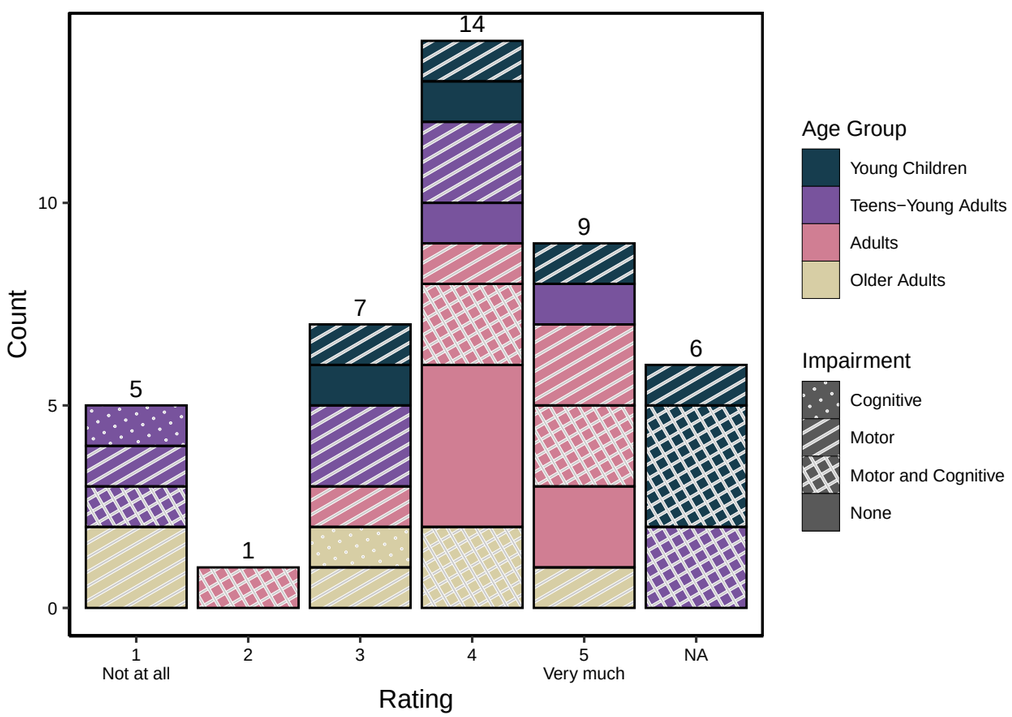
Please rank which interaction you thought was best, second best, and worst:

see preference_question.Rmd

Change in care due to telepresence

Do you think telehealth would change how you manage your health and medical needs if you and your clinician used it?

```
plot_col_age_impairment(combined_data, "exit_telemed", c("1\nNot at all", "2", "3", "4", "5\nVery much"))
```



N/A isn't an option, some people just didn't fill in this question?

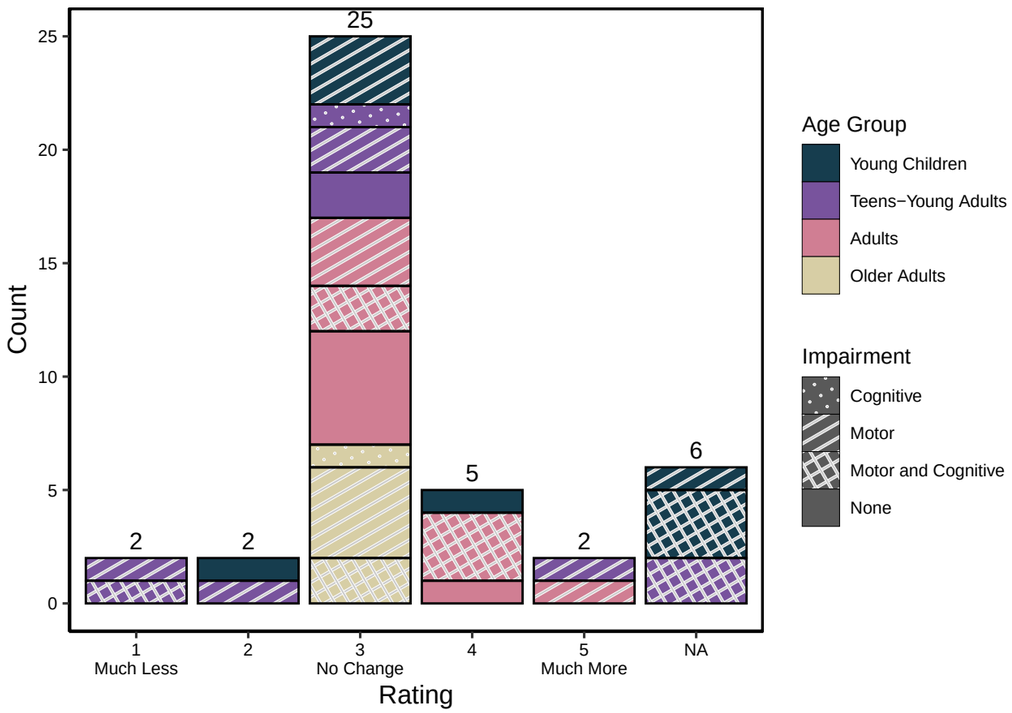
```
combined_data %>%
  select(record_id, exit_telemed) %>%
  filter(is.na(exit_telemed))
```

```
##   record_id exit_telemed
## 1        36           NA
## 2        41           NA
## 3        44           NA
## 4        45           NA
## 5        48           NA
## 6        66           NA
```

- 36 : did not fill out
- 41 : did not fill out
- 44 : did not fill out
- 45 : did not fill out
- 48 : did not fill out

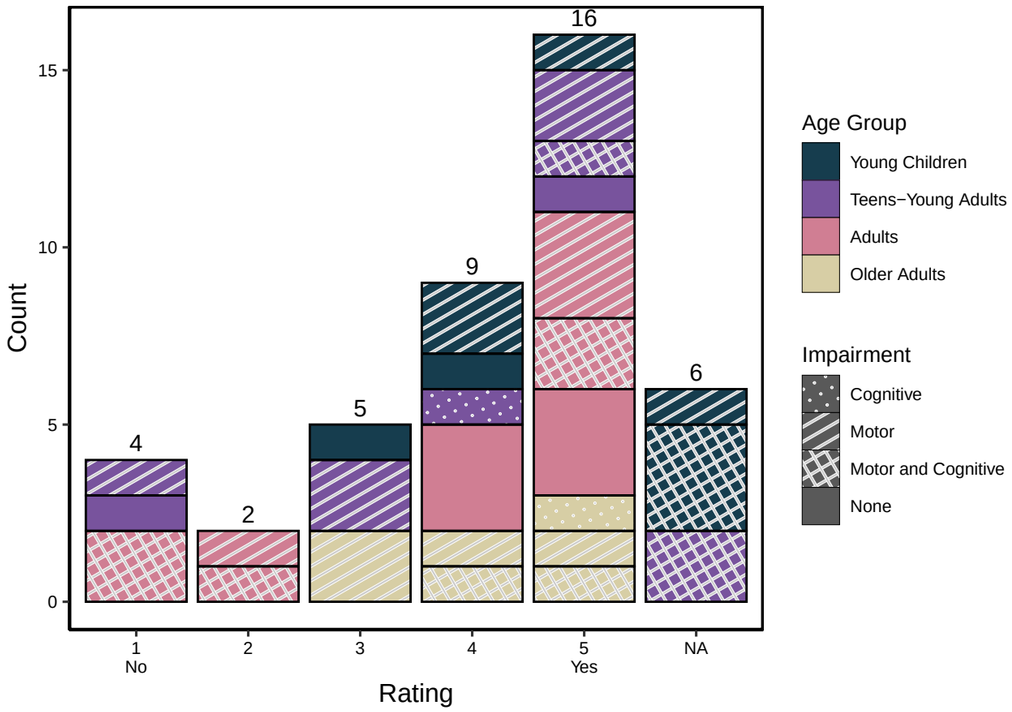
Would you follow your doctor's/therapist's/nurse's advice less or more if they worked with a telehealth system?

```
plot_col_age_impairment(combined_data, "exit_dr_advice", c("1\nMuch Less", "2", "3\nNo Change", "4", "5\nMuch More"))
```



Would video visits be a convenient form of healthcare delivery for you?

```
plot_col_age_impairment(combined_data, "exit_telemed_conv", c("1\nNo", "2", "3", "4", "5\nYes"))
```



Please rate how you believe that using the humanoid robot (like Lil'Flo, with arms and a head) with video telepresence will compare to using video telepresence alone:

```
combined_data %>%
  select(record_id, starts_with("exit_aims2_") & !ends_with("p") & !ends_with("factor")) %>%
  filter(is.na(exit_aims2_motivation))
```

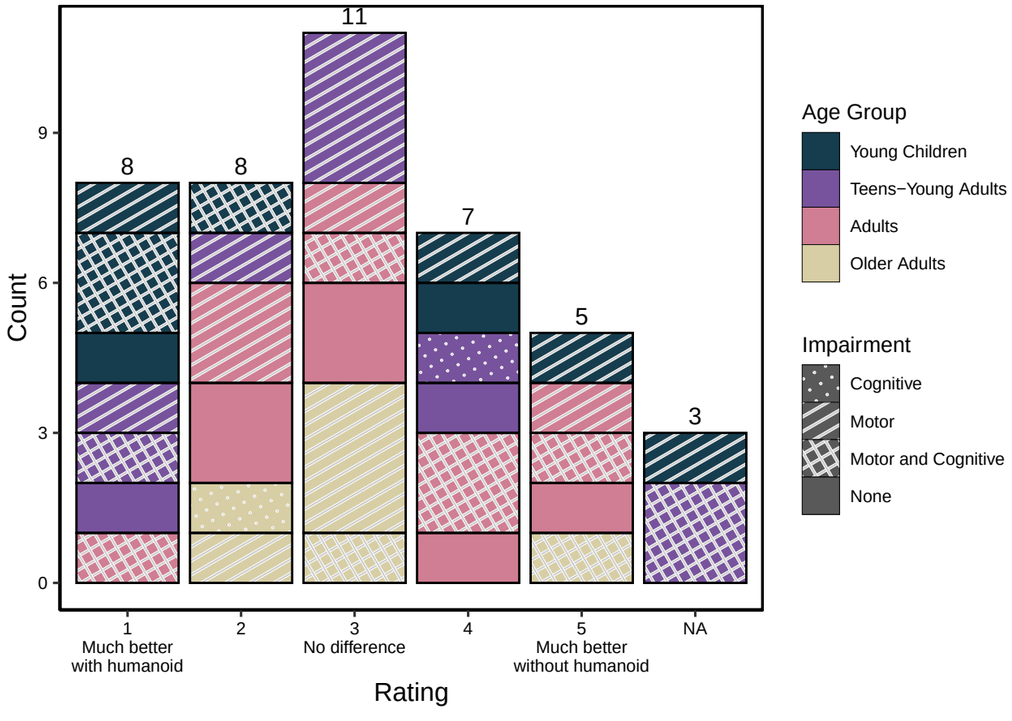
```
##   record_id exit_aims2_communication exit_aims2_motivation exit_aims2_compliance exit_aims2_adherence
## 1        45                       NA                    NA                    NA                   NA
## 2        48                       NA                    NA                    NA                   NA
## 3        66                       NA                    NA                    NA                   NA
```

- 45 was not able to understand these questions, exclude
- 48 was not able to understand these questions, exclude

Communication between me and the clinician

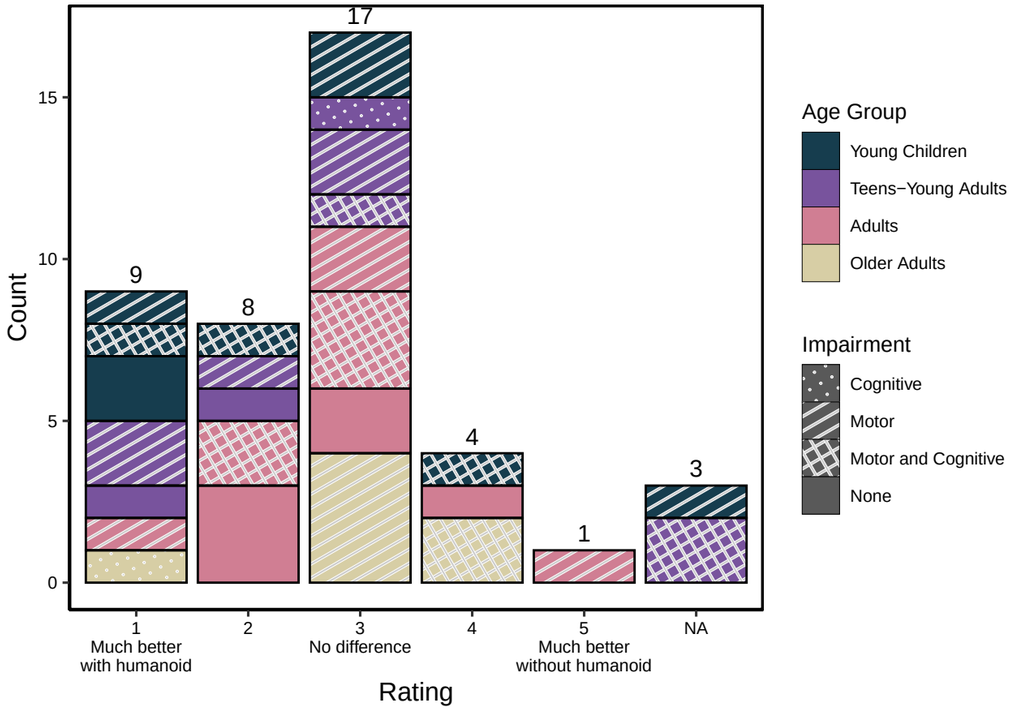
```
aims_labels <- c("1\nMuch better\nwith humanoid", "2", "3\nNo difference", "4", "5\nMuch better\nwithout humanoid")
```

```
plot_col_age_impairment(combined_data, "exit_aims2_communication", aims_labels)
```



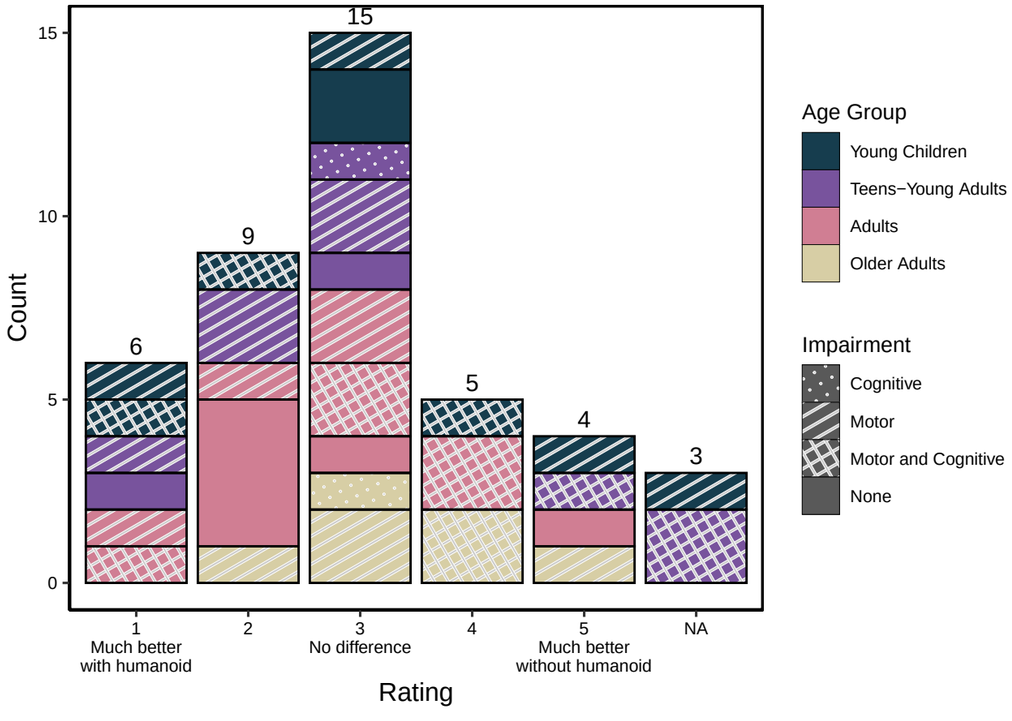
My motivation to do rehab activities

```
plot_col_age_impairment(combined_data, "exit_aims2_motivation", aims_labels)
```



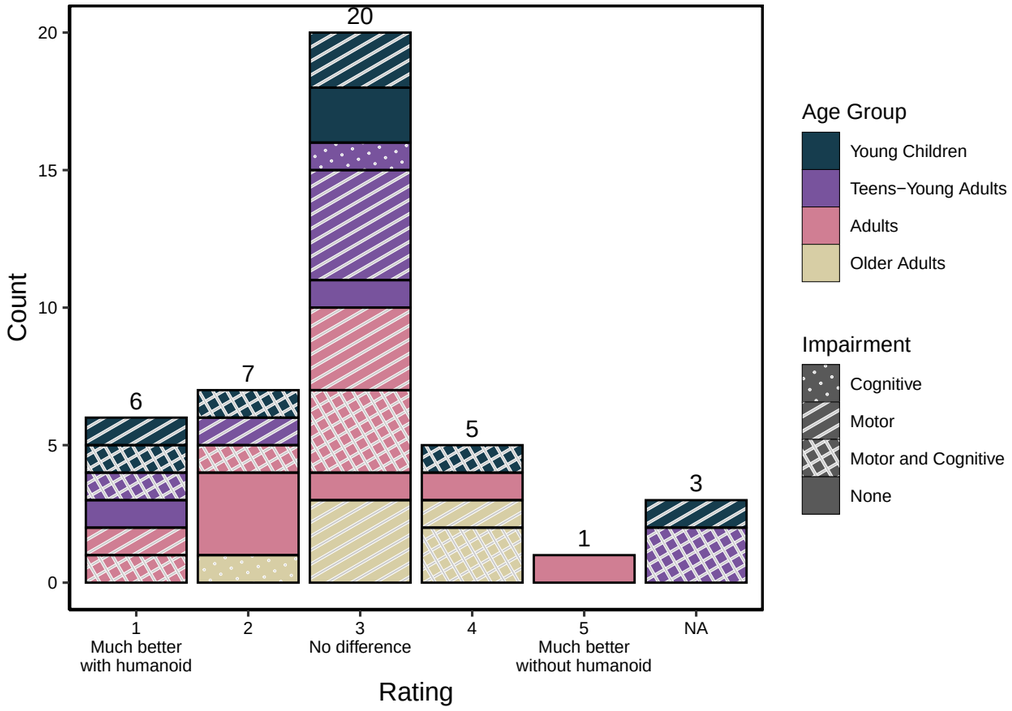
My compliance with instructions during interactions

```
plot_col_age_impairment(combined_data, "exit_aims2_compliance", aims_labels)
```



My adherence to treatment plans after interactions

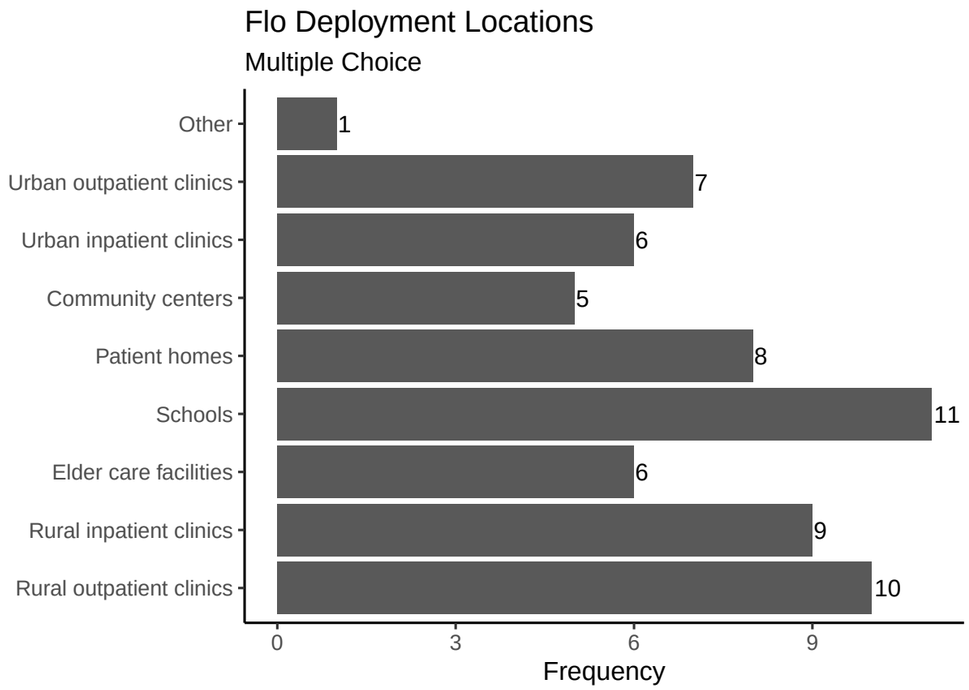
```
plot_col_age_impairment(combined_data, "exit_aims2_adherence", aims_labels)
```



Locations for Flo deployment

What locations do you think Lil'Flo could be deployed in?

```
plot_multi_choice(combined_data, "exit_locations_2", 1:10, "Flo Deployment Locations")
```



Godspeed Questionaire - III

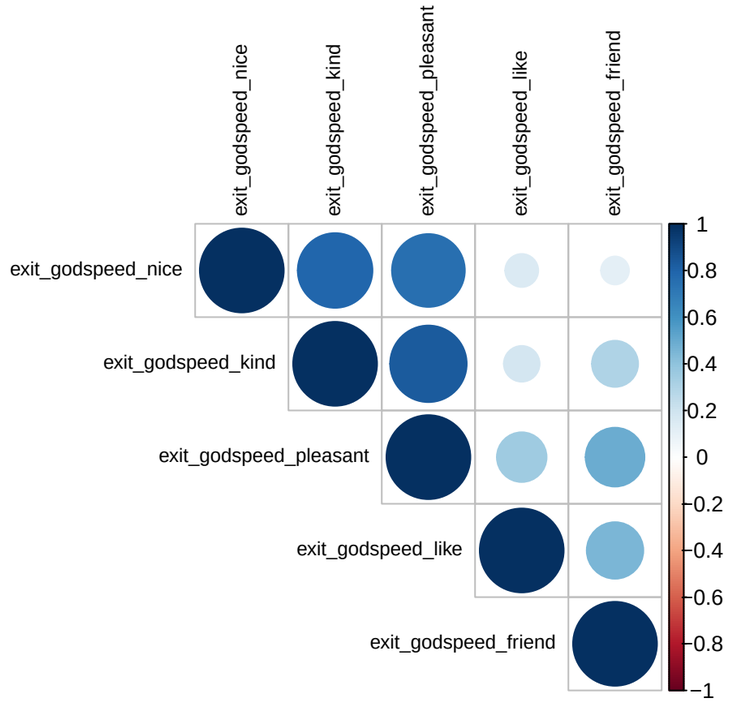
Please rate your impression of Lil'Flo on these scales:

Unfortunately, subject 60 did not fill out godspeed survey Subject 48 skipped one question of the survey, so we can't use them for finding correlation, but can use their values

```
godspeed_data <- combined_data %>%
  filter(record_id != 60 & record_id != 66) %>%
  select(record_id, starts_with("exit_godspeed_") & !ends_with("factor"))
```

First need to check consistency, will look at a correlation plot (for analysis, not publication) and cronbach's alpha

```
corr_data <- godspeed_data %>%
  filter(record_id != 48) %>%
  select(!record_id)
corrplot::corrplot(
  cor(corr_data),
  order = "hclust",
  tl.col = "black",
  tl.cex = .75,
  type = "upper",
)
```




```
psych::alpha(corr_data)
```

```
##
## Reliability analysis
## Call: psych::alpha(x = corr_data)
##
##   raw_alpha std.alpha G6(smc) average_r S/N  ase mean   sd median_r
##       0.8       0.8    0.85      0.44   4 0.05  4.7 0.59      0.4
##
##  lower alpha upper     95% confidence boundaries
## 0.7 0.8 0.89
##
##  Reliability if an item is dropped:
##                       raw_alpha std.alpha G6(smc) average_r S/N alpha se var.r med.r
## exit_godspeed_like          0.84      0.83    0.87      0.55 4.9    0.034 0.087  0.62
## exit_godspeed_friend        0.80      0.81    0.84      0.51 4.2    0.055 0.100  0.55
## exit_godspeed_kind          0.71      0.72    0.78      0.39 2.5    0.073 0.056  0.40
## exit_godspeed_pleasant      0.65      0.67    0.73      0.33 2.0    0.094 0.066  0.24
## exit_godspeed_nice          0.74      0.76    0.79      0.44 3.1    0.066 0.050  0.40
##
##  Item statistics
##                        n raw.r std.r r.cor r.drop mean   sd
## exit_godspeed_like     39  0.59  0.58  0.40   0.33  4.6 0.91
## exit_godspeed_friend   39  0.59  0.63  0.53   0.45  4.7 0.56
## exit_godspeed_kind     39  0.84  0.84  0.83   0.73  4.7 0.76
## exit_godspeed_pleasant 39  0.93  0.92  0.94   0.85  4.6 0.96
## exit_godspeed_nice     39  0.77  0.76  0.73   0.63  4.8 0.73
##
## Non missing response frequency for each item
##                           1    2    3    4    5 miss
## exit_godspeed_like     0.03 0.03 0.05 0.10 0.79    0
## exit_godspeed_friend   0.00 0.00 0.05 0.18 0.77    0
## exit_godspeed_kind     0.03 0.00 0.03 0.13 0.82    0
## exit_godspeed_pleasant 0.03 0.05 0.03 0.05 0.85    0
## exit_godspeed_nice     0.03 0.00 0.03 0.05 0.90    0
```

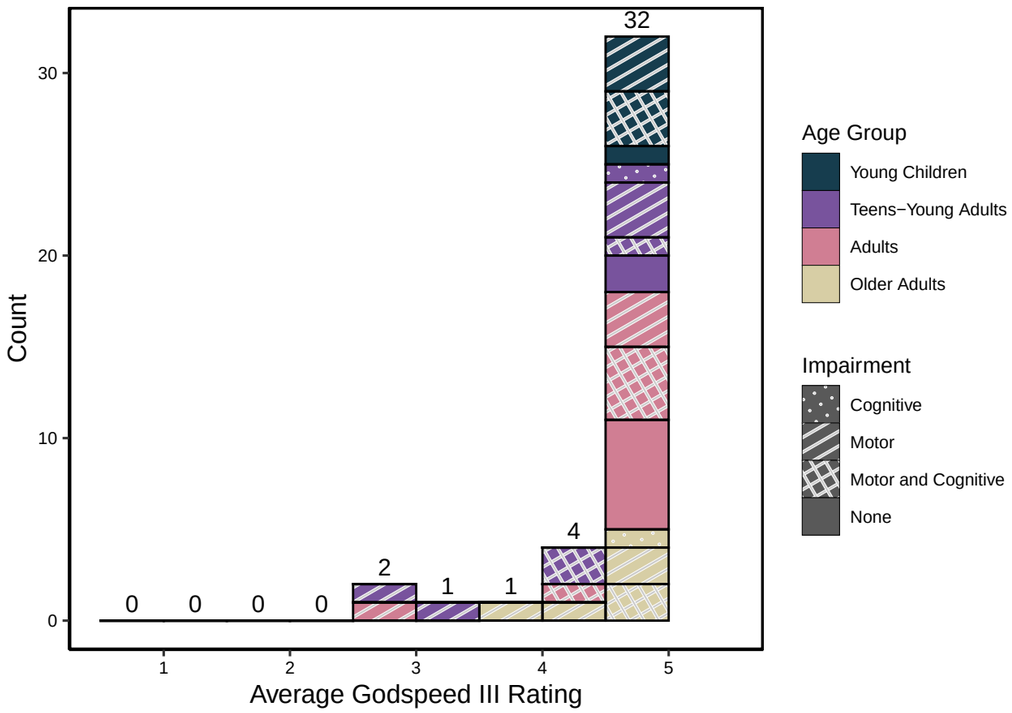
```
godspeed_avg_data <-
  godspeed_data %>%
```

```r
  mutate(godspeed_avg = rowMeans(select(., !record_id), na.rm = TRUE)) %>%
  select(record_id, godspeed_avg) %>%
  left_join(combined_data %>% select(record_id, age, age_group, impairment), by = "record_id")

ggplot(godspeed_avg_data, aes(godspeed_avg)) +
  stat_bin(
    aes(fill = age_group, pattern = impairment),
    geom = "bar_pattern",
    breaks = 0:10 * .5,
    stat = "count",
    pattern_density = .2,
    pattern_size = .01,
    pattern_spacing = .02,
    pattern_color = "white",
    color = "black"
  ) +
  geom_text(
    stat = "bin",
    aes(y = ..count.., label = ..count..),
    breaks = 0:10 * .5,
    vjust = -.5
  ) +
  ylab("Count") +
  plt_theme +
  scale_fill_manual(
    values = cust_color(4),
    name = "Age Group",
    guide = guide_legend(override.aes = list(pattern = "none"))
  ) +
  scale_pattern_discrete(
    choices = c("circle", "stripe", "crosshatch", "none"),
    name = "Impairment"
  ) +
  scale_x_continuous(limits = c(.5, 5.5), name = "Average Godspeed III Rating")
```

```
## Warning: Ignoring unknown parameters: stat
```

```
## Warning: Removed 13 rows containing missing values (geom_bar_pattern).
```

```
## Warning: Removed 1 rows containing missing values (geom_text).
```



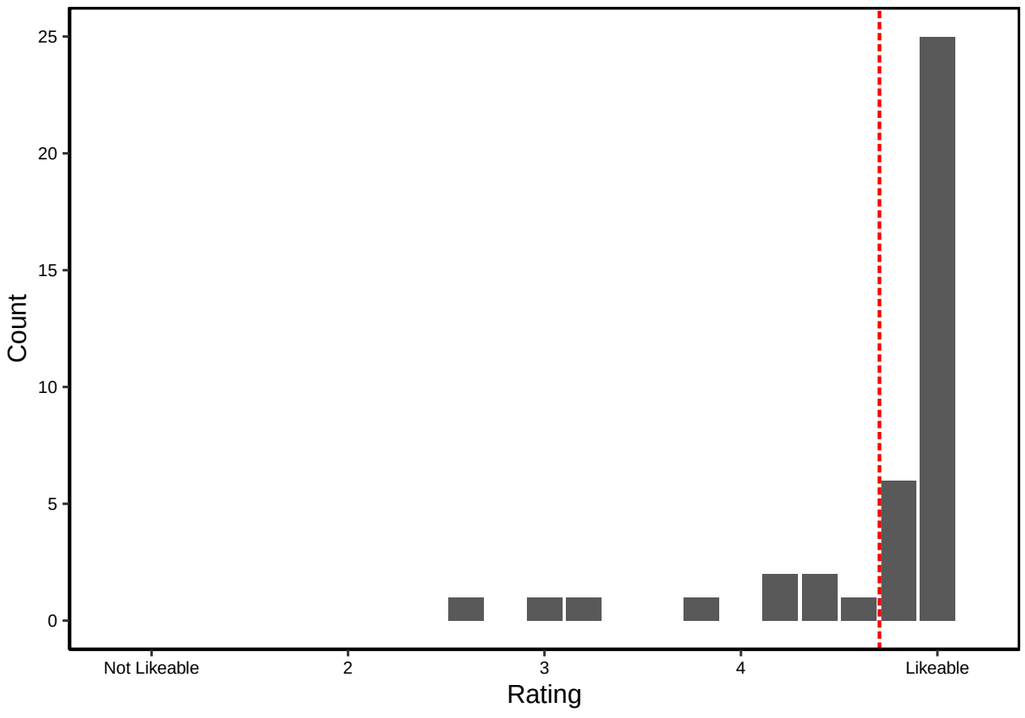

```
godspeed_plt_data <- godspeed_avg_data %>%
  select(godspeed_avg) %>%
  rename(`Godspeed III: Likability` = godspeed_avg)

godspeed_plt <- plot_likert_hist(godspeed_plt_data) + xlab("Rating") + ylab("Count") + theme(strip.text.y = element_blank()) +
  scale_x_continuous(limits = c(.8, 5.2), breaks = c(1, 2, 3, 4, 5), labels = c("Not Likeable", "2", "3", "4", "Likeable"))
```

```
## Scale for 'x' is already present. Adding another scale for 'x', which will replace the existing scale.
```

```
#   ylim(c(0,10))

fn <- file.path(out_dir, "tikz-godspeed.tex")
tikz(
  file = fn,
  width = 5.8,
  height = 1.25,
  sanitize = TRUE
)
print(godspeed_plt)
dev.off()
```

```
## pdf
##   2
```

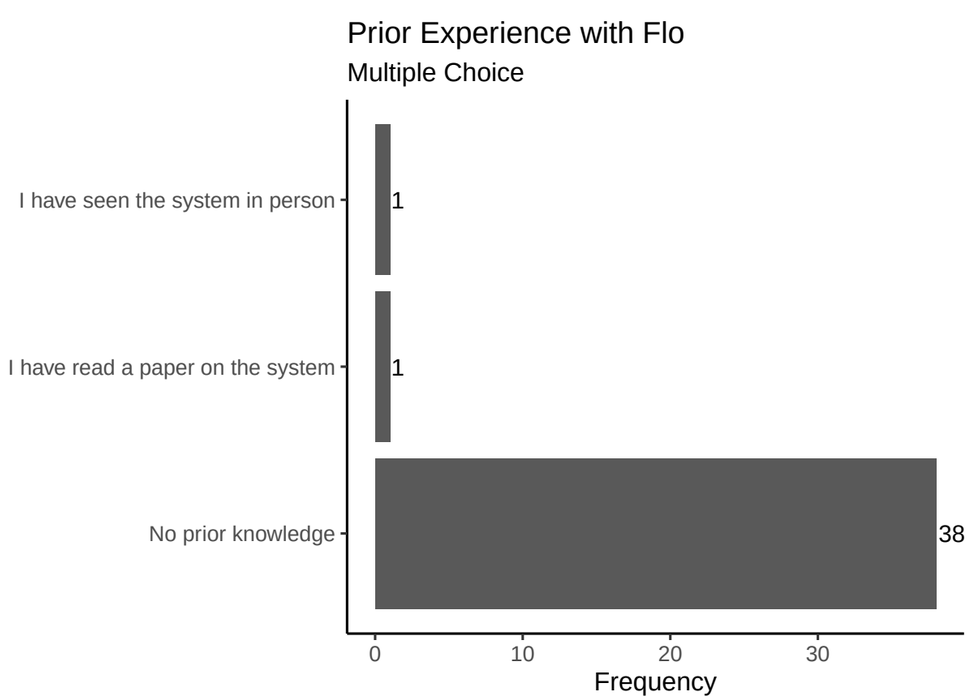
```
strip_tikz_white(fn)
print(godspeed_plt)
```



Prior experience with Flo

Before this study, did you have any prior experience with Lil'Flo?

```
plot_multi_choice(combined_data, "flo_prior_experience", 1:5, "Prior Experience with Flo")
```




```
combined_data %>%
  filter(flo_prior_experience___2 == TRUE | flo_prior_experience___3 == TRUE) %>%
  select(record_id)
```

```
##   record_id
```

```
## 1         17
## 2         49
```

- Not clear under what context 17 had read a paper on the system
- 49 had previously seen the system driving in the hallway at the hospital