

Effects of Ambient Illumination and Screen Luminance on
Mixed Reality Interaction
Supplementary Material

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1. Introduction

This supplementary material provides additional details supporting our study on the effects of ambient illumination and screen luminance on mixed reality interaction. Specifically, we include the subjective visual fatigue questionnaire, along with the statistical models, figures, and results used in our analysis. To evaluate performance in direct target selection, ray-cast target selection, and text entry tasks, we applied Bayesian regression models [1]. We present visualizations of the results and report posterior probabilities to strengthen the validity of our findings.

2. Visual Fatigue Questionnaire

The Visual Fatigue Questionnaire (VSQ) developed by Hayes et al. [2] was employed in our study to assess participants' subjective experience of visual fatigue.

Table 1: Visual Fatigue Questionnaire

Symptom	Scale (0–10)
Blurred vision while viewing the text	0 1 2 3 4 5 6 7 8 9 10
Blurred vision when looking into the distance at the end of the near task	0 1 2 3 4 5 6 7 8 9 10
Difficulty or slowness in refocusing my eyes from one distance to another	0 1 2 3 4 5 6 7 8 9 10
Irritated or burning eyes	0 1 2 3 4 5 6 7 8 9 10
Dry eyes	0 1 2 3 4 5 6 7 8 9 10
Eyestrain	0 1 2 3 4 5 6 7 8 9 10
Headache	0 1 2 3 4 5 6 7 8 9 10
Tired eyes	0 1 2 3 4 5 6 7 8 9 10
Sensitivity to bright lights	0 1 2 3 4 5 6 7 8 9 10
Discomfort in your eyes	0 1 2 3 4 5 6 7 8 9 10

3. Library

```
cat("lme4:", as.character(packageVersion("lme4")),  
    "glmmTMB:", as.character(packageVersion("glmmTMB")),  
    "brms:", as.character(packageVersion("brms")),  
    "betareg:", as.character(packageVersion("betareg")),  
    "bayestestR:", as.character(packageVersion("bayestestR")),  
    "ggplot2:", as.character(packageVersion("ggplot2")))
```

lme4: 1.1.136 glmmTMB: 1.1.11 brms: 2.22.0 betareg: 3.2.3 bayestestR: 0.15.3 ggplot2: 3.5.1

4. Target Selection Task

4.1 Movement Time

Direct Target Selection

```
priors <- c(  
  prior(normal(0, 1), class = "b")  
)  
  
mt_model <- brm(  
  MT ~ 1 + (1|participant) + order + ID * (illuminance * brightness),
```

```

data = no_error_poke,
family = shifted_lognormal(),
prior = priors,
iter = 5000,
save_pars = save_pars(all = TRUE),
cores = 4,
backend = "cmdstanr",
seed = 1234
)
saveRDS(mt_model, file = "brm_model/mt_model_poke.rds")

mt_model_poke <- readRDS("brm_model/mt_model_poke.rds")
summary(mt_model_poke)

```

```

Family: shifted_lognormal
Links: mu = identity; sigma = identity; ndt = identity
Formula: MT ~ 1 + (1 | participant) + order + ID * (illuminance * brightness)
Data: no_error_poke (Number of observations: 6335)
Draws: 4 chains, each with iter = 5000; warmup = 2500; thin = 1;
       total post-warmup draws = 10000

```

```

Multilevel Hyperparameters:
~participant (Number of levels: 24)
      Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
sd(Intercept)    0.29    0.05    0.22    0.40 1.00    1459    1975

```

```

Regression Coefficients:
      Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
Intercept      6.20     0.08     6.04     6.36 1.00    1586    3459
order          -0.05     0.00    -0.06    -0.04 1.00     8218    6612
ID              0.30     0.06     0.18     0.43 1.00     2863    4825
illuminanceH    0.11     0.08    -0.04     0.26 1.00     2864    4477
illuminanceL   -0.11     0.08    -0.26     0.04 1.00     2832    3974
brightnessH    -0.02     0.08    -0.17     0.14 1.00     2580    3749
illuminanceH:brightnessH  0.00     0.11    -0.21     0.21 1.00     2605    4451
illuminanceL:brightnessH  0.20     0.11    -0.01     0.42 1.00     2768    3975
ID:illuminanceH -0.01     0.09    -0.19     0.16 1.00     2866    4607
ID:illuminanceL  0.11     0.09    -0.06     0.28 1.00     2862    4357
ID:brightnessH  -0.03     0.09    -0.21     0.14 1.00     2564    3688
ID:illuminanceH:brightnessH  0.09     0.12    -0.15     0.34 1.00     2627    4637
ID:illuminanceL:brightnessH -0.14     0.12    -0.39     0.10 1.00     2763    3933

```

```

Further Distributional Parameters:
      Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
sigma    0.43     0.00     0.42     0.44 1.00     7692     6627
ndt     229.79     1.29    227.03    232.12 1.00     7627     6237

```

Draws were sampled using `sample(hmc)`. For each parameter, Bulk_ESS and Tail_ESS are effective sample size measures, and Rhat is the potential scale reduction factor on split chains (at convergence, Rhat = 1).

Ray-Cast Target Selection

```

priors <- c(
  prior(normal(0, 1), class = "b")
)

mt_model <- brm(
  MT ~ 1 + (1|participant) + order + ID * (illuminance * brightness),
  data = no_error_ray,
  family = shifted_lognormal(),
  prior = priors,
  iter = 5000,

```

```

save_pars = save_pars(all = TRUE),
cores = 4,
backend = "cmdstanr",
seed = 1234
)
saveRDS(mt_model, file = "brm_model/mt_model_ray.rds")

mt_model_ray <- readRDS("brm_model/mt_model_ray.rds")
summary(mt_model_ray)

Family: shifted_lognormal
Links: mu = identity; sigma = identity; ndt = identity
Formula: MT ~ 1 + (1 | participant) + order + ID * (illuminance * brightness)
Data: no_error_ray (Number of observations: 6336)
Draws: 4 chains, each with iter = 5000; warmup = 2500; thin = 1;
       total post-warmup draws = 10000

Multilevel Hyperparameters:
~participant (Number of levels: 24)
      Estimate Est.Error 1-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
sd(Intercept)      0.30      0.05      0.22      0.41 1.00      1426      1830

Regression Coefficients:
      Estimate Est.Error 1-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
Intercept      6.88      0.09      6.71      7.06 1.00      1635      2889
order          -0.04      0.00     -0.05     -0.03 1.00      8300      6336
ID              0.21      0.07      0.07      0.36 1.00      2888      4170
illuminanceH    0.02      0.09     -0.20      0.15 1.00      2859      4202
illuminanceL    0.10      0.09     -0.08      0.28 1.00      2830      3806
brightnessH    -0.11      0.09     -0.29      0.07 1.00      2476      4336
illuminanceH:brightnessH -0.02      0.13     -0.28      0.23 1.00      2665      4400
illuminanceL:brightnessH  0.14      0.13     -0.11      0.39 1.00      2630      4395
ID:illuminanceH  0.26      0.10      0.06      0.46 1.00      2812      4095
ID:illuminanceL  0.25      0.10      0.05      0.46 1.00      2797      3757
ID:brightnessH   0.18      0.10     -0.02      0.38 1.00      2438      4047
ID:illuminanceH:brightnessH -0.09      0.15     -0.37      0.20 1.00      2728      4154
ID:illuminanceL:brightnessH -0.21      0.14     -0.49      0.08 1.00      2603      4493

Further Distributional Parameters:
      Estimate Est.Error 1-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
sigma      0.50      0.01      0.49      0.51 1.00      5784      6462
ndt       350.89      4.79    340.90    359.57 1.00      5872      5440

Draws were sampled using sample(hmc). For each parameter, Bulk_ESS
and Tail_ESS are effective sample size measures, and Rhat is the potential
scale reduction factor on split chains (at convergence, Rhat = 1).

```

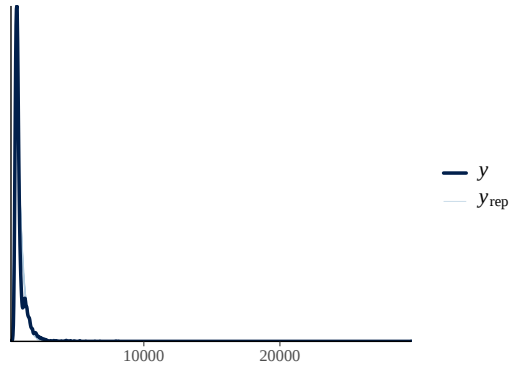
Validation

Posterior Probability Check

```

# Direct target selection movement time model
pp_check(mt_model_poke)

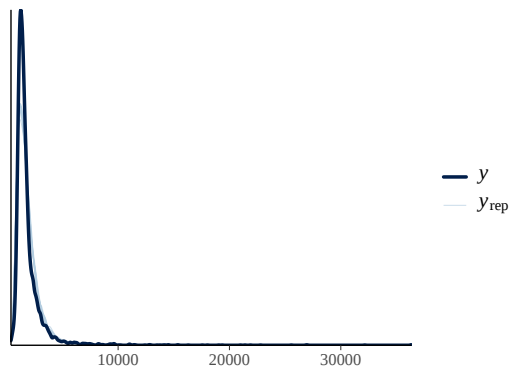
```



```
# Direct target selection movement time model
post <- as_draws_df(mt_model_poke)
cat("Illuminance (High): pp =", mean(post$b_illuminanceH > 0), "\n",
    "Illuminance (Low): pp =", mean(post$b_illuminanceL > 0), "\n",
    "Brightness (High): pp =", mean(post$b_brightnessH > 0), "\n",
    "Illuminance (High) × Brightness (High): pp =",
    mean(post$b_illuminanceH:brightnessH` > 0), "\n",
    "Illuminance (Low) × Brightness (High): pp =",
    mean(post$b_illuminanceL:brightnessH` > 0), "\n")
```

```
Illuminance (High): pp = 0.9169
Illuminance (Low): pp = 0.072
Brightness (High): pp = 0.408
Illuminance (High) × Brightness (High): pp = 0.5117
Illuminance (Low) × Brightness (High): pp = 0.9669
```

```
# Ray-cast target selection movement time model
pp_check(mt_model_ray)
```



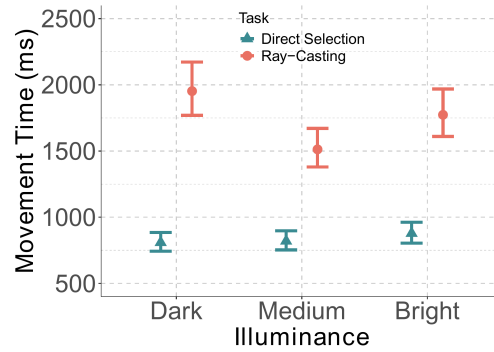
```
# Ray-cast target selection movement time model
post <- as_draws_df(mt_model_ray)
cat("Illuminance (High): pp =", mean(post$b_illuminanceH > 0), "\n",
    "Illuminance (Low): pp =", mean(post$b_illuminanceL > 0), "\n",
    "Brightness (High): pp =", mean(post$b_brightnessH > 0), "\n",
    "Illuminance (High) × Brightness (High): pp =",
    mean(post$b_illuminanceH:brightnessH` > 0), "\n",
    "Illuminance (Low) × Brightness (High): pp =",
    mean(post$b_illuminanceL:brightnessH` > 0), "\n")
```

```
Illuminance (High): pp = 0.4053
Illuminance (Low): pp = 0.8769
Brightness (High): pp = 0.1026
```

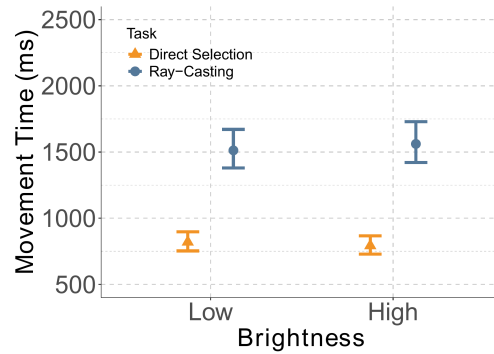
Illuminance (High) × Brightness (High): pp = 0.4314
 Illuminance (Low) × Brightness (High): pp = 0.8694

Plot

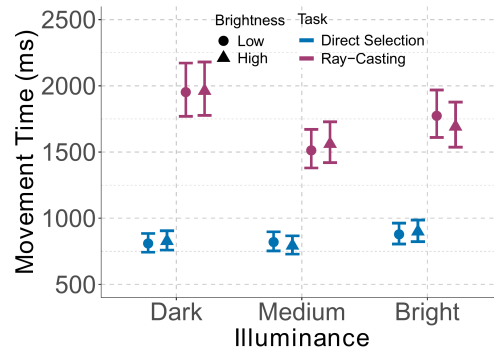
combined_illuminance_plot



combined_brightness_plot



combined_interaction_plot



4.2 Pointing Offset

Direct Target Selection

```
priors <- c(
  prior(normal(0, 1), class = "b")
)
```

```
acc_model_poke <- brm(
```

```

offset ~ 1 + (1|participant) + order + width * (illuminance * brightness),
data = no_error_poke,
family = shifted_lognormal(),
prior = priors,
iter = 5000,
save_pars = save_pars(all = TRUE),
cores = 4,
backend = "cmdstanr",
seed = 1234
)
saveRDS(acc_model_poke, file = "brm_model/offset_model_poke.rds")

```

```

acc_model_poke <- readRDS("brm_model/offset_model_poke.rds")
summary(acc_model_poke)

```

```

Family: shifted_lognormal
Links: mu = identity; sigma = identity; ndt = identity
Formula: offset ~ 1 + (1 | participant) + order + width * (illuminance * brightness)
Data: no_error_poke (Number of observations: 6335)
Draws: 4 chains, each with iter = 5000; warmup = 2500; thin = 1;
       total post-warmup draws = 10000

```

```

Multilevel Hyperparameters:
~participant (Number of levels: 24)
      Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
sd(Intercept)    0.16     0.03    0.12    0.23 1.00    1638     3106

```

```

Regression Coefficients:
      Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
Intercept          2.27     0.10    2.08    2.47 1.00    2030     4763
order              -0.01     0.00   -0.01    0.00 1.00   12432     7864
width               0.01     0.00    0.01    0.01 1.00    2304     4683
illuminanceH        0.32     0.13    0.06    0.59 1.00    2665     4835
illuminanceL        0.12     0.13   -0.14    0.37 1.00    2487     4712
brightnessH         0.09     0.13   -0.16    0.35 1.00    2046     3941
illuminanceH:brightnessH -0.29    0.18   -0.64    0.07 1.00    2369     4326
illuminanceL:brightnessH -0.15    0.18   -0.51    0.21 1.00    2208     4052
width:illuminanceH   -0.00     0.00   -0.01    0.00 1.00    2643     5077
width:illuminanceL   -0.00     0.00   -0.01    0.00 1.00    2469     4661
width:brightnessH    -0.00     0.00   -0.01    0.00 1.00    2068     3926
width:illuminanceH:brightnessH 0.01     0.00    0.00    0.01 1.00    2365     4540
width:illuminanceL:brightnessH 0.00     0.00   -0.00    0.01 1.00    2177     4091

```

```

Further Distributional Parameters:
      Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
sigma    0.61     0.01    0.60    0.62 1.00    10926     7904
ndt      0.01     0.01    0.00    0.02 1.00     8245     4716

```

Draws were sampled using `sample(hmc)`. For each parameter, `Bulk_ESS` and `Tail_ESS` are effective sample size measures, and `Rhat` is the potential scale reduction factor on split chains (at convergence, `Rhat` = 1).

Ray-Cast Target Selection

```

priors <- c(
  prior(normal(0, 1), class = "b")
)

acc_model_ray <- brm(
  offset ~ 1 + (1|participant) + order + width * (illuminance * brightness),
  data = no_error_ray,
  family = shifted_lognormal(),
  prior = priors,

```

```

iter = 5000,
save_pars = save_pars(all = TRUE),
cores = 4,
backend = "cmdstanr",
seed = 1234
)

saveRDS(acc_model_ray, file = "brm_model/offset_model_ray.rds")

acc_model_ray <- readRDS("brm_model/offset_model_ray.rds")
summary(acc_model_ray)

```

```

Family: shifted_lognormal
Links: mu = identity; sigma = identity; ndt = identity
Formula: offset ~ 1 + (1 | participant) + order + width * (illuminance * brightness)
Data: no_error_ray (Number of observations: 6336)
Draws: 4 chains, each with iter = 5000; warmup = 2500; thin = 1;
       total post-warmup draws = 10000

```

```

Multilevel Hyperparameters:
~participant (Number of levels: 24)
      Estimate Est.Error 1-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
sd(Intercept)    0.08    0.01    0.05    0.11 1.00    2706    3497

```

```

Regression Coefficients:
      Estimate Est.Error 1-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
Intercept      2.67    0.09    2.49    2.86 1.00    4408    5579
order          -0.00    0.00   -0.01    0.01 1.00   14502    6287
width           0.01    0.00    0.00    0.01 1.00    4210    6563
illuminanceH    0.19    0.13   -0.45    0.06 1.00    4898    6451
illuminanceL    0.19    0.13   -0.45    0.05 1.00    4209    5668
brightnessH   -0.19    0.13   -0.44    0.06 1.00    3822    5136
illuminanceH:brightnessH  0.24    0.18   -0.12    0.59 1.00    3924    5423
illuminanceL:brightnessH  0.23    0.18   -0.12    0.59 1.00    3937    5602
width:illuminanceH    0.00    0.00    0.00    0.01 1.00    5002    6195
width:illuminanceL    0.00    0.00    0.00    0.01 1.00    4149    5764
width:brightnessH     0.00    0.00   -0.00    0.00 1.00    3857    5811
width:illuminanceH:brightnessH -0.00    0.00   -0.01    0.00 1.00    4008    5678
width:illuminanceL:brightnessH -0.00    0.00   -0.01    0.00 1.00    4009    6005

```

```

Further Distributional Parameters:
      Estimate Est.Error 1-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
sigma    0.59    0.01    0.58    0.60 1.00   12472    7360
ndt      0.05    0.05    0.00    0.18 1.00    7794    4314

```

Draws were sampled using `sample(hmc)`. For each parameter, Bulk_ESS and Tail_ESS are effective sample size measures, and Rhat is the potential scale reduction factor on split chains (at convergence, Rhat = 1).

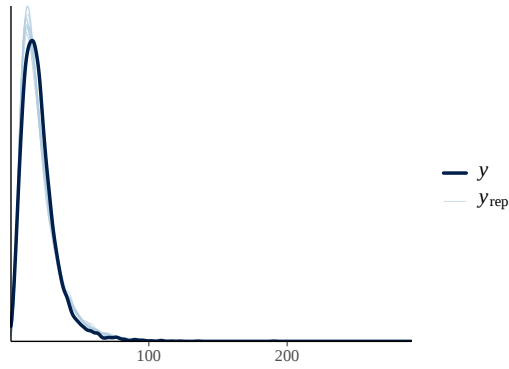
Validation

Posterior Probability Check

```

# Direct target selection pointing offset model
pp_check(acc_model_poke)

```



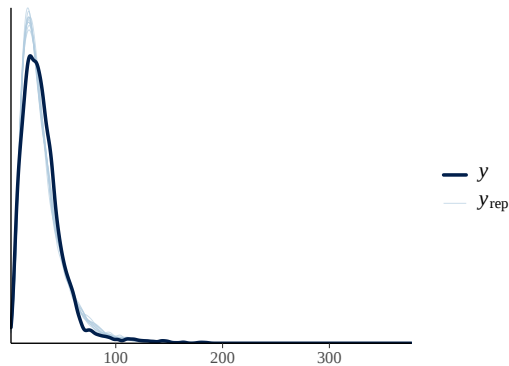
```
# Direct target selection pointing offset model
```

```
post <- as_draws_df(acc_model_poke)
cat("Illuminance (High): pp =", mean(post$b_illuminanceH > 0), "\n",
    "Illuminance (Low): pp =", mean(post$b_illuminanceL > 0), "\n",
    "Brightness (High): pp =", mean(post$b_brightnessH > 0), "\n",
    "Illuminance (High) × Brightness (High): pp =",
    mean(post$b_illuminanceH:brightnessH` > 0), "\n",
    "Illuminance (Low) × Brightness (High): pp =",
    mean(post$b_illuminanceL:brightnessH` > 0), "\n")
```

```
Illuminance (High): pp = 0.9925
Illuminance (Low): pp = 0.8157
Brightness (High): pp = 0.7623
Illuminance (High) × Brightness (High): pp = 0.0581
Illuminance (Low) × Brightness (High): pp = 0.2069
```

```
# Ray-cast target selection pointing offset model
```

```
pp_check(acc_model_ray)
```



```
# Ray-cast target selection pointing offsetmodel
```

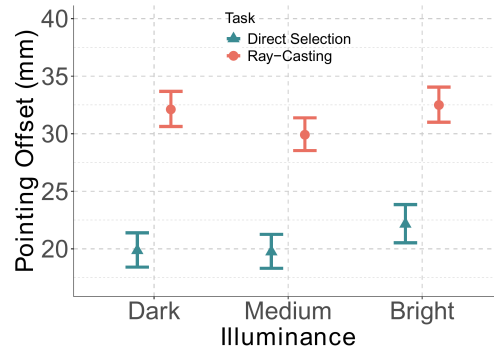
```
post <- as_draws_df(acc_model_ray)
cat("Illuminance (High): pp =", mean(post$b_illuminanceH > 0), "\n",
    "Illuminance (Low): pp =", mean(post$b_illuminanceL > 0), "\n",
    "Brightness (High): pp =", mean(post$b_brightnessH > 0), "\n",
    "Illuminance (High) × Brightness (High): pp =",
    mean(post$b_illuminanceH:brightnessH` > 0), "\n",
    "Illuminance (Low) × Brightness (High): pp =",
    mean(post$b_illuminanceL:brightnessH` > 0), "\n")
```

```
Illuminance (High): pp = 0.0636
Illuminance (Low): pp = 0.0664
Brightness (High): pp = 0.0637
```

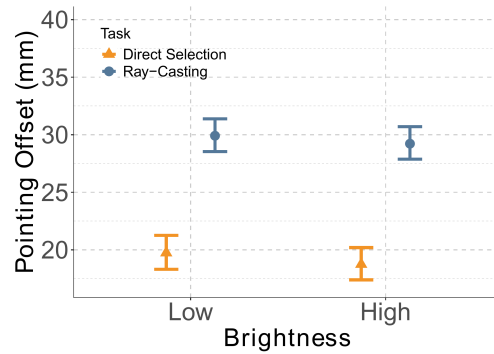
Illuminance (High) × Brightness (High): pp = 0.9039
 Illuminance (Low) × Brightness (High): pp = 0.9046

Plot

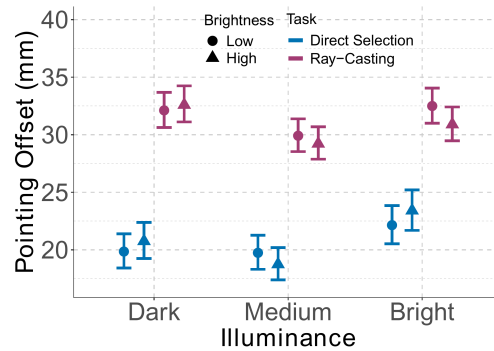
combined_illuminance_plot



combined_brightness_plot



combined_interaction_plot



4.3 Error Rate

Direct Target Selection

```
priors <- c(
  prior(normal(0, 1), class = "b")
)

err_model_poke <- brm(
```

```

error ~ 1 + (1|participant) + order + ID * (illuminance * brightness),
data = poke,
family = poisson(),
prior = priors,
iter = 6000,
control = list(adapt_delta = 0.95),
save_pars = save_pars(all = TRUE),
cores = 4,
backend = "cmdstanr",
seed = 1234
)

```

```
saveRDS(err_model_poke, file = "brm_model/err_model_poke.rds")
```

```
err_model_poke <- readRDS("brm_model/err_model_poke.rds")
summary(err_model_poke)
```

```

Family: poisson
Links: mu = log
Formula: error ~ 1 + (1 | participant) + order + ID * (illuminance * brightness)
Data: poke (Number of observations: 6361)
Draws: 4 chains, each with iter = 6000; warmup = 3000; thin = 1;
       total post-warmup draws = 12000

```

Multilevel Hyperparameters:

```

~participant (Number of levels: 24)
      Estimate Est.Error 1-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
sd(Intercept)      1.38      0.47      0.67      2.52 1.00      4561      6894

```

Regression Coefficients:

	Estimate	Est.Error	1-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
Intercept	-4.97	0.94	-6.89	-3.21	1.00	12441	9758
order	-0.31	0.13	-0.57	-0.06	1.00	23243	8894
ID	-1.15	0.76	-2.66	0.33	1.00	18447	9849
illuminanceH	0.89	0.70	-0.52	2.27	1.00	14713	9728
illuminanceL	0.71	0.69	-0.65	2.07	1.00	15572	10032
brightnessH	-0.54	0.71	-1.95	0.85	1.00	14854	10038
illuminanceH:brightnessH	0.30	0.76	-1.18	1.77	1.00	16745	9213
illuminanceL:brightnessH	0.24	0.76	-1.27	1.74	1.00	16884	9151
ID:illuminanceH	0.05	0.76	-1.45	1.52	1.00	15767	9756
ID:illuminanceL	0.06	0.76	-1.44	1.57	1.00	15647	9886
ID:brightnessH	-0.26	0.77	-1.80	1.23	1.00	16150	10112
ID:illuminanceH:brightnessH	0.15	0.84	-1.50	1.78	1.00	18818	9808
ID:illuminanceL:brightnessH	0.45	0.83	-1.17	2.11	1.00	18798	9522

Draws were sampled using `sample(hmc)`. For each parameter, Bulk_ESS and Tail_ESS are effective sample size measures, and Rhat is the potential scale reduction factor on split chains (at convergence, Rhat = 1).

Ray-Cast Target Selection

```

priors <- c(
  prior(normal(0, 1), class = "b")
)

err_model_ray <- brm(
  error ~ 1 + (1|participant) + order + ID * (illuminance * brightness),
  data = ray,
  family = poisson(),
  prior = priors,
  iter = 6000,
  control = list(adapt_delta = 0.95),

```

```

save_pars = save_pars(all = TRUE),
cores = 4,
backend = "cmdstanr",
seed = 1234
)

saveRDS(err_model_ray, file = "brm_model/err_model_ray.rds")

err_model_ray <- readRDS("brm_model/err_model_ray.rds")
summary(err_model_ray)

Family: poisson
Links: mu = log
Formula: error ~ 1 + (1 | participant) + order + ID * (illuminance * brightness)
Data: ray (Number of observations: 6516)
Draws: 4 chains, each with iter = 6000; warmup = 3000; thin = 1;
       total post-warmup draws = 12000

```

Multilevel Hyperparameters:

~participant (Number of levels: 24)

	Estimate	Est.Error	1-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	1.38	0.29	0.91	2.06	1.00	3786	5980

Regression Coefficients:

	Estimate	Est.Error	1-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
Intercept	-4.67	0.56	-5.78	-3.59	1.00	6614	8427
order	-0.02	0.05	-0.11	0.08	1.00	17427	7904
ID	0.09	0.47	-0.83	1.02	1.00	9931	9363
illuminanceH	0.07	0.52	-0.95	1.10	1.00	8741	8863
illuminanceL	0.23	0.50	-0.75	1.21	1.00	9391	8396
brightnessH	0.02	0.50	-0.97	0.99	1.00	9255	8125
illuminanceH:brightnessH	0.17	0.59	-1.01	1.31	1.00	9753	8041
illuminanceL:brightnessH	0.04	0.59	-1.11	1.17	1.00	9853	9544
ID:illuminanceH	-0.14	0.58	-1.27	0.98	1.00	9134	8959
ID:illuminanceL	0.20	0.54	-0.86	1.26	1.00	9103	8531
ID:brightnessH	-0.19	0.55	-1.28	0.89	1.00	8962	8009
ID:illuminanceH:brightnessH	0.06	0.66	-1.22	1.36	1.00	9980	8548
ID:illuminanceL:brightnessH	-0.34	0.66	-1.62	0.94	1.00	9851	8766

Draws were sampled using sample(hmc). For each parameter, Bulk_ESS and Tail_ESS are effective sample size measures, and Rhat is the potential scale reduction factor on split chains (at convergence, Rhat = 1).

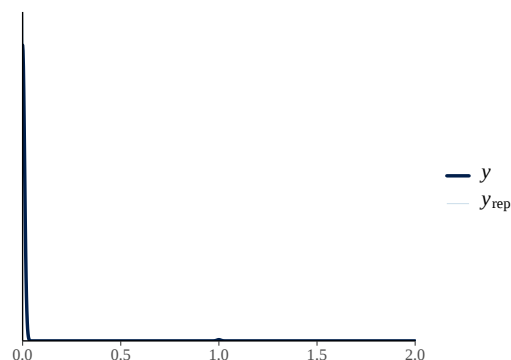
Validation

Posterior Probability Check

```

# Direct target selection error rate model
pp_check(err_model_poke)

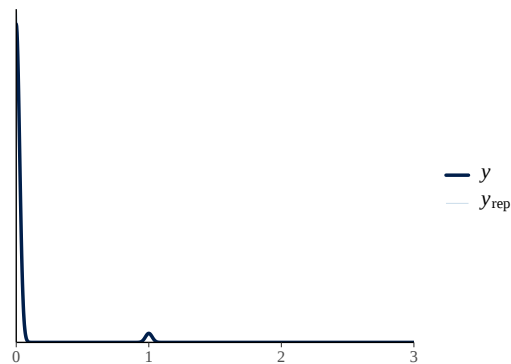
```



```
# Direct target selection movement time model
post <- as_draws_df(err_model_poke)
cat("Illuminance (High): pp =", mean(post$b_illuminanceH > 0), "\n",
    "Illuminance (Low): pp =", mean(post$b_illuminanceL > 0), "\n",
    "Brightness (High): pp =", mean(post$b_brightnessH > 0), "\n",
    "Illuminance (High) × Brightness (High): pp =",
    mean(post$b_illuminanceH:brightnessH` > 0), "\n",
    "Illuminance (Low) × Brightness (High): pp =",
    mean(post$b_illuminanceL:brightnessH` > 0), "\n")
```

```
Illuminance (High): pp = 0.89875
Illuminance (Low): pp = 0.8501667
Brightness (High): pp = 0.22575
Illuminance (High) × Brightness (High): pp = 0.6546667
Illuminance (Low) × Brightness (High): pp = 0.6265
```

```
# Ray-cast target selection error rate model
pp_check(err_model_ray)
```

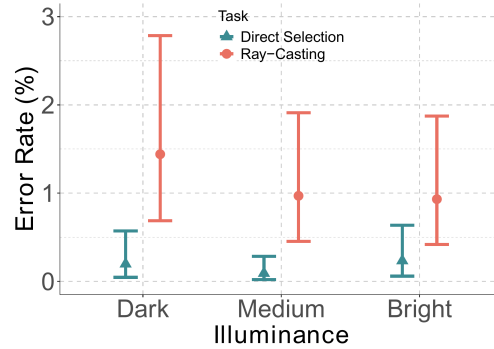


```
# Ray-cast target selection movement time model
post <- as_draws_df(err_model_ray)
cat("Illuminance (High): pp =", mean(post$b_illuminanceH > 0), "\n",
    "Illuminance (Low): pp =", mean(post$b_illuminanceL > 0), "\n",
    "Brightness (High): pp =", mean(post$b_brightnessH > 0), "\n",
    "Illuminance (High) × Brightness (High): pp =",
    mean(post$b_illuminanceH:brightnessH` > 0), "\n",
    "Illuminance (Low) × Brightness (High): pp =",
    mean(post$b_illuminanceL:brightnessH` > 0), "\n")
```

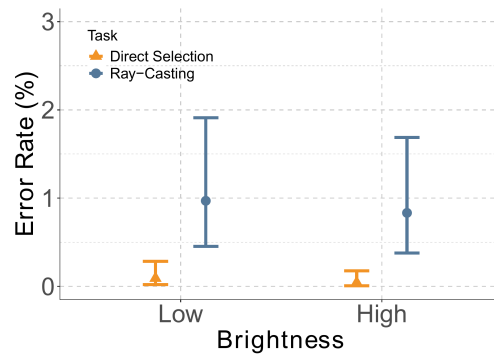
```
Illuminance (High): pp = 0.55625
Illuminance (Low): pp = 0.67675
Brightness (High): pp = 0.5129167
Illuminance (High) × Brightness (High): pp = 0.6100833
Illuminance (Low) × Brightness (High): pp = 0.52625
```

Plot

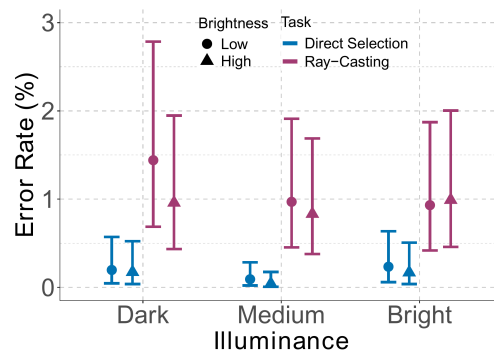
```
combined_illuminance_plot
```



combined_brightness_plot



combined_interaction_plot



5. Text Entry

5.1 Text Entry Throughput

Model

```
priors <- c(
  prior(normal(0, 1), class = "b")
)

tp_nozero_model <- brm(
  TP ~ 1 + (1|participant) + order + illuminance * brightness,
  data = text_nozero,
  family = gaussian(),
  prior = priors,
```

```

iter = 5000,
save_pars = save_pars(all = TRUE),
cores = 4,
backend = "cmdstanr",
seed = 1234
)

saveRDS(tp_nozero_model, file = "brm_model/tp_nozero_model.rds")

tp_nozero_model <- readRDS("brm_model/tp_nozero_model.rds")
summary(tp_nozero_model)

```

```

Family: gaussian
Links: mu = identity; sigma = identity
Formula: TP ~ 1 + (1 | participant) + order + illuminance * brightness
Data: text_nozero (Number of observations: 422)
Draws: 4 chains, each with iter = 5000; warmup = 2500; thin = 1;
       total post-warmup draws = 10000

```

```

Multilevel Hyperparameters:
~participant (Number of levels: 24)
      Estimate Est.Error 1-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
sd(Intercept)      1.08      0.18   0.79   1.48 1.00    1298    2678

```

```

Regression Coefficients:
      Estimate Est.Error 1-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
Intercept      3.38      0.26   2.87   3.87 1.00    1229    2490
order           0.16      0.02   0.11   0.20 1.00    6994    6678
illuminanceH    -0.32      0.14  -0.60  -0.02 1.00    3534    6130
illuminanceL    -0.93      0.14  -1.21  -0.65 1.00    3610    6520
brightnessH      0.29      0.14   0.01   0.57 1.00    3181    5087
illuminanceH:brightnessH -0.50      0.21  -0.92  -0.11 1.00    3182    5184
illuminanceL:brightnessH -0.06      0.20  -0.46   0.33 1.00    3367    5550

```

```

Further Distributional Parameters:
      Estimate Est.Error 1-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
sigma      0.88      0.03   0.82   0.94 1.00    6448    6610

```

Draws were sampled using `sample(hmc)`. For each parameter, Bulk_ESS and Tail_ESS are effective sample size measures, and Rhat is the potential scale reduction factor on split chains (at convergence, Rhat = 1).

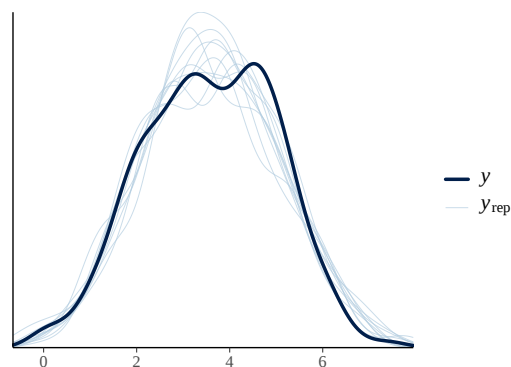
Validation

Posterior Probability Check

```

# Text Entry throughput model
pp_check(tp_nozero_model)

```



```

# Text Entry throughput model
post <- as_draws_df(tp_nozero_model)

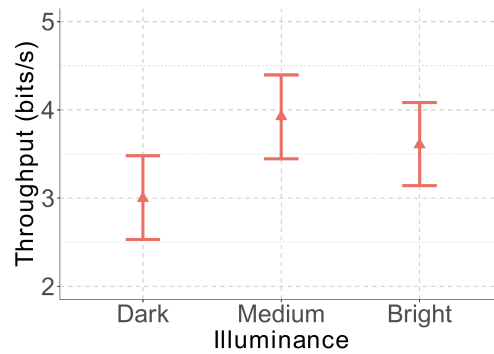
```

```
cat("Illuminance (High): pp =", mean(post$b_illuminanceH > 0), "\n",
    "Illuminance (Low): pp =", mean(post$b_illuminanceL > 0), "\n",
    "Brightness (High): pp =", mean(post$b_brightnessH > 0), "\n",
    "Illuminance (High) × Brightness (High): pp =",
    mean(post$b_illuminanceH:brightnessH` > 0), "\n",
    "Illuminance (Low) × Brightness (High): pp =",
    mean(post$b_illuminanceL:brightnessH` > 0), "\n")
```

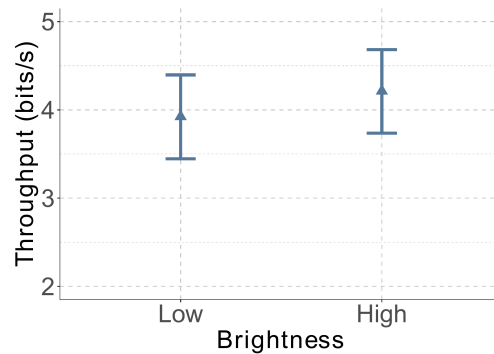
```
Illuminance (High): pp = 0.016
Illuminance (Low): pp = 0
Brightness (High): pp = 0.9777
Illuminance (High) × Brightness (High): pp = 0.0053
Illuminance (Low) × Brightness (High): pp = 0.3874
```

Plot

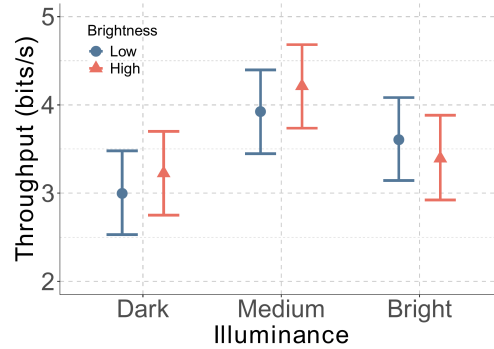
combined_illuminance_plot



combined_brightness_plot



combined_interaction_plot



5.2 Error Rate

Uncorrected Error Rate

```
priors <- c(
  prior(normal(0, 1), class = "b")
)

uer_nozero_model <- brm(
  UER ~ 1 + (1|participant) + order + illuminance * brightness,
  data = text_nozero,
  family = zero_inflated_beta(),
  prior = priors,
  iter = 5000,
  save_pars = save_pars(all = TRUE),
  cores = 4,
  backend = "cmdstanr",
  seed = 1234
)

saveRDS(uer_nozero_model, file = "brm_model/uer_nozero_model.rds")

uer_nozero_model <- readRDS("brm_model/uer_nozero_model.rds")
summary(uer_nozero_model)
```

```
Family: zero_inflated_beta
Links: mu = logit; phi = identity; zi = identity
Formula: UER ~ 1 + (1 | participant) + order + illuminance * brightness
Data: text_nozero (Number of observations: 421)
Draws: 4 chains, each with iter = 5000; warmup = 2500; thin = 1;
       total post-warmup draws = 10000

Multilevel Hyperparameters:
~participant (Number of levels: 24)
      Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
sd(Intercept)    0.32     0.20   0.02   0.74 1.00    1932    3185

Regression Coefficients:
      Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
Intercept    -1.44     0.32  -2.07  -0.81 1.00    5873    6656
order         -0.07     0.06  -0.19   0.05 1.00    9225    7480
illuminanceH   -0.14     0.34  -0.81   0.51 1.00    4635    6546
illuminanceL    0.07     0.31  -0.52   0.67 1.00    4915    6974
brightnessH     0.40     0.35  -0.27   1.08 1.00    3619    5311
illuminanceH:brightnessH  0.13     0.42  -0.70   0.96 1.00    3777    5379
illuminanceL:brightnessH -0.28     0.43  -1.13   0.54 1.00    3866    5290

Further Distributional Parameters:
```

	Estimate	Est.Error	1-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
phi	3.69	0.57	2.71	4.93	1.00	4093	5395
zi	0.72	0.02	0.68	0.76	1.00	11795	6958

Draws were sampled using `sample(hmc)`. For each parameter, `Bulk_ESS` and `Tail_ESS` are effective sample size measures, and `Rhat` is the potential scale reduction factor on split chains (at convergence, `Rhat = 1`).

Corrected Error Rate

```
priors <- c(
  prior(normal(0, 1), class = "b")
)

cer_nozero_model <- brm(
  CER ~ 1 + (1|participant) + order + illuminance * brightness,
  data = text_nozero,
  family = zero_inflated_beta(),
  prior = priors,
  iter = 5000,
  save_pars = save_pars(all = TRUE),
  cores = 4,
  backend = "cmdstanr",
  seed = 1234
)

saveRDS(cer_nozero_model, file = "brm_model/cer_nozero_model.rds")

cer_nozero_model <- readRDS("brm_model/cer_nozero_model.rds")
summary(cer_nozero_model)
```

```
Family: zero_inflated_beta
Links: mu = logit; phi = identity; zi = identity
Formula: CER ~ 1 + (1 | participant) + order + illuminance * brightness
Data: text_nozero (Number of observations: 421)
Draws: 4 chains, each with iter = 5000; warmup = 2500; thin = 1;
       total post-warmup draws = 10000
```

Multilevel Hyperparameters:

```
~participant (Number of levels: 24)
      Estimate Est.Error 1-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
sd(Intercept)    0.28    0.06    0.17    0.42 1.00    4267    5847
```

Regression Coefficients:

	Estimate	Est.Error	1-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
Intercept	-2.06	0.13	-2.33	-1.81	1.00	7631	7630
order	-0.05	0.02	-0.09	-0.01	1.00	21979	7415
illuminanceH	0.23	0.13	-0.02	0.48	1.00	8704	7864
illuminanceL	0.39	0.12	0.15	0.63	1.00	8718	8329
brightnessH	-0.02	0.13	-0.27	0.23	1.00	7097	8431
illuminanceH:brightnessH	0.06	0.18	-0.29	0.41	1.00	8122	7980
illuminanceL:brightnessH	-0.16	0.17	-0.49	0.18	1.00	7797	8333

Further Distributional Parameters:

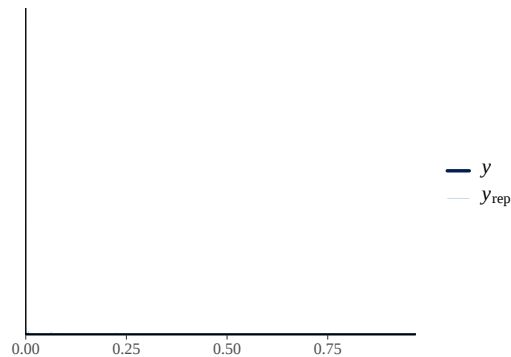
	Estimate	Est.Error	1-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
phi	19.41	1.63	16.37	22.70	1.00	15643	7981
zi	0.24	0.02	0.20	0.28	1.00	19639	6816

Draws were sampled using `sample(hmc)`. For each parameter, `Bulk_ESS` and `Tail_ESS` are effective sample size measures, and `Rhat` is the potential scale reduction factor on split chains (at convergence, `Rhat = 1`).

Validation

Posterior Probability Check

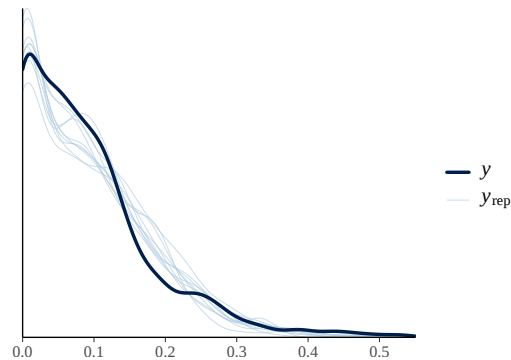
```
# Text entry uncorrected error rate model
pp_check(uer_nozero_model)
```



```
# Text entry uncorrected error rate model
post <- as_draws_df(uer_nozero_model)
cat("Illuminance (High): pp =", mean(post$b_illuminanceH > 0), "\n",
    "Illuminance (Low): pp =", mean(post$b_illuminanceL > 0), "\n",
    "Brightness (High): pp =", mean(post$b_brightnessH > 0), "\n",
    "Illuminance (High) × Brightness (High): pp =",
    mean(post$b_illuminanceH:brightnessH` > 0), "\n",
    "Illuminance (Low) × Brightness (High): pp =",
    mean(post$b_illuminanceL:brightnessH` > 0), "\n")
```

```
Illuminance (High): pp = 0.3363
Illuminance (Low): pp = 0.5945
Brightness (High): pp = 0.8729
Illuminance (High) × Brightness (High): pp = 0.6145
Illuminance (Low) × Brightness (High): pp = 0.2543
```

```
# Text entry corrected error rate model
pp_check(cer_nozero_model)
```

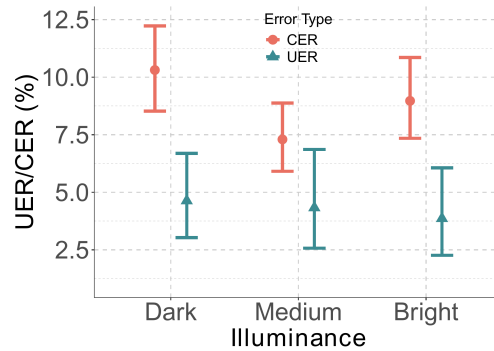


```
# Text entry corrected error rate model
post <- as_draws_df(cer_nozero_model)
cat("Illuminance (High): pp =", mean(post$b_illuminanceH > 0), "\n",
    "Illuminance (Low): pp =", mean(post$b_illuminanceL > 0), "\n",
    "Brightness (High): pp =", mean(post$b_brightnessH > 0), "\n",
    "Illuminance (High) × Brightness (High): pp =",
    mean(post$b_illuminanceH:brightnessH` > 0), "\n",
    "Illuminance (Low) × Brightness (High): pp =",
    mean(post$b_illuminanceL:brightnessH` > 0), "\n")
```

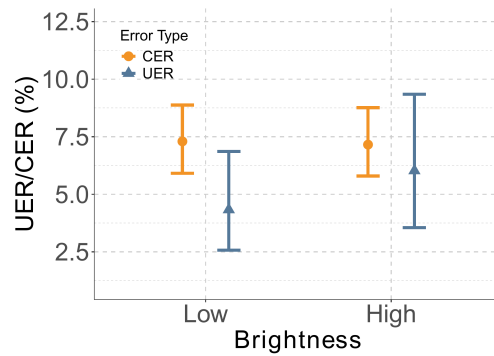
Illuminance (High): pp = 0.9638
 Illuminance (Low): pp = 0.9994
 Brightness (High): pp = 0.4431
 Illuminance (High) × Brightness (High): pp = 0.6291
 Illuminance (Low) × Brightness (High): pp = 0.1854

Plot

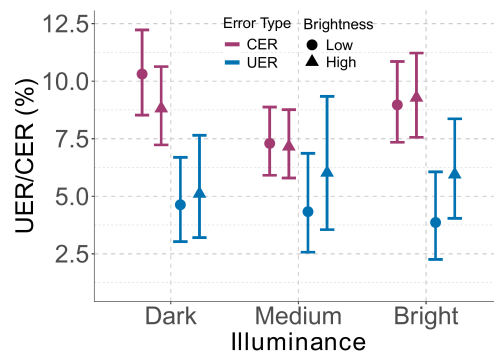
combined_illuminance_plot



combined_brightness_plot



combined_interaction_plot



6. Visual Fatigue

6.1 Blink Rate

Model

```
priors <- c(
  prior(normal(0, 5), class = "b")
)

blink_model <- brm(
  blink_rate_change ~ 1 + (1|participant) + order + illuminance * brightness,
  data = visual,
  family = skew_normal(),
  prior = priors,
  iter = 5000,
  save_pars = save_pars(all = TRUE),
  cores = 4,
  backend = "cmdstanr",
  seed = 1234
)
saveRDS(blink_model, file = "brm_model/blink_model_poke.rds")
```

```
blink_model <- readRDS("brm_model/blink_model_poke.rds")
summary(blink_model)
```

```
Family: skew_normal
Links: mu = identity; sigma = identity; alpha = identity
Formula: blink_rate_change ~ 1 + (1 | participant) + order + illuminance * brightness
Data: visual (Number of observations: 144)
Draws: 4 chains, each with iter = 5000; warmup = 2500; thin = 1;
       total post-warmup draws = 10000
```

Multilevel Hyperparameters:

```
~participant (Number of levels: 24)
      Estimate Est.Error 1-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
sd(Intercept)    5.34    0.88    3.90    7.31 1.00    1623    2941
```

Regression Coefficients:

	Estimate	Est.Error	1-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
Intercept	8.47	1.39	5.68	11.10	1.00	1705	3464
order	-0.18	0.16	-0.48	0.14	1.00	6147	6735
illuminanceH	4.93	0.97	3.06	6.91	1.00	4579	5743
illuminanceL	1.69	0.90	-0.05	3.49	1.00	4556	5746
brightnessH	1.86	0.85	0.23	3.55	1.00	3939	5727
illuminanceH:brightnessH	-0.68	1.24	-3.15	1.78	1.00	4119	5714
illuminanceL:brightnessH	2.81	1.23	0.45	5.31	1.00	4018	5377

Further Distributional Parameters:

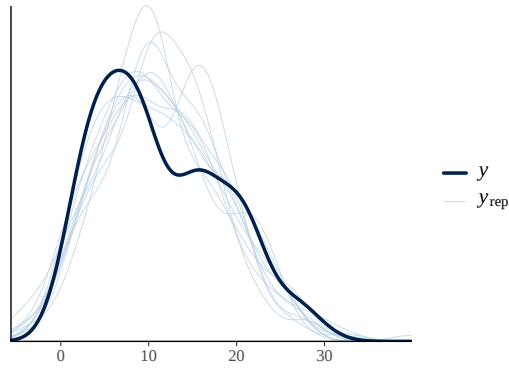
	Estimate	Est.Error	1-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sigma	3.86	0.27	3.37	4.43	1.00	6191	6952
alpha	5.84	2.42	1.52	11.11	1.00	3777	4343

Draws were sampled using `sample(hmc)`. For each parameter, `Bulk_ESS` and `Tail_ESS` are effective sample size measures, and `Rhat` is the potential scale reduction factor on split chains (at convergence, `Rhat = 1`).

validation

Posterior Probability Check

```
# Changes in blink rate model
pp_check(blink_model)
```

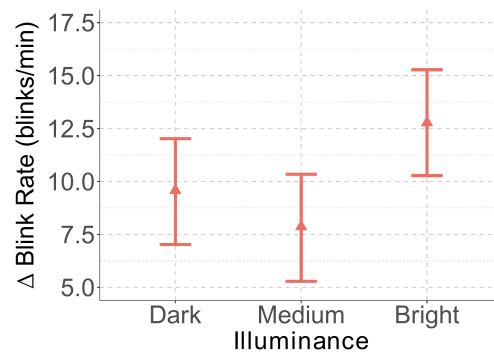


```
# Changes in blink rate model
post <- as_draws_df(blink_model)
cat("Illuminance (High): pp =", mean(post$b_illuminanceH > 0), "\n",
    "Illuminance (Low): pp =", mean(post$b_illuminanceL > 0), "\n",
    "Brightness (High): pp =", mean(post$b_brightnessH > 0), "\n",
    "Illuminance (High) × Brightness (High): pp =",
    mean(post$b_illuminanceH:brightnessH` > 0), "\n",
    "Illuminance (Low) × Brightness (High): pp =",
    mean(post$b_illuminanceL:brightnessH` > 0), "\n")
```

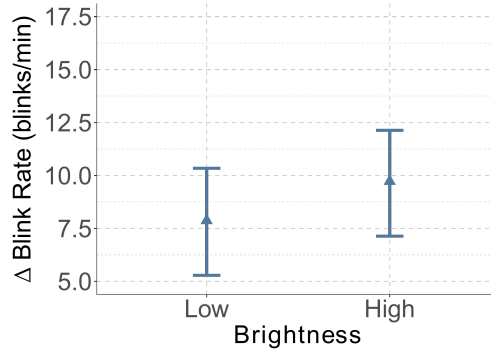
```
Illuminance (High): pp = 1
Illuminance (Low): pp = 0.9713
Brightness (High): pp = 0.9873
Illuminance (High) × Brightness (High): pp = 0.2917
Illuminance (Low) × Brightness (High): pp = 0.9907
```

Plot

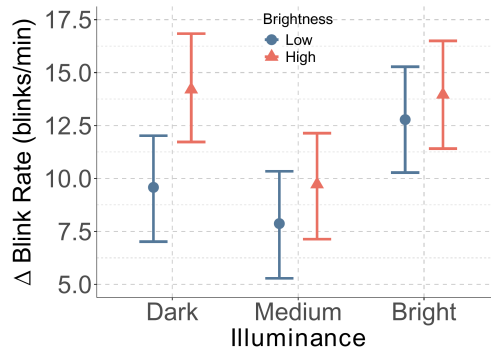
combined_illuminance_plot



combined_brightness_plot



combined_interaction_plot



6.2 Visual Fatigue Score

Model

```
priors <- c(
  prior(normal(0, 5), class = "b")
)

ques_model <- brm(
  ques_change ~ 1 + (1|participant) + order + illuminance * brightness,
  data = visual,
  family = skew_normal(),
  prior = priors,
  iter = 5000,
  save_pars = save_pars(all = TRUE),
  cores = 4,
  backend = "cmdstanr"
)

saveRDS(ques_model, file = "brm_model/ques_model_poke.rds")

ques_model <- readRDS("brm_model/ques_model_poke.rds")
summary(ques_model)
```

```
Family: skew_normal
Links: mu = identity; sigma = identity; alpha = identity
Formula: ques_change ~ 1 + (1 | participant) + order + illuminance * brightness
Data: visual (Number of observations: 144)
Draws: 4 chains, each with iter = 5000; warmup = 2500; thin = 1;
       total post-warmup draws = 10000
```

```
Multilevel Hyperparameters:
~participant (Number of levels: 24)
```

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.36	0.07	0.25	0.51	1.00	2536	4407

Regression Coefficients:

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
Intercept	0.37	0.11	0.15	0.57	1.00	2167	4033
order	0.01	0.01	-0.02	0.03	1.00	9419	7519
illuminanceH	0.32	0.09	0.15	0.49	1.00	4296	6437
illuminanceL	0.21	0.08	0.05	0.38	1.00	4704	6222
brightnessH	0.26	0.08	0.10	0.43	1.00	3660	5195
illuminanceH:brightnessH	-0.19	0.12	-0.43	0.04	1.00	4063	5527
illuminanceL:brightnessH	0.12	0.12	-0.11	0.35	1.00	4361	6337

Further Distributional Parameters:

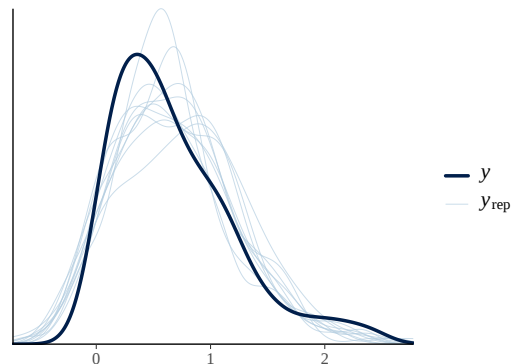
	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sigma	0.33	0.02	0.29	0.38	1.00	6468	7161
alpha	4.09	2.21	0.03	9.05	1.00	3759	4984

Draws were sampled using `sample(hmc)`. For each parameter, Bulk_ESS and Tail_ESS are effective sample size measures, and Rhat is the potential scale reduction factor on split chains (at convergence, Rhat = 1).

validation

Posterior Probability Check

```
# Changes in fatigue score model
pp_check(ques_model)
```

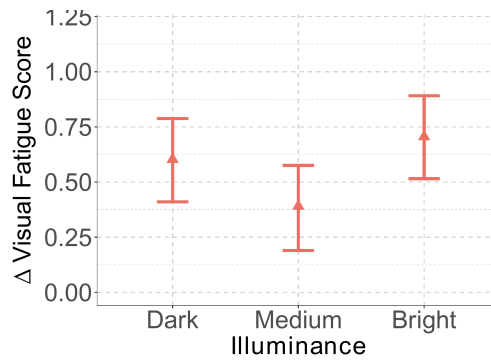


```
# Changes in fatigue score model
post <- as_draws_df(ques_model)
cat("Illuminance (High): pp =", mean(post$b_illuminanceH > 0), "\n",
    "Illuminance (Low): pp =", mean(post$b_illuminanceL > 0), "\n",
    "Brightness (High): pp =", mean(post$b_brightnessH > 0), "\n",
    "Illuminance (High) × Brightness (High): pp =",
    mean(post$b_illuminanceH:brightnessH > 0), "\n",
    "Illuminance (Low) × Brightness (High): pp =",
    mean(post$b_illuminanceL:brightnessH > 0), "\n")
```

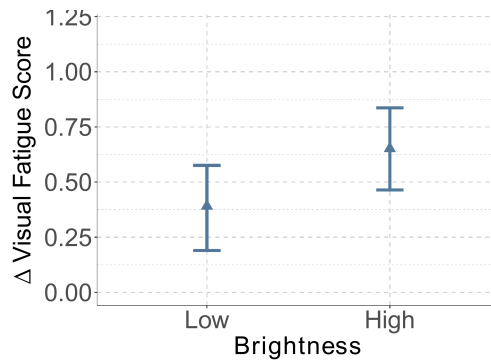
```
Illuminance (High): pp = 0.9998
Illuminance (Low): pp = 0.9947
Brightness (High): pp = 0.9995
Illuminance (High) × Brightness (High): pp = 0.0473
Illuminance (Low) × Brightness (High): pp = 0.8477
```

Plot

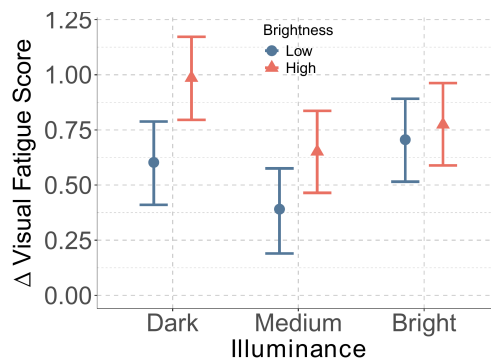
```
combined_illuminance_plot
```



combined_brightness_plot



combined_interaction_plot



References

- [1] P.-C. Bürkner, "**Brms** : An R package for bayesian multilevel models using Stan," *Journal of Statistical Software*, vol. 80, no. 1, 2017, doi: [10.18637/jss.v080.i01](https://doi.org/10.18637/jss.v080.i01).
- [2] J. R. Hayes, J. E. Sheedy, J. A. Stelmack, and C. A. Heaney, "Computer use, symptoms, and quality of life," *Optometry and vision science*, vol. 84, no. 8, pp. E738–E755, 2007.