Figures’ note for N-back ipRGC study

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# Article information

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# Results

### Stimulus tuning experiment

In order to tune a metameric stimulus which has a higher ipRGC contrast but independent from the cones activities taking into account individual differences in cone distribution (reference), we first identified a metermaric light with high ipRGC light by 2AFC experiment. Figure 2D shows the CIE xy of the candidate low ipRGC light and number of participants in each light that was judged to be regarded as a metameric to the high ipRGC light. In all subjects, the selected light was reported as being perceived as the same color at least once (Supplementary Figure 1). The averaged luminance of selected low ipRGC calculated based upon CIE photoreceptor sensitivities was 708.615 17.355 cd/m2. The averaged Michelson contrast of ipRGC across used metamar pair was 24.757 2.517%.

CIE xy (0.412, 0.241)

### Brightness

By using the metermaric light in each participants, we confirmed the activation of ipRGC by the brightness judgement experiment. Figure 1E shows the ratio of adjusted luminance to high ipRGC light. The high ipRGC light was perceived around 20% more brighter than the low ipRGC light ((26) = 4.53, < 0.001, Cohen’s = 1.233, > 100), consistent with previous studies (Brown et al., 2012, Yamakawa et al.,2019).

### Tonic pupil response

Pupil size was measured using an infrared camera while participants were lighted low and high ipRGC light and engaged in 1- or 2-back task (see Method). Figure 2B illustrates the averaged pupil size during 1- and 2-back task in each lighting condition. A two-way repeated measures ANOVA for the main effect of light showed that the pupil size for high ipRGC light was significantly smaller than for low ipRGC light ((1,25) = 21.614, p < 0.001, = 0.464, > 100), consistent with the previous studies as an effect of activation of ipRGC. Following post analysis also showed that the pupil size in both N-back task for high ipRGC light was smaller than for low ipRGC light ((25) = -4.489, < 0.001, Cohen’s = -0.603, > 100, (25) = -4.619, < 0.001, Cohen’s = -0.676, > 100). In addition, the pupil size of 2-back task was larger than of 1-back task as reported an effect of cognitive load differences previously ((1,25) = 14.086, = 0.001, = 0.36, = 0.981), as reported here and elsewhere.

### Accuracy

To see the effect of light on the task performance of N-back task, we compared the hit rate between the lighting condition as illustrated in Figure 2C. We found the main effect of light showing that the the hit rate under high ipRGC was higher than under low ipRGC ((1,25) = 4.872, = 0.037, = 0.163, = 0.683). There are significant of interaction between N-back and light condition ((1,25) = 5.298, = 0.03, = 0.175, = 0.584). Post analysis showed that the higher accuracy under high ipRGC was seen in the 2-back but not in the 1-back (1-back;(25) = 0.702, = 0.489, Cohen’s = 0.078, = 0.259, 2-back;(25) = 2.728, = 0.011, Cohen’s = 0.508, = 4.2). As an effect of working memory load on accuracy, the hit rate of 1-back task is higher than of 2-back task ((1,25) = 30.83, p < 0.001, = 0.552, > 100). The False alarm also decreased in the 2-back task under high ipRGC with marginaly significance ((25) = 1.914, = 0.067, Cohen’s = 0.421, = 1.003). The details of hit, miss, false alarm and correct rejection are shown in Tables S1.

### RT

Response time (RT) was calculated from the stimulus onset to the participants’ key presses. Linear mixed model analyses were conducted corresponds to the following formula: . To statistically assess whether the RTs differed between lighting conditions, 95% confidence intervals (CI) for the RTs were estimated with 10000 bootstrap samples. The estimated CIs of RTs between low and high ipRGC was [-27.586, -9.405], (26) = 4.536, < 0.001 for 1-back and [-18.313, 10.051], (26) = 0.364, =0.716 for 2-back shown at top in Figure2D. The RTs was significantly faster for high ipRGC light for both 1- and 2-back task.

## Questionare

To test whether the light condition affect to participants’ fatigue and Sleepiness, we asked the participants to rate their subjective Fatigue and Sleepiness from 0-10. We report the fixed effects of following model including the order of the session is better than the model with light and run. The scores was negatively affected by the light condition, indicating that the high ipRGC light contributed less subjective score for both fatigue and Sleepiness ((26) = -2.157, =0.032, (26) = -4.602, < 0.001). With increasing time on the task, the subjective fatigue and Sleepiness score was significantly increased from run 1 to 6 ((26) = 4.058, < 0.001, (26) = 3.699, < 0.001)

To determine how the light condition affected the hit rate compared with participants’ fatigue and Sleepiness, we modeled the LME using light condition, Sleepiness, and Fatigue as fixed effects. Light condition and Fatigue are positively affected by the hit rate for 2-back task ( i.e., higher ipRGC and subjective fatigue increased the hit rate) (=2.858, =0.005; =2.394, =0.018). On the other hand, Sleepiness negatively contributed to the hit rate (i.e., lower Sleepiness improved the hit rate) (=-1.991, =0.048).

### Phasic pupil response

# Supplementary Figure

## Table for hit, miss, FA and CR

### 1-back

| sdt | low\_ipRGC | high\_ipRGC |
| --- | --- | --- |
| hit(n.s.) | 95.93 ± 7.254 | 96.491 ± 4.977 |
| miss(n.s.) | 0.041 ± 0.073 | 0.035 ± 0.05 |
| FA(n.s.) | 0.325 ± 0.456 | 0.366 ± 0.364 |
| CR(n.s.) | 99.675 ± 0.456 | 99.634 ± 0.364 |

### 2-back

| sdt | low\_ipRGC | high\_ipRGC |
| --- | --- | --- |
| hit(\*) | 88.754 ± 6.378 | 91.718 ± 4.996 |
| miss(\*) | 0.112 ± 0.064 | 0.083 ± 0.05 |
| FA(+) | 1.875 ± 1.403 | 1.373 ± 0.828 |
| CR(+) | 98.125 ± 1.403 | 98.627 ± 0.828 |

# corr

# regress out the effect of time-on-task

# f = list.files(folderName, pattern = "questionaire.json", full.names=T)  
# df = fromJSON(file=f[1])  
#   
# for(iName in 1:length(df)){  
# df[[iName]] = unlist(df[[iName]])  
# }  
# df = as.data.frame(df)  
#   
# f = list.files(folderName, pattern = "data\_timeCourse\_RunAve.json", full.names=T)  
# df2 = fromJSON(file=f[1])  
#   
# for(iName in 1:length(df2)){  
# df2[[iName]] = unlist(df2[[iName]])  
# }  
#   
# df2 = as.data.frame(df2)  
# df2 = df2[order(df2$sub,df2$Run,df2$Nback),]  
# df = df[order(df$sub,df$Run),]  
#   
# f = list.files(folderName, pattern = "df\_targetAll", full.names=T)  
# df\_pupil = fromJSON(file=f[1])  
#   
# for(iName in 1:length(df\_pupil)){  
# df\_pupil[[iName]] = unlist(df\_pupil[[iName]])  
# }  
# df\_pupil = as.data.frame(df\_pupil)  
#   
# df\_RT = df\_pupil[df\_pupil$hit==1,]  
# df\_RT = aggregate( . ~ sub\*Run\*light\*Nback, data = df\_RT, FUN = 'mean')  
#   
# df\_pupil$PD\_phasic= df\_pupil$Pupil.a.u..  
#   
# df\_pupil = aggregate( . ~ sub\*Run\*light\*Nback, data = df\_pupil, FUN = 'mean')  
# # df\_pupil = aggregate( . ~ sub\*Run\*light\*Nback, data = df\_pupil, FUN = 'sd')  
#   
# df\_pupil = df\_pupil[order(df\_pupil$sub,df\_pupil$Run,df\_pupil$Nback),]  
# df\_RT = df\_RT[order(df\_RT$sub,df\_RT$Run,df\_RT$Nback),]  
#   
# df\_pupil$RT = df\_RT$RT  
# df\_pupil$Sleepiness = df2$Sleepiness  
# df\_pupil$Fatigue = df2$Fatigue  
#   
# df\_pupil$lightNum = 0  
# df\_pupil[df\_pupil$light=="high ipRGC",]$lightNum = 1  
#   
#   
# df\_pupil = aggregate( . ~ sub\*light\*Nback, data = df\_pupil, FUN = 'mean')  
#   
# modelList = c(  
# # "hit ~ lightNum + Sleepiness + Fatigue + (1+Run| sub)",  
# # "hit ~ Sleepiness + Fatigue + (1+Run| sub)",  
# # "hit ~ lightNum + Sleepiness + (1+Run| sub)",  
# # "hit ~ lightNum + Fatigue + (1+Run| sub)",  
# # "hit ~ Sleepiness + (1+Run| sub)",  
# # "hit ~ Fatigue + (1+Run| sub)",  
# # "hit ~ lightNum \* Sleepiness \* Fatigue + (1+Run| sub)",  
# # "hit ~ Sleepiness \* Fatigue + (1+Run| sub)",  
# "hit ~ lightNum \* Sleepiness \* Fatigue + (1| sub)"  
# )  
#   
# df\_pupil$hit <- scale(df\_pupil$hit)[,1]  
# df\_pupil$RT <- scale(df\_pupil$RT)[,1]  
# df\_pupil$lightNum <- scale(df\_pupil$lightNum)[,1]  
# df\_pupil$Sleepiness <- scale(df\_pupil$Sleepiness)[,1]  
# df\_pupil$Fatigue <- scale(df\_pupil$Fatigue)[,1]  
#   
# # estimateAll = NULL  
# # aic\_res = NULL  
# # bic\_res = NULL  
# for( m in modelList){  
# inback= "2-back"  
# # for(inback in unique(df\_pupil$Nback)){  
#   
# tmp\_df = df\_pupil[(df\_pupil$Nback==inback),]  
#   
# # tmp\_df = aggregate( . ~ sub\*light\*Nback, data = tmp\_df, FUN = 'mean')  
#   
# eval(parse(text=paste0(" model\_cand <- lmer(",m,", data=tmp\_df)")))  
# # print(summary(model\_cand))  
# sm = summary(model\_cand)  
# # print(AIC(model\_cand))  
# # fixef(model\_cand)  
# # aic\_res = c(aic\_res,AIC(model\_cand))  
# # bic\_res = c(bic\_res,BIC(model\_cand))  
#   
# sm = summary(model\_cand)  
# print(inback)  
# print(m)  
# print(sm$coefficients)  
# }  
 # }  
   
 # eval(parse(text=paste0(" m <- lmer(",modelList[which.min(aic\_res)],", data=tmp\_df)")))  
 # eval(parse(text=paste0(" m <- lmer(",modelList[which.min(bic\_res)],", data=tmp\_df)")))  
 #   
 # print(modelList[which.min(aic\_res)])  
 # sm = summary(m)  
 # print(sm)  
  
  
 # tmp = data.frame(  
 # Estimate = c(  
 # # sm$coefficients["BP",]["Estimate"],  
 # # sm$coefficients["PD\_phasic",]["Estimate"],  
 # sm$coefficients["Sleepiness",]["Estimate"],  
 # sm$coefficients["Fatigue",]["Estimate"],  
 # sm$coefficients["lightNum",]["Estimate"]),  
 # factor = c(  
 # # "Baseline",  
 # # "Transient",  
 # "Sleepiness",  
 # "Fatigue",  
 # "ipRGC"),  
 # pVal = c(  
 # # sm$coefficients["BP",]["Pr(>|t|)"],  
 # # sm$coefficients["PD\_phasic",]["Pr(>|t|)"],  
 # sm$coefficients["Sleepiness",]["Pr(>|t|)"],  
 # sm$coefficients["Fatigue",]["Pr(>|t|)"],  
 # sm$coefficients["lightNum",]["Pr(>|t|)"]),  
 # min = c(  
 # # sm$coefficients["BP",]["Pr(>|t|)"],  
 # # sm$coefficients["PD\_phasic",]["Pr(>|t|)"],  
 # sm$coefficients["Sleepiness",]["Estimate"]-sm$coefficients["Sleepiness",]["Std. Error"],  
 # sm$coefficients["Fatigue",]["Estimate"]-sm$coefficients["Fatigue",]["Std. Error"],  
 # sm$coefficients["lightNum",]["Estimate"]-sm$coefficients["lightNum",]["Std. Error"]),  
 # max = c(  
 # # sm$coefficients["BP",]["Pr(>|t|)"],  
 # # sm$coefficients["PD\_phasic",]["Pr(>|t|)"],  
 # sm$coefficients["Sleepiness",]["Estimate"]+sm$coefficients["Sleepiness",]["Std. Error"],  
 # sm$coefficients["Fatigue",]["Estimate"]+sm$coefficients["Fatigue",]["Std. Error"],  
 # sm$coefficients["lightNum",]["Estimate"]+sm$coefficients["lightNum",]["Std. Error"]),  
 # t = c(  
 # # sm$coefficients["BP",]["Pr(>|t|)"],  
 # # sm$coefficients["PD\_phasic",]["Pr(>|t|)"],  
 # sm$coefficients["Sleepiness",]["t value"],  
 # sm$coefficients["Fatigue",]["t value"],  
 # sm$coefficients["lightNum",]["t value"])  
 # )  
 #   
 # tmp$formula = c(sm$call$formula)  
 # tmp$Nback = inback  
 #   
 # estimateAll = rbind(estimateAll,tmp)

# Path analysis

# Figure