《对Design factors in mouse-tracking: What makes a difference的可重复性研究》

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数据预处理和环境配置

加载 R 包

```r
# 加载所需的 R 包：mousetrap 用于鼠标轨迹分析，ggplot2 用于绘图，dplyr、tidyr 用于数据处理，
# afex 和 MBESS 用于方差分析与效应量估计，ordinal 用于有序回归分析。
library(mousetrap)
```

```
## Warning: package 'mousetrap' was built under R version 4.4.3
```

```r
library(ggplot2)
```

```
## Warning: package 'ggplot2' was built under R version 4.4.3
```

```r
library(dplyr)
```

```
## Warning: package 'dplyr' was built under R version 4.4.3
```

```r
library(tidyr)
```

```
## Warning: package 'tidyr' was built under R version 4.4.3
```

```r
library(afex)
```

```
## Warning: package 'afex' was built under R version 4.4.3
## Warning: package 'lme4' was built under R version 4.4.3
## Warning: package 'Matrix' was built under R version 4.4.3
```

```r
library(MBESS)
```

```
## Warning: package 'MBESS' was built under R version 4.4.3
```

```r
library(ordinal)
```

```
## Warning: package 'ordinal' was built under R version 4.4.3
```

```r
library(emmeans)
```

```
## Warning: package 'emmeans' was built under R version 4.4.3
```

```r
library(maps)
```

```
## Warning: package 'maps' was built under R version 4.4.3
```

```r
options(warn = -1)  # 关闭所有警告
```

自定义 ggplot2 主题

```r
# 设置 ggplot2 图形的主题，使图形更美观且更适合科研展示。
theme_set(theme_classic()+
  theme(
    axis.line = element_line(colour = "black"),
    axis.ticks = element_line(colour = "black"),
    axis.text = element_text(colour = "black"),
    panel.border = element_rect(colour = "black", fill=NA)
  ))
```

自定义函数

```r
# 自定义函数：计算偏 Eta 平方（partial eta-squared）及其置信区间，
# 用于衡量方差分析中的效应量。
get_partial_etas <- function(anova_table, conf.level=.90){
  partial_etas <- sapply(row.names(anova_table),function(i){
    F <- anova_table[i,"F"]
    df1 <- anova_table[i,"num Df"]
    df2 <- anova_table[i,"den Df"]
    ci <- conf.limits.ncf(F.value=F,conf.level=conf.level,df.1=df1,df.2=df2)
    return(
      c(pes=((F*df1)/(F*df1+df2)),
        lower=ci$Lower.Limit/(ci$Lower.Limit+df1+df2+1),
        upper=ci$Upper.Limit/(ci$Upper.Limit+df1+df2+1)))
  })
  return(t(partial_etas))
}
```

导入数据

```r
# 导入原始实验数据，并将 Condition 和 group 设置为因子类型，指定顺序。
raw_data <- read.csv("C:/Users/86139/Desktop/exp3.csv")
raw_data$Typicality <- factor(raw_data$Condition,levels=c("Typical","Atypical"))
raw_data$group <- factor(raw_data$group,levels=c("static","rtmax","initmax","dynamic"))
```

正确性分析 - 包括所有试次

每个条件的正确反应比例

```
# 计算每组中正确反应的比例。
with(raw_data,table(group, correct)/c(table(group)))
```

```
##          correct
## group              0          1
##   static  0.05887600 0.94112400
##   rtmax   0.10877193 0.89122807
##   initmax 0.10287081 0.89712919
##   dynamic 0.06403509 0.93596491
```

卡方检验

```
# 使用卡方检验检验正确率是否在各组之间有显著差异。
chisq.test(with(raw_data,table(group, correct)),correct = FALSE)
```

```
##
##  Pearson's Chi-squared test
##
## data:  with(raw_data, table(group, correct))
## X-squared = 29.927, df = 3, p-value = 1.43e-06
```

广义线性混合模型

```
# 使用 GLMM 检验 group 是否对正确率有影响，包含被试作为随机效应。
contrasts(raw_data$group)
```

```
##         rtmax initmax dynamic
## static      0       0       0
## rtmax       1       0       0
## initmax     0       1       0
## dynamic     0       0       1
```

```
summary(glmer(correct~(1|subject_nr)+group,family="binomial",data=raw_data))
```

```
## Generalized linear mixed model fit by maximum likelihood (Laplace
##   Approximation) [glmerMod]
##  Family: binomial  ( logit )
## Formula: correct ~ (1 | subject_nr) + group
##    Data: raw_data
##
##      AIC      BIC   logLik deviance df.resid
```

```
##    2642.0    2674.2   -1316.0    2632.0      4650
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -4.3273  0.2066  0.2595  0.3245  0.5809
##
## Random effects:
##  Groups     Name        Variance Std.Dev.
##  subject_nr (Intercept) 0.386    0.6213
## Number of obs: 4655, groups:  subject_nr, 245
##
## Fixed effects:
##              Estimate Std. Error z value Pr(>|z|)
## (Intercept)   2.94406    0.16032  18.363  < 2e-16 ***
## grouprtmax   -0.70835    0.20093  -3.525 0.000423 ***
## groupinitmax -0.61969    0.19836  -3.124 0.001784 **
## groupdynamic -0.09055    0.21484  -0.421 0.673407
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) grprtm grpntm
## grouprtmax  -0.761
## groupinitmx -0.760  0.602
## groupdynamc -0.694  0.554  0.560
```

正确性分析 - 排除 rtmax 条件下超时试次

排除超时试次

```
# 计算 rtmax 条件下响应为 None（超时）的试次数量和比例。
n_eligible <- sum(with(raw_data,group=="rtmax" & response!="None"))
n_noneligible <- sum(with(raw_data,group=="rtmax" & response=="None"))
n_noneligible/(n_eligible+n_noneligible)
```

```
## [1] 0.0377193
```

```
# 删除超时的试次。
raw_data <- subset(raw_data, response!="None")
```

每个条件的正确反应比例（更新）

```
# 重新计算每组的正确率。
with(raw_data,table(group, correct)/c(table(group)))
```

```
##            correct
## group                0          1
```

```
##   static  0.05887600 0.94112400
##   rtmax   0.07383774 0.92616226
##   initmax 0.10287081 0.89712919
##   dynamic 0.06403509 0.93596491
```

卡方检验（更新）

```
# 再次进行卡方检验。
chisq.test(with(raw_data,table(group, correct)),correct = FALSE)
```

```
##
##  Pearson's Chi-squared test
##
## data:  with(raw_data, table(group, correct))
## X-squared = 20.044, df = 3, p-value = 0.0001662
```

GLMM 模型（更新）

```
# 再次拟合 GLMM 模型，排除超时试次后的数据。
summary(glmer(correct~(1|subject_nr)+group,family="binomial",data=raw_data))
```

```
## Generalized linear mixed model fit by maximum likelihood (Laplace
##   Approximation) [glmerMod]
##  Family: binomial  ( logit )
## Formula: correct ~ (1 | subject_nr) + group
##    Data: raw_data
##
##      AIC      BIC   logLik deviance df.resid
##   2430.3   2462.5  -1210.2   2420.3     4607
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -4.3768  0.1987  0.2359  0.2906  0.6089
##
## Random effects:
##  Groups     Name        Variance Std.Dev.
##  subject_nr (Intercept) 0.4761   0.69
## Number of obs: 4612, groups:  subject_nr, 245
##
## Fixed effects:
##              Estimate Std. Error z value Pr(>|z|)
## (Intercept)    2.9800     0.1676  17.780  < 2e-16 ***
## grouprtmax    -0.2606     0.2204  -1.182  0.23716
## groupinitmax  -0.6258     0.2073  -3.018  0.00254 **
## groupdynamic  -0.0915     0.2237  -0.409  0.68254
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
```

```
##              (Intr) grprtm grpntm
## grouprtmax  -0.708
## groupinitmx -0.756  0.567
## groupdynamc -0.691  0.524  0.558
```

排除错误试次

```r
# 进一步排除错误试次，只保留正确的反应。
raw_data <- subset(raw_data, correct==1)
```

鼠标轨迹预处理

```r
# 导入鼠标轨迹数据，进行坐标映射、起点对齐、导数计算、标准指标提取、时间标准化。
mt_data <- mt_import_mousetrap(raw_data,
  xpos_label = c("xpos_initial_phase","xpos_get_response"),
  ypos_label = c("ypos_initial_phase","ypos_get_response"),
  timestamps_label = c("timestamps_initial_phase","timestamps_get_response"))
mt_data <- mt_remap_symmetric(mt_data)
mt_data <- mt_align_start(mt_data, start=c(0,0))
mt_data <- mt_derivatives(mt_data)
mt_data <- mt_measures(mt_data)
mt_data <- mt_time_normalize(mt_data)
```

操作检验（平均值）

聚合每位参与者的时间变量

```r
# 添加时间变量，并按被试聚合计算均值。
mt_data$measures$RT_initial <- mt_data$data$response_time_initial_phase
mt_data$measures$IT <- mt_data$measures$initiation_time
mt_data$measures$RT_post <- mt_data$data$response_time_get_response

agg_times <- mt_aggregate_per_subject(mt_data,
  use_variables = c("RT_initial","IT","RT","RT_post"),
  use2_variables = "group",subject_id="subject_nr")
```

描述性统计

```r
# 输出各组的均值和标准差。
mean_times <- agg_times %>%
  group_by(group) %>%
  summarize(
    N = n(),
```

```
    M_RT_inital = mean(RT_initial),
    SD_RT_initial = sd(RT_initial),
    M_IT = mean(IT),
    SD_IT = sd(IT),
    M_RT = mean(RT),
    SD_RT = sd(RT)
    ) %>%
  as.data.frame()
print(mean_times, digits=5)
```

```
##     group  N M_RT_inital SD_RT_initial   M_IT  SD_IT  M_RT   SD_RT
## 1  static 59      808.47        324.06 508.69 215.60 2110.4  654.06
## 2   rtmax 60      650.12        176.61 437.25 159.98 1521.6  183.42
## 3 initmax 66      377.43        159.49 243.14 142.76 1471.7  248.62
## 4 dynamic 60      773.38        752.17 348.67 233.25 2805.4 1199.82
```

```
# 分析 RT_post（动态条件）
agg_times %>%
  group_by(group) %>%
  summarize(
    M_RT_post = mean(RT_post),
    SD_RT_post = sd(RT_post)
  )%>%
  as.data.frame()
```

```
##     group M_RT_post SD_RT_post
## 1  static 1291.0419   584.8519
## 2   rtmax  860.5363   190.2649
## 3 initmax 1083.3367   308.9183
## 4 dynamic 2021.0729   671.1218
```

设置对比矩阵

```
# 定义三种实验条件相对于 static 基线组的对比。
contrast_matrix_separate <- list(
  rtmax_vs_static = c(-1,1,0,0),
  initmax_vs_static = c(-1,0,1,0),
  dynamic_vs_static= c(-1,0,0,1))
```

比较 RT_initial

```
# RT_initial 的方差分析与对比分析。
anova_RT_initial <- aov_ez(data=agg_times,dv = "RT_initial", between = "group", id = "subject_nr")
```

```
## Contrasts set to contr.sum for the following variables: group
```

```r
nice(anova_RT_initial,es = c("pes","ges"))
```

```
## Anova Table (Type 3 tests)
##
## Response: RT_initial
##   Effect     df       MSE         F  ges  pes p.value
## 1  group 3, 241 178274.40 13.64 *** .145 .145   <.001
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '+' 0.1 ' ' 1
```

```r
round(get_partial_etas(anova_RT_initial$anova_table, conf.level=.90),2)
```

```
##        pes lower upper
## group 0.15  0.08  0.21
```

```r
anova_RT_initial_grid <- lsmeans(anova_RT_initial,~group)
contrast(anova_RT_initial_grid,contrast_matrix_separate)
```

```
##  contrast           estimate   SE  df t.ratio p.value
##  rtmax_vs_static      -158.4 77.4 241  -2.046  0.0419
##  initmax_vs_static    -431.0 75.6 241  -5.698  <.0001
##  dynamic_vs_static     -35.1 77.4 241  -0.453  0.6507
```

比较启动时间 IT

```r
# IT 的方差分析与对比分析。
anova_IT <- aov_ez(data=agg_times,dv = "IT", between = "group", id = "subject_nr")
```

```
## Contrasts set to contr.sum for the following variables: group
```

```r
nice(anova_IT,es = c("pes","ges"))
```

```
## Anova Table (Type 3 tests)
##
## Response: IT
##   Effect     df      MSE         F  ges  pes p.value
## 1  group 3, 241 36268.60 22.69 *** .220 .220   <.001
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '+' 0.1 ' ' 1
```

```r
round(get_partial_etas(anova_IT$anova_table, conf.level=.90),2)
```

```
##        pes lower upper
## group 0.22  0.14  0.29
```

```r
anova_IT_grid <- lsmeans(anova_IT,~group)
contrast(anova_IT_grid,contrast_matrix_separate)
```

```
##  contrast          estimate   SE  df t.ratio p.value
##  rtmax_vs_static      -71.4 34.9 241  -2.046  0.0418
##  initmax_vs_static   -265.6 34.1 241  -7.783  <.0001
##  dynamic_vs_static   -160.0 34.9 241  -4.583  <.0001
```

比较总 RT

```r
# 总 RT 的方差分析与对比分析。
anova_RT <- aov_ez(data=agg_times,dv = "RT", between = "group", id = "subject_nr")
```

```
## Contrasts set to contr.sum for the following variables: group
```

```r
nice(anova_RT,es = c("pes","ges"))
```

```
## Anova Table (Type 3 tests)
##
## Response: RT
##   Effect      df       MSE         F  ges  pes p.value
## 1  group 3, 241 480287.20 49.61 *** .382 .382   <.001
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '+' 0.1 ' ' 1
```

```r
round(get_partial_etas(anova_RT$anova_table, conf.level=.90),2)
```

```
##        pes lower upper
## group 0.38   0.3  0.44
```

```r
anova_RT_grid <- lsmeans(anova_RT,~group)
contrast(anova_RT_grid,contrast_matrix_separate)
```

```
##  contrast          estimate  SE  df t.ratio p.value
##  rtmax_vs_static       -589 127 241  -4.634  <.0001
##  initmax_vs_static     -639 124 241  -5.144  <.0001
##  dynamic_vs_static      695 127 241   5.469  <.0001
```

操作检验（中位数）

中位数聚合数据

```r
# 使用中位数对时间变量按参与者聚合。
agg_times <- mt_aggregate_per_subject(mt_data,
  use_variables = c("IT","RT_initial","RT"),
  use2_variables = "group",subject_id="subject_nr",
  .funs="median")
```

描述性统计

```r
# 输出中位数聚合后的均值和标准差。
mean_times <- agg_times %>%
  group_by(group) %>%
  summarize(
    N = n(),
    M_RT_inital = mean(RT_initial),
    SD_RT_initial = sd(RT_initial),
    M_IT = mean(IT),
    SD_IT = sd(IT),
    M_RT = mean(RT),
    SD_RT = sd(RT)
    ) %>%
  as.data.frame()

print(mean_times, digits=5)
```

```
##     group  N M_RT_inital SD_RT_initial   M_IT  SD_IT   M_RT  SD_RT
## 1  static 59      760.84        297.31 497.36 207.87 1934.0 588.13
## 2   rtmax 60      630.30        178.20 437.12 163.29 1476.9 206.95
## 3 initmax 66      355.22        166.27 231.51 152.07 1376.4 238.00
## 4 dynamic 60      516.82        329.58 267.10 164.41 2461.7 859.45
```

比较 RT_initial

```r
# 中位数方式的 RT_initial 方差分析与对比分析。
anova_RT_initial <- aov_ez(data=agg_times,dv = "RT_initial", between = "group", id = "subject_nr")
```

```
## Contrasts set to contr.sum for the following variables: group
```

```r
nice(anova_RT_initial,es = c("pes","ges"))
```

```
## Anova Table (Type 3 tests)
##
## Response: RT_initial
##   Effect     df      MSE         F  ges  pes p.value
## 1  group 3, 241 63095.60 29.35 *** .268 .268   <.001
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '+' 0.1 ' ' 1
```

```r
round(get_partial_etas(anova_RT_initial$anova_table, conf.level=.90),2)
```

```
##        pes lower upper
## group 0.27  0.19  0.33
```

```r
anova_RT_initial_grid <- lsmeans(anova_RT_initial,~group)
contrast(anova_RT_initial_grid,contrast_matrix_separate)
```

```
##  contrast           estimate   SE  df t.ratio p.value
##  rtmax_vs_static        -131 46.1 241  -2.834  0.0050
##  initmax_vs_static      -406 45.0 241  -9.013  <.0001
##  dynamic_vs_static      -244 46.1 241  -5.299  <.0001
```

比较启动时间 IT

```r
# 中位数方式的 IT 方差分析与对比分析。
anova_IT <- aov_ez(data=agg_times,dv = "IT", between = "group", id = "subject_nr")
```

```
## Contrasts set to contr.sum for the following variables: group
```

```r
nice(anova_IT,es = c("pes","ges"))
```

```
## Anova Table (Type 3 tests)
##
## Response: IT
##   Effect     df      MSE         F  ges  pes p.value
## 1  group 3, 241 29781.04 34.37 *** .300 .300  <.001
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '+' 0.1 ' ' 1
```

```r
round(get_partial_etas(anova_IT$anova_table, conf.level=.90),2)
```

```
##       pes lower upper
## group 0.3  0.22  0.36
```

```r
anova_IT_grid <- lsmeans(anova_IT,~group)
contrast(anova_IT_grid,contrast_matrix_separate)
```

```
##  contrast           estimate   SE  df t.ratio p.value
##  rtmax_vs_static       -60.2 31.6 241  -1.904  0.0581
##  initmax_vs_static    -265.9 30.9 241  -8.598  <.0001
##  dynamic_vs_static    -230.3 31.6 241  -7.278  <.0001
```

比较总 RT

```r
# 中位数方式的总 RT 方差分析与对比分析。
anova_RT <- aov_ez(data=agg_times,dv = "RT", between = "group", id = "subject_nr")
```

```
## Contrasts set to contr.sum for the following variables: group
```

```r
nice(anova_RT,es = c("pes","ges"))
```

```
## Anova Table (Type 3 tests)
##
## Response: RT
##   Effect     df       MSE         F  ges  pes p.value
## 1  group 3, 241 289840.97 52.25 *** .394 .394  <.001
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '+' 0.1 ' ' 1
```

```r
round(get_partial_etas(anova_RT$anova_table, conf.level=.90),2)
```

```
##        pes lower upper
## group 0.39  0.31  0.46
```

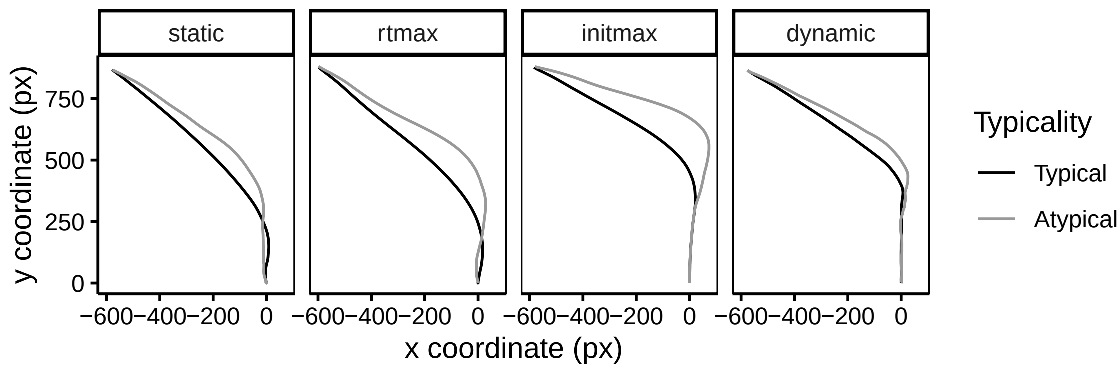
```r
anova_RT_grid <- lsmeans(anova_RT,~group)
contrast(anova_RT_grid,contrast_matrix_separate)
```

```
##  contrast          estimate   SE  df t.ratio p.value
##  rtmax_vs_static       -457 98.7 241  -4.631  <.0001
##  initmax_vs_static     -558 96.5 241  -5.780  <.0001
##  dynamic_vs_static      528 98.7 241   5.346  <.0001
```

聚合轨迹弯曲度

平均时间标准化轨迹图

```r
# 绘制时间标准化后的轨迹图，按 group 分面，颜色区分典型性。
mt_plot_aggregate(mt_data, use = "tn_trajectories", facet_col = "group",
  x = "xpos", y = "ypos", color = "Typicality", subject_id = "subject_nr")+
  xlab("x coordinate (px)") + ylab("y coordinate (px)")+
  scale_color_manual(values = c("black","grey60"))
```



比较 MAD 指标

每位参与者聚合 MAD 数据

```
# 按 group 和 Typicality 聚合 MAD 指标，用于分析轨迹弯曲度的差异。
agg_mad <- mt_aggregate_per_subject(mt_data, subject_id = "subject_nr",
  use_variables = "MAD", use2_variables = c("Typicality","group"))
```

Descriptive 和 配对 t 检验

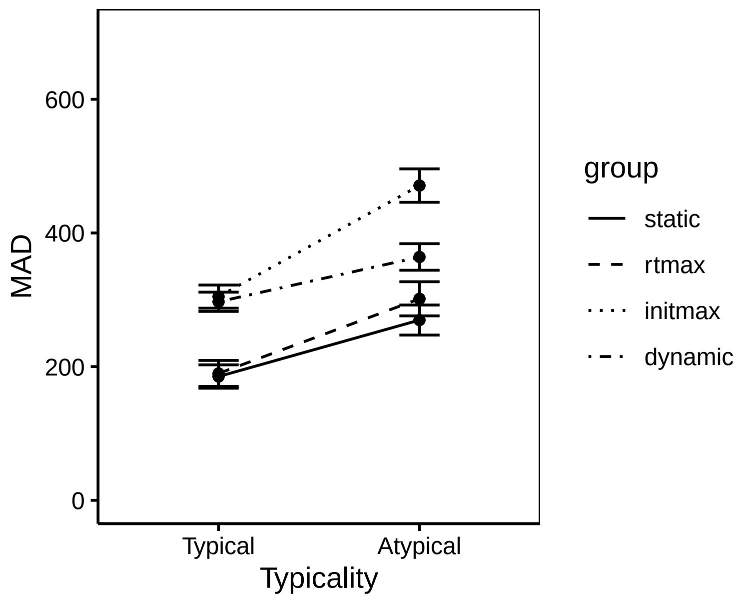
```
mad_table <- agg_mad %>%
  group_by(group) %>%
  select(MAD,group,Typicality) %>%
  summarize(
    N =  length(MAD[Typicality=="Typical"]),                         # 典型条件下的样本数量
    M_t = mean(MAD[Typicality=="Typical"]),                          # 典型条件下 MAD 的平均值
    SD_t = sd(MAD[Typicality=="Typical"]),                           # 典型条件下 MAD 的标准差
    M_a = mean(MAD[Typicality=="Atypical"]),                         # 非典型条件下 MAD 的平均值
    SD_a = sd(MAD[Typicality=="Atypical"]),                          # 非典型条件下 MAD 的标准差
    t = t.test(MAD[Typicality=="Atypical"],MAD[Typicality=="Typical"],paired=TRUE)$statistic, # 配对样本 t 检
    p = t.test(MAD[Typicality=="Atypical"],MAD[Typicality=="Typical"],paired=TRUE)$p.value,   # 配对样本 t 检
    d = (M_a-M_t)/sd(MAD[Typicality=="Atypical"]-MAD[Typicality=="Typical"])          # 效应量 Cohen's
    )

mad_table %>%
  as.data.frame() %>%
  print(digits=3)
```

```
##     group  N M_t SD_t M_a SD_a    t        p     d
## 1  static 59 185  134 270  173 4.18 1.01e-04 0.544
## 2   rtmax 60 190  151 301  198 4.32 6.00e-05 0.558
## 3 initmax 66 305  141 471  203 7.39 3.50e-10 0.910
## 4 dynamic 60 297  112 364  154 3.95 2.09e-04 0.510
```

图表

```
ggplot(agg_mad,aes(x=Typicality,y=MAD,linetype=group,group=group))+
  geom_line(stat="summary",fun.y="mean")+                    # 绘制平均值的折线图
  geom_point(stat="summary",fun.y="mean")+                   # 绘制平均值的点
  geom_errorbar(stat="summary",fun.data="mean_se",width=.2,linetype=1)+  # 添加误差条（标准误）
  scale_linetype_manual(values=c(1,2,3,4))+                    # 手动设置线型样式
  coord_cartesian(ylim=c(0,700))                              # 设置 y 轴范围
```

```
## No summary function supplied, defaulting to `mean_se()`
## No summary function supplied, defaulting to `mean_se()`
```



方差分析 ANOVA

```
anova_mad <- aov_ez(data=agg_mad, dv = "MAD", between = "group", within = "Typicality",
                    id = "subject_nr")
```

```
## Contrasts set to contr.sum for the following variables: group
```

```
nice(anova_mad,es = c("pes","ges"))                    # 显示 ANOVA 结果和效应量（部分 eta 平方、广义 e
```

```
## Anova Table (Type 3 tests)
##
## Response: MAD
##             Effect     df      MSE         F  ges  pes p.value
## 1            group 3, 241 37593.62 18.67 *** .144 .189   <.001
## 2       Typicality 1, 241 14412.64 97.72 *** .101 .289   <.001
## 3 group:Typicality 3, 241 14412.64    4.12 ** .014 .049    .007
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '+' 0.1 ' ' 1
```

```
# 计算部分 eta 平方的 90% 置信区间
round(get_partial_etas(anova_mad$anova_table, conf.level=.90),2)
```

```
##                   pes lower upper
## group            0.19  0.11  0.25
## Typicality       0.29  0.21  0.36
## group:Typicality 0.05  0.01  0.09
```

对比分析

```r
# 获取估计边际均值的组合
anova_mad_grid <- lsmeans(anova_mad,~Typicality:group)

# 指定对比矩阵
contrast_matrix_complete <- list(
  typicality_static = c(-1,1,0,0,0,0,0,0),                # 静态条件下典型性主效应
  rtmax_static_main=  c(-1,-1,1,1,0,0,0,0)/2,             # RTmax vs 静态 的主效应
  initmax_static_main = c(-1,-1,0,0,1,1,0,0)/2,           # Initmax vs 静态 的主效应
  dynamic_static_main = c(-1,-1,0,0,0,0,1,1)/2,           # 动态 vs 静态 的主效应
  rtmax_static_int = c(1,-1,-1,1,0,0,0,0),                # RTmax vs 静态 的交互效应
  initmax_static_int = c(1,-1,0,0,-1,1,0,0),              # Initmax vs 静态 的交互效应
  dynamic_static_int = c(1,-1,0,0,0,0,-1,1))              # 动态 vs 静态 的交互效应

# 进行对比检验
contrast(anova_mad_grid,contrast_matrix_complete)
```

```
##  contrast            estimate   SE  df t.ratio p.value
##  typicality_static       84.5 22.1 241   3.822  0.0002
##  rtmax_static_main       18.2 25.1 241   0.723  0.4702
##  initmax_static_main    160.4 24.6 241   6.529  <.0001
##  dynamic_static_main    103.1 25.1 241   4.101  0.0001
##  rtmax_static_int        27.2 31.1 241   0.873  0.3833
##  initmax_static_int      81.6 30.4 241   2.684  0.0078
##  dynamic_static_int     -17.4 31.1 241  -0.560  0.5763
```

轨迹形状的分布

双峰系数（Bimodality Coefficient）

```r
# 按参与者标准化 MAD 值
mt_data <- mt_standardize(mt_data, use_variables = "MAD", within = "subject_nr")

# 计算双峰系数
mt_check_bimodality(mt_data, use_variables = "z_MAD",
  grouping_variables = c("group","Typicality"), methods = "BC")
```

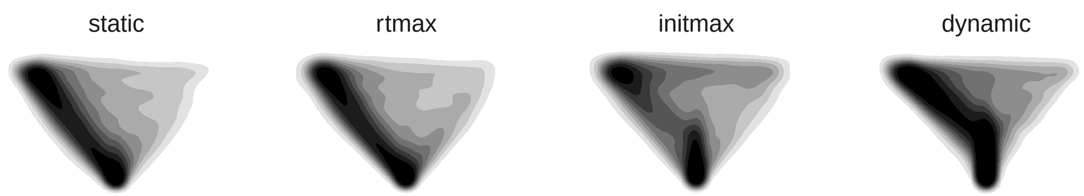
```
## $BC
##     group Typicality     z_MAD
## 1  static    Typical 0.5202425
## 2  static   Atypical 0.5479891
## 3   rtmax    Typical 0.5356378
## 4   rtmax   Atypical 0.5014132
## 5 initmax    Typical 0.5097199
## 6 initmax   Atypical 0.4731716
## 7 dynamic    Typical 0.5596031
## 8 dynamic   Atypical 0.5080918
```

平滑热图

```
heatmap_smoothed <- mt_heatmap_ggplot(mt_data,
  xres = 1000,                          # x 轴分辨率
  smooth_radius = 20,                  # 平滑半径
  n_shades = 10,                       # 阴影层级
  mean_image = 0.2,                    # 平均图像透明度
  colors=c("white","black"),           # 使用黑白色调
  facet_col="group")                 # 按组分面显示
```

```
## spatializing trajectories
## calculate image
## smooth image
## enhance image by 4
## spatializing trajectories
## calculate image
## smooth image
## enhance image by 3.8
## spatializing trajectories
## calculate image
## smooth image
## enhance image by 3.7
## spatializing trajectories
## calculate image
## smooth image
## enhance image by 6.1
```

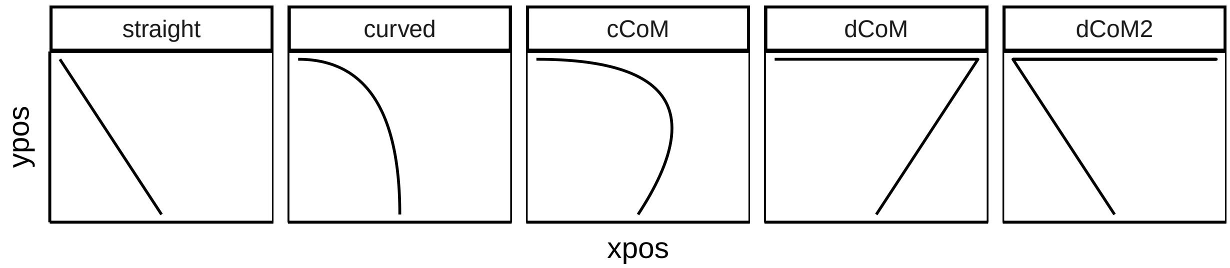
```
heatmap_smoothed+
  theme(strip.background = element_rect(colour = NA))  # 去除分面背景边框
```



原型分类（标准集合）

绘制原型轨迹

```
mt_plot(mt_prototypes,facet_col="mt_id",only_ggplot = TRUE)+
  geom_path()+
  facet_grid(cols = vars(factor(mt_id,levels=rownames(mt_prototypes))))+  # 自定义排列顺序
  theme(axis.text=ggplot2::element_blank(),axis.ticks=ggplot2::element_blank())  # 隐藏坐标轴文本与刻度
```



将轨迹映射到原型

```
mt_data <- mt_spatialize(mt_data)
mt_data <- mt_map(mt_data,prototypes = mt_prototypes,
  save_as = "measures", grouping_variables = "group")
mt_data$data$prototype_label <- mt_data$measures$prototype_label
```

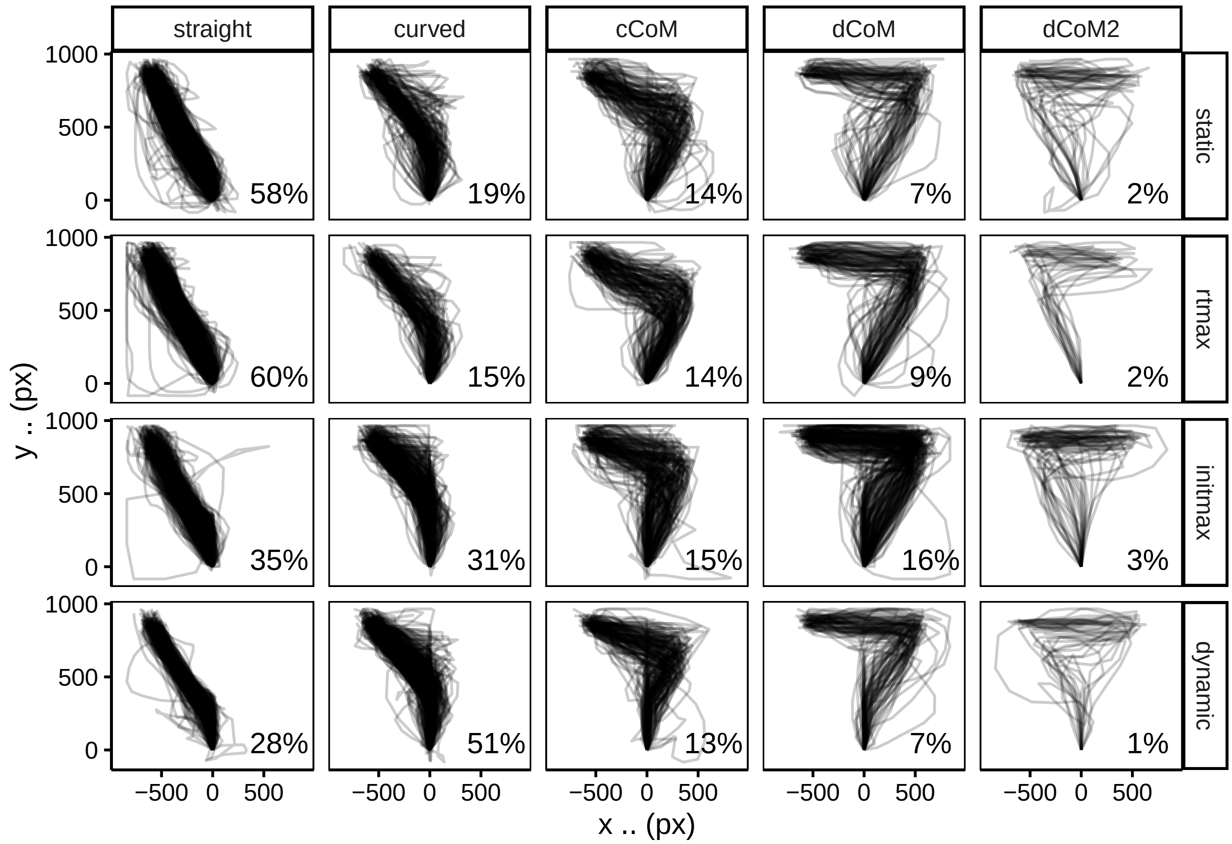
每组的轨迹分类

```
prototype_percentages <- mt_data$data %>%
  group_by(group,prototype_label) %>%
  summarise(n=n()) %>%
  mutate(Percent=paste(round(100*n/sum(n)),"%",sep=""))
```

相对频率

```
## `summarise()` has grouped output by 'group'. You can override using the
## `.groups` argument.
```

```
mt_plot(mt_data, use = "sp_trajectories",
  x = "xpos", y = "ypos", facet_col = "prototype_label", facet_row="group",alpha=.2)+
  xlab("x 坐标 (px)") + ylab("y 坐标 (px)")+
  geom_text(data=prototype_percentages,aes(label=Percent),x=650,y=50)+
  scale_y_continuous(breaks=c(0,500,1000))+
  coord_cartesian(xlim=c(-900,900))
```




```
chisq.test(with(mt_data$data,table(group, prototype_label)))
```

卡方检验

```
##
## 	Pearson's Chi-squared test
##
## data:  with(mt_data$data, table(group, prototype_label))
## X-squared = 535.73, df = 12, p-value < 2.2e-16
```

每组 X 典型性条件的轨迹分类

```
rel_freq_agg <- mt_data$data %>%
  group_by(group,Typicality,prototype_label) %>%
  summarise(n=n()) %>%
  mutate(Percent=n/sum(n))
```

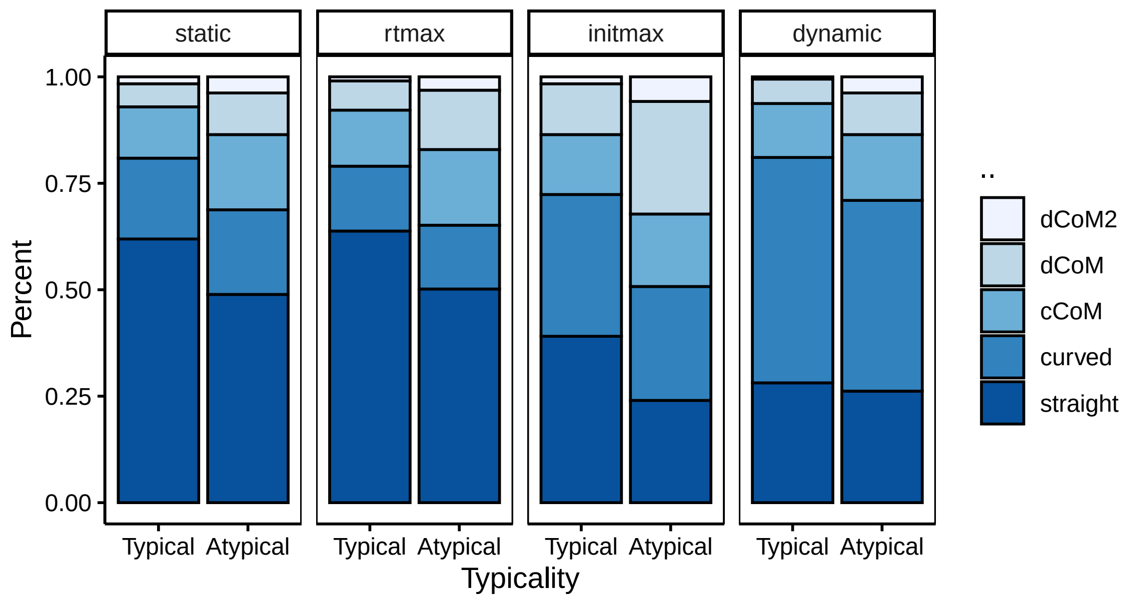
相对频率

```
## `summarise()` has grouped output by 'group', 'Typicality'. You can override
## using the `.groups` argument.
```

```
spread(rel_freq_agg[,-4],"prototype_label","Percent",fill = 0) %>%
  as.data.frame()%>%
  print(digits=2)
```

```
##     group Typicality straight curved cCoM  dCoM  dCoM2
## 1  static    Typical     0.62   0.19 0.12 0.054 0.0163
## 2  static   Atypical     0.49   0.20 0.18 0.098 0.0379
## 3   rtmax    Typical     0.64   0.15 0.13 0.069 0.0096
## 4   rtmax   Atypical     0.50   0.15 0.18 0.139 0.0314
## 5 initmax    Typical     0.39   0.33 0.14 0.119 0.0163
## 6 initmax   Atypical     0.24   0.27 0.17 0.264 0.0578
## 7 dynamic    Typical     0.28   0.53 0.13 0.057 0.0053
## 8 dynamic   Atypical     0.26   0.45 0.15 0.098 0.0379
```

```
ggplot(rel_freq_agg,aes(x=Typicality,y=Percent,fill=forcats::fct_rev(prototype_label)))+
  geom_bar(stat="identity",color="black")+
  scale_fill_brewer(type="seq",name="分类")+
  facet_grid(.~group)
```




```
contrasts(mt_data$data$Typicality) <- c(-0.5,0.5)
# 对 group 使用默认对比（以 static 为基线的虚拟编码）
contrasts(mt_data$data$group)
```

有序混合回归

```
##         rtmax initmax dynamic
```

```
## static       0        0        0
## rtmax        1        0        0
## initmax      0        1        0
## dynamic      0        0        1
```

```
summary(clmm(prototype_label~Typicality*group+(1|subject_nr),data=mt_data$data))
```

```
## Cumulative Link Mixed Model fitted with the Laplace approximation
##
## formula: prototype_label ~ Typicality * group + (1 | subject_nr)
## data:    mt_data$data
##
##  link  threshold nobs logLik   AIC      niter      max.grad cond.H
##  logit flexible  4263 -5228.98 10481.96 1420(5684) 4.99e-03 2.4e+02
##
## Random effects:
##  Groups     Name        Variance Std.Dev.
##  subject_nr (Intercept) 0.6917   0.8317
## Number of groups:  subject_nr 245
##
## Coefficients:
##                            Estimate Std. Error z value Pr(>|z|)
## Typicality1                 0.69431    0.13716   5.062 4.15e-07 ***
## grouprtmax                  0.05605    0.18342   0.306   0.7599
## groupinitmax                1.05662    0.17657   5.984 2.18e-09 ***
## groupdynamic                0.77965    0.17838   4.371 1.24e-05 ***
## Typicality1:grouprtmax      0.15934    0.20078   0.794   0.4274
## Typicality1:groupinitmax    0.30873    0.18414   1.677   0.0936 .
## Typicality1:groupdynamic   -0.39681    0.18115  -2.191   0.0285 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Threshold coefficients:
##                 Estimate Std. Error z value
## straight|curved   0.1227     0.1296   0.946
## curved|cCoM       1.6248     0.1323  12.283
## cCoM|dCoM         2.6964     0.1371  19.667
## dCoM|dCoM2        4.6552     0.1693  27.504
```

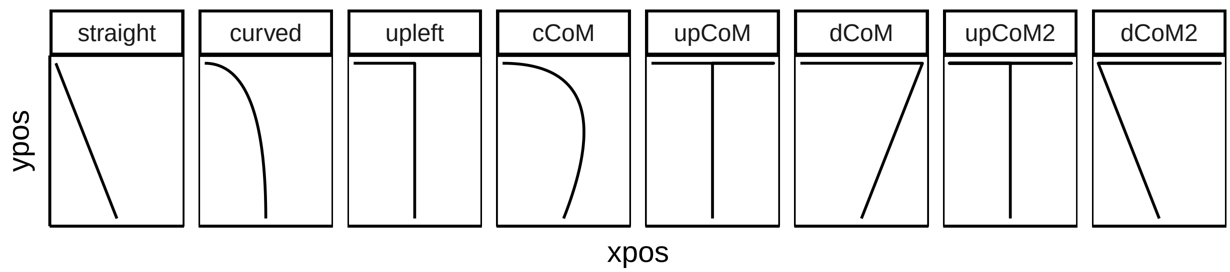
原型分类（扩展原型集）

扩展原型集

包含轨迹先向上移动到屏幕顶部然后… * 向左到达被选选项（upleft） * 向右到未被选选项然后再向左（upCoM） * 向左到被选项，然后向右到未被选项，再向左一次（upCoM2）

```
mt_prototypes_ext <- mt_add_trajectory(mt_prototypes,
   xpos = c(0,0,-1), ypos = c(0,1.5,1.5), id = "upleft"
)

mt_prototypes_ext <- mt_add_trajectory(mt_prototypes_ext,
   xpos = c(0,0,1,-1), ypos = c(0,1.5,1.5,1.5), id = "upCoM"
```

```
)

mt_prototypes_ext <- mt_add_trajectory(mt_prototypes_ext,
   xpos = c(0,0,-1,1,-1), ypos = c(0,1.5,1.5,1.5,1.5), id = "upCoM2"
)

prototype_labels_extended <-
  c("straight","curved","upleft","cCoM","upCoM","dCoM","upCoM2","dCoM2")

mt_plot(mt_prototypes_ext,facet_col="mt_id",only_ggplot = TRUE)+
  geom_path()+
  facet_grid(cols = vars(factor(mt_id,levels=prototype_labels_extended)))+
  theme(axis.text=ggplot2::element_blank(),axis.ticks=ggplot2::element_blank())
```



将轨迹映射到原型

```
mt_data <- mt_spatialize(mt_data)
mt_data <- mt_map(mt_data,prototypes = mt_prototypes_ext,
  save_as="measures", grouping_variables = "group")

# 创建包含所有原型按升序排列的变量
mt_data$data$prototype_label <- factor(mt_data$measures$prototype_label,
  levels=prototype_labels_extended)

# 创建变量，将“up”类型的原型归为其弯曲（curved）等价类别
mt_data$data$prototype_label_red <- factor(mt_data$measures$prototype_label,
  levels=c("straight","curved","upleft","cCoM","upCoM","dCoM","upCoM2","dCoM2"),
  labels=c("straight","curved","curved","cCoM","cCoM", "dCoM","dCoM2", "dCoM2"))
```

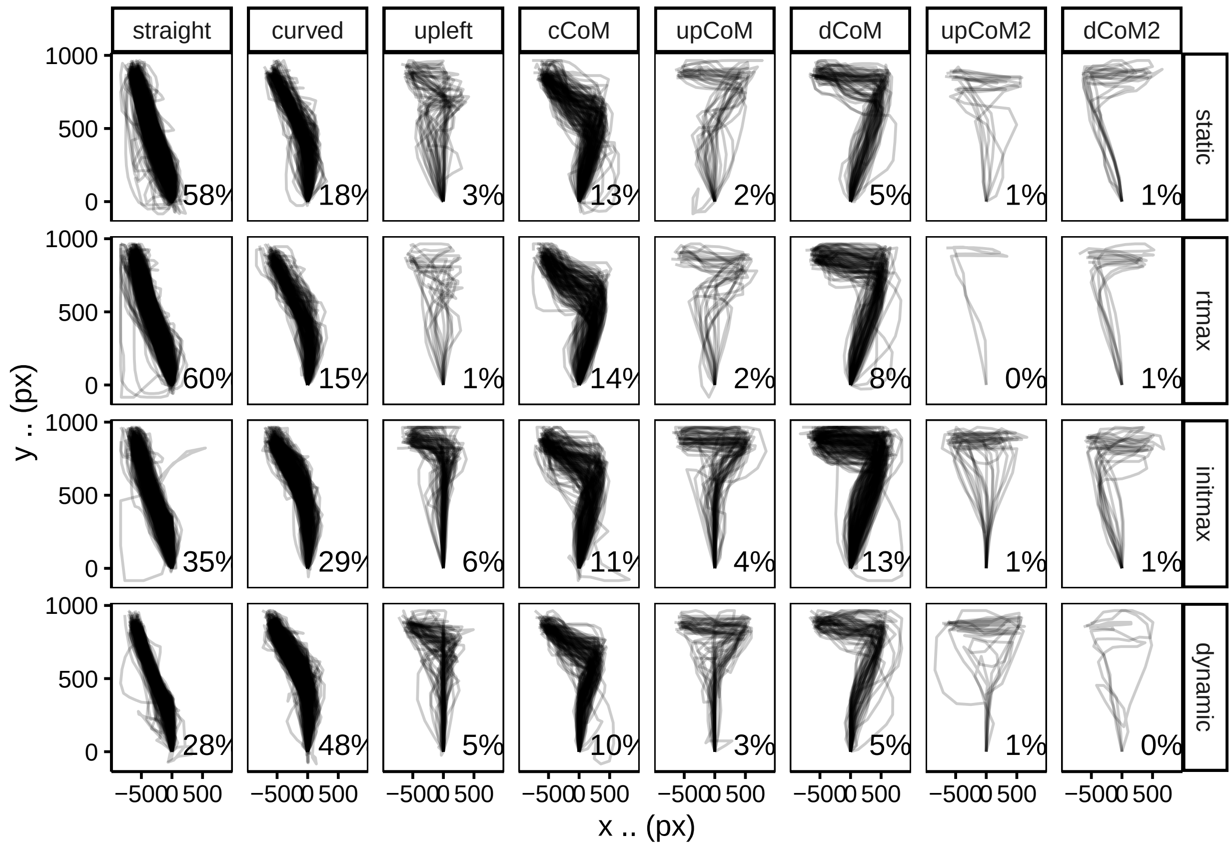
每组的轨迹分类

```
prototype_percentages <- mt_data$data %>%
  group_by(group,prototype_label) %>%
  summarise(n=n()) %>%
  mutate(Percent=paste(round(100*n/sum(n)),"%",sep=""))
```

相对频率

```
## `summarise()` has grouped output by 'group'. You can override using the
## `.groups` argument.
```

```
mt_plot(mt_data, use = "sp_trajectories",
  x = "xpos", y = "ypos", facet_col = "prototype_label", facet_row="group",alpha=.2)+
  xlab("x 坐标 (px)") + ylab("y 坐标 (px)")+
  geom_text(data=prototype_percentages,aes(label=Percent),x=650,y=50)+
  scale_y_continuous(breaks=c(0,500,1000))+
  coord_cartesian(xlim=c(-900,900))
```




```
chisq.test(with(mt_data$data,table(group, prototype_label)))
```

卡方检验

```
##
##  Pearson's Chi-squared test
##
## data:  with(mt_data$data, table(group, prototype_label))
## X-squared = 580.8, df = 21, p-value < 2.2e-16
```

每组 X 典型性条件的轨迹分类

```r
rel_freq_agg <- mt_data$data %>%
  group_by(group,Typicality,prototype_label) %>%
  summarise(n=n()) %>%
  mutate(Percent=n/sum(n), Percent_rounded = round(Percent,2))
```

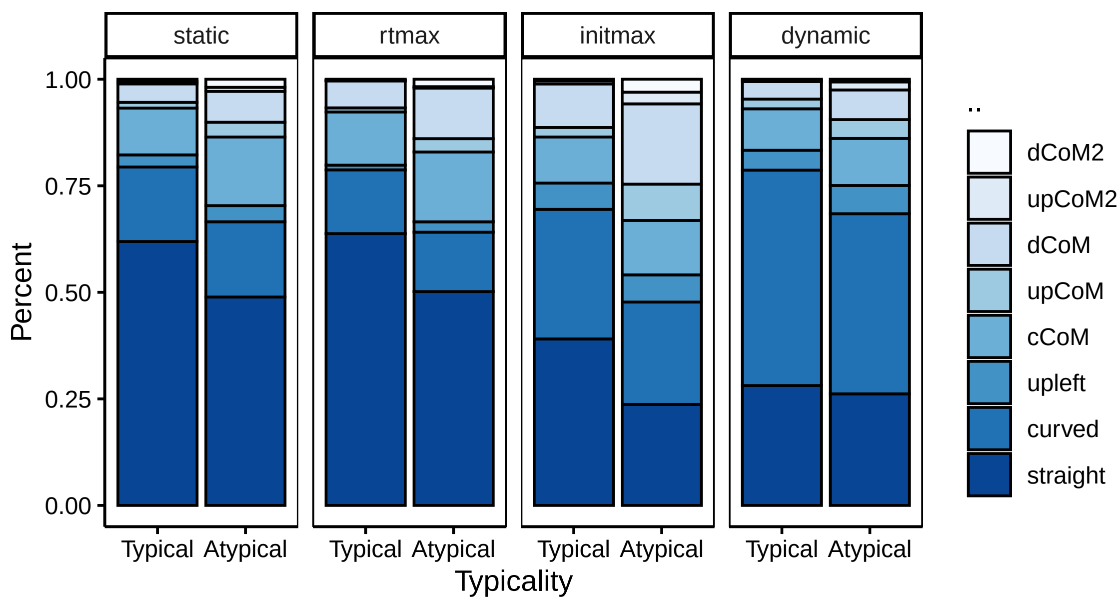
相对频率

```
## `summarise()` has grouped output by 'group', 'Typicality'. You can override
## using the `.groups` argument.
```

```r
spread(rel_freq_agg[,-c(4:5)],"prototype_label","Percent_rounded",fill = 0) %>%
  as.data.frame()
```

```
##     group Typicality straight curved upleft cCoM upCoM dCoM upCoM2 dCoM2
## 1  static    Typical     0.62   0.17   0.03 0.11  0.01 0.04   0.01  0.01
## 2  static   Atypical     0.49   0.18   0.04 0.16  0.03 0.07   0.01  0.02
## 3   rtmax    Typical     0.64   0.15   0.01 0.12  0.01 0.06   0.00  0.00
## 4   rtmax   Atypical     0.50   0.14   0.02 0.16  0.03 0.12   0.00  0.02
## 5 initmax    Typical     0.39   0.30   0.06 0.11  0.02 0.10   0.01  0.00
## 6 initmax   Atypical     0.24   0.24   0.06 0.13  0.09 0.19   0.03  0.03
## 7 dynamic    Typical     0.28   0.51   0.05 0.10  0.02 0.04   0.00  0.00
## 8 dynamic   Atypical     0.26   0.42   0.07 0.11  0.04 0.07   0.02  0.01
```

```r
ggplot(rel_freq_agg,aes(x=Typicality,y=Percent,fill=forcats::fct_rev(prototype_label)))+
  geom_bar(stat="identity",color="black")+
  scale_fill_brewer(type="seq",name="分类")+
  facet_grid(.~group)
```



```r
summary(clmm(prototype_label~Typicality*group+(1|subject_nr),data=mt_data$data))
```

有序混合回归（将所有原型视为有序）

```
## Cumulative Link Mixed Model fitted with the Laplace approximation
##
## formula: prototype_label ~ Typicality * group + (1 | subject_nr)
## data:    mt_data$data
##
##  link  threshold nobs logLik   AIC      niter      max.grad cond.H
##  logit flexible  4263 -5931.81 11893.62 1877(7512) 6.95e-03 1.3e+03
##
## Random effects:
##  Groups     Name        Variance Std.Dev.
##  subject_nr (Intercept) 0.6844   0.8273
## Number of groups:  subject_nr 245
##
## Coefficients:
##                            Estimate Std. Error z value Pr(>|z|)
## Typicality1                 0.69787    0.13624   5.122 3.02e-07 ***
## grouprtmax                  0.05277    0.18253   0.289   0.7725
## groupinitmax                1.05239    0.17554   5.995 2.03e-09 ***
## groupdynamic                0.75655    0.17732   4.267 1.99e-05 ***
## Typicality1:grouprtmax      0.15942    0.19994   0.797   0.4252
## Typicality1:groupinitmax    0.29571    0.18243   1.621   0.1050
## Typicality1:groupdynamic   -0.42175    0.17959  -2.348   0.0189 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Threshold coefficients:
##                  Estimate Std. Error z value
## straight|curved    0.1154     0.1290   0.895
## curved|upleft      1.5138     0.1313  11.527
## upleft|cCoM        1.7538     0.1320  13.291
## cCoM|upCoM         2.6757     0.1362  19.640
## upCoM|dCoM         2.9829     0.1386  21.525
## dCoM|upCoM2        4.9358     0.1794  27.519
## upCoM2|dCoM2       5.6185     0.2156  26.057
```

```r
summary(clmm(prototype_label_red~Typicality*group+(1|subject_nr),data=mt_data$data))
```

有序混合回归（将“up”和弯曲原型视为相同）

```
## Cumulative Link Mixed Model fitted with the Laplace approximation
##
## formula: prototype_label_red ~ Typicality * group + (1 | subject_nr)
## data:    mt_data$data
##
```

```
##  link  threshold nobs logLik   AIC      niter      max.grad cond.H
##  logit flexible  4263 -5096.38 10216.75 1282(5132) 6.32e-03 2.0e+02
##
## Random effects:
##  Groups     Name        Variance Std.Dev.
##  subject_nr (Intercept) 0.6424   0.8015
## Number of groups:  subject_nr 245
##
## Coefficients:
##                            Estimate Std. Error z value Pr(>|z|)
## Typicality1                 0.68476    0.13706   4.996 5.85e-07 ***
## grouprtmax                  0.06289    0.17878   0.352   0.7250
## groupinitmax                1.02893    0.17197   5.983 2.19e-09 ***
## groupdynamic                0.77148    0.17363   4.443 8.86e-06 ***
## Typicality1:grouprtmax      0.13949    0.20085   0.694   0.4874
## Typicality1:groupinitmax    0.26787    0.18403   1.456   0.1455
## Typicality1:groupdynamic   -0.44088    0.18113  -2.434   0.0149 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Threshold coefficients:
##                  Estimate Std. Error z value
## straight|curved    0.1281     0.1263   1.014
## curved|cCoM        1.7488     0.1294  13.519
## cCoM|dCoM          2.9604     0.1359  21.778
## dCoM|dCoM2         4.9059     0.1772  27.679
```