Supplementary materials

for Flipping the world upside down: Using eye tracking in virtual reality to study visual search in inverted scenes.

Here, we report full results for all linear and generalized linear mixed effects models reported in the manuscript. Result tables and model equations are based on Hoffman and Rovine (2007). Marginal and conditional R^2 are estimated using the method implemented in the MuMIn package provided by Nakagawa and Schielzeth (2013).

Supplementary analysis 1 – Search accuracy

For modeling search accuracy, we calculated a generalized linear mixed effects model using a binomial distribution. To model search accuracy, we applied the following equation (1):

$$
\begin{aligned}
Level\ 1: \quad & y_{ijk} = \beta_{0jk} + \beta_{1jk}SO_{ijk} + \beta_{2jk}G_{ijk} + \varepsilon_{ijk} \\
Level\ 2: \quad & \beta_{0jk} = \gamma_{00} + U_{0j} + V_{0k} \\
& \beta_{1jk} = \gamma_{10} + U_{1j} + V_{1k} \\
& \beta_{2jk} = \gamma_{20},
\end{aligned}
$$

$$\tag{1}$$

where y_{ijk} is the observed accuracy (0 for incorrect, 1 for correct) and ε_{ijk} is the residual for target k in search trial j for individual i, SO is scene orientation (inverted vs. upright), G is gaze duration on object, and U and V are the random effects for individuals and targets, respectively.

Supplementary table 1. Modeling results of search accuracy.

Parameter	Model Search Accuracy		
	Estimate	SE	p
Fixed effects			
Intercept (γ_{00})	3.57	0.26	**< .001**
Scene orientation (γ_{10})	–0.08	0.48	.088
Gaze duration (γ_{20})	0.55	0.18	**.002**
Variance components			
Target (V_{0k})	1.81	1.35	
	1.86	1.36	
Participant (U_{0j})	0.17	0.41	
	0.30	0.55	
Fit statistics			
Pseudo-R^2_m; Pseudo-R^2_c	.0670; .4715		
AIC; BIC	977.2; 1027.6		

Note. Bold p-values indicate significance at an alpha level of 5%.

Supplementary analysis 2 – Search times

For modeling search times (also called response times), we calculated linear mixed effects models using a Gaussian distribution and log-transformed response times. To model response times, we applied the following equations (2; 3):

$$
\begin{aligned}
Level\ 1: \quad & y_{ijk} = \beta_{0jk} + \beta_{1jk}SO_{ijk} + \beta_{2jk}G_{ijk} + \varepsilon_{ijk} \\
Level\ 2: \quad & \beta_{0jk} = \gamma_{00} + U_{0j} + V_{0k} \\
& \beta_{1jk} = \gamma_{10} + V_{1k} \\
& \beta_{2jk} = \gamma_{20},
\end{aligned}
\tag{2}
$$

and

$$
\begin{aligned}
Level\ 1: \quad & y_{ijk} = \beta_{0jk} + \beta_{1jk}SO_{ijk} + \beta_{2jk}T_{ijk}+ \\
& \qquad \beta_{3jk}SO_{ijk}*T_{ijk} + \beta_{4jk}G_{ijk} + \varepsilon_{ijk} \\
Level\ 2: \quad & \beta_{0jk} = \gamma_{00} + U_{0j} + V_{0k} \\
& \beta_{1jk} = \gamma_{10} + U_{1j} + V_{1k} \\
& \beta_{2jk} = \gamma_{20} \\
& \beta_{3jk} = \gamma_{30} \\
& \beta_{4jk} = \gamma_{40},
\end{aligned}
\tag{3}
$$

where y_{ijk} is the observed log-transformed response time and ε_{ijk} is the residual for target k in search trial j for individual i, SO is scene orientation (inverted vs. upright), G is gaze duration on object, T is trial number in the scene, and U and V are the random effects for individuals and targets, respectively.

Supplementary table 2. Modeling results of search times.

Parameter	Model Search Times 1			Model Search Times 2		
	Estimate	SE	p	Estimate b	SE	p
Fixed effects						
Intercept (γ_{00})	7.88	0.04	**< .001**	7.96	0.05	**< .001**
Scene orientation (γ_{10})	0.31	0.03	**< .001**	0.30	0.06	**< .001**
Trial (γ_{20})				–0.02	0.01	**.003**
Scene orientation × Trial (γ_{30})				0.00	0.01	.934
Gaze duration (γ_{40})	–0.10	0.02	**< .001**	–0.08	0.02	**< .001**
Variance components						
Target (V_{0k})	0.10	0.32		0.10	0.32	
	0.03	0.16		0.02	0.16	
Participant (U_{0j})	0.01	0.11		0.01	0.11	
				0.00	0.52	
Residual variance (e_{ij})	0.27	0.52		0.27	0.52	
Fit statistics						
Pseudo-R^2_m; Pseudo-R^2_c	.0709; .3526			.0739; .3592		
AIC; BIC	2849.8; 2892.9			2848.7; 2913.4		

Note. Bold p-values indicate significance at an alpha level of 5%.

Supplementary analysis 3 – Eye movement measures of search efficiency

For modeling initiation time, scanning time, verification time and fixation duration, we calculated a linear mixed effects model using a Gaussian distribution and log-transformed data. We used the following equation (4):

$$
\begin{aligned}
\text{Level 1}: \quad & y_{ijk} = \beta_{0jk} + \beta_{1jk}SO_{ijk} + \beta_{2jk}G_{ijk} + \varepsilon_{ijk} \\
\text{Level 2}: \quad & \beta_{0jk} = \gamma_{00} + U_{0j} + V_{0k} \\
& \beta_{1jk} = \gamma_{10} + V_{1k} \\
& \beta_{2jk} = \gamma_{20},
\end{aligned}
$$

$$(4)$$

where y_{ijk} is the observed log-transformed time and ε_{ijk} is the residual for target k in search trial j for individual i, SO is scene orientation (inverted vs. upright), G is gaze duration on object, and U and V are the random effects for individuals and targets, respectively.

Supplementary table 3. Modeling results of initiation time, scanning time, and verification time.

Parameter	Model Initiation Time			Model Scanning Time			Model Verification Time		
	Estimate	*SE*	*p*	Estimate	*SE*	*p*	Estimate	*SE*	*p*
Fixed effects									
Intercept (γ_{00})	4.58	0.05	**< .001**	7.22	0.05	**< .001**	6.76	0.05	**< .001**
Scene orientation (γ_{10})	–0.02	0.06	.715	0.42	0.05	**< .001**	0.14	0.02	**< .001**
Gaze duration (γ_{20})	0.62	0.03	.050	–0.16	0.03	**< .001**	–0.13	0.01	.272
Variance components									
Target (V_{0k})	0.03	0.17		0.19	0.43		0.07	0.26	
	0.06	0.25		0.03	0.18		0.01	0.11	
Participant (U_{0j})	0.02	0.14		0.02	0.14		0.04	0.20	
Residual variance (e_{ij})	1.50	1.22		0.86	0.93		0.17	0.42	
Fit statistics									
Pseudo-R^2_m; Pseudo-R^2_c	.0024; .0441			.0535; .2427			.0164; .3922		
AIC; BIC	5350.3; 5393.4			4625.2; 4668.4			2126.0; 2169.2		

Note. Bold *p*-values indicate significance at an alpha level of 5%.

Supplementary table 4. Modeling results of fixation duration.

Parameter	Model Fixation Duration		
	Estimate	SE	p
Fixed effects			
Intercept (γ_{00})	5.34	0.02	**< .001**
Scene orientation (γ_{10})	–0.02	0.03	.623
Gaze duration (γ_{20})	–0.00	0.01	.898
Variance components			
Target (V_{0k})	0.01	0.09	
	0.03	0.17	
Participant (U_{0j})	0.01	0.07	
Residual variance (e_{ij})	0.31	0.55	
Fit statistics			
Pseudo-R^2_{m}; Pseudo-R^2_{c}	.0002; .0653		
AIC; BIC	2785.2; 2828.3		

Note. Bold p-values indicate significance at an alpha level of 5%.

Supplementary analysis 4 – Eye movement count analyses

For modeling fixation count, fixated objects count, and target refixations, we calculated a generalized linear mixed effects model using a Poisson distribution. We used the following equation (5):

$$
\begin{aligned}
Level\ 1: \quad & y_{ijk} = \beta_{0jk} + \beta_{1jk}SO_{ijk} + \beta_{2jk}G_{ijk} + \varepsilon_{ijk} \\
Level\ 2: \quad & \beta_{0jk} = \gamma_{00} + U_{0j} + V_{0k} \\
& \beta_{1jk} = \gamma_{10} + U_{1j} + V_{1k} \\
& \beta_{2jk} = \gamma_{20},
\end{aligned}
\tag{5}
$$

where y_{ijk} is the observed count and ε_{ijk} is the residual for target k in search trial j for individual i, SO is scene orientation (inverted vs. upright), G is prior gaze duration on target, and U and V are the random effects for individuals and targets, respectively.

Supplementary table 5. Modeling results of fixation count, fixated objects count, and target refixations.

Parameter	Model Fixation Count			Model Fixated Objects Count			Model Target Refixations		
	Estimate	SE	p	Estimate	SE	p	Estimate	SE	p
Fixed effects									
Intercept (γ_{00})	2.08	0.05	**< .001**	1.48	0.05	**< .001**	–0.08	0.11	0.435
Scene orientation (γ_{10})	0.32	0.05	**< .001**	0.14	0.04	**< .001**	0.37	0.09	**< .001**
Gaze duration (γ_{20})	–0.13	0.01	**< .001**	–0.10	0.02	**< .001**	–0.24	0.04	**< .001**
Variance components									
Target (V_{0k})	0.16	0.40		0.11	0.33		0.27	0.53	
	0.18	0.42		0.07	0.26		0.26	0.51	
Participant (U_{0j})	0.04	0.19		0.03	0.17		0.19	0.43	
	0.02	0.15		0.01	0.09		0.08	0.27	
Fit statistics									
Pseudo-R^2_m; Pseudo-R^2_c	.0972; .7233			.0345; .4327			.0543; .4103		
AIC; BIC	10769.7; 10818.2			7756.0; 7804.5			4725.0; 4773.6		

Note. Bold p-values indicate significance at an alpha level of 5%.

Supplementary analysis 5 – Gaze and head directions

For gaze and head directions, we calculated a generalized linear mixed effects model using a Poisson distribution. We used the following equation (6):

$$
\begin{aligned}
Level\ 1: \quad y_{ijk} &= \beta_{0jk} + \beta_{1jk}SO_{ijk} + \beta_{2jk}AC_{ijk} + \\
&\quad \beta_{3jk}SO_{ijk} * AC_{ijk} + \varepsilon_{ijk} \\
Level\ 2: \quad \beta_{0jk} &= \gamma_{00} + U_{0j} \\
\beta_{1jk} &= \gamma_{10} + U_{1j} \\
\beta_{2jk} &= \gamma_{20} \\
\beta_{3jk} &= \gamma_{30},
\end{aligned}
$$

$$(6)$$

where y_{ijk} is the observed count and ε_{ijk} is the residual for target k in search trial j for individual i, SO is scene orientation (inverted vs. upright), AC is angle category (i.e., right, left, down, and up), and U is the random effects for individuals, respectively.

Supplementary table 6. Modeling results of gaze and head directions.

Parameter	Model Gaze Directions			Model Head Directions		
	Estimate	SE	p	Estimate	SE	p
Fixed effects						
Intercept (γ_{00})	4.40	0.04	**< .001**	4.22	0.04	**< .001**
Scene orientation (γ_{10})	0.31	0.03	**< .001**	–0.39	0.05	**< .001**
Angle category (γ_{20})						
Right–Left	0.16	0.02	**< .001**	0.17	0.02	**< .001**
Down–Up	0.05	0.03	**< .001**	–0.28	0.04	**< .001**
Up-Right	–1.19	0.03	.154	–1.62	0.03	**< .001**
Scene orientation × Angle category (γ_{30})						
Orientation×Right–Left	0.07	0.04	**.080**	0.07	0.04	.057
Orientation×Down–Up	–0.39	0.07	**< .001**	–0.65	0.09	**<. 001**
Orientation×Up–Right	–0.12	0.05	**.026**	–0.13	0.06	**.027**
Variance components						
Participant (U_{0j})	0.03	0.17		0.03	0.17	
	0.03	0.18		0.03	0.18	
Fit statistics						
Pseudo-R^2_m; Pseudo-R^2_c	.8731; .9733			.9418; .9878		
AIC; BIC	1389.5; 1423.3			1414.9; 1448.7		

Note. Bold p-values indicate significance at an alpha level of 5%.

Supplementary analysis 6 – Gaze latitude, gaze and head amplitudes

For gaze latitude, we calculated a linear mixed effects model using a Gaussian distribution. To model gaze and head amplitudes, we calculated a generalized linear mixed effects model using a Gamma distribution. We used the following equation (7) to model the fixed and random effects structure:

$$
\begin{aligned}
Level\ 1: \quad & y_{ijk} = \beta_{0jk} + \beta_{1jk}SO_{ijk} + \beta_{2jk}G_{ijk} + \varepsilon_{ijk} \\
Level\ 2: \quad & \beta_{0jk} = \gamma_{00} + U_{0j} + V_{0k} \\
& \beta_{1jk} = \gamma_{10} + U_{1j} + V_{1k} \\
& \beta_{2jk} = \gamma_{20},
\end{aligned}
\tag{7}
$$

where y_{ijk} is the observed latitude or amplitude and ε_{ijk} is the residual for target k in search trial j for individual i, SO is scene orientation (inverted vs. upright), G is prior gaze duration on target, and U and V are the random effects for individuals and targets, respectively.

Supplementary table 7. Modeling results of gaze latitude, gaze and head amplitude.

Parameter	Model Gaze Latitude			Model Gaze Amplitude			Model Head Amplitude		
	Estimate	SE	p	Estimate	SE	p	Estimate	SE	p
Fixed effects									
Intercept (γ_{00})	0.45	0.01	**< .001**	1.45	0.03	**< .001**	1.57	0.03	**< .001**
Scene orientation (γ_{10})	0.16	0.01	**< .001**	–0.07	0.03	**.049**	0.03	0.04	.439
Gaze duration (γ_{20})	–0.00	0.00	.530	–0.01	0.01	.648	–0.01	0.01	.331
Variance components									
Target (V_{0k})	0.00	0.01		0.03	0.17		0.07	0.26	
	0.01	0.09		0.02	0.13		0.02	0.14	
Participant (U_{0j})	0.00	0.02		0.01	0.09		0.02	0.12	
	0.00	0.01		0.01	0.09		0.02	0.16	
Residual variance (e_{ij})	0.01	0.08		0.95	0.97		1.25	1.11	
Fit statistics									
Pseudo-R^2_m; Pseudo-R^2_c	.3934; .5711			.0010; .0420			.0000; .0710		
AIC; BIC	–32047.5; –32000.0			19974.9; 20051.0			17832.4; 17909.0		

Note. Bold p-values indicate significance at an alpha level of 5%.

References

Hoffman, L., & Rovine, M. J. (2007). Multilevel models for the experimental psychologist: Foundations and illustrative examples. *Faculty Publications, Department of Psychology*, 421. https://digitalcommons.unl.edu/psychfacpub/421

Nakagawa, S., & Schielzeth, H. (2013). A general and simple method for obtaining R^2 from generalized linear mixed-effects models. *Methods in Ecology and Evolution, 4*(2), 133–142. https://doi.org/10.1111/j.2041-210x.2012.00261.x