

## Supplemental Material

Native language promotes access to visual consciousness

Martin Maier<sup>1,2</sup> and Rasha Abdel Rahman<sup>1,2</sup>

<sup>1</sup>Humboldt-Universität zu Berlin

<sup>2</sup>Berlin School of Mind and Brain

This Supplemental Material presents results of additional analyses that may support a more detailed understanding of the results. Experiment 1 established that categorical perception (CP) of light and dark shades of blue in Greek native speakers promotes the access of target stimuli to visual consciousness in the attentional blink paradigm (AB), as demonstrated in behavior and ERP signatures. These effects can be attributed to linguistically induced CP because matched shades of green—measured to be equally salient—were used as a control condition for the blue stimuli. Experiment 2 further ruled out the possibility that the premise of equally salient stimuli in the blue and green condition could be false due to measuring inaccuracy or inaccuracy of the Munsell color system. Experiment 3 replicated the behavioral results of Experiment 1 with a different group, Russian native speakers, who, like Greek speakers, make a basic-level categorical distinction between light and dark shades of blue.

Here, we first report additional analyses of the EEG data of Experiments 1 and 2 with experiment as a factor. We then report an additional analysis of behavioral data across Experiments 1 to 3 to confirm that the overall AB effect was comparable across experiments. Finally, we report an analysis of the behavioral data of Experiments 1 and 3 including several covariates. We explored whether the behavioral CP effect was associated with general task

performance (as indicated by correct rejection rates), the amount of time spent in Germany, and self-rated proficiency in German.

### **Supplemental ERP results**

Table S1 shows ERP results of an LMM analyzing the P1 and N2 components in Lag 3 hit trials with the fixed effects color contrast and experiment (2-1). In both, P1 and N2, interactions of color contrast (blue-green)  $\times$  experiment suggest that electrophysiological signatures of processing blue vs. green targets differed between Greek and German speakers.

Table S2 summarizes the results of a GLMM analyses on the relationship between ERPs and lag 3 hit rates across Experiments 1 and 2. The GLMM included the fixed factors P1 amplitude, N2 amplitude, color contrast, and experiment. Removing interactions with the fixed effect N2 amplitude improved model fit ( $\Delta_{AIC} = -12$ ,  $\Delta_{BIC} = -97$ ). Main effects of P1 amplitude and N2 amplitude showed that P1 and N2 predicted hit rates in both experiments. The interaction of experiment  $\times$  color contrast (blue-green)  $\times$  P1 amplitude reflects the fact that the larger P1 for the blue compared to the green contrast observed in Greek speakers predicted hit rates in Experiment 1, while there was no such relationship in Experiment 2. This supports the interpretation in the main article that differences in early visual processing are an underlying mechanism of the behavioral CP-effect in Greek speakers specifically.

Table S1

LMM statistics for mean ERP-amplitudes in the P1 and N2 time windows across Experiments 1 and 2

Variable	P1				N2			
	<i>b</i>	<i>SE</i>	<i>t</i>	<i>p</i>	<i>b</i>	<i>SE</i>	<i>t</i>	<i>p</i>
Mean amplitude (intercept)	0.728	0.174	4.190	<.001***	-0.419	0.161	-2.608	.012*
Color contrast (B-G)	0.063	0.129	0.492	.625	-0.132	0.108	1.218	.223
Color contrast (M-B)	-0.042	0.122	-0.343	.733	0.115	0.107	1.077	.282
Color contrast (M-G)	0.021	0.113	0.188	.851	0.247	0.107	2.302	.021*
Exp (2-1)	-0.711	0.347	-2.048	.045*	-0.054	0.322	-0.169	.886
Exp:Color contrast (B-G)	-0.577	0.258	-2.234	.031*	-0.474	0.216	-2.193	.028*
Exp:Color contrast (M-B)	0.051	0.245	2.069	.045*	0.399	0.214	1.867	.062
Exp:Color contrast (M-G)	-0.069	0.227	-0.303	.763	-0.075	0.214	-0.352	.725
Variance components	<i>SD</i>	Goodness of fit			<i>SD</i>	Goodness of fit		
Participants	1.248	Log likelihood		-27394.8	1.149	Log likelihood		-27158.4
Color contrast (B-G)	0.457	REML deviance		54789.6	- <sup>†</sup>	REML deviance		54316.7
Color contrast (M-B)	0.385				-			
Color contrast (M-G)	0.202				-			
Residuals	4.351				4.249			

*Note.* B = blue contrast, G = green contrast, M = mixed contrast, Exp = Experiment, “:” indicates interactions between factors or covariables. \*\*\*  $p < .001$ , \*  $p < .05$ . <sup>†</sup>In the reduced LMM for the N2 time window, only the random intercept for Participants remained in the random structure.

Table S2

Binomial GLMM statistics for the association between lag 3 Hit rates and ERP-amplitudes in the P1 and N2 across Experiments 1 and 2

Variables relevant for ERP-behavior associations	<i>b</i>	<i>SE</i>	<i>z</i>	<i>p</i>
Logit mean hit rate (intercept)	0.442	0.157	2.820	.005**
P1 amp	0.109	0.022	4.920	<.001***
N2 amp	-0.264	0.023	-11.709	<.001***
Exp:P1 amp	0.049	0.039	1.276	.202
Color contrast (B-G):P1 amp	0.030	0.045	0.654	.513
Color contrast (M-B):P1 amp	0.036	0.046	0.783	.434
Color contrast (M-G):P1 amp	0.066	0.046	1.434	.152
Exp:Color contrast (B-G): P1 amp	-0.226	0.090	-2.510	.012*
Exp:Color contrast (M-B):P1 amp	0.155	0.092	1.683	.092
Exp:Color contrast (M-G):P1 amp	-0.071	0.092	-0.777	.437
<b>Other variables</b>				
Color contrast (B-G)	0.074	0.046	1.600	.110
Color contrast (M-B)	0.132	0.046	2.845	.004**
Color contrast (M-G)	0.206	0.046	4.465	<.001***
Exp (2-1)	-0.153	0.314	-0.487	.626
Exp:Color contrast (B-G)	-0.092	0.092	-1.004	.316
Exp:Color contrast (M-B)	-0.072	0.093	-0.778	.437
Exp:Color contrast (M-G)	-0.165	0.092	-1.786	.074
<b>Variance components</b>		<i>SD</i>	Goodness of fit	
Participants	1.174	Log likelihood	-8647.3	
		REML deviance	17294.6	

*Note.* B = blue contrast, G = green contrast, M = mixed contrast, Exp = Experiment, amp = mean amplitude, “:” indicates interactions between factors or covariables. \*\*\*  $p < .001$ , \*\*  $p < .01$ , \*  $p < .05$ .

### Supplemental Behavioral Results across Experiments 1–3

Table S3 summarizes the results of the GLMM analysis on hit rates by lag, and experiment. The main effect of lag shows that Experiments 1 to 3 yielded an AB effect of comparable size.

Table S3

Binomial GLMM statistics for Hit rates across Experiments 1 to 3

Variable	<i>b</i>	<i>SE</i>	<i>z</i>	<i>p</i>
Logit mean hit rate (intercept)	1.092	0.104	10.475	<.001***
Exp (2-1)	-0.123	0.275	-0.447	0.655
Exp (3-2)	0.149	0.244	0.611	0.541
Lag (7-3)	1.131	0.077	14.653	<.001***
Exp(2-1):Lag(7-3)	0.116	0.199	0.583	0.560
Exp(3-2):Lag(7-3)	-0.311	0.178	-1.746	0.081
Variance components	<i>SD</i>	Goodness of fit		
Participants	1.011	Log likelihood	-20358.5	
Lag	-0.200	REML deviance	40717.1	

Note. Exp = Experiment, “:” indicates interactions between factors or covariables.

\*\*\*  $p < .001$ .

### Does the CP-effect depend on the definition of hits?

All behavioral results of the main article are based on analyses of hit rates. Hits were defined in terms of successful task performance, that is, correct objective report of targets T1 and T2, as well as subjectively seeing T2. Thus, a hit was a combination of an objective measure (correct classification of the direction of the triangle) and a subjective measure of how much of T2 was seen in each trial (nothing – slight impression – strong impression – complete). To rule out that the subjective confidence in seeing a target could drive the observed effects, we analyzed the behavioral data with a more relaxed definition of hits, by omitting the subjective part and using the objective measure (T2 classification) only. Note that correct classification can also contain guessing of the direction of T2 without actually seeing T2. Table S4 summarizes the results of a GLMM analysis of correct T2 classification

rates across Experiments 1 to 3 with the factor language (cf. Table 6 in the main article). As depicted in Figure S1 (cf. Figures 2, 5, and 8), the results based on a more relaxed definition of hits replicate the results based on the original definition reported in the main article. To conclude, the behavioral effects do not appear to be driven by participants' subjective impression of seeing T2 on top of the objective report.

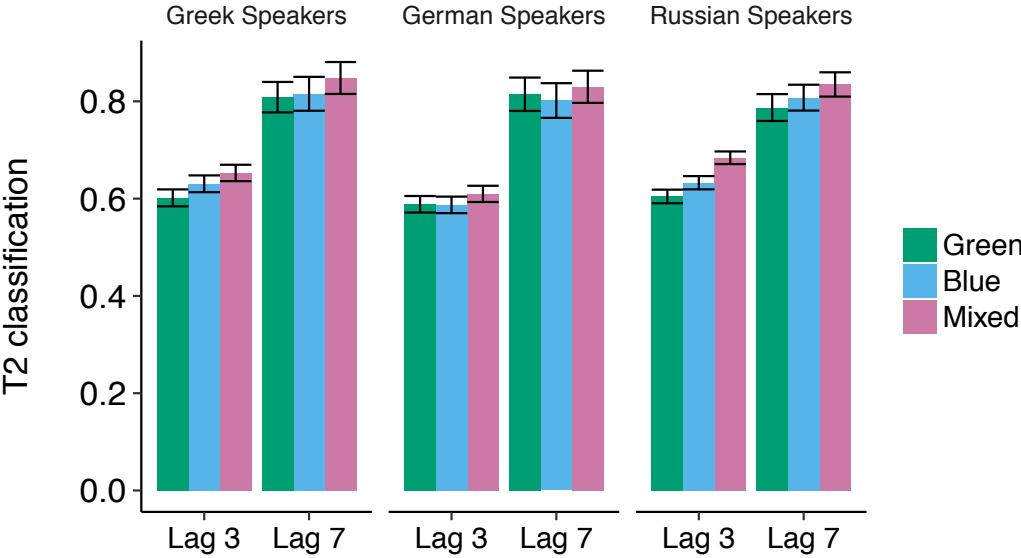


Figure S1: T2 classification performance of Greek, German and Russian speakers. Correct T2 classification rates per group, lag, and color contrast. Error bars represent 95% CI. The results closely resemble the results based on more strictly defined hit rates reported in the main article.

Table S4

GLMM statistics for T2 classification rates with the factor language

Variable	<i>b</i>	<i>SE</i>	<i>z</i>	<i>p</i>
Logit mean classification rate (intercept)	1.132	0.113	9.984	<.001***
Language (GrRu-De)	0.124	0.227	0.544	.587
Color contrast (B-G)	0.050	0.034	1.489	.137
Color contrast (M-B)	0.191	0.034	5.595	<.001***
Lag (7-3)	1.136	0.079	14.442	<.001***
Language:Color contrast (B-G)	0.152	0.068	2.254	.024*
Language:Color contrast (M-B)	0.081	0.068	1.192	.233
Variance components	<i>SD</i>	Goodness of fit		
Participants	1.013	Log likelihood		-20178.5
Lag	0.669	REML deviance		40357.0

*Note.* GrRu = grouped Greek and Russian speakers, De = German speakers, B = blue contrast, G = green contrast, M = mixed contrast, “:” indicates interactions between factors or covariables. \*  $p < .05$ , \*\*\*  $p < .001$ .

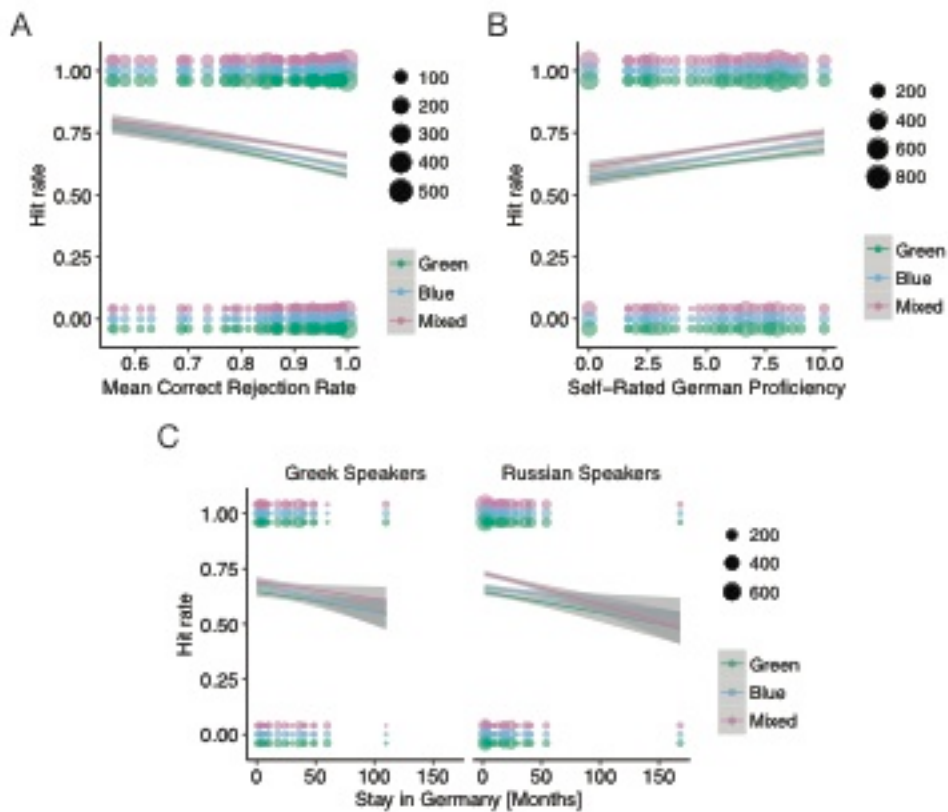
### Influences of covariates on hit rates

To test whether general task performance in terms of correct rejection rate, the amount of time spent in Germany and proficiency in German influence the behavioral CP effect, we included these covariates in an exploratory analysis of hit rates in Experiments 1 and 2. Note, however, that recruitment of participants aimed to find Greek and Russian native speakers with a short stay in Germany and little German skills. This was not always feasible and no participants were excluded based on the time spent in Germany and their German skills. However, in the present study, these covariates likely contain a too limited data range to draw general conclusions on their relationship with CP. Self-rated proficiency in German was calculated as the average score of three items in the Language Experience and Proficiency Questionnaire (LEAP-Q; Marian, Blumenfeld, & Kaushanskaya, 2007), indicated on a scale ranging from 0 to 10: speaking, understanding spoken language, and reading. Data from four participants were missing. While these participants indicated in the questionnaire that German was one of their spoken languages, they did not indicate their proficiency level.

In the final GLMM, interaction terms with the factors proficiency in German, lag, and individual mean correct rejection rate were excluded because they were not supported by the data. Furthermore, random effects other than the participant intercept prevented model convergence and were excluded. Table S5 summarizes the results of this GLMM analysis.

The results showed that the CP effect (i.e. a difference between the blue and green contrast in hit rates) was not influenced by any of the covariates. Next to the main effects of color contrast and lag reported in the main article, the analysis revealed a main effect of self-rated proficiency in German, which was associated with higher hit rates (Figure S2). Furthermore, there was a significant three-way interaction of group (Russian-Greek)  $\times$  color contrast (mixed-blue)  $\times$  stay in Germany (Figure S2). A subsequent nested model revealed that the advantage in the mixed condition decreased with more time spent in Germany in Russian speakers ( $b = -0.091, z = -2.292, p = .022$ ) but not in Greek speakers ( $b = 0.094, z = 1.343, p = .179$ ). We are not sure why the influence of the bottom-up saliency of the mixed contrast should get weaker as Russian speakers spend time in Germany. In fact, we would have expected no influence, as observed in Greek speakers. Visual impression (Figure S2) suggests that outliers might as well fuel this relationship.





*Figure S2: Relation between covariates and hit rates in Greek and Russian speakers (Experiments 1 and 3). (A) Individual mean correct rejection rates did not significantly influence hit rates or the CP effect. (B) Self-rated proficiency in German was significantly associated with higher hit rates. (C) With increasing time spent in Germany, the advantage of the mixed contrast condition diminished significantly in Russian speakers, but not in Greek speakers. *Note:* Dots visualize the range and distribution of the covariates across participants. Dot size indicates the number of hits and misses per color contrast at each value of the respective covariate. Gray shading around regression lines indicates 95% CI.*

Table S5

Binomial GLMM statistics on Hit rates in Experiments 1 and 2 including covariates

Variable	<i>b</i>	<i>SE</i>	<i>z</i>	<i>p</i>
Logit mean hit rate (intercept)	1.174	0.127	9.258	<.001***
Group (Ru-Gr)	- 0.100	0.275	-0.364	.716
Color contrast (B-G)	0.136	0.037	3.672	<.001***
Color contrast (M-B)	0.212	0.038	5.631	<.001***
Stay_c	-0.223	0.152	-1.469	.142
Lag (7-3)	1.055	0.045	23.388	<.001***
Prof_c	0.310	0.152	2.031	.042*
Rej_c	-0.165	0.127	-1.300	.194
Group:Color contrast (B-G)	0.042	0.074	0.570	.569
Group:Color contrast (M-B)	0.110	0.075	1.465	.143
Group:Stay_c	0.081	0.266	0.304	.761
Color contrast (B-G):Stay_c	-0.027	0.039	-0.688	.492
Color contrast (M-B):Stay_c	0.002	0.040	0.043	.966
Group:Color contrast (B-G):Stay_c	0.113	0.079	1.432	.152
Group:Color contrast (M-B):Stay_c	-0.185	0.080	-2.297	.022*
Variance components	<i>SD</i>	Goodness of fit		
Participants	0.996	Log likelihood		-13839.3
		REML deviance		27678.7

*Note.* Ru = Russian Speakers, Gr = Greek Speakers, Stay\_c = Months Stayed in Germany (centered), Prof\_c = Self-rated Proficiency in German (centered), Rej\_c = Individual Mean Correct Rejection Rate (centered), “:” indicates interactions between factors or covariables.

\*  $p < .05$ , \*\*\*  $p < .001$ .

### References

- Marian, V., Blumenfeld, H. K., & Kaushanskaya, M. (2007). The Language Experience and Proficiency Questionnaire (LEAP-Q): Assessing Language Profiles in Bilinguals and Multilinguals. *Journal of Speech, Language, and Hearing Research*, 50(4), 940-967. doi:10.1044/1092-4388(2007/067)