

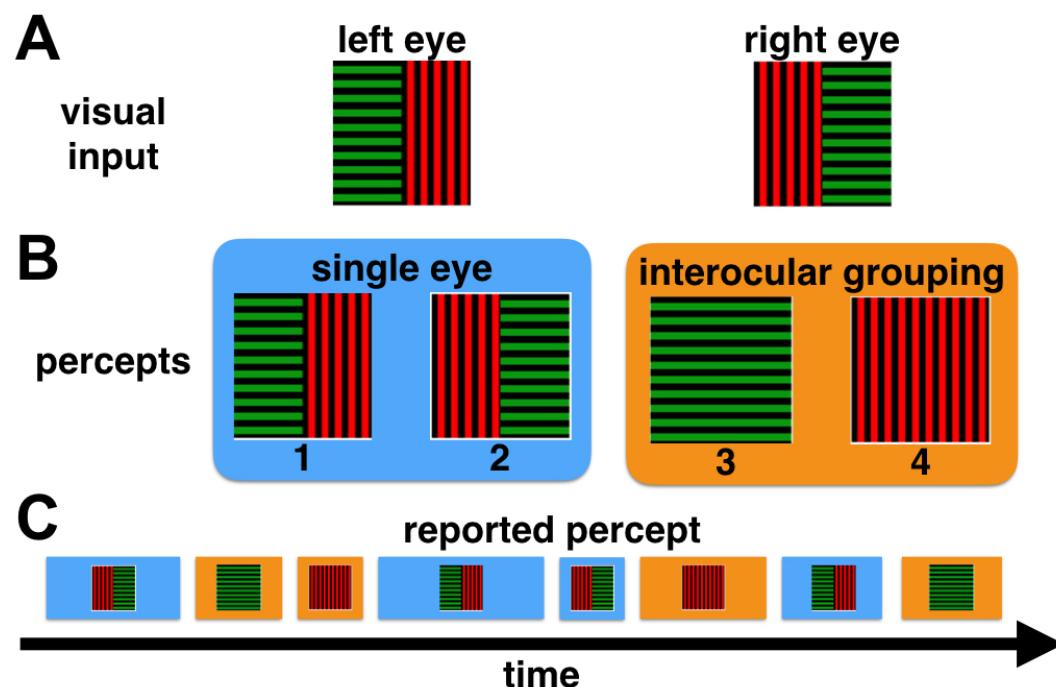
Binocular Rivalry Data Fitting

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Description of experiments.

Subjects viewed the stimulus depicted in the figure below, each consisting of half a horizontal grating and half of a vertical grating.



In addition, grating halves were chosen randomly to be either red (HSV color space coordinates: 0.497, 0.4/0.9, 0.7) or green (120.23, 0.4/0.9, 0.7), but commensurate halves always had the same color. The stimulus was displayed on a grey background (0.0, 0.0, 0.2) and two unfilled squares and two horizontal and vertical lines were added on top of it in order to help the subject align the two images. Two different levels of saturation were used for each color, 0.4 and 0.9.

One session was divided into six 3-minute trials. Trials were separated by a 90-second resting period. To allow subjects time to adapt to the stimulus and form a stable percept, the first 30 seconds of each trial were not recorded. The association between color and orientation was kept the same within each session, but was randomized across sessions. For example, the vertical grating was red within a session, whereas the horizontal grating was always green. In contrast, saturation was randomized across trials, as was the position of the split gratings (left or right eye), to avoid any dominant eye effects. The randomization was such that within one session, each saturation level appeared in three trials and each grating positioning occurred in three trials.

Each subject of nine subjects was planned to participate in six total sessions three per orientation/color pairing: four subjects finished 6 total sessions (AJ, MA, ZK, ND), three subjects finished 5 sessions (FG, YW, ML), one subject finished 4 sessions (AB) and the remaining one finished 7 sessions (ZM). More specifically,

- ZM: a total of 42 trials and 21 trials at each saturations for each subject.
- AJ, MA, ZK, ND: a total of 36 trials and 18 trials at each saturations for each subject.
- FG, YW, ML: a total of 30 trials and 15 trials at each saturations for each subject.
- AB: a total of 24 trials and 12 trials at each saturations.

The observers were asked to indicate dominance duration of four different percepts in the figure above by holding down four different buttons on a gamepad. Subjects were instructed to press button 1 if they perceive a single-eye percept (a percept composed of a vertical and horizontal part) with a red left half, button 2 for a stimulus with a red left half, button 3 for an fused, entirely green percept, and button 4 for an fused, entirely red percept. When the subjects perceived anything different from the four percepts, they were instructed not to press any button.

Description of the data

The data is given in a single frame with several columns. The subject ID and trial number are listed first. Each trial has an associated color saturation value (0.4 or 0.9). Each trial is also characterized by which color is associated with the vertical direction. For instance G_V means that the vertical bars are green. The last two columns list the percepts (Tdata.perc): 0 represents transition between two percepts, 1 represents percept 1, 2 represents percept 2 and so on. and the duration of the percept (Tdata.duration) in microseconds, in the order reported by each subject.

```
data <- read.csv('dataInOneTable.csv')
head(data)
```

##	X	IDs	nTrial	Conds	Sat	Tdata.perc	Tdata.duration
## 1	1	AJ	1	G_V	0.9	0	48
## 2	2	AJ	1	G_V	0.9	2	696112
## 3	3	AJ	1	G_V	0.9	0	280000
## 4	4	AJ	1	G_V	0.9	3	3600240
## 5	5	AJ	1	G_V	0.9	0	55952
## 6	6	AJ	1	G_V	0.9	4	3688288

From this we computed the ratio of the total time, T_{grouped} , that observers reported a grouped percept out of the time they reported seeing a coherent percept (Percepts 1, 2, 3 and 4) during each trial. We thus recorded for each trial, i , of each subject,

$$\text{ratio}(i) = \frac{T_{\text{grouped}}(i)}{T_{\text{grouped}}(i) + T_{\text{single}}(i)}.$$

```
data.ratios <- read.csv('fused_over_fusedNSingle_ratios.csv')
names(data.ratios) <- c("ID", "Sat", "ratio")
head(data.ratios)
```

```

##   ID Sat      ratio
## 1 AJ  0.9  0.6585479
## 2 AJ  0.9  0.5770041
## 3 AJ  0.4  0.3014873
## 4 AJ  0.4  0.5236174
## 5 AJ  0.9  0.3669277
## 6 AJ  0.4  0.2498100

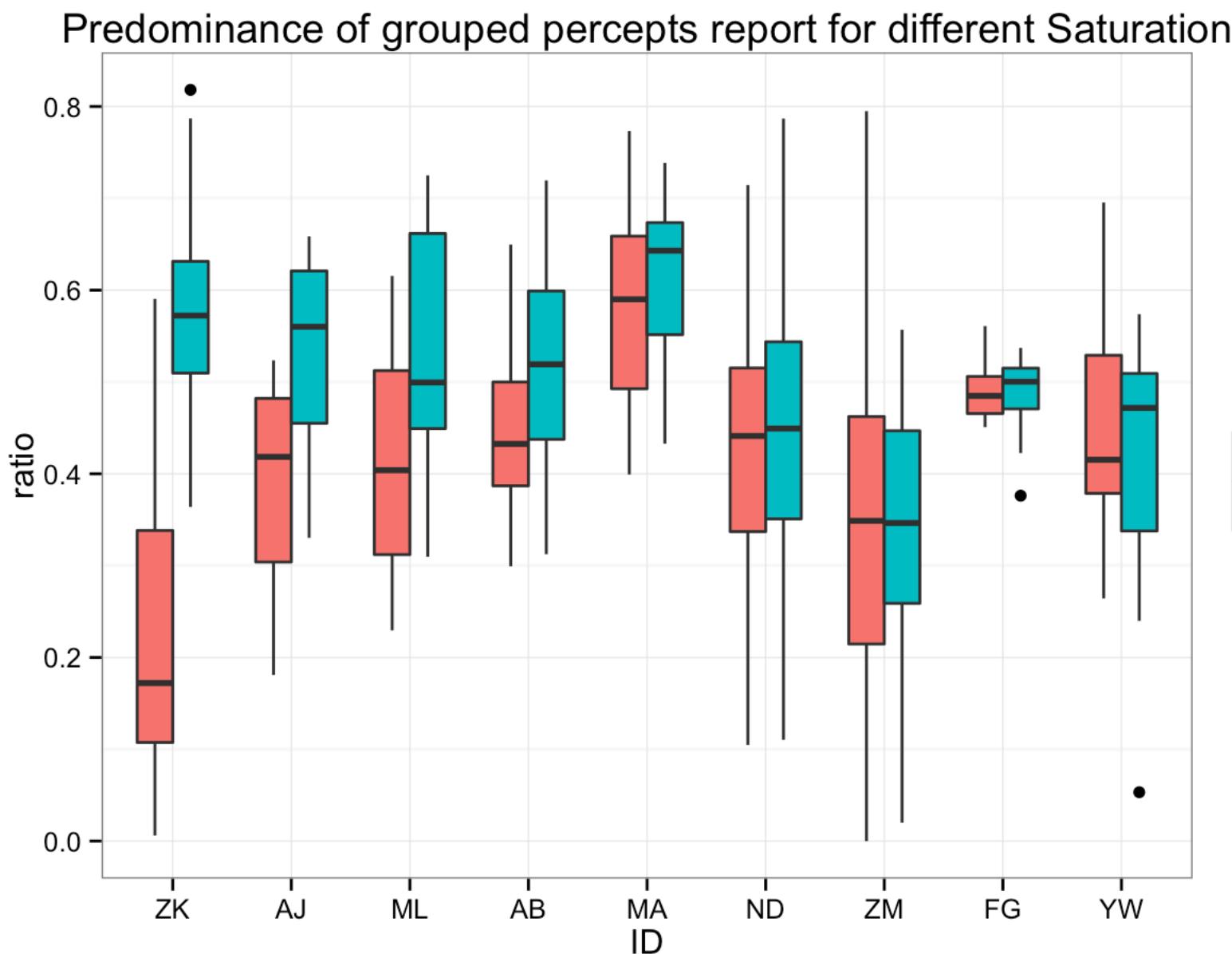
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In the following analysis we account for the subject and saturation factors, and pool data over all trials of the same subject. Thus the percept reported by pressing button 1 was always had a red left, and green right half, but the orientation (vertical or horizontal) of each half depended on the trial.

Predominance of grouped and single-eye percepts

Predominance of a percept here means the fraction of time that the percept is perceived. We first check if there is a difference in the predominance of grouped percepts. Our hypothesis was that the predominance increases with saturation as the cue relating the two halves of the stimulus became stronger.

We first present the ratios in each condition computed directly from individual subject data.



The predominance of grouped states tends to increase for most observers. We next compute the probability to show that this increase is real. To do so, we partitioned trials based on the color saturation level used for each trial, grouping across all other conditions.

Letting r_{ij} be the predominance for subject j in trial i , the model is specified as:

$$\begin{aligned} r_{ij} &\sim t_4(\mu_{ij}, \sigma^2) \\ \mu_{ij} &= \beta_{0j} + \beta_{1j} x_{ij} \\ \beta_{0j} &\sim \text{Normal}(\beta_0, \tau_0^2), \beta_{1j} \sim \text{Normal}(\beta_1, \tau_1^2) \end{aligned}$$

where x_{ij} is the color saturation indicator (1 for 0.9, 0 for 0.4). The random regression coefficients β_{0j} and β_{1j} allow the effects of color saturation to vary across subjects. We used a linear Student-t regression model to account for skewness in the data. This hierarchical model assumes that the effects from different subjects are similar but not identical and come from the same population with overall means of β_0 and β_1 . Prior distributions for the overall saturation effects β_0 and β_1 were independent and normal with mean 0, and variance 10^4 . We used Uniform(0, 100) priors for the standard deviation of the random effects, τ_0 and τ_1 and Uniform(0, 1000) for σ . We estimated the mean difference in the fraction of time and its 95% credible interval (CI) and the probability that the difference is greater than 0.

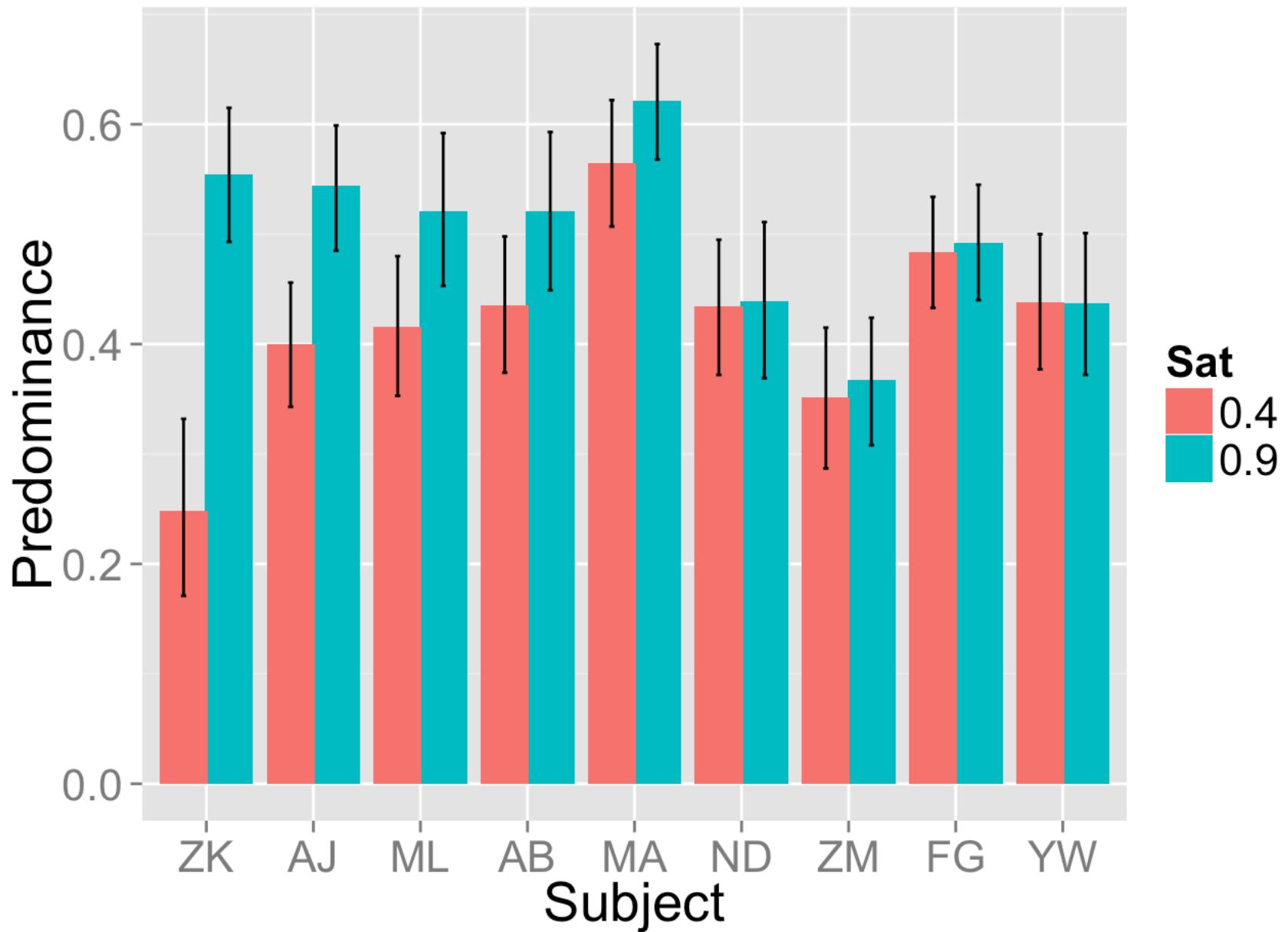
The results are presented in the table below. The table suggests that this is a real effect for five subjects (ZK, AJ, ML, AB, MA). In these subjects, the fraction of time they perceive a grouped states goes up with probability higher than 0.9.

Predominance

ID	^a diff.	low CI	high CI	prob.
ZK	0.307	0.201	0.407	0.999
AJ	0.143	0.065	0.221	0.999
ML	0.105	0.016	0.197	0.989
AB	0.086	-0.006	0.177	0.966
MA	0.057	-0.020	0.132	0.928
ND	0.006	-0.085	0.095	0.552
ZM	0.014	-0.070	0.098	0.634
FG	0.009	-0.063	0.080	0.596
YW	-0.001	-0.089	0.084	0.492

^adiff. = mean at saturation 0.9 - mean at saturation 0.4

The resulting data is shown in the figure below



The data is also summarized in the following table.

Effect of saturation level on predominance of grouped percepts

Sat=0.4					Sat=0.9				
ID	mean	low CI	high CI	^a prob	ID	mean	low CI	high CI	^a prob
ZK	0.248	0.171	0.332	0.999	ZK	0.554	0.493	0.615	0.041
AJ	0.400	0.343	0.456	0.999	AJ	0.544	0.485	0.599	0.068
ML	0.416	0.353	0.480	0.995	ML	0.521	0.453	0.592	0.275
AB	0.435	0.374	0.498	0.978	AB	0.521	0.449	0.593	0.280
MA	0.565	0.507	0.622	0.014	MA	0.621	0.568	0.673	0.000
ND	0.434	0.372	0.495	0.983	ND	0.439	0.369	0.511	0.954
ZM	0.352	0.287	0.415	0.999	ZM	0.367	0.308	0.424	0.999
FG	0.484	0.433	0.534	0.738	FG	0.492	0.440	0.545	0.613
YW	0.438	0.377	0.500	0.974	YW	0.437	0.372	0.501	0.974

^aprob = probability of mean <0.5

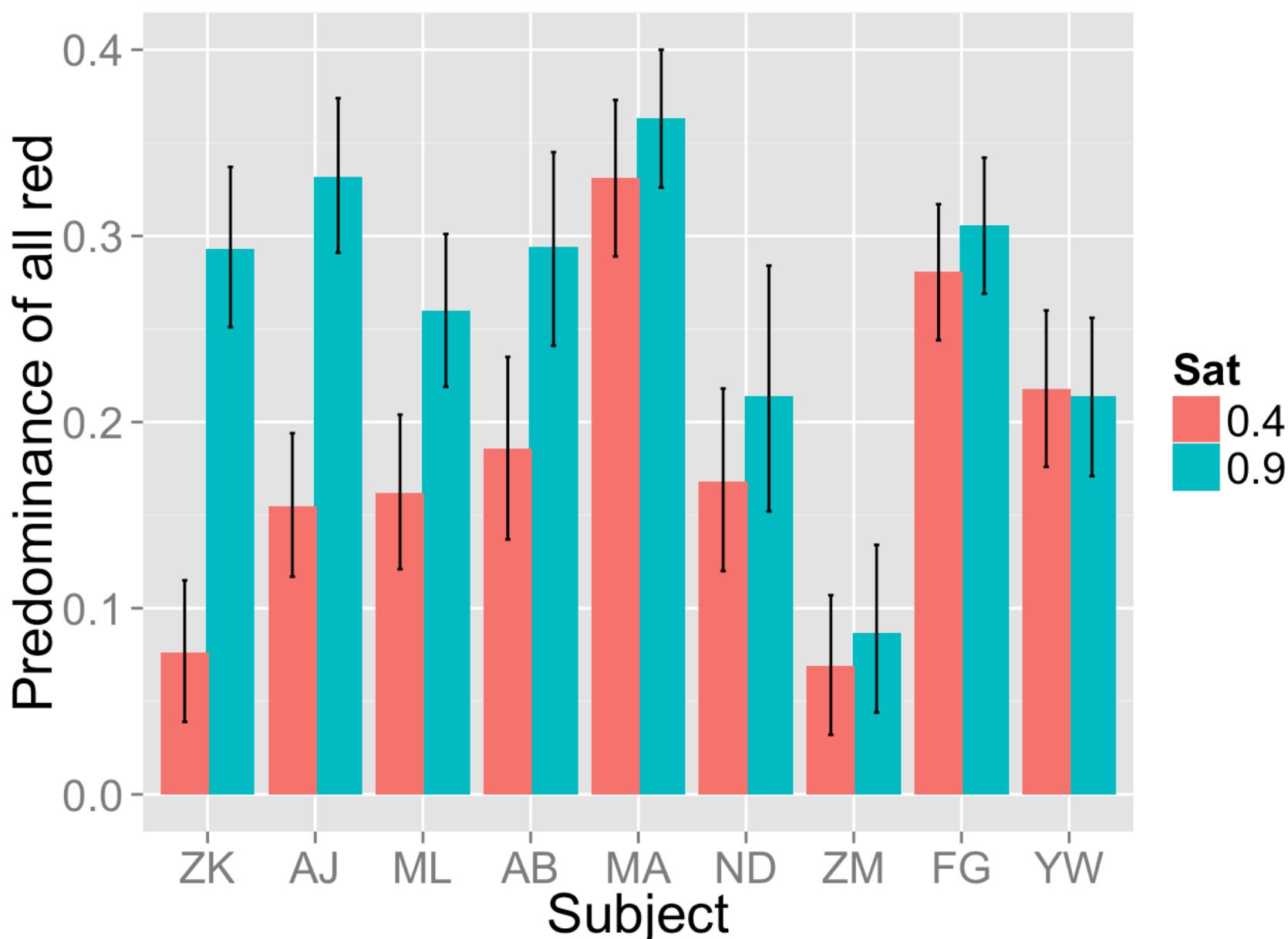
Predominance of grouped red

We use the same Bayesian models for grouped red precepts and the results are shown below

Predominance of all Red

ID	^a diff.	low CI	high CI	prob.
ZK	0.218	0.160	0.275	0.999
AJ	0.177	0.122	0.233	0.999
ML	0.098	0.042	0.155	0.999
AB	0.108	0.040	0.177	0.999
MA	0.032	-0.023	0.087	0.877
ND	0.046	-0.031	0.126	0.879
ZM	0.018	-0.038	0.076	0.736
FG	0.025	-0.025	0.075	0.834
YW	-0.004	-0.063	0.054	0.441

^adiff. = mean at saturation 0.9 - mean at saturation 0.4



Predominance of grouped green

We next analyze the effect of color saturation on predominance of grouped green by using the same Bayesian method.

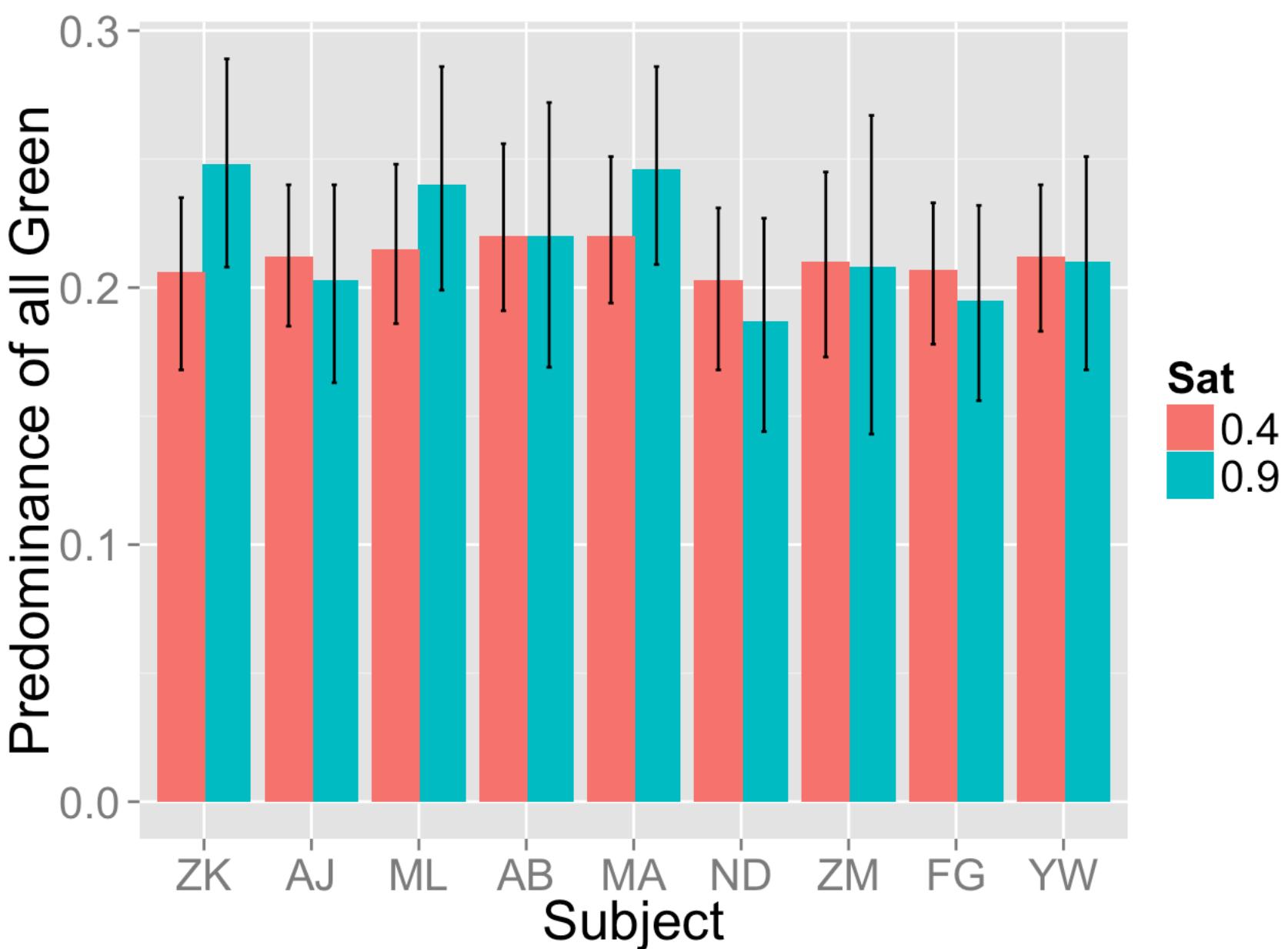
Results are shown below.

Predominance of all Green

ID	^a diff.	low CI	high CI	prob.
ZK	0.042	-0.006	0.097	0.954

AJ	-0.009	-0.056	0.032	0.350
ML	0.025	-0.021	0.077	0.849
AB	0.001	-0.055	0.054	0.525
MA	0.027	-0.016	0.074	0.881
ND	-0.016	-0.065	0.028	0.257
ZM	-0.002	-0.068	0.057	0.496
FG	-0.013	-0.058	0.030	0.295
YW	-0.001	-0.049	0.044	0.491

^adiff. = mean at saturation 0.9 - mean at saturation 0.4



Saturation level effects on dominance duration and number of visits

We next examine whether this increase in the predominance of grouped percepts is due to an increase in the mean time of grouped percepts reports, a decrease in the mean time single eye percept reports, or an increased probability of switching to a grouped percept (number of visits to grouped percepts).

Increase in color saturation decreases dominance duration of single-eye percepts

We next compared the mean dominance duration for both single-eye and grouped percepts under the two conditions

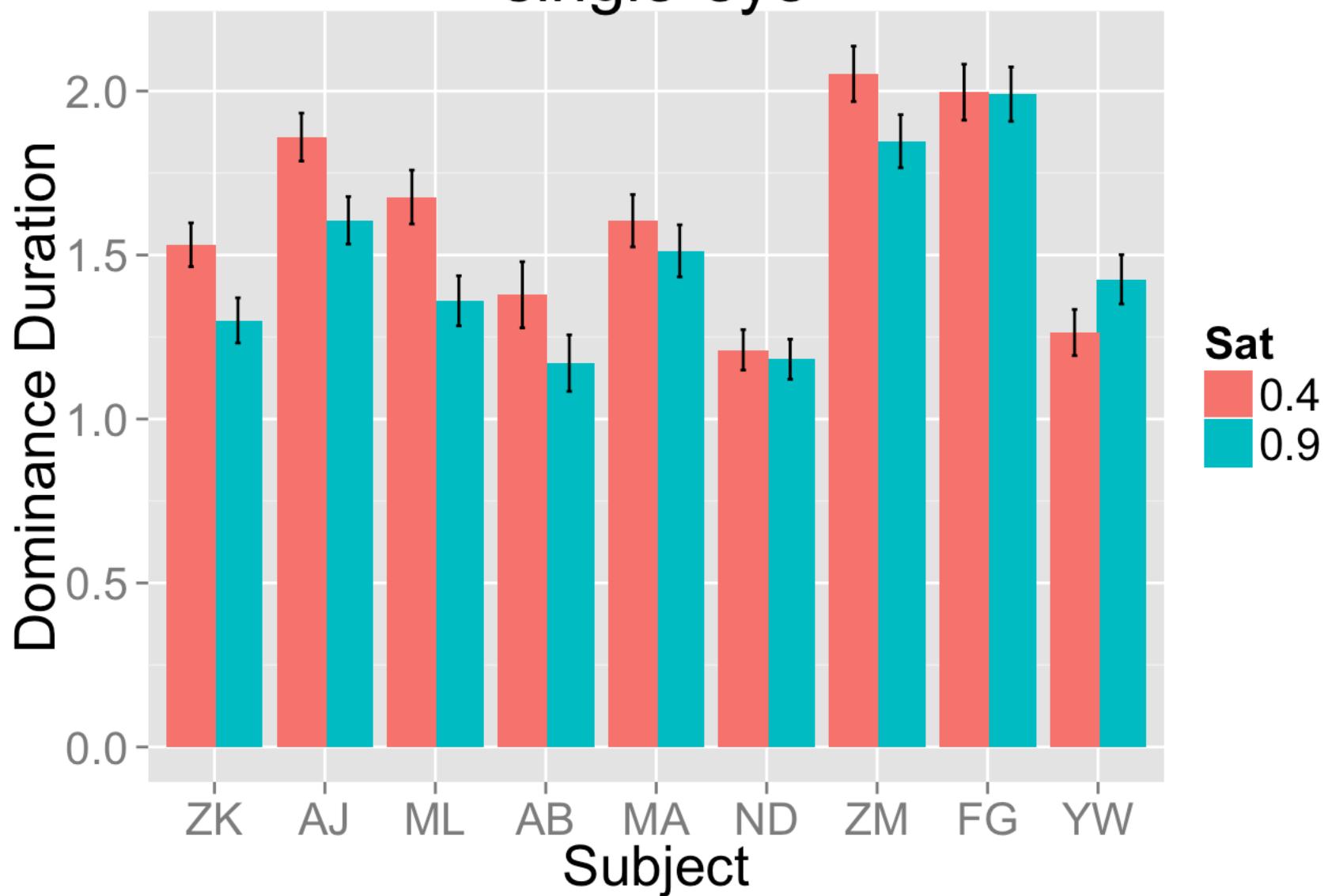
The following table shows the inferred mean difference in the dominance duration of single eye percept and grouped percepts across the low and high saturation conditions separately. A negative value indicates a decrease in the duration from the low to the high saturation condition. Six subjects, including all five who showed an increased ratios of observing grouped percepts show a decrease in mean dominance duration of single-eye percepts with probability larger than 0.9. Comparing with the single-eye dominance duration, grouped percept dominance duration show less change. There was no evidence of a probable change in mean dominance duration of grouped percept for any subject.

Effect of saturation level on dominance duration

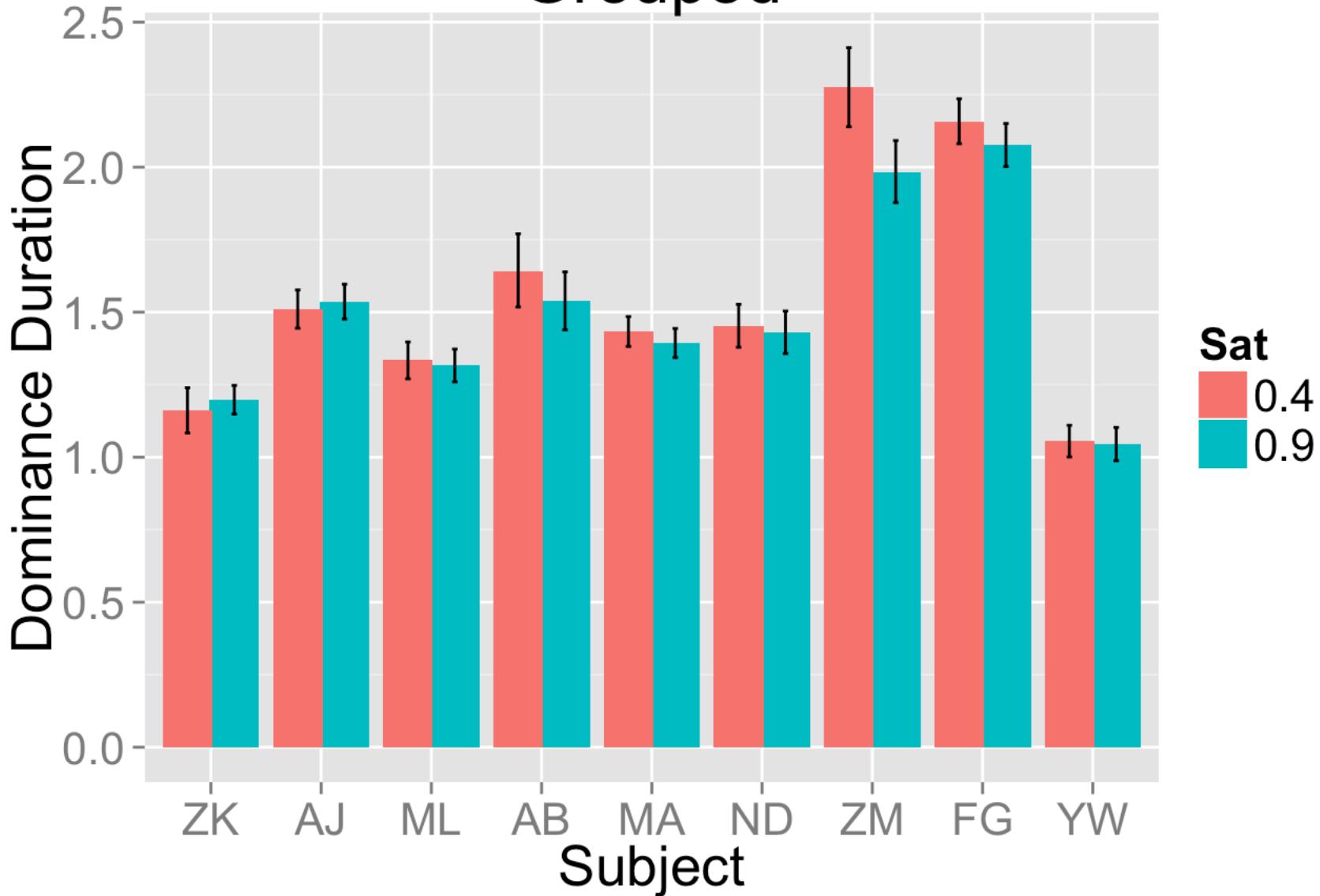
single-eye perc				grouped perc.					
ID	diff.	low CI	high CI	^a D-prob.	ID	diff.	low CI	high CI	^a D-prob.
ZK	-0.230	-0.325	-0.136	0.999	ZK	0.036	-0.053	0.128	0.779
AJ	-0.254	-0.355	-0.154	0.999	AJ	0.025	-0.060	0.113	0.714
ML	-0.316	-0.427	-0.205	0.999	ML	-0.018	-0.099	0.065	0.332
AB	-0.208	-0.336	-0.080	0.999	AB	-0.102	-0.256	0.039	0.079
MA	-0.093	-0.201	0.017	0.952	MA	-0.040	-0.110	0.030	0.133
ND	-0.028	-0.114	0.057	0.741	ND	-0.023	-0.121	0.075	0.318
ZM	-0.206	-0.320	-0.091	0.999	ZM	-0.293	-0.475	-0.104	0.000
FG	-0.007	-0.122	0.111	0.549	FG	-0.081	-0.186	0.019	0.057
YW	0.162	0.059	0.265	0.001	YW	-0.011	-0.087	0.066	0.387

^aD-prob. =Decreasing probability

single-eye



Grouped



Effect of color statuation on dominance of grouped red.

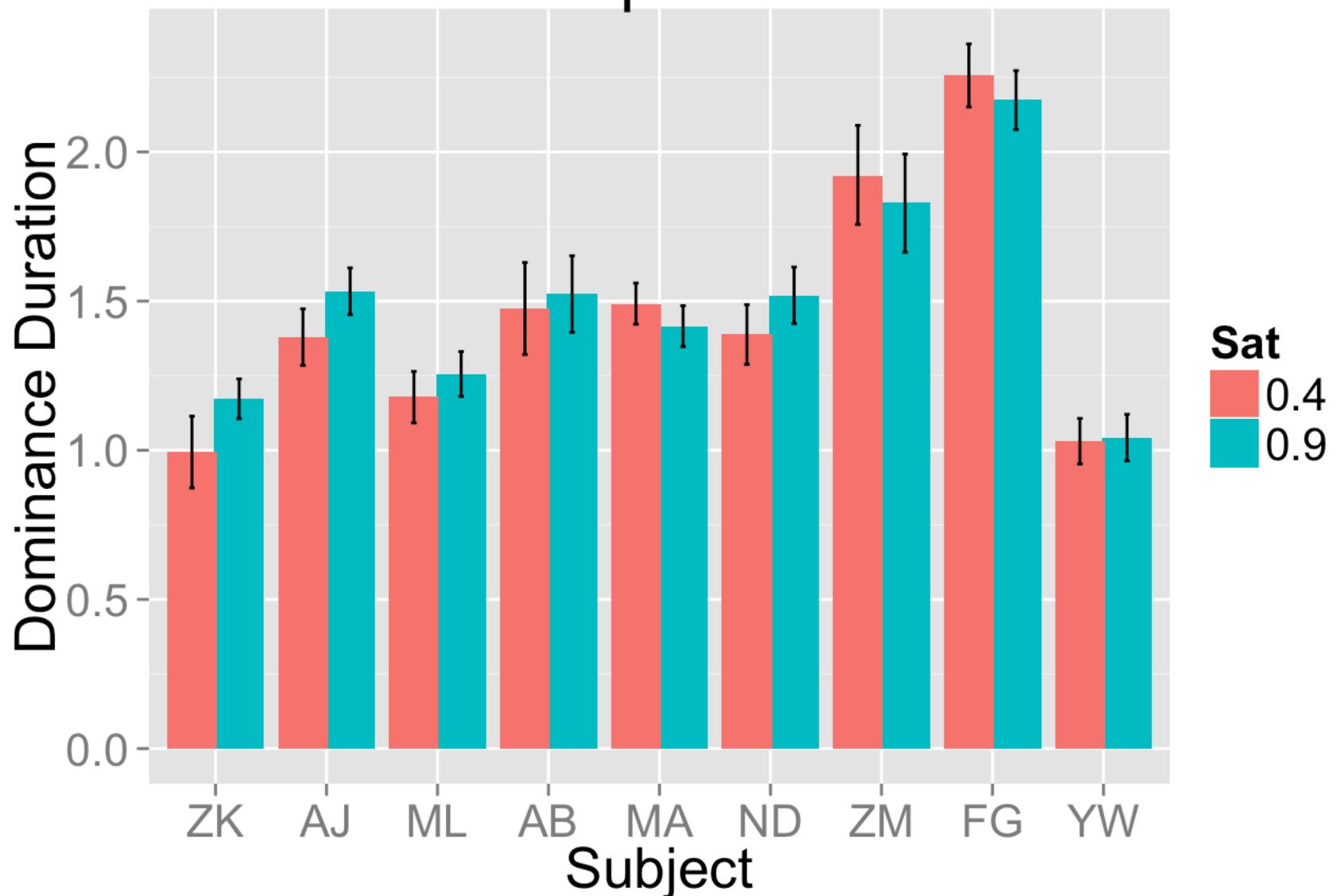
The result on the dominance of all green is shown below

Effect of saturation level on dominance duration

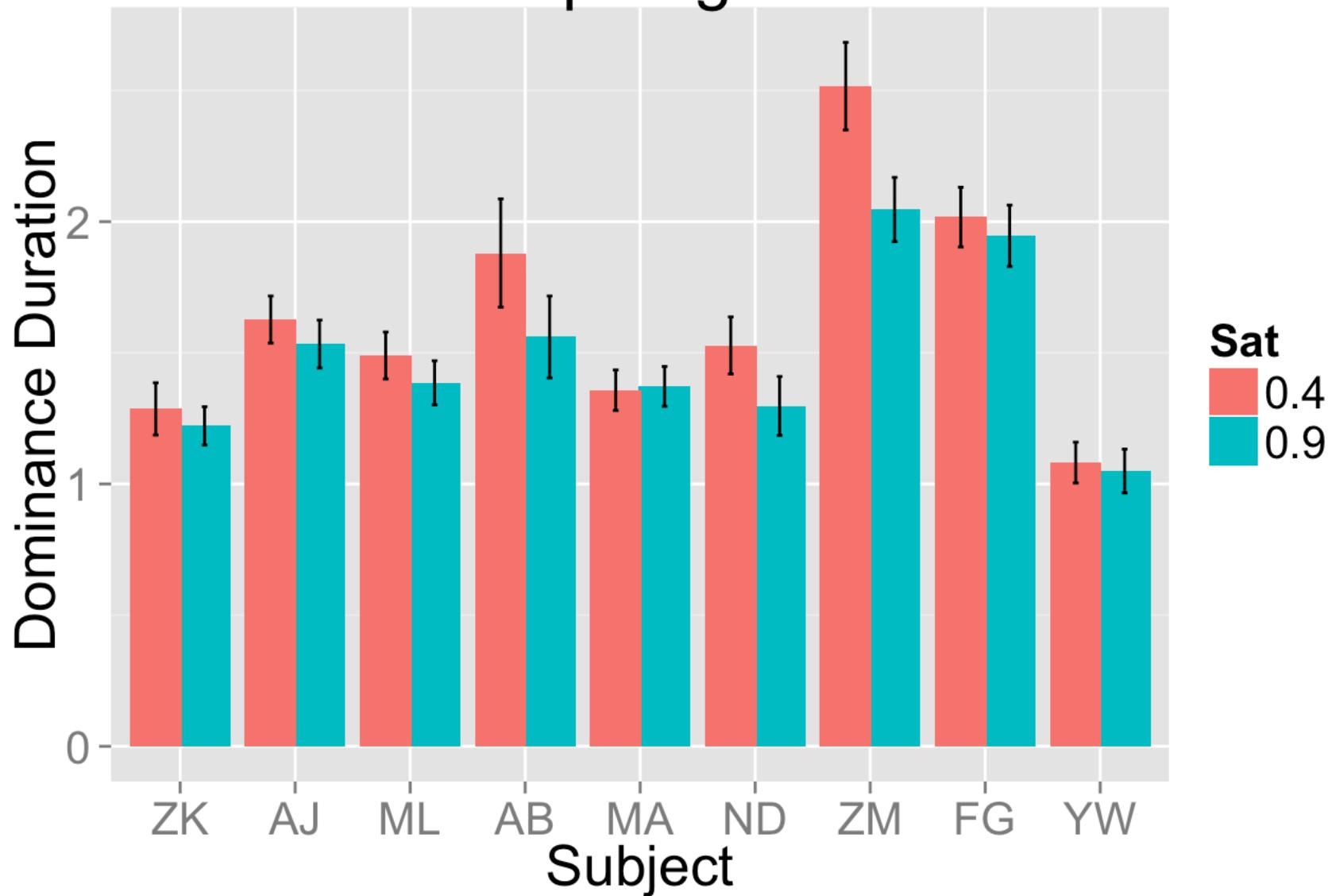
Grouped red					Grouped green				
ID	diff.	low CI	high CI	^a D-prob.	ID	diff.	low CI	high CI	^a prob.
ZK	0.176	0.045	0.314	0.997	ZK	-0.065	-0.184	0.056	0.854
AJ	0.154	0.038	0.274	0.995	AJ	-0.094	-0.217	0.031	0.930
ML	0.077	-0.030	0.188	0.920	ML	-0.104	-0.223	0.015	0.957
AB	0.049	-0.126	0.226	0.713	AB	-0.315	-0.566	-0.084	0.997
MA	-0.076	-0.173	0.021	0.061	MA	0.014	-0.093	0.121	0.401
ND	0.130	0.002	0.266	0.977	ND	-0.230	-0.381	-0.083	0.999
ZM	-0.089	-0.314	0.105	0.205	ZM	-0.470	-0.682	-0.259	0.999
FG	-0.081	-0.224	0.055	0.125	FG	-0.073	-0.227	0.086	0.825
YW	0.012	-0.093	0.117	0.594	YW	-0.032	-0.144	0.080	0.714

^aD-prob. =Decreasing probability

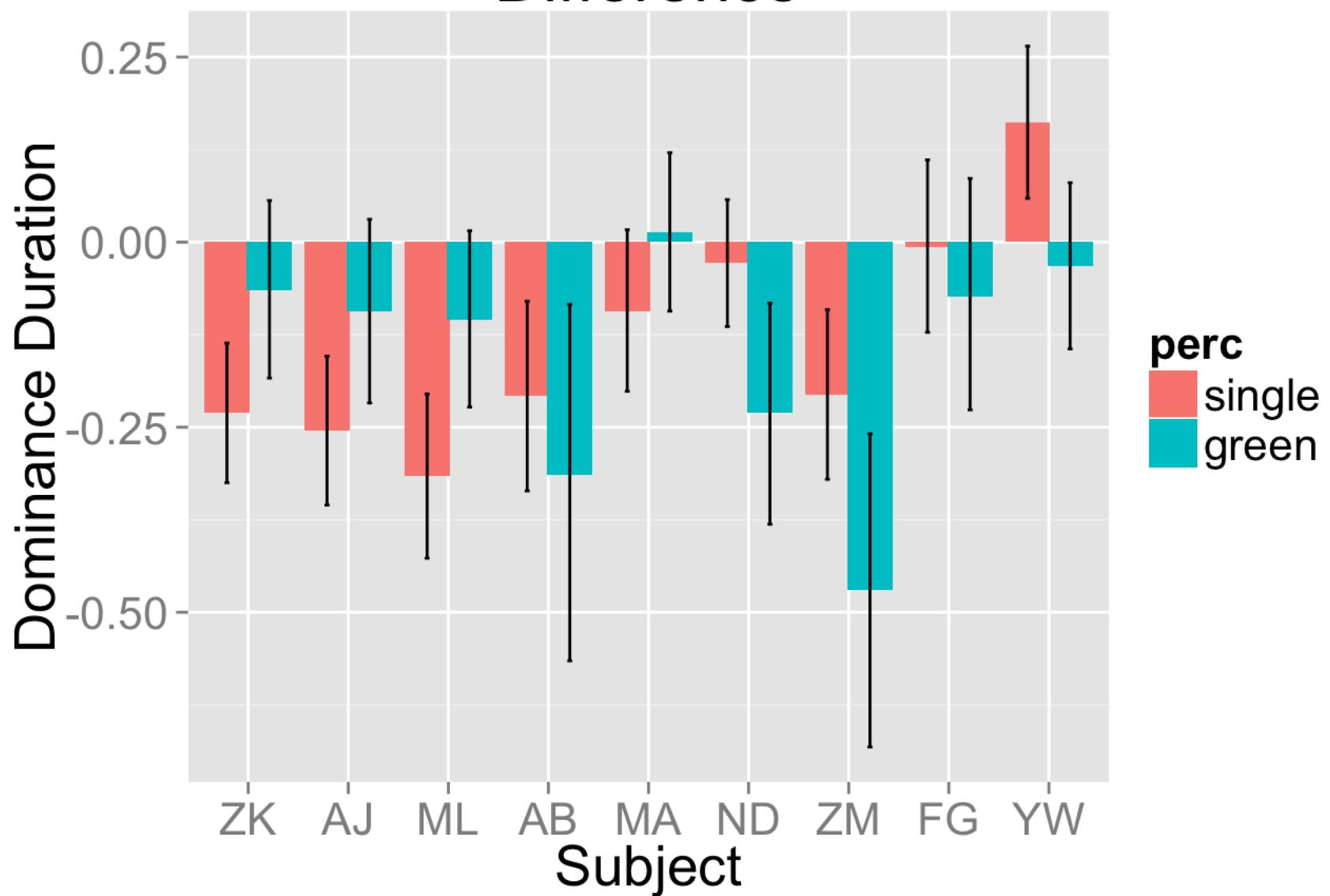
Grouped red



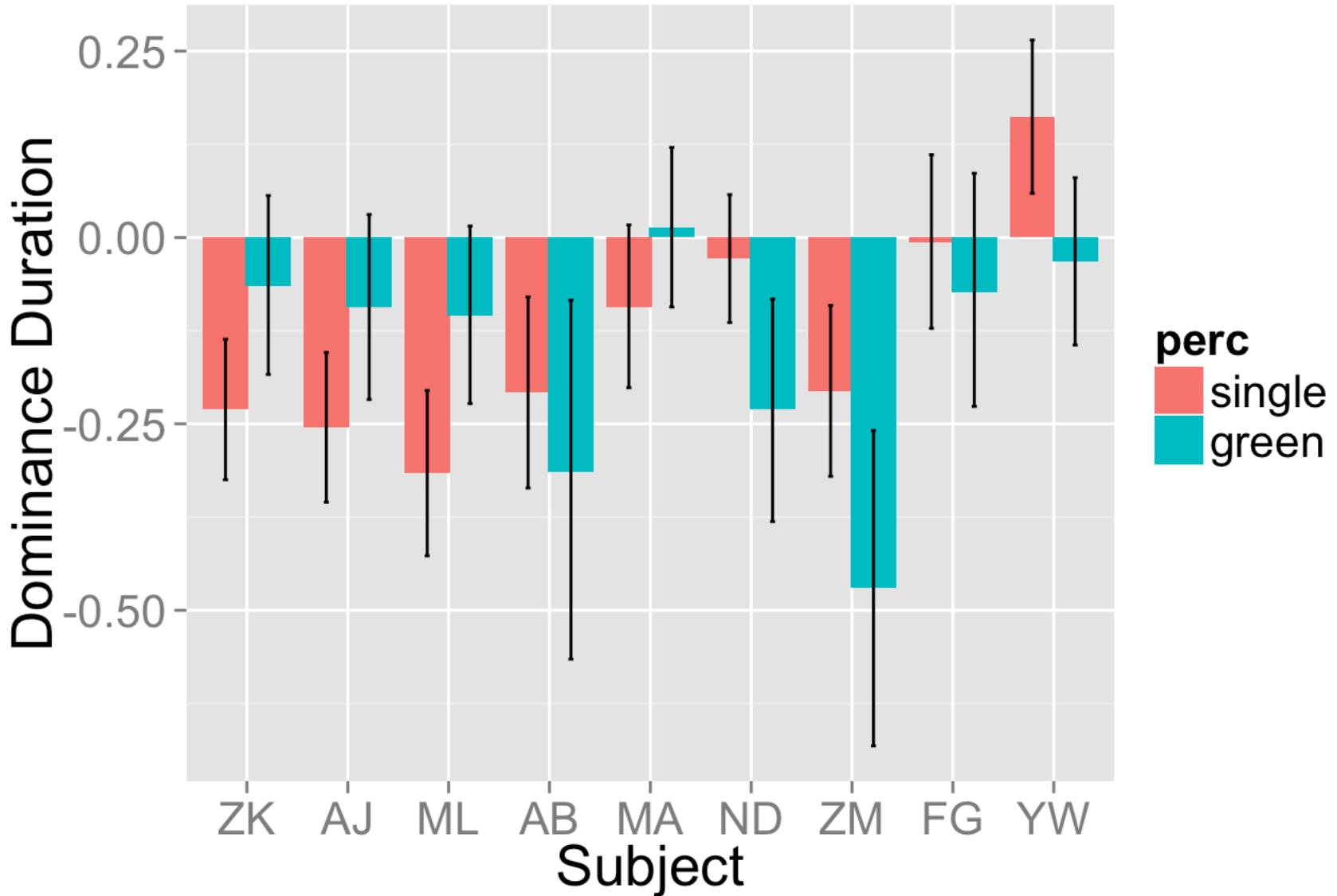
Grouped green



Difference



Difference



Increasing saturation level increases ratios of the number of visits to grouped percepts.

We next use the same data as above to compute ratios of the number of visits to grouped percepts.

$$\frac{N_{\text{grouped}}}{N_{\text{grouped}} + N_{\text{single-eye}}}$$

Based on these ratios, we compute the mean for each subject at the each saturation condition. We use the same analysis as in the case of the predominance of grouped percepts to compute the posterior probability of a change in this ratio. The results are shown in the following figure. The analysis is consistent with the result of predominance: the subjects ZK, AJ, ML and AB, and to a lesser degree MA and ZM, show a consistent increase in the number of visits to grouped percepts.

In summary, in some subjects an increase in color saturation level leads to an increase in the predominance of grouped percepts. This increase is due to two factors: the decrease in the domininace duration of single-eye percepts and the increase in the fraction of visits to grouped percepts.

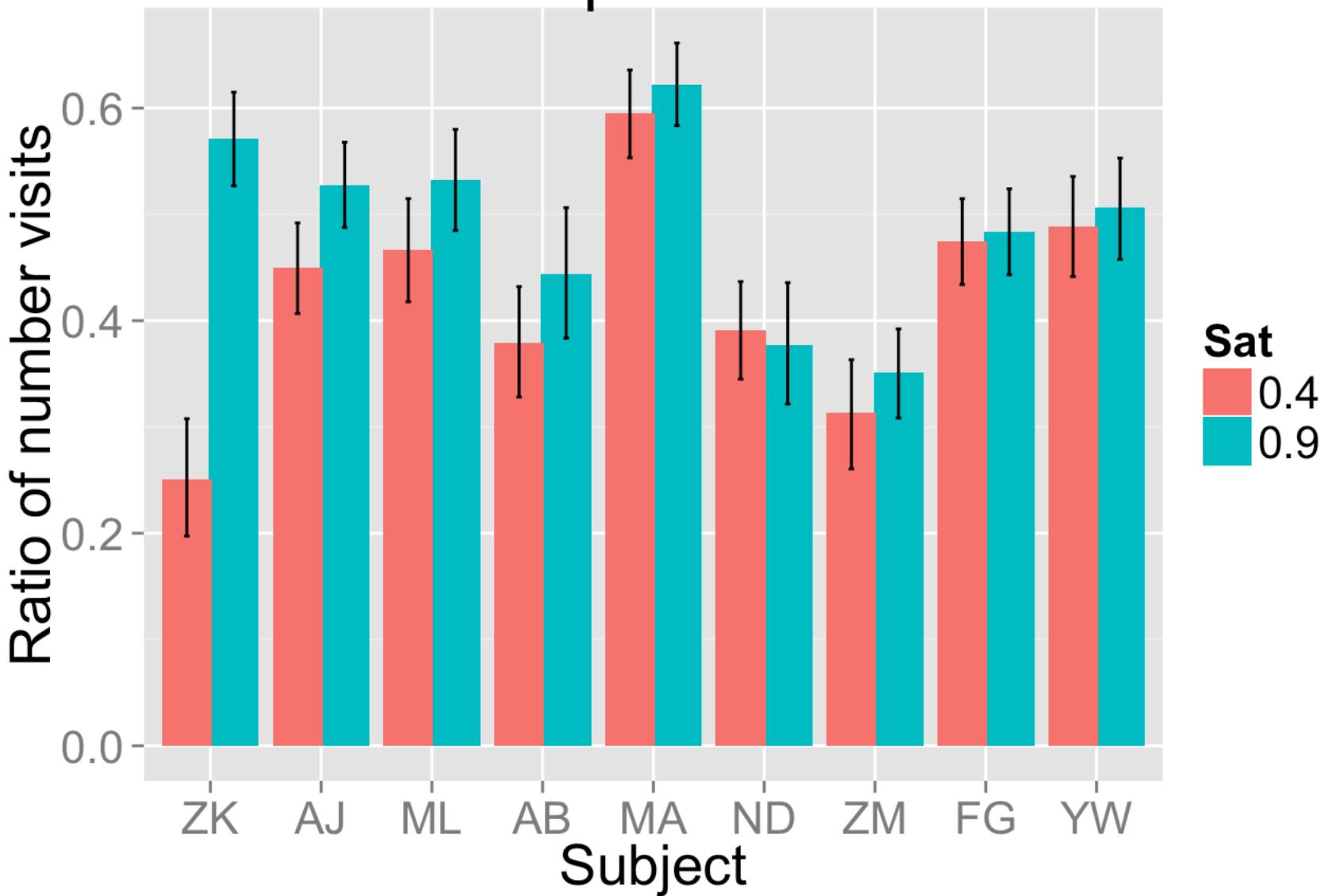
Ratios of number of visits to grouped percepts

ID	^a diff.	low CI	high CI	prob.
ZK	0.320	0.248	0.391	0.999
AJ	0.077	0.021	0.136	0.996

ML	0.066	0.000	0.132	0.976
AB	0.065	-0.013	0.143	0.948
MA	0.027	-0.028	0.084	0.832
ND	-0.014	-0.085	0.058	0.350
ZM	0.038	-0.026	0.104	0.877
FG	0.009	-0.047	0.066	0.631
YW	0.018	-0.049	0.082	0.702

^adiff. = mean at saturation 0.9 - mean at saturation 0.4

Grouped Perc.



Changes in transition probabilities

We next examine whether there is a change in the probability of transitions between and among the grouped and single eye stimuli with an increase in color saturation. To estimate the transition probabilities between percept types, we classified percepts into two states: single-eye, S, corresponding to percepts 1 and 2, and grouped, G, corresponding to percepts 3 and 4. For each trial, we converted the data into two binary data sequences: One sequence contained all transitions from state S with transitions from S to S denoted by 1, and from S to G by 0. The second sequence contained transitions from G, those from G to G denoted by 1, and from G to S by 0. We used data obtained from all subjects in a given condition (low/high color saturation) to estimate the transition probability from S to S, and from G to G by fitting a hierarchical binomial model. The model is specified by

$$y_{ij} \sim \text{Bernoulli}(p_{ij})$$

$$p_{ij} = \theta_{0j} + \theta_{1j} x_{ij}$$

$$\theta_{0j} \sim \text{Beta}(\omega * (\kappa - 2) + 1, (1 - \omega) * (\kappa - 2) + 1), \theta_{1j} \sim \text{Normal}(\theta_1, \tau_1^2)$$

where x_{ij} is the color saturation indicator (1 for 0.9, 0 for 0.4). We used vague priors: a uniform prior on the interval [0, 1] for the mode, ω , and a Gamma prior with rate and shape both equal to 0.01 for the concentration parameter, κ . Prior distributions for the overall saturation effects θ_1 was independent of these, and normal with mean 0, and variance 10^4 . We used Uniform(0, 100) prior for the standard deviation of the random effect τ_1 .

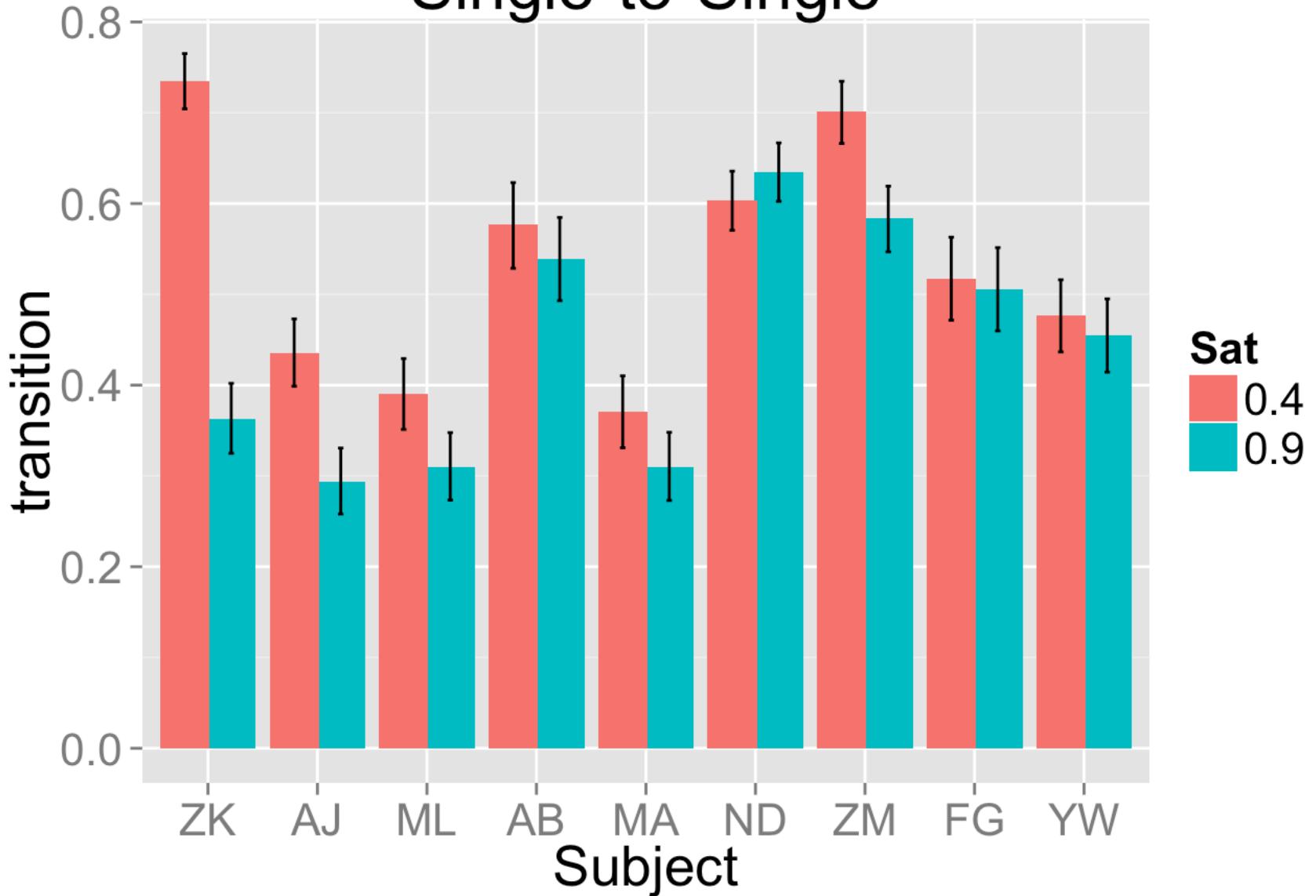
The results presented in the table below show that six of the subjects (ZK, AB, AJ, ML, MA, ZM) show a decrease in single-eye to single-eye transition with probability higher than 0.87 and four of these (ZK, AB, AJ, ML) also show an increase in grouped-to-grouped transitions with probability higher than 0.9. This subset again belongs to those that experienced an increased predominance of grouped percepts with an increase in color saturation.

Effect of saturation level on transitions

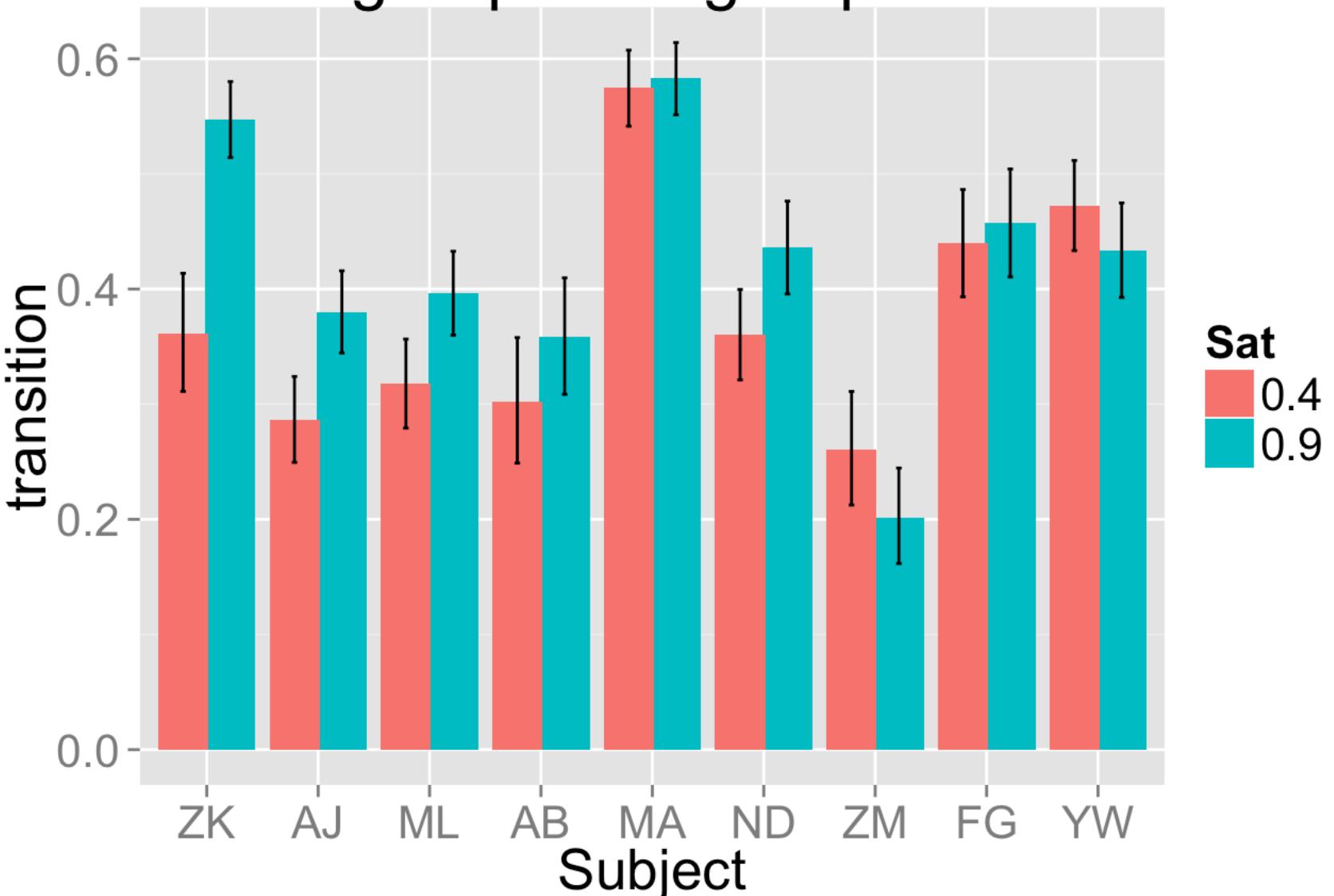
single-to-single				grouped-to-grouped					
ID	diff.	low CI	high CI	^a D-prob.	ID	diff.	low CI	high CI	prob.
ZK	-0.372	-0.421	-0.323	0.999	ZK	0.186	0.125	0.246	0.999
AJ	-0.142	-0.193	-0.091	0.999	AJ	0.094	0.043	0.144	0.999
ML	-0.080	-0.134	-0.027	0.998	ML	0.079	0.027	0.131	0.998
AB	-0.037	-0.102	0.028	0.868	AB	0.056	-0.015	0.127	0.940
MA	-0.061	-0.114	-0.006	0.986	MA	0.008	-0.036	0.053	0.642
ND	0.032	-0.014	0.078	0.090	ND	0.076	0.021	0.131	0.996
ZM	-0.118	-0.167	-0.068	0.999	ZM	-0.059	-0.122	0.004	0.034
FG	-0.012	-0.076	0.052	0.644	FG	0.018	-0.046	0.081	0.713
YW	-0.022	-0.078	0.034	0.776	YW	-0.039	-0.095	0.017	0.085

^aD-prob. =Decreasing probability

Single-to-Single



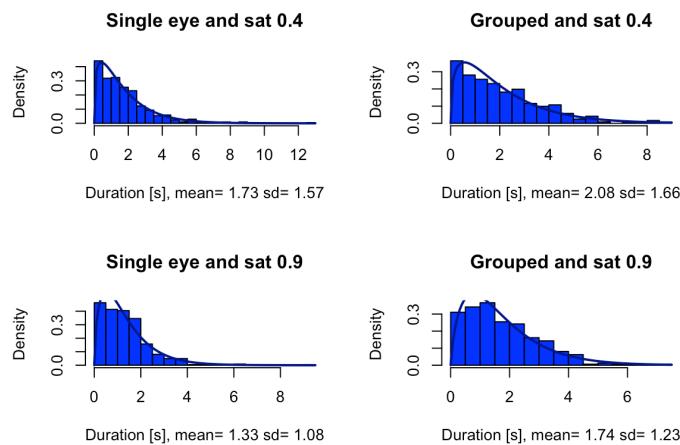
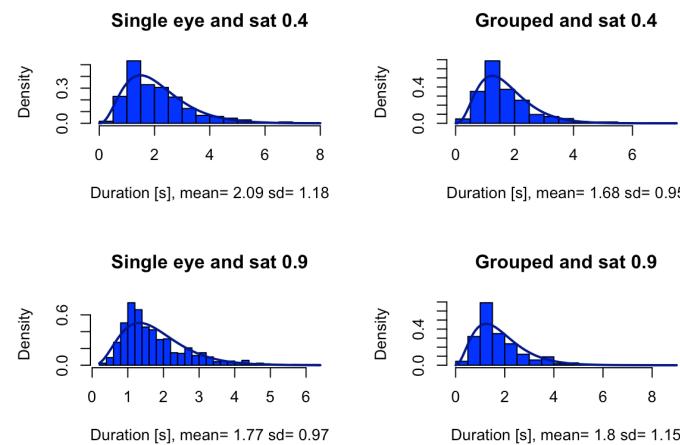
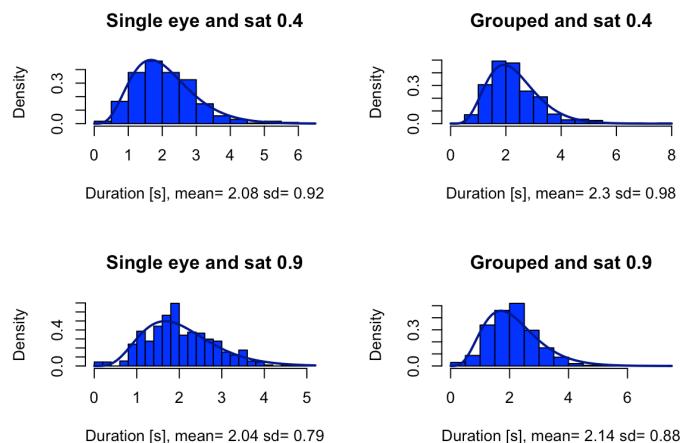
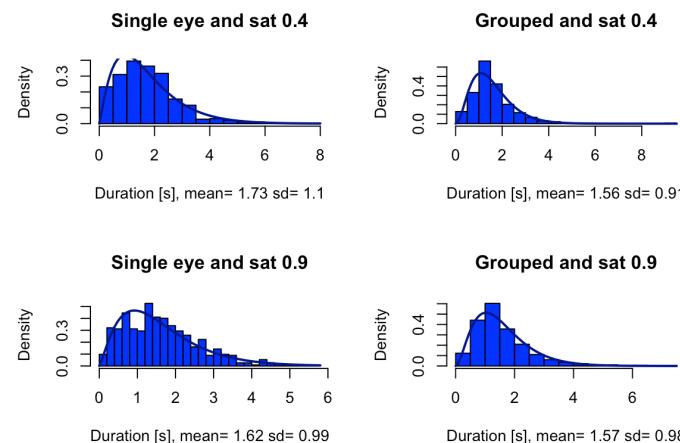
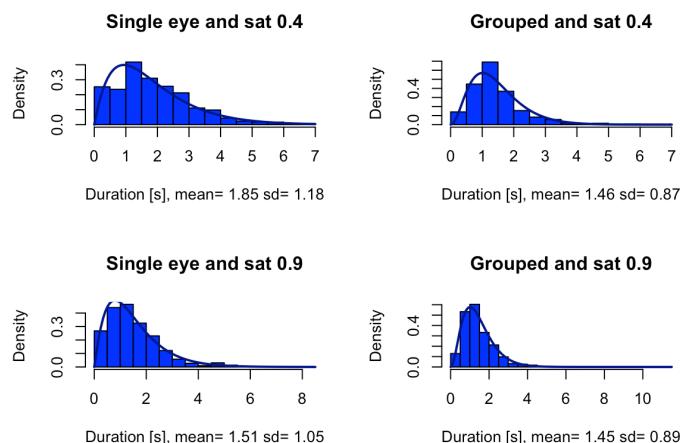
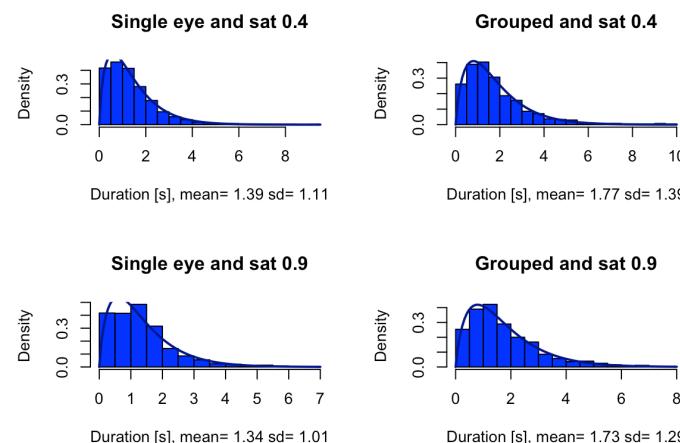
grouped-to-grouped

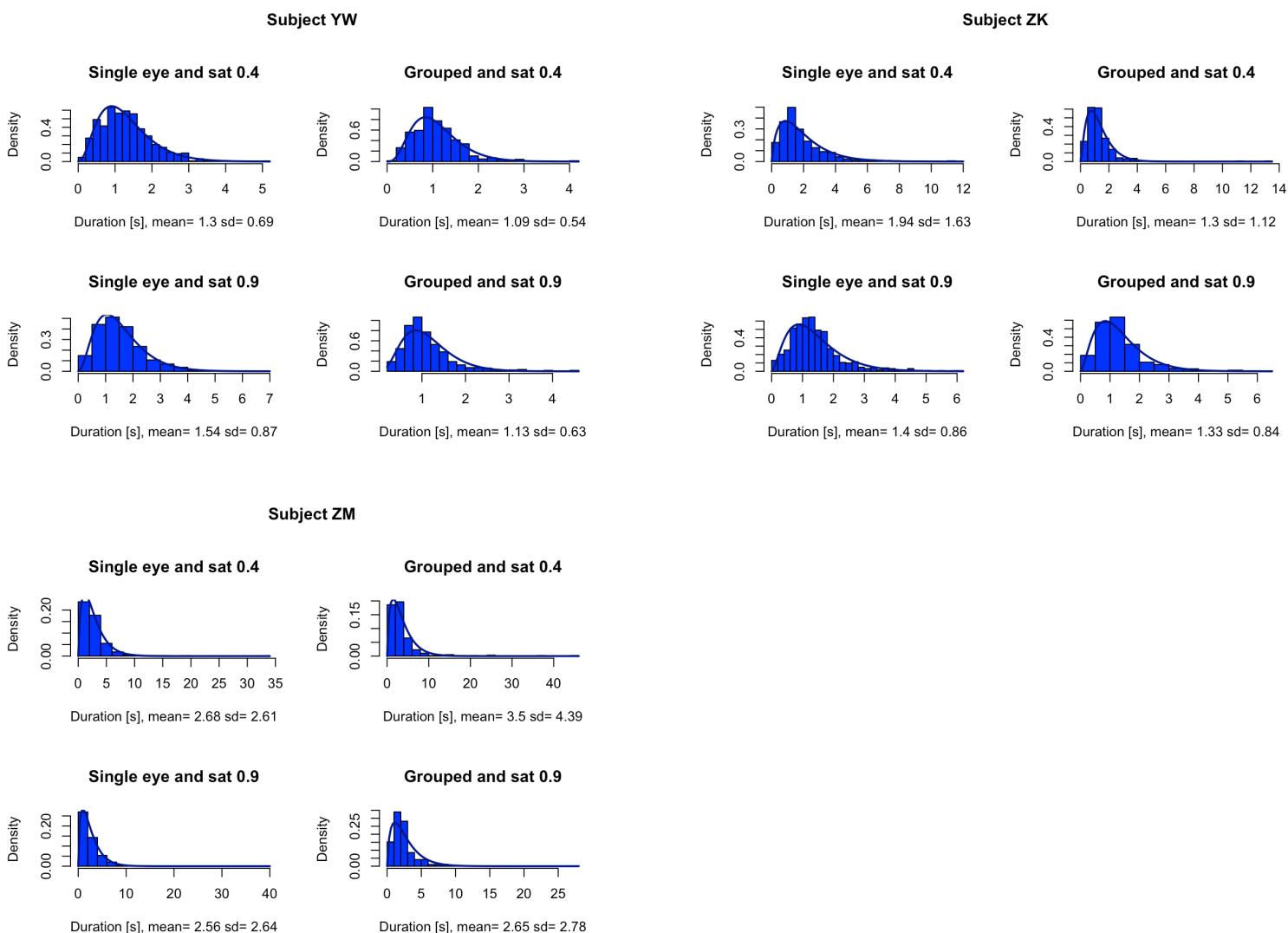


Full distributions of different quantities per subject

Distribution of observation times

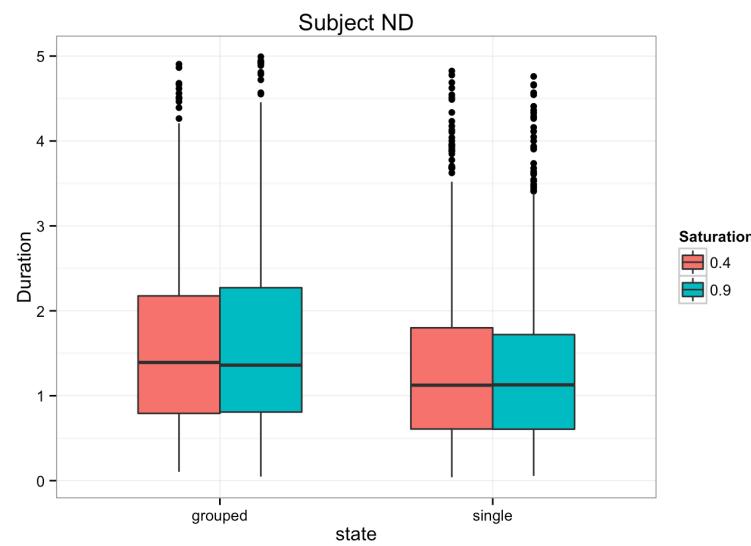
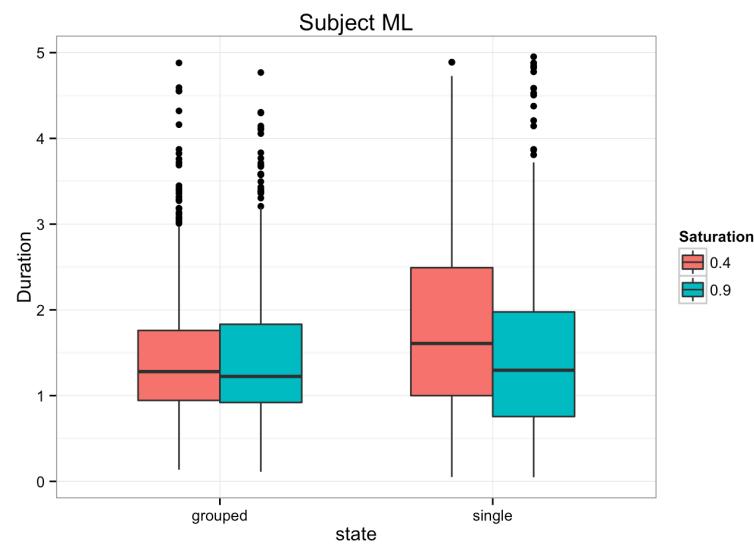
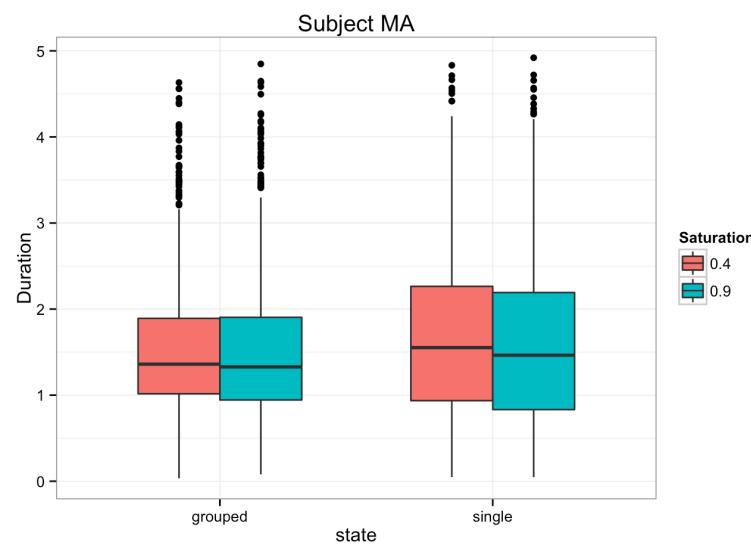
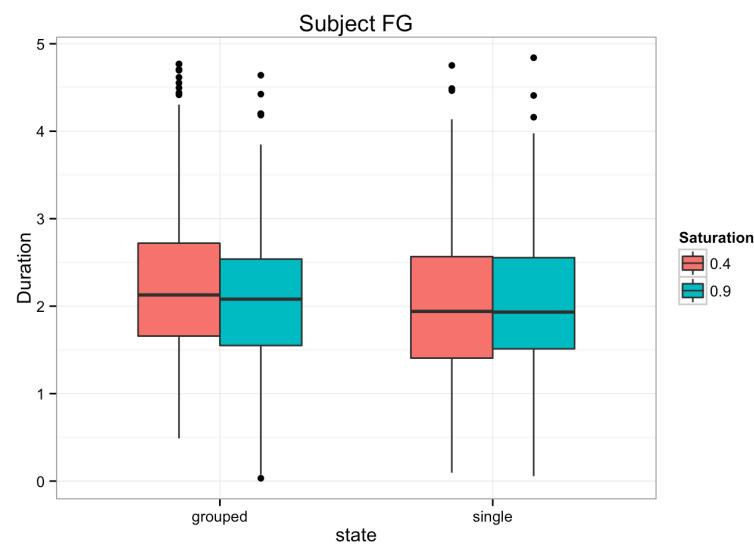
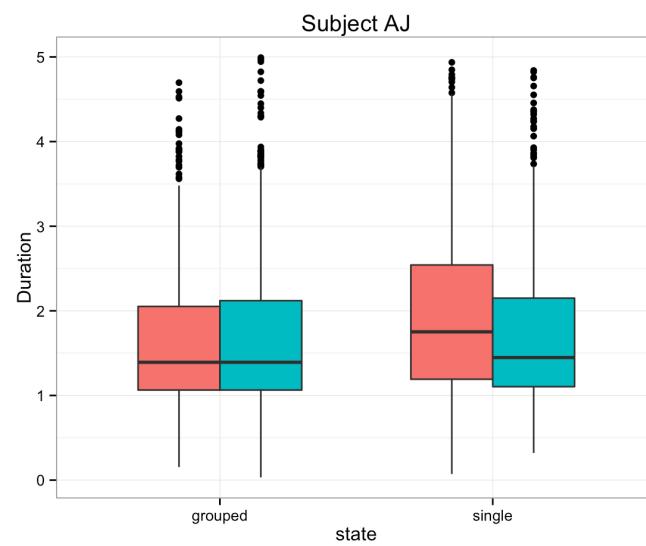
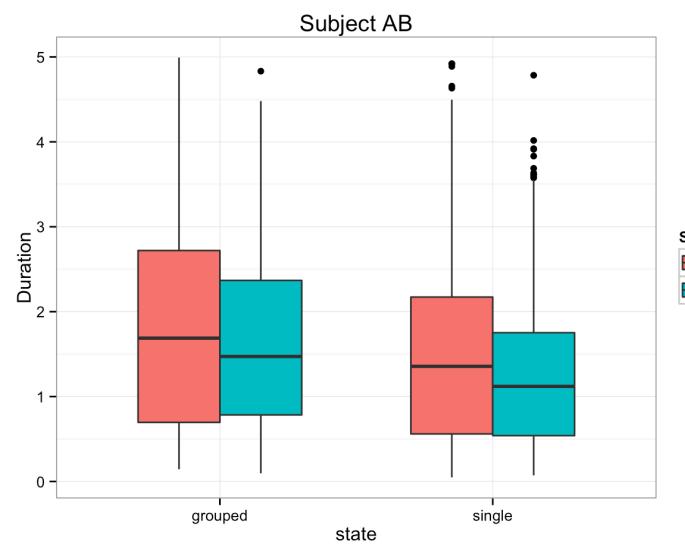
This is the distribution of times for each of the percepts under the four conditions. The four percepts are separated into single-eye and grouped groups. We fit a gamma distribution for each condition using max likelihood and the **fitdistr** function.

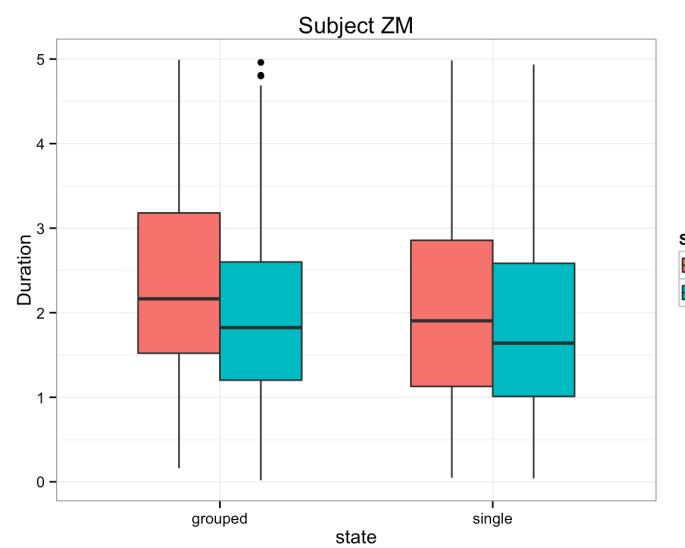
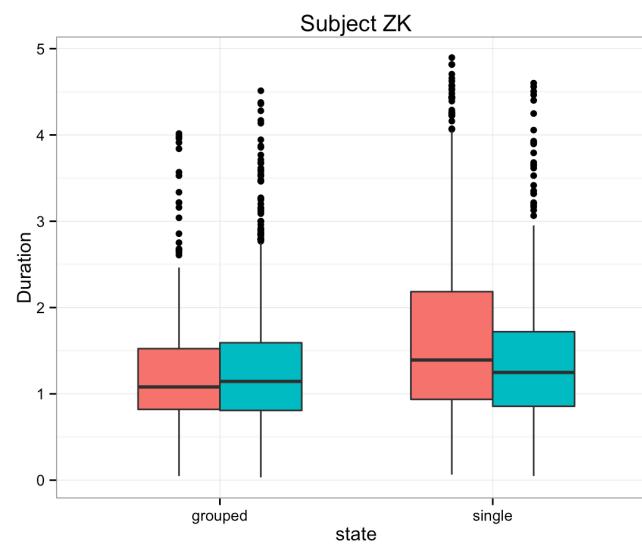
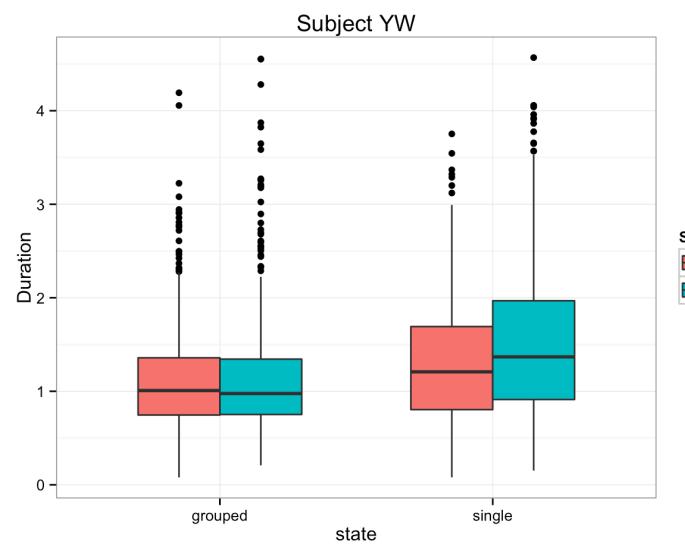
Subject AB**Subject AJ****Subject FG****Subject MA****Subject ML****Subject ND**



The observations are overall well fit by a gamma distribution, although there is some variability in the goodness of fit across distributions.

To get an idea of how the average duration of the grouped and single eye percepts compare across conditions, we can look at the boxplots comparing the distribution of durations. It would be better to show color saturation levels side-by-side, since we want to compare single to single in either color saturation level, same for grouped.

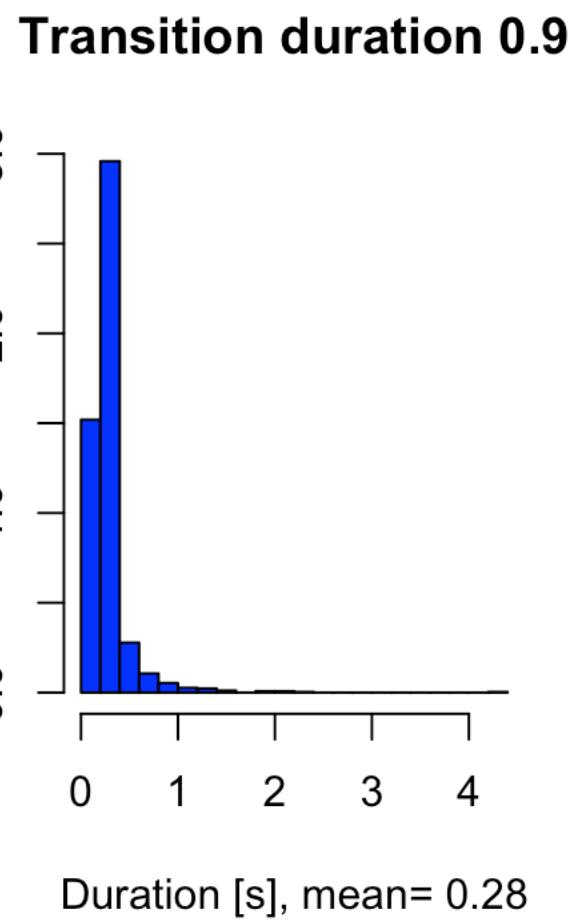
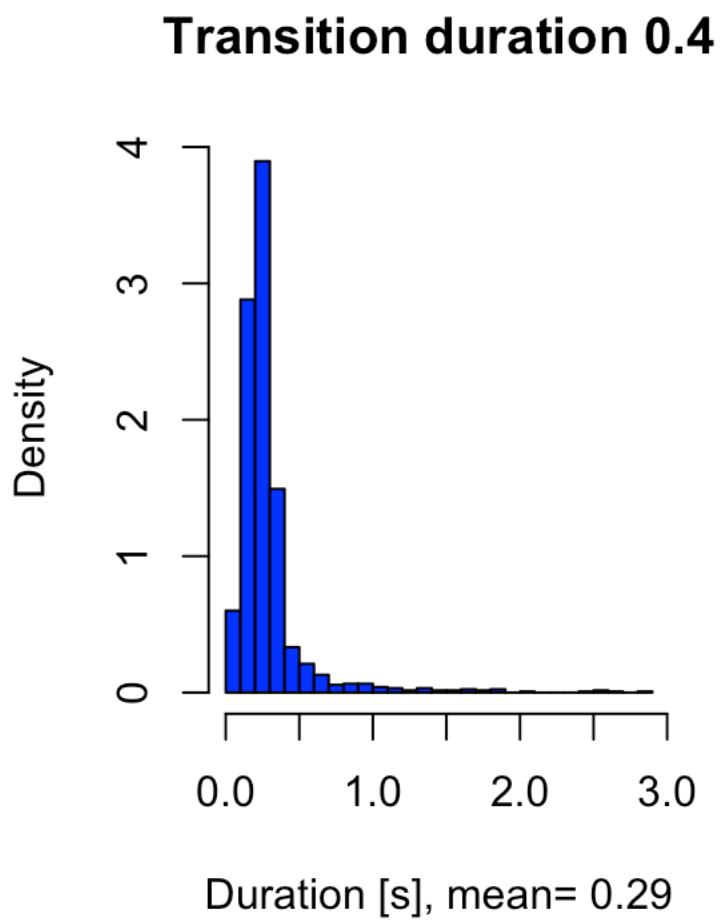




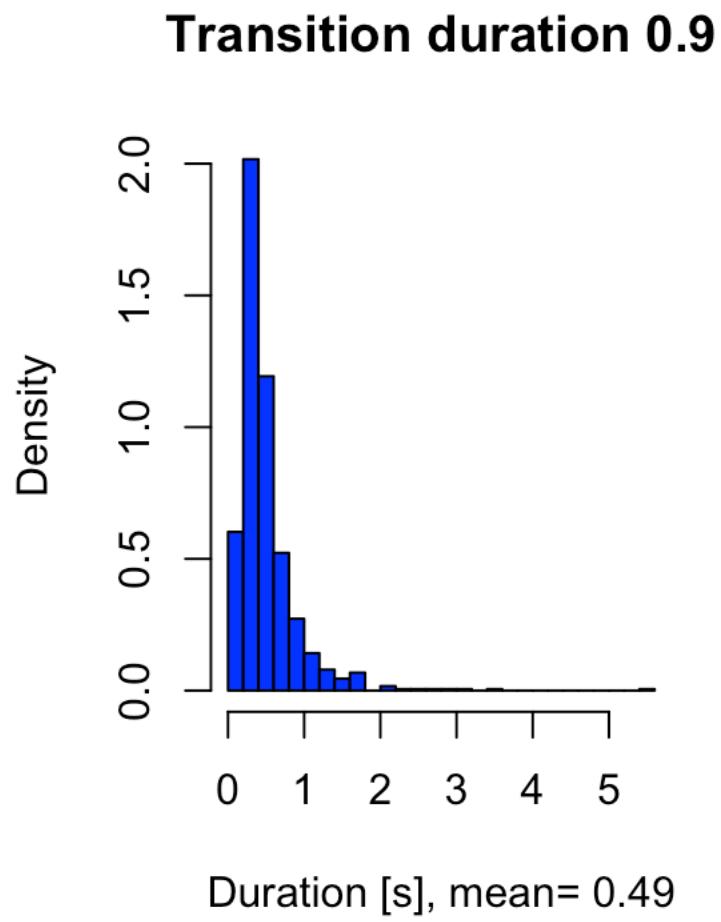
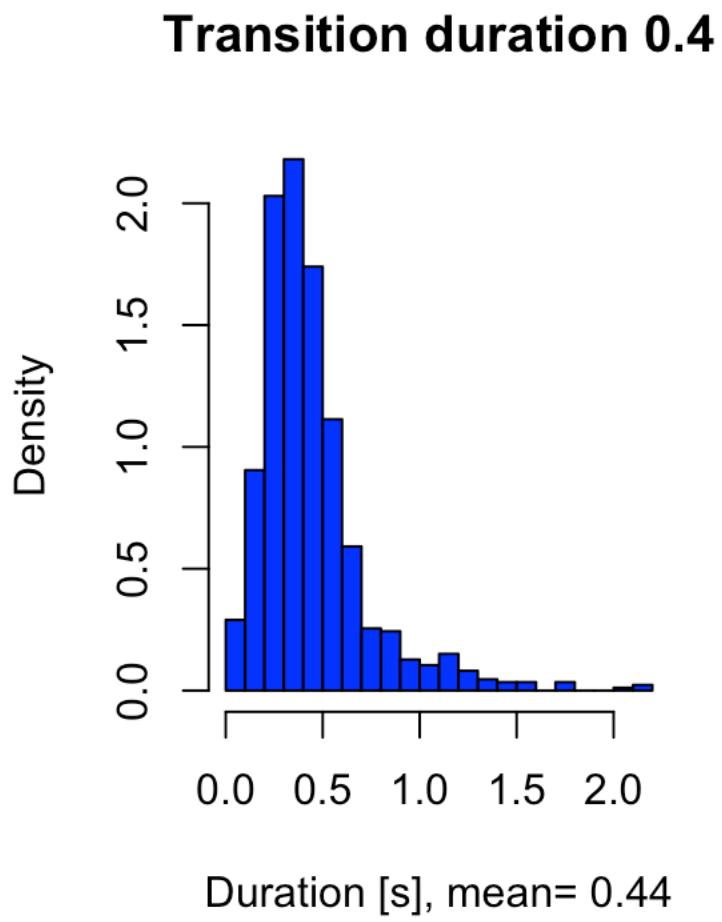
Distribution of time duration without stable percept

Now we check the duration of the these transition duration

Subject AJ

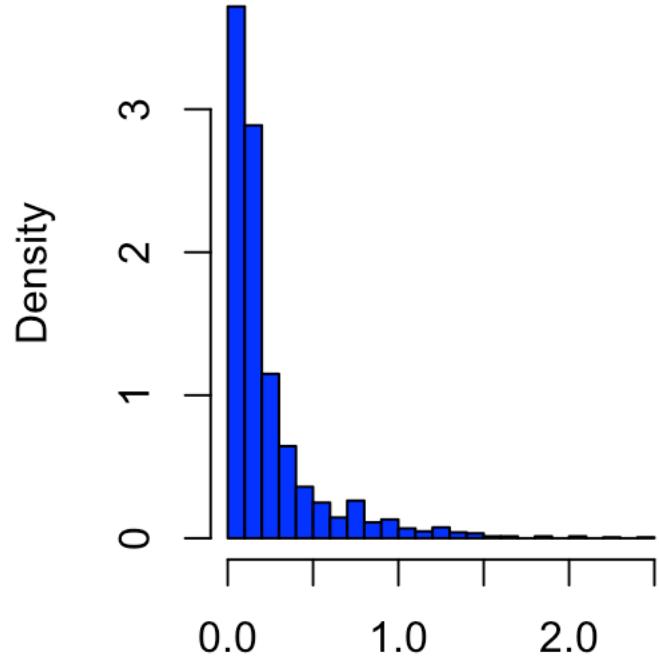


Subject FG

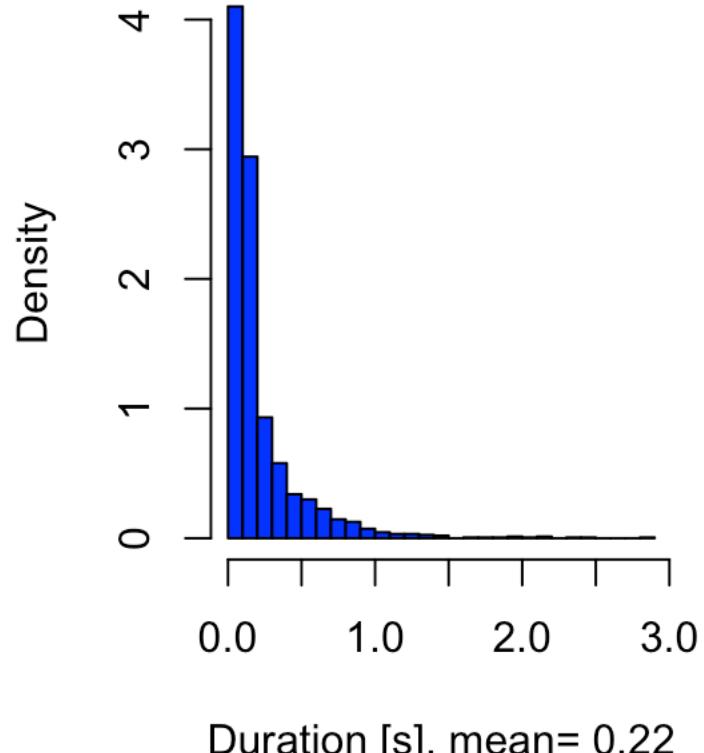


Subject MA

Transition duration 0.4



Transition duration 0.9

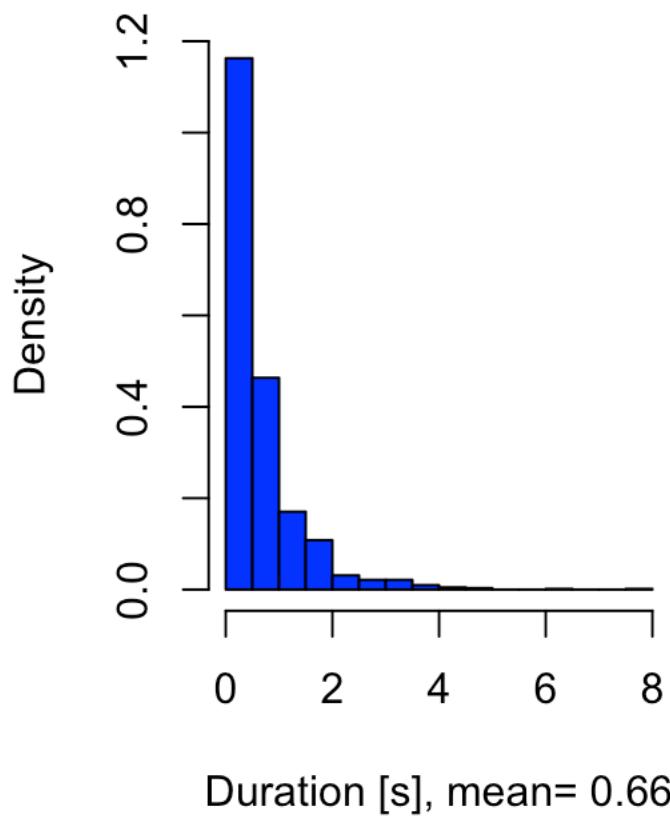


Duration [s], mean= 0.24

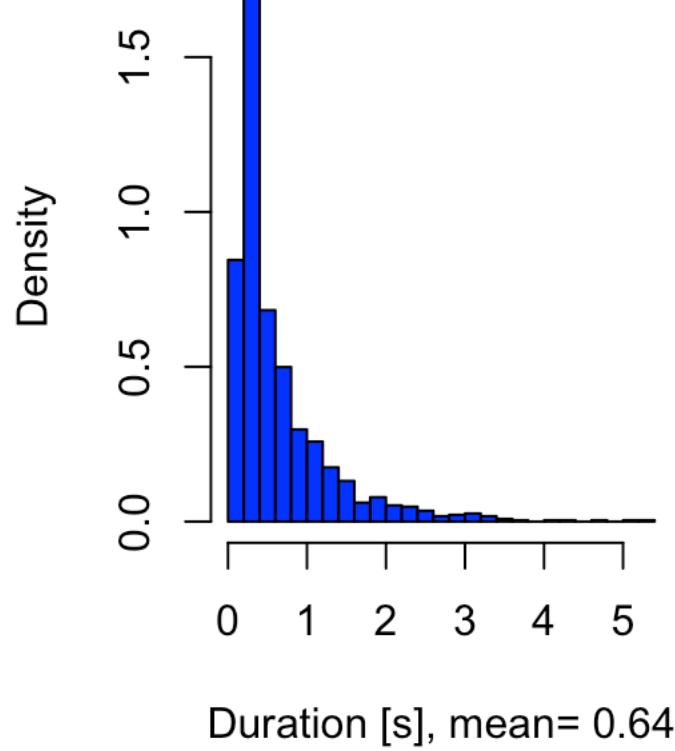
Duration [s], mean= 0.22

Subject YW

Transition duration 0.4

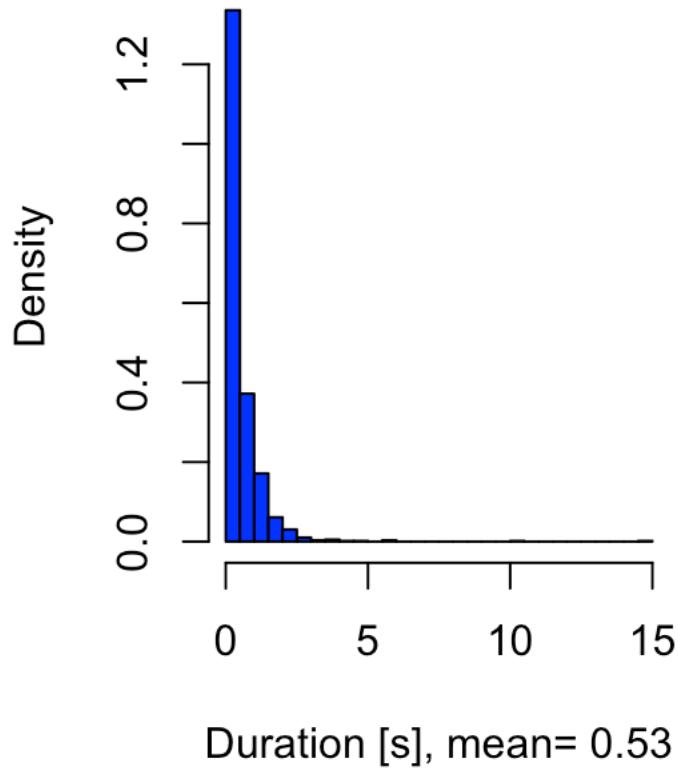


Transition duration 0.9

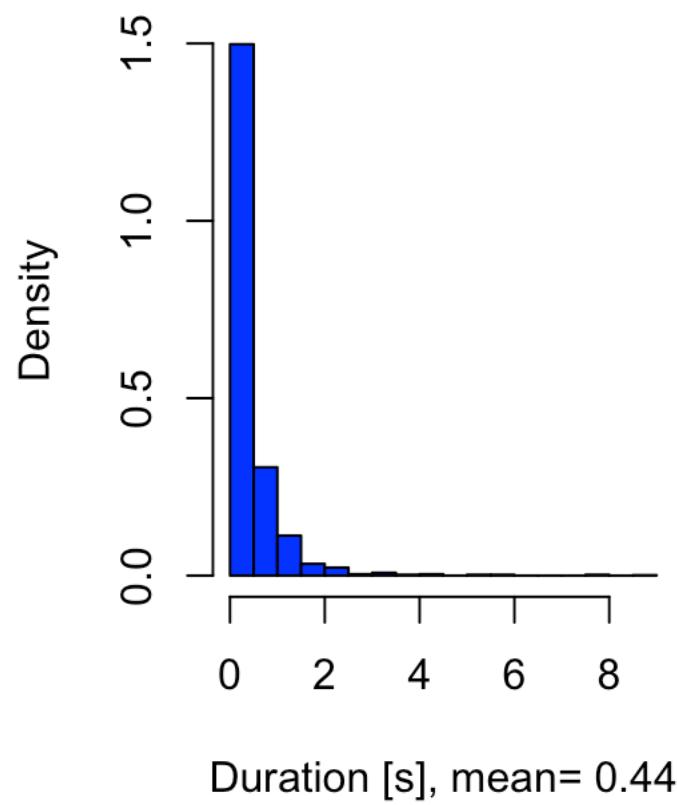


Subject ZK

Transition duration 0.4

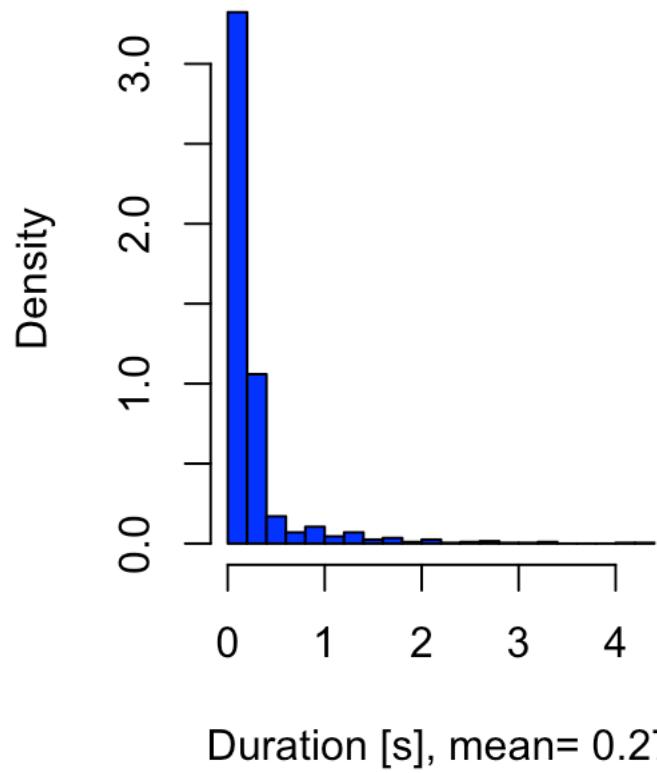


Transition duration 0.9

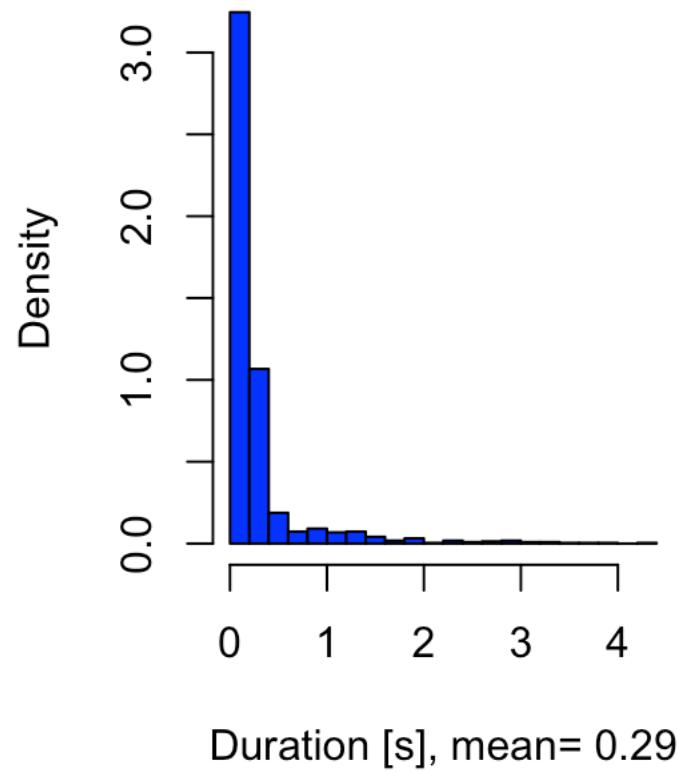


Subject ZM

Transition duration 0.4

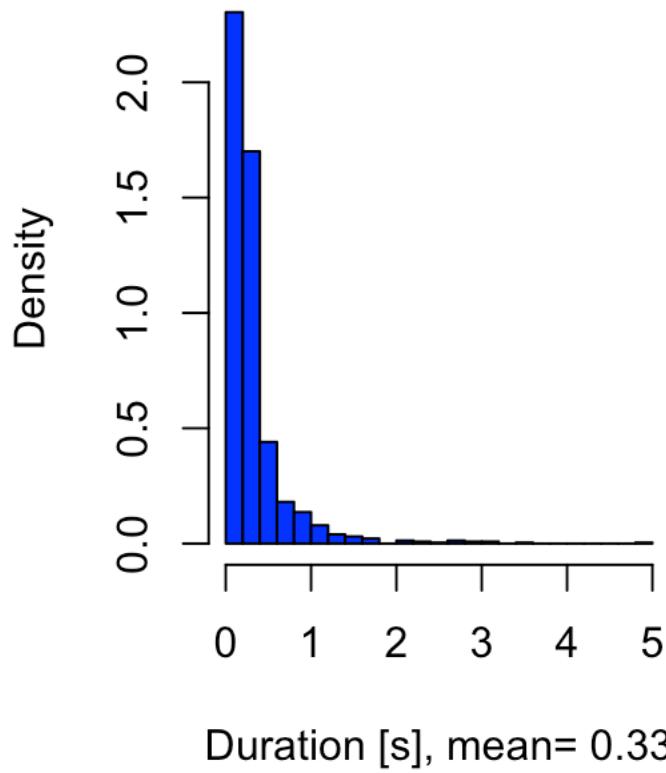


Transition duration 0.9

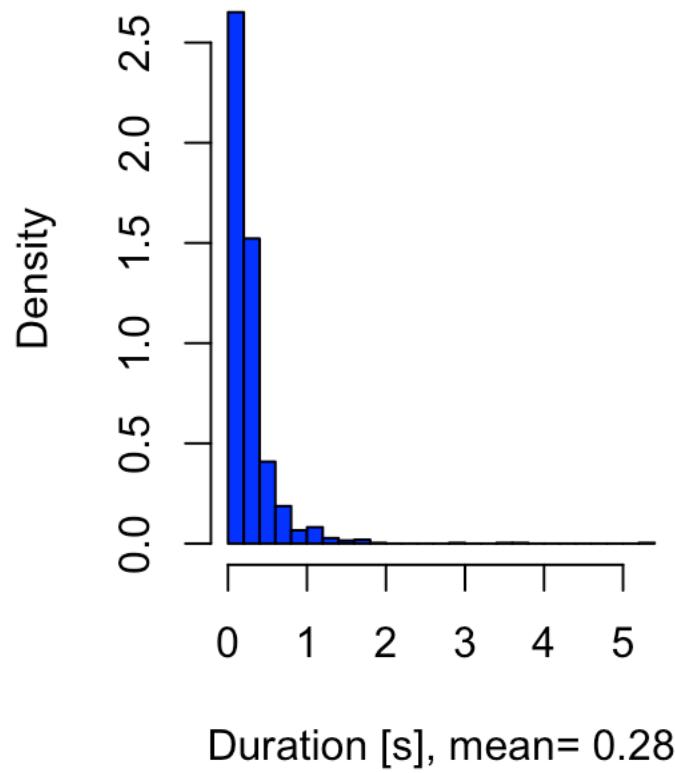


Subject ML

Transition duration 0.4

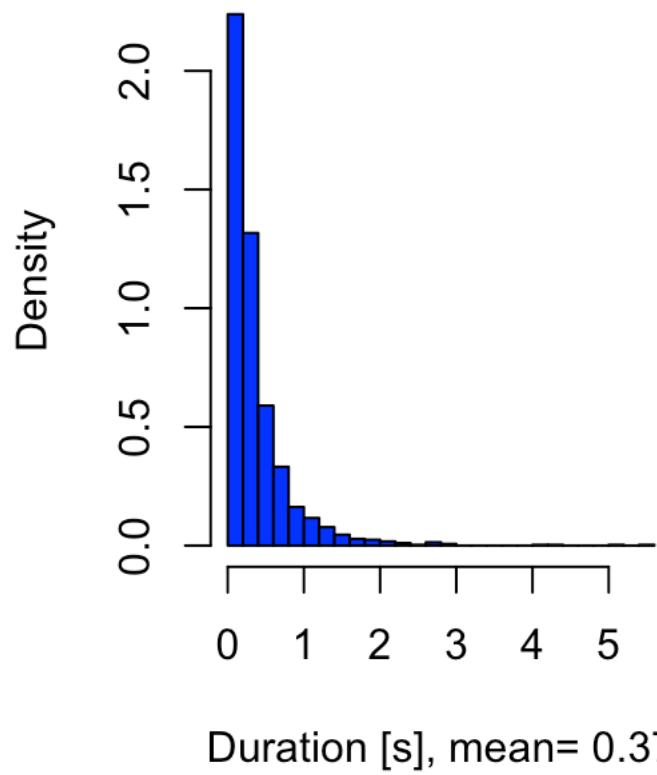


Transition duration 0.9

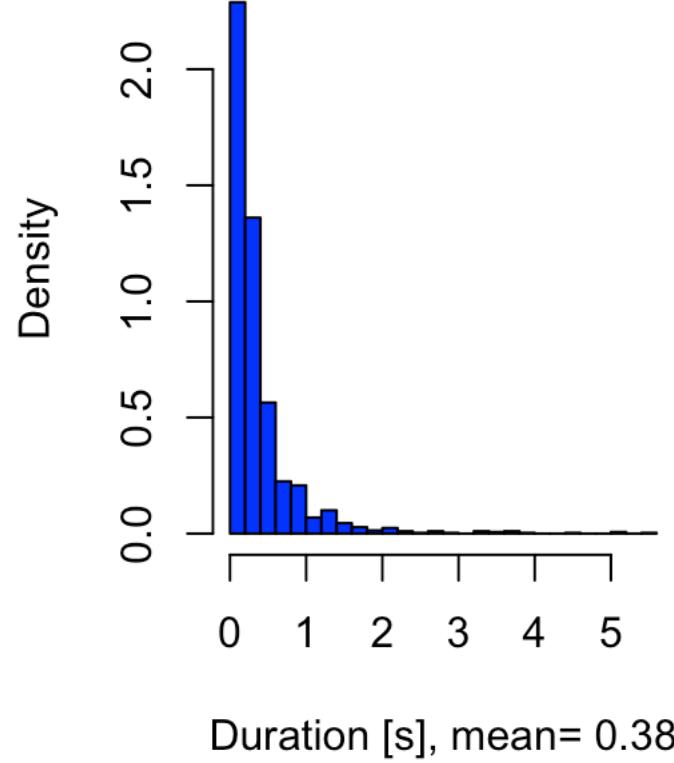


Subject ND

Transition duration 0.4

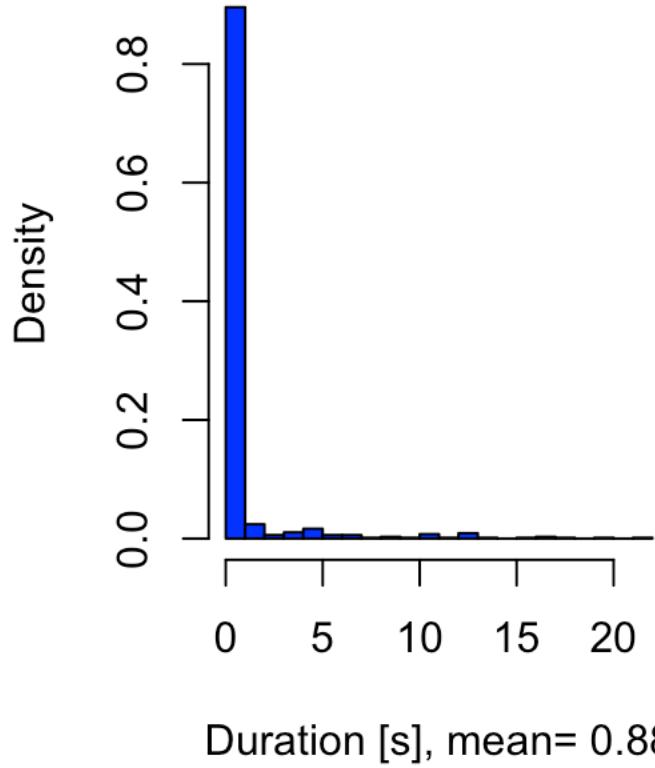


Transition duration 0.9

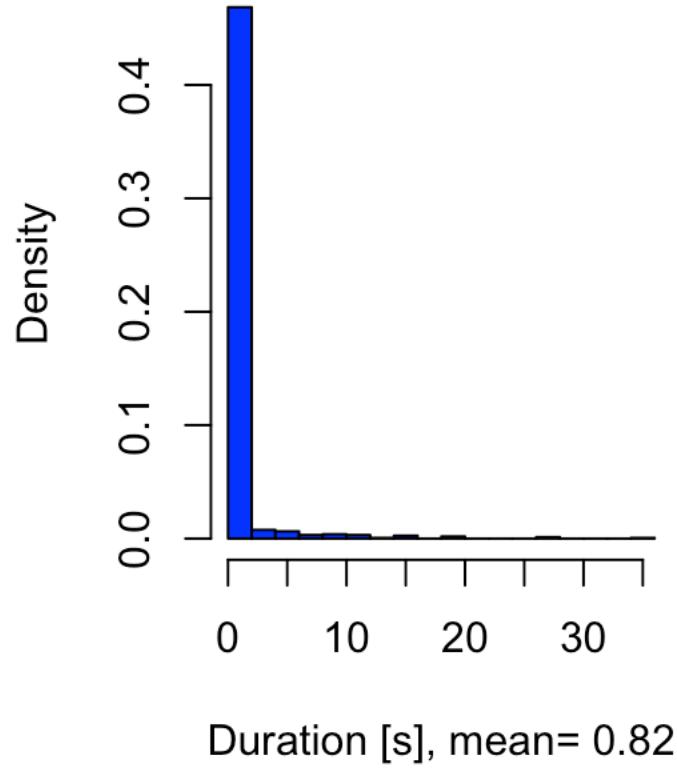


Subject AB

Transition duration 0.4

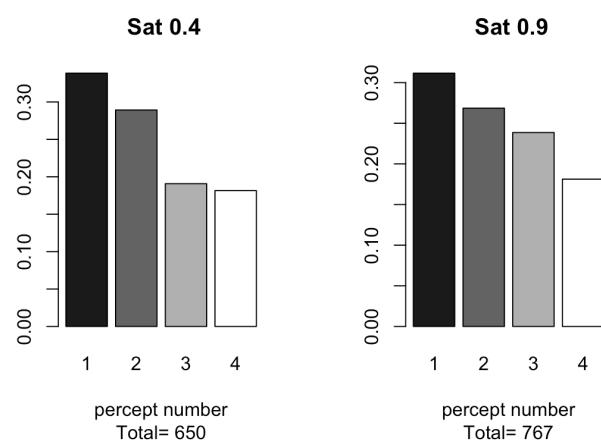
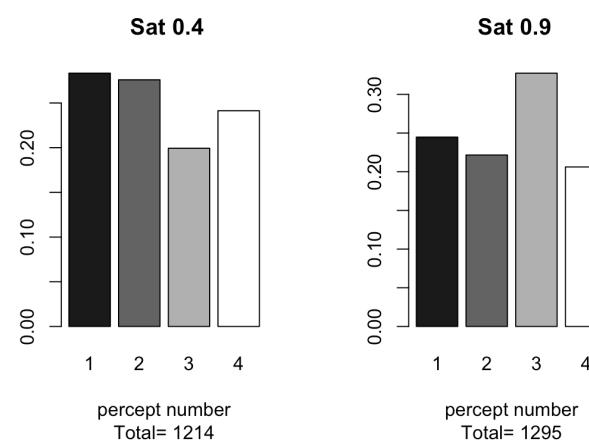
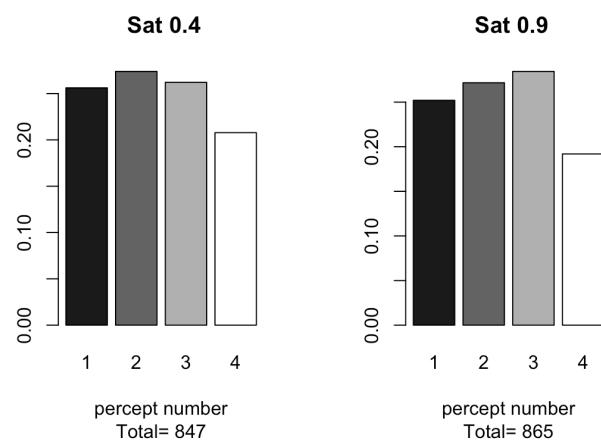
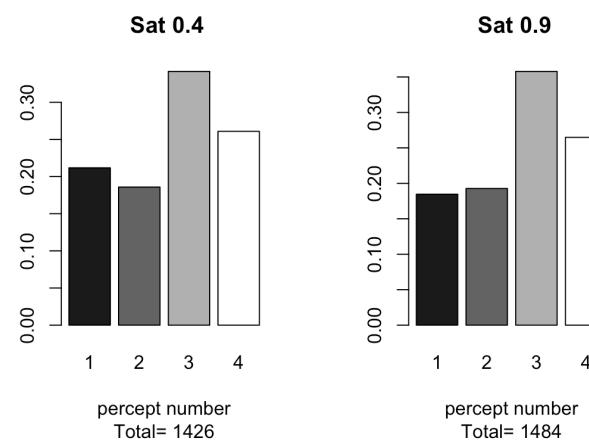
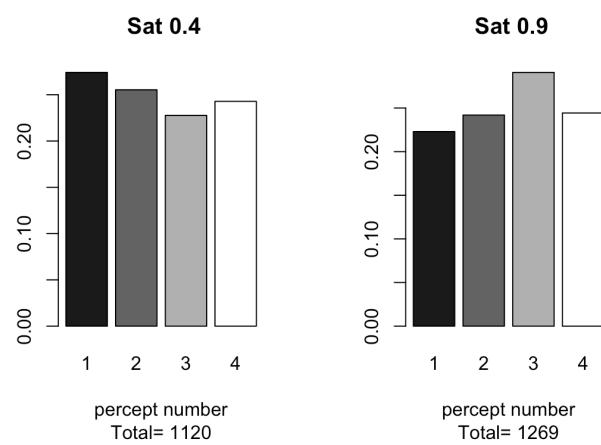
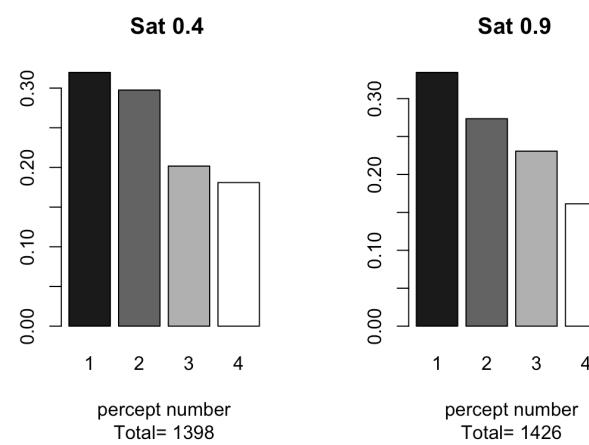


Transition duration 0.9

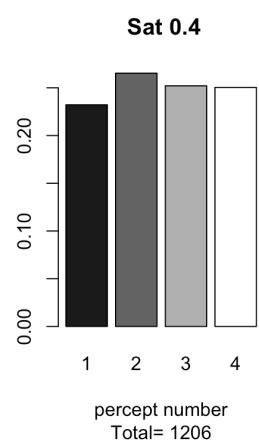


Frequency of individual percepts

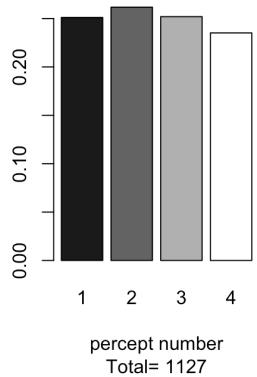
The following are the fraction that each percept is reported of the individual percepts per subject. Is there any significant pattern here?

Subject AB**Subject AJ****Subject FG****Subject MA****Subject ML****Subject ND**

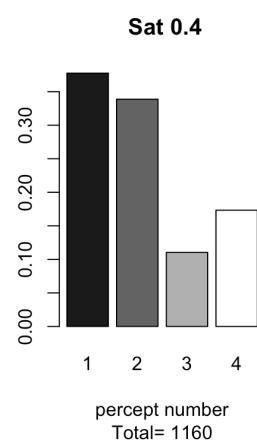
Subject YW



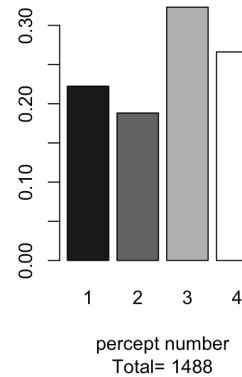
Sat 0.9



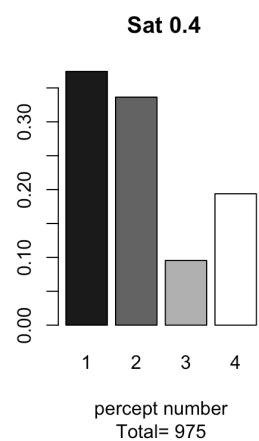
Subject ZK



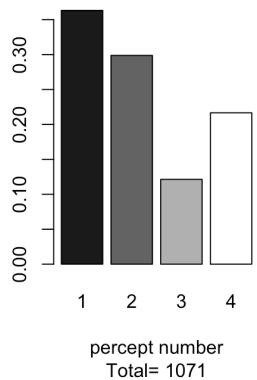
Sat 0.9



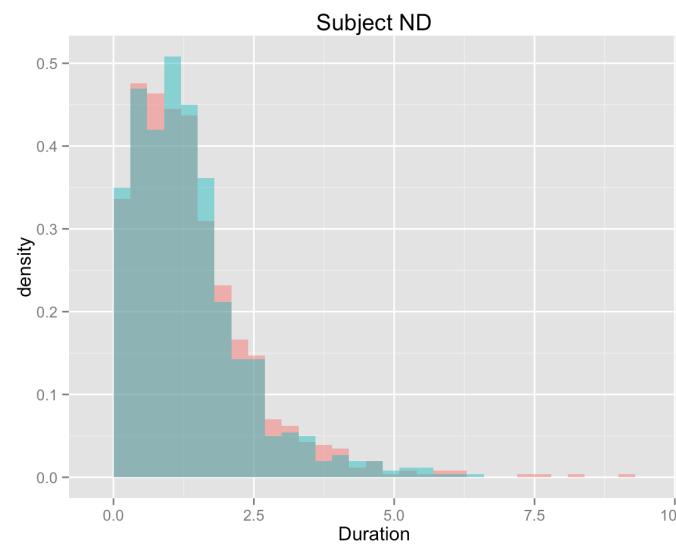
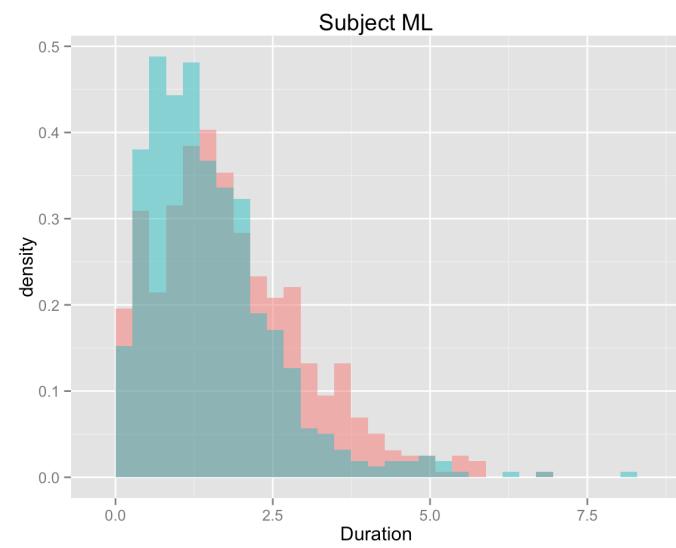
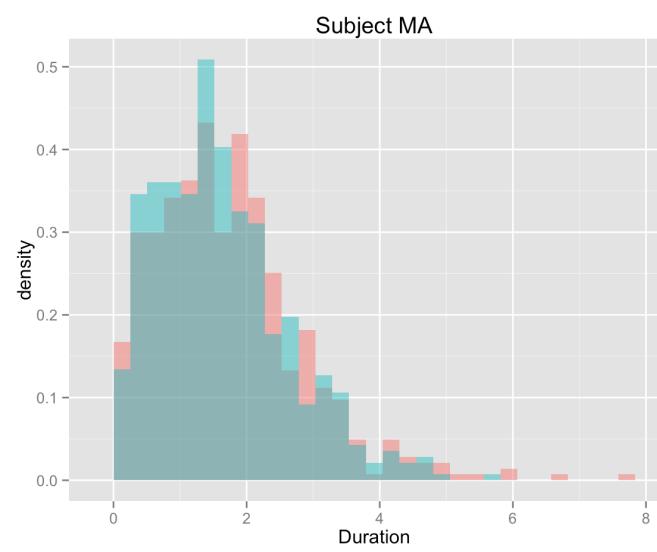
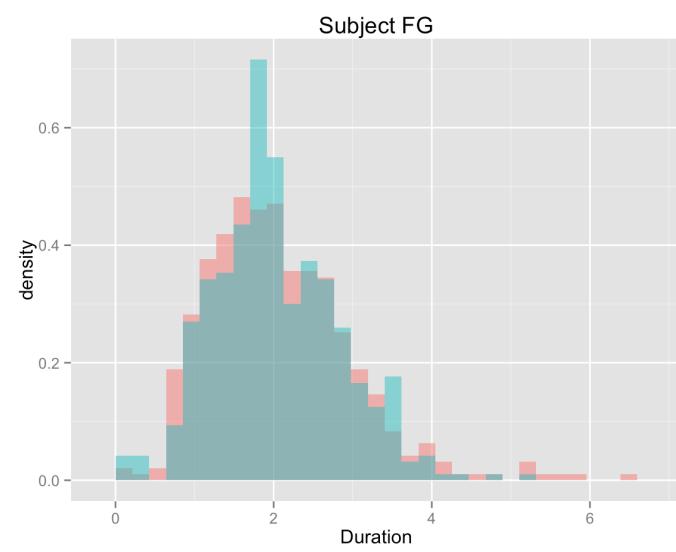
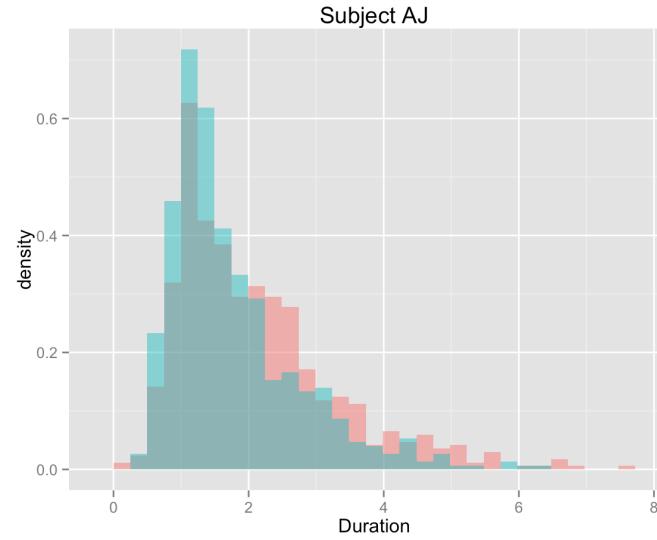
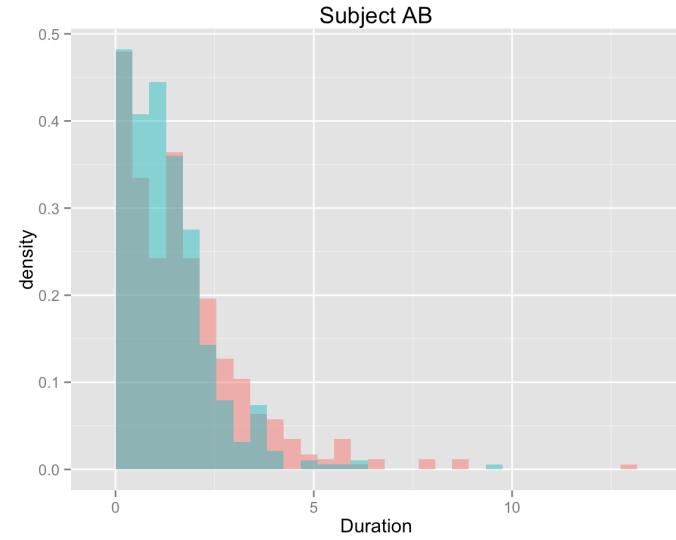
Subject ZM

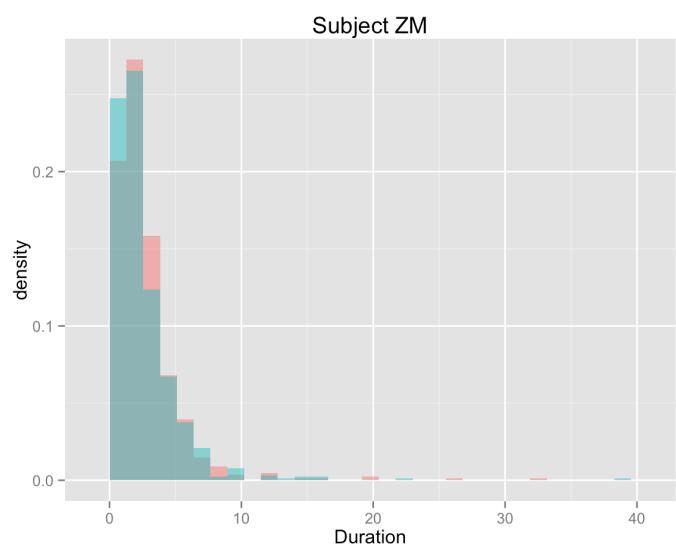
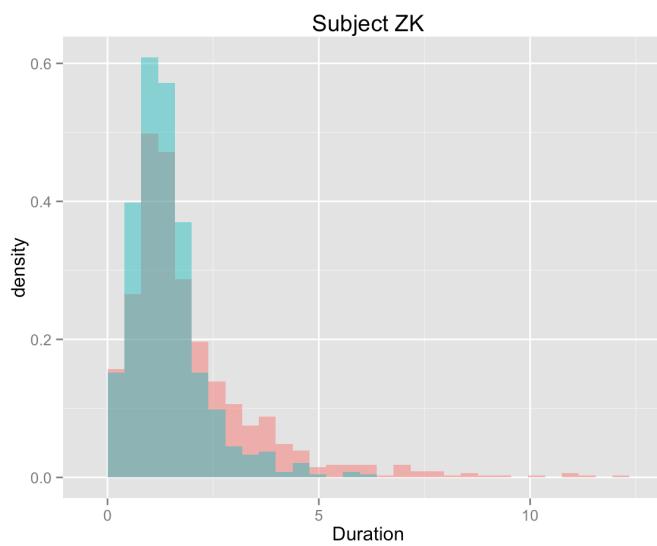
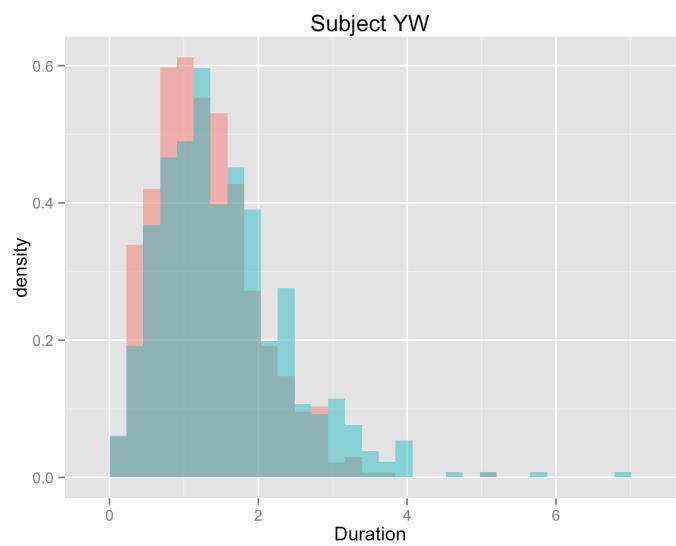


Sat 0.9

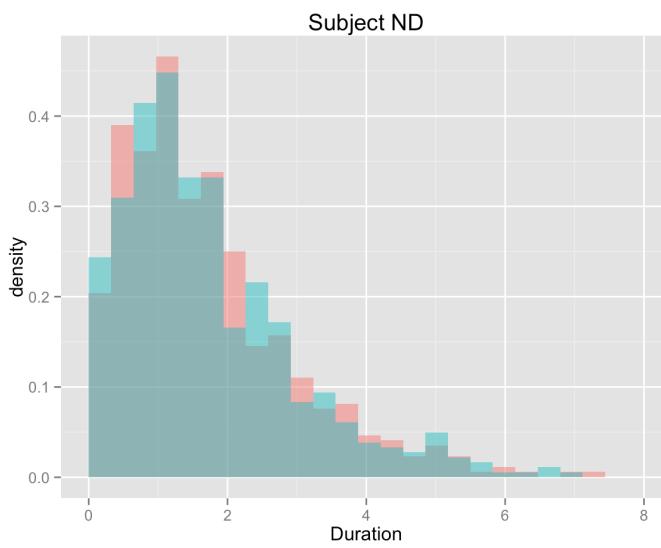
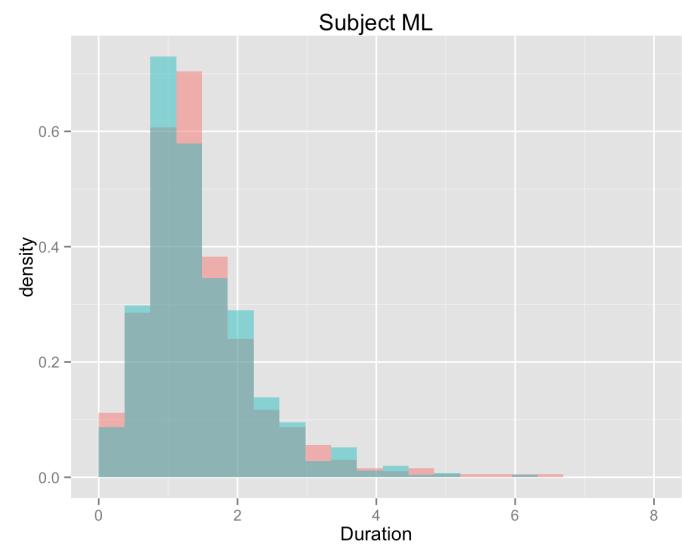
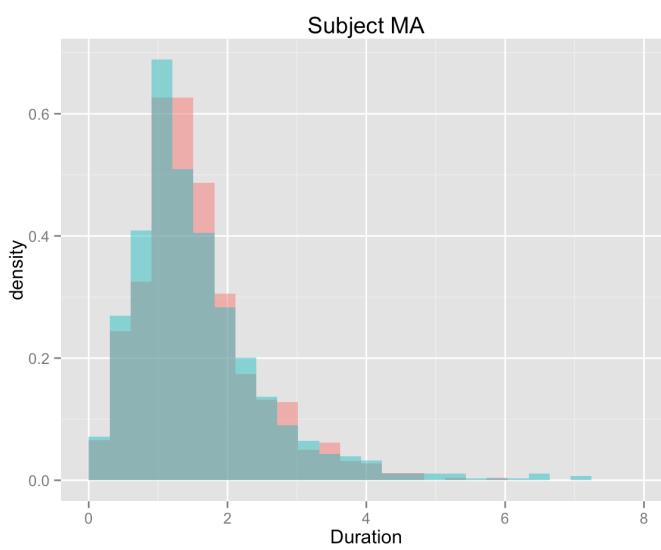
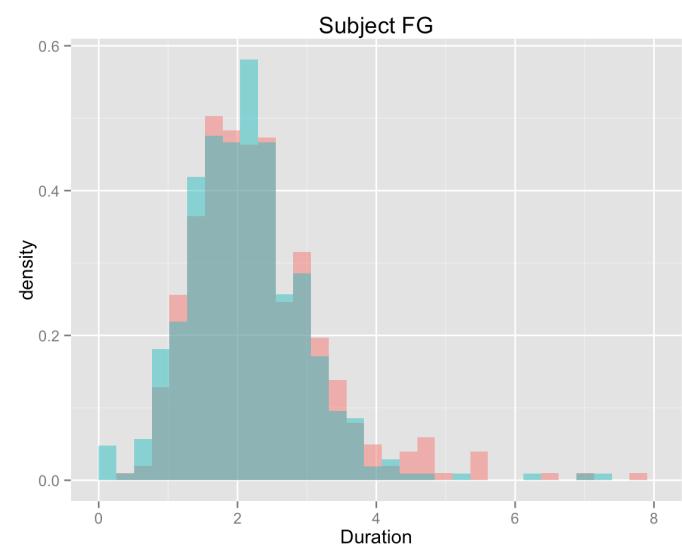
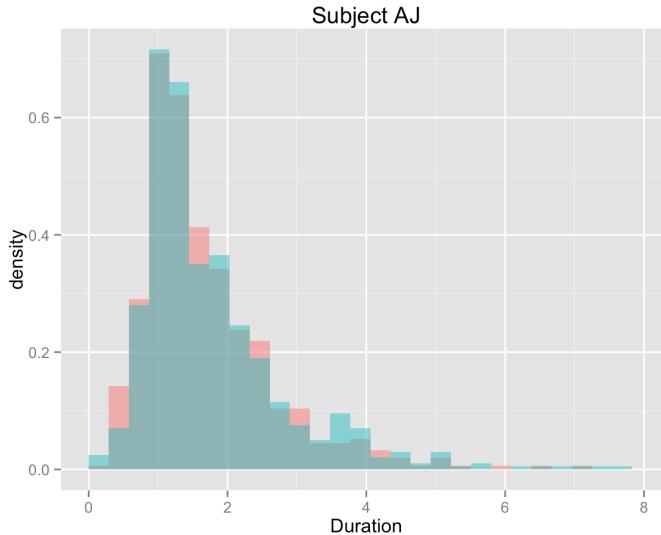
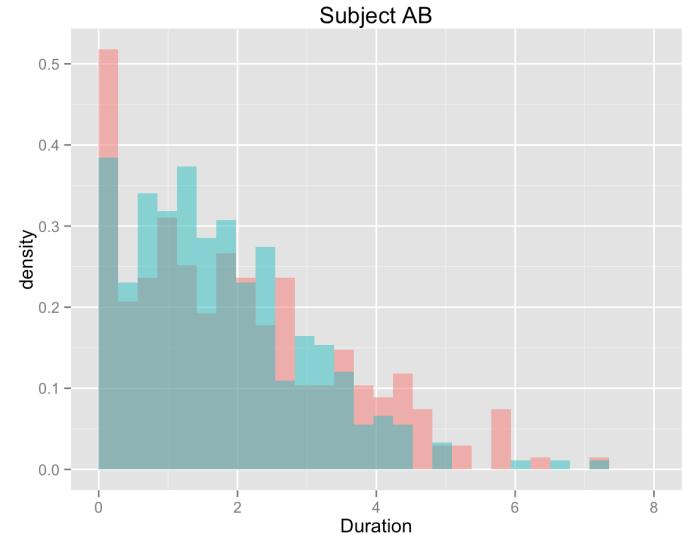


The overlay of dominance duration distribution of single-eye percepts.

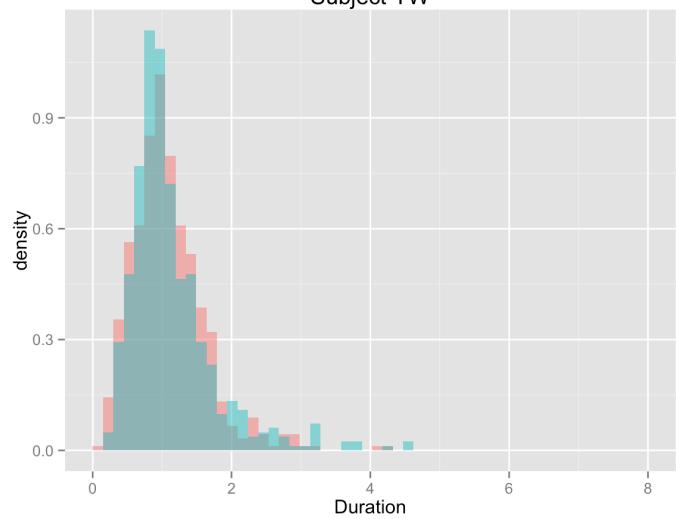




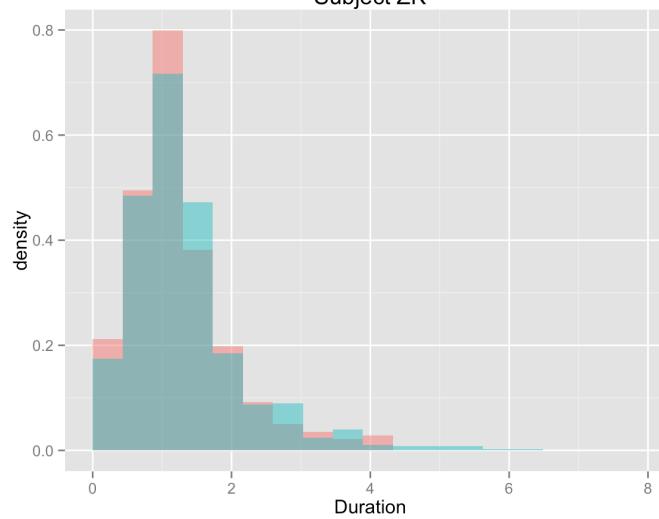
overlay plot of grouped percepts



Subject YW



Subject ZK



Subject ZM

