Supplementary Material for:

Welke, D., & Vessel, E.A. (2022). Naturalistic viewing conditions can increase task engagement and aesthetic preference but have only minimal impact on EEG quality.

Participant demographics

See Supp.Tabs. 1 and 2 for full sample demographics.

Supp.Table 1: Categorical demographic factors

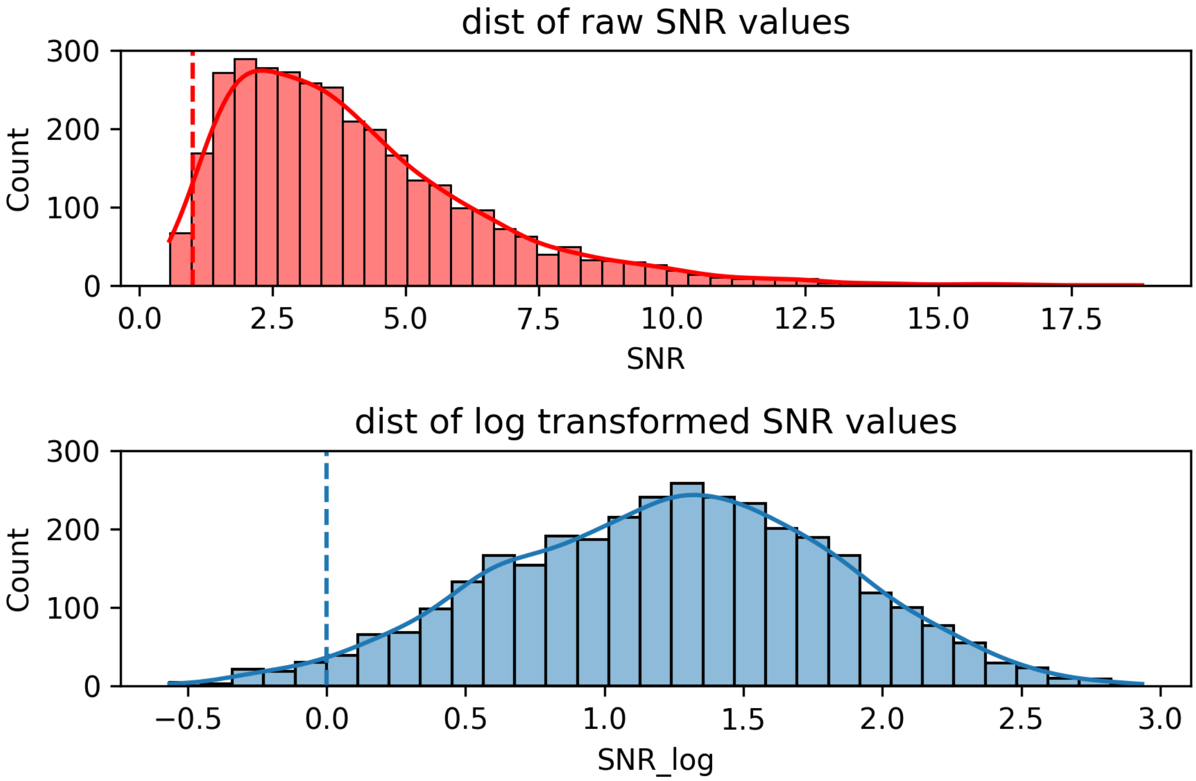
Variable	n
Sex	
Female	26
Male	17
Other	0
Handedness	
Right	39
Left	2
Ambidextrous	2
Eye dominance	
Right	33
Left	6
No dominance	4
Highest degree of education	
Mittlere Reife	2
Ausbildung	1
Abitur	24
Studium	16
Mental disorder	
No	34
Yes	9
Neurological disorder	
No	42
Yes	1

Supp.Table 2: Continuous demographic factors

Variable	n	M	SD	min	max	25%	50%	75%
Age	43	27.1	7.06	19	52	22.5	25	30
Years of education	43	17.8	3.55	9	25	15	18	20
Caffeine intake [mg/kg]	43	0.84	1.041	0.00	4.28	0.00	0.52	1.43
BFI (range 3-15)								
extraversion	43	9.30	1.897	5	13	8	9	10.5
open mindedness	43	12.14	1.684	8	15	11	13	13
agreeableness	43	11.28	1.894	7	15	10	12	12.5
conscientiousness	43	10.65	2.516	5	15	9	11	13
negative emotionality	43	8.23	2.983	3	15	6	8	10
PANAS (range 6-30)								
positive	43	17.60	4.588	9	25	14	18	21
negative	43	7.47	2.364	6	15	6	6	7.5
SHAPS (range 0-14)	43	1.02	1.318	0	5	0	1	2
BPS (range 8-56)	43	19.07	8.213	8	49	15.5	17	21.5

Log transformation of ASSR SNR

SNR values were log transformed to shift them from a skewed gamma to a more gaussian distribution (see Supp.Fig. 1). We applied the natural logarithm to average SNR values over all EEG channels for each participant and each trial.



Supp.Figure 1: Distribution of raw and log transformed SNR values across all participants (N=43)

Full ANOVA tables

Results of all repeated measures ANOVA models in the study are compiled in Supp.Tab. 3.

Supp.Table 3: Full ANOVA results

Measure	n	M	SD	$F\,(1, 42)$	η_p^2
ASSR SNR	344	1.430	0.499		
fixation task				6.24*	0.13
stimulus dynamics				0.81	0.02
stimulus content				2.47	0.06
dynamics x task				1.83	0.04
dynamics x content				2.04	0.05
content x task				0.01	0.00
dynamics x content x task				0.94	0.02
Aesthetic rating	344	0.18	0.32		
fixation task				4.02	0.09
stimulus dynamics				29.72***	0.41
stimulus content				50.21***	0.54
dynamics x task				2.63	0.06
dynamics x content				18.50***	0.31
content x task				0.02	0.00
dynamics x content x task				3.29	0.07
Boredom rating	344	-0.19	0.36		
fixation task				2.16	0.05
stimulus dynamics				41.18***	0.50
stimulus content				1.30	0.03
dynamics x task				0.15	0.00
dynamics x content				18.92***	0.31
content x task				0.97	0.02
dynamics x content x task				0.03	0.00

Measure	n	M	SD	$F\,(1, 42)$	η_p^2
Eye blinks	344	0.51	0.78		
fixation task				27.46^{***}	0.40
stimulus dynamics				4.96^{*}	0.11
stimulus content				3.63	0.08
dynamics x task				0.90	0.02
dynamics x content				9.89^{**}	0.19
content x task				2.49	0.06
dynamics x content x task				3.46	0.08
Saccades	344	6.91	6.25		
fixation task				420.17^{***}	0.91
stimulus dynamics				152.88^{***}	0.78
stimulus content				135.02^{***}	0.76
dynamics x task				125.92^{***}	0.75
dynamics x content				58.36^{***}	0.58
content x task				113.23^{***}	0.73
dynamics x content x task				28.85^{***}	0.41
Microsaccades	344	8.67	4.54		
fixation task				0.45	0.01
stimulus dynamics				79.49^{***}	0.65
stimulus content				25.43^{*}	0.11
dynamics x task				0.86	0.02
dynamics x content				24.13^{***}	0.36
content x task				31.25^{***}	0.43
dynamics x content x task				7.83^{**}	0.16

Measure	n	M	SD	$F\,(1,\,42)$	η_p^2
Heart rate deceleration	344	-3.55	2.00		
fixation task				3.90	0.08
stimulus dynamics				11.24^{**}	0.21
stimulus content				0.13	0.00
dynamics x task				0.30	0.01
dynamics x content				0.34	0.01
content x task				1.07	0.02
dynamics x content x task				0.53	0.01

Trial wise correlation of all dependent measures

See Supp.Tab. 4 for full trial wise correlation structure of the collected dependent measures.

Supp.Table 4: Full correlation table for trialwise measures

Measure	n	M	SD	1	2	3	4	5	6
ASSR SNR	3349	1.43	0.64	–					
Ratings									
aesthetic	3349	.19	.53	−.046	–				
boredom	3349	-.19	.58	.038	−.580***	–			
Eye movements									
eye blinks	3189	0.54	1.06	−.053*	−.059*	.078***	–		
saccades	3349	7.03	6.91	−.041	.018	.029	–	–	
microsaccades	3349	8.64	6.01	.000	−.086***	.126***	–	–	–
Heart rate change (bpm)	3336	-3.57	4.48	−.036	.005	−.010	.049	.059*	−.000

Note: *r* values computed using repeated measures correlation (Bakdash & Marusich, 2017). $^{*}p < .05$, $^{***}p < .001$. p values corrected using Holm's method (Holm, 1979). n trials for eye blinks is lower because two participants exhibited zero blinks over all trials, which prevented the model to converge; n trials for HR deceleration is lower because outliers were rejected. Correlation between the different eye measures was not investigated.

Frequency dependent correlation of eye tracking signal and EEG

As it is unclear whether our proxy measure for signal quality, SNR of the 40 Hz ASSR, might be confined to detect noise only of a specific frequency characteristic (e.g. close to the low gamma range) we wanted to investigate another frequency dependant measures for noise detection. Given the well known physiological effect of eye movements on EEG, we want to test whether the time-varying band power in a given frequency band of the EEG signal is correlated with band power of the EOG in the same frequency band. This might hint at an induction of artifactual eye movement related signal into the EEG, thereby potentially confounding frequency based analysis. Here we correlated global field power (GFP) of EEG and eye tracking data in the commonly used frequency bands delta (1-3 Hz), theta (4-7 Hz), alpha (8-12 Hz), beta (13-25 Hz), low gamma (30-45 Hz), and high gamma (45 – 120 Hz).

Methods: We largely followed the analysis as described in (Engemann & Appelhoff, n.d.), which uses an adapted version of the method described in (Hari, 1997).

As we did not record EOG, X and Y coordinates of the fixation time series from the calibrated eye tracking data were taken as the raw data to indicate eyeball movements. These two signals can be expected to carry similar information, as changes in X and Y fixation location on the screen are caused by horizontal and vertical eye movements and directly reflect eyeball rotation. Missing values (e.g. caused by blinks) were exchanged with zeros. EEG data were down-sampled to 500 Hz, the sampling frequency of the eye tracker.

First EEG and ET data were bandpass filtered according to the respective frequency band (FIR, zero-phase, 1 Hz transition band, filter length automatically chosen based on the size of the transition regions). Then a Hilbert transform was applied. Next, the evoked response was subtracted from every single trial of the EEG to reveal oscillatory activity (but not from the eye tracking signal). The signals were rectified per channel by taking the magnitude of the Hilbert transform. Then the GFP was computed using the sum of squares, across all channels (EEG) and across left and right eye channels of binocular recordings respectively. The procedure was repeated for each frequency band of interest and the correlation between EEG GFP on the one hand and GFP of vertical and horizontal component of the eye movements on the other hand was computed for each participant. Repeated measures correlation (Bakdash & Marusich, 2017) was used to account for the trial structure of the data (using the trial number as grouping variable). This procedure was conducted with all trials from all conditions. In a last step, average correlation coefficients across participants were calculated for all frequency bands. Significance statements are difficult, as the multiple comparison problem cannot be addressed in a straightforward manner. We decided for the following approach: as individual correlation coefficients on the participant level have corresponding p-values, these were corrected for multiple comparison using Holm's method (Holm, 1979), and the average Holm-corrected p-value as well as the percentage of significant data points is reported for each frequency band. However, we think that the resulting significance values should not be over-interpreted.

Results: Supp.Tab. 5 summarizes the results of the correlation analysis. We see that there is indeed a substantial correlation between oscillatory dynamics in EEG and Eye movements in certain frequency bands. Especially in the lower frequencies (Delta, Theta) the two signals correlate very strongly, while the correlation falls off steeply in the medium and high frequency bands starting with the alpha-band around 8 Hz. Qualitatively, horizontal eye movements seem to be slightly stronger linked to EEG band power dynamics.

Average Holm-corrected p-values across participants are reported in Tab. 6. Most of the correlation coefficients (per participant) between eye movements and EEG were significant after multiple-comparison correction ($p < .05$): 84.9 % for horizontal eye movements and 82.2 % for vertical eye movements.

Supp.Table 5: Correlation between global field power of EEG and eye tracking (ET) signal in different frequency bands

Frequency band	EEG x horizontal ET	EEG x vertical ET
Delta (1-4 Hz)	.68***	.61*
Theta (4-7 Hz)	.51***	.47*
Alpha (8-12 Hz)	.10*	.10*
Beta (13-25 Hz)	.03	.03
Gamma low (30-45 Hz)	.01	.01
Gamma high (46-120 Hz)	.01	.01

Note: r values computed using repeated measures correlation (Bakdash & Marusich, 2017) across trials for each participants; depicted values are grand averages across all participants. p-values for each participant corrected using Holm's method (Holm, 1979) and averaged across participants. $^{*}p < .05$, $^{***}p < .001$

Discussion: In general, the analysis shows that in our data oscillatory dynamics of EEG and eye movements can be linked, depending on the frequency band. This is in line with an induction of artifactual signal into the EEG, which was already known from the literature. Especially in the lower frequencies (delta and theta) the two signals correlate very strongly, which might reflect the large signal offsets induced in the EEG by rotation of the eyes' dipoles (this offset was shown to increased linearly with the size of the eye movement; Plöchl et al., 2012). This finding is of particular relevance for research interested in oscillatory dynamics in these low frequencies: for such studies, removing the fixation task and refraining from rejecting trials with eye movements might not be an option, as it bears the risk of misinterpreting artifacts induced by eye movements as neuronal effects. We want to note though, that additional cleaning of the EEG using ICA or similar approaches might well remove or reduce the correlation of the two signals; we did not explicitly test for this, though.

High frequent EEG artifacts in the gamma band, induced by e.g. saccadic spike potentials or microsaccades (see Plöchl et al., 2012; Yuval-Greenberg et al., 2008), were not reflected by a correlation between the two signals, despite the fact that there must have been eye movements during each single trial, regardless of the condition (see Fig. 3 eye tracking). Apparently, the GFP correlation method is insensitive to these high frequent eye movement artifacts. This might be due to the fact that the raw eye trace, as opposed to EOG proper, does not contain thes signal components; unfortunately, our dataset does not allow to test for this. Our ASSR SNR measure, on the other hand, did correlate with blinks and larger saccades, but not with microsaccades. It seems possible that ASSR SNR mainly reacts to these high frequent noise components, as they are in the same frequency range as the signal (40 Hz), even though more broadband. If this where true, it would question the usability of the proxy metric. However, previous research has shown that the effect of spike potentials and eyelid-induced signal changes is strongest on frontal channels (Plöchl et al., 2012), while the topography contrasts of our ASSR measure revealed that effects of the fixation task were only significant in occipital channels (see Fig. 4e). We thus do believe that the ASSR metric is sensitive to a broader set of artifactual signal distortions.

The small correlation of the signals in the alpha and beta band might be less of a concern for future research. There might be some amount of eye induced signal reflected in this frequency range, but it seems unlikely that this might flaw an entire study, especially if approaches like trial averaging or signal cleaning are involved.

On a sidenote, previous work indicated that artifacts caused by vertical eye movements would have a higher influence on the EEG (Plöchl et al., 2012). In this analysis however, the correlation of EEG bandpower with the horizontal component of the eye movements was stronger than with the vertical component.

References

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