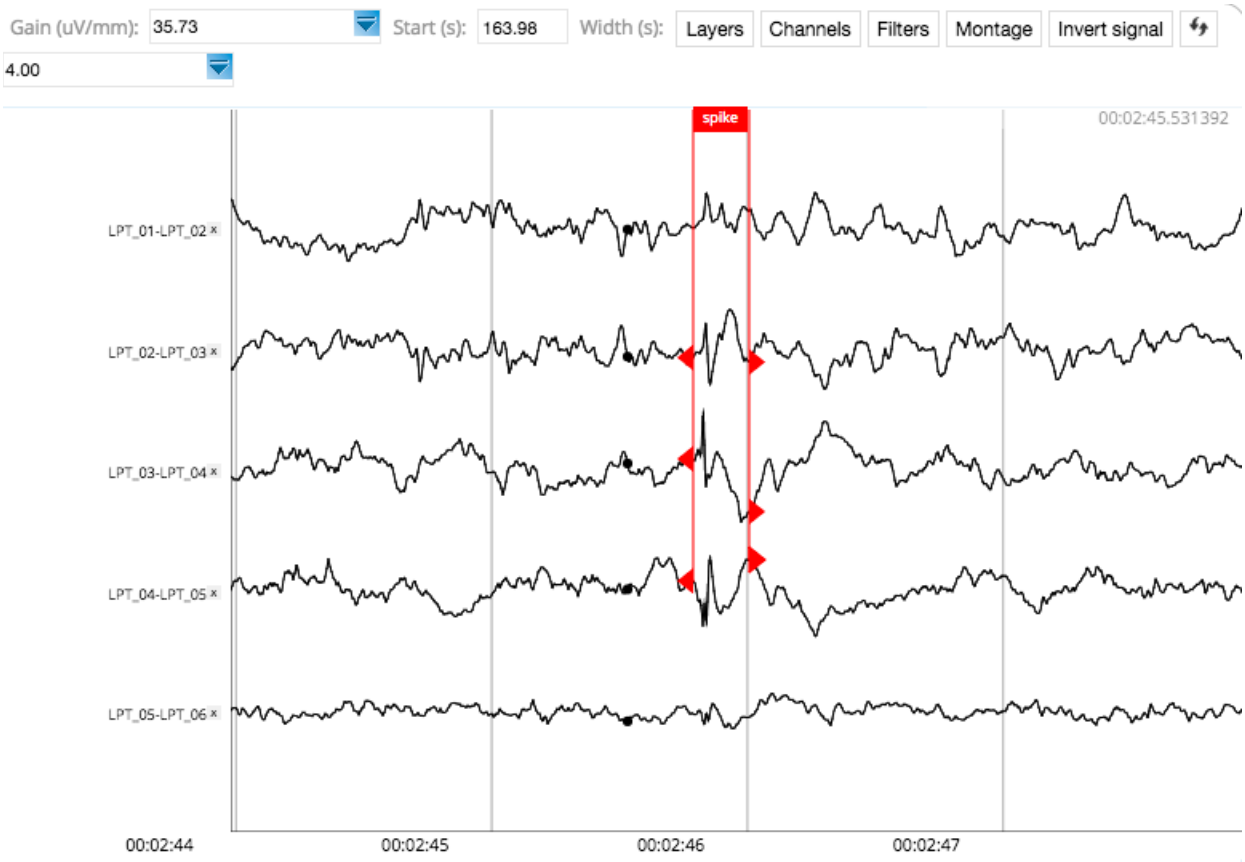
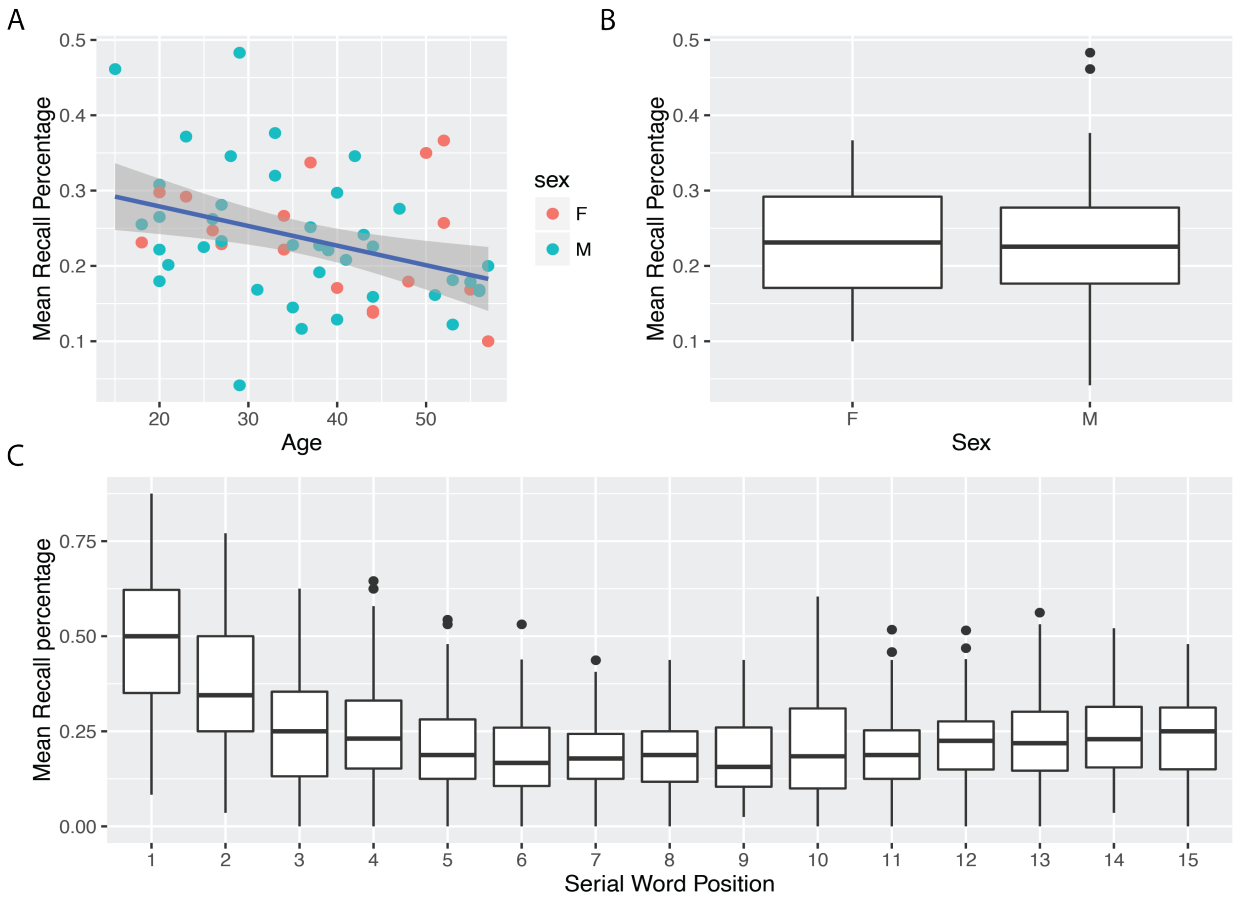
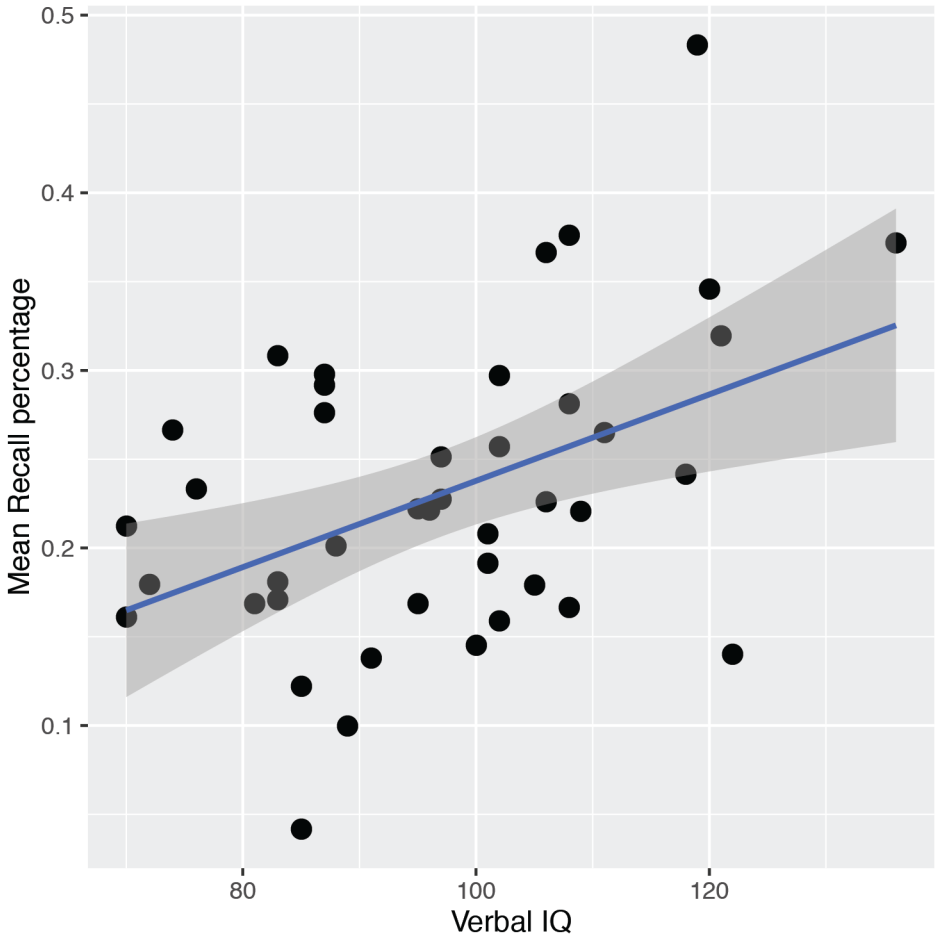
Supplementary Materials



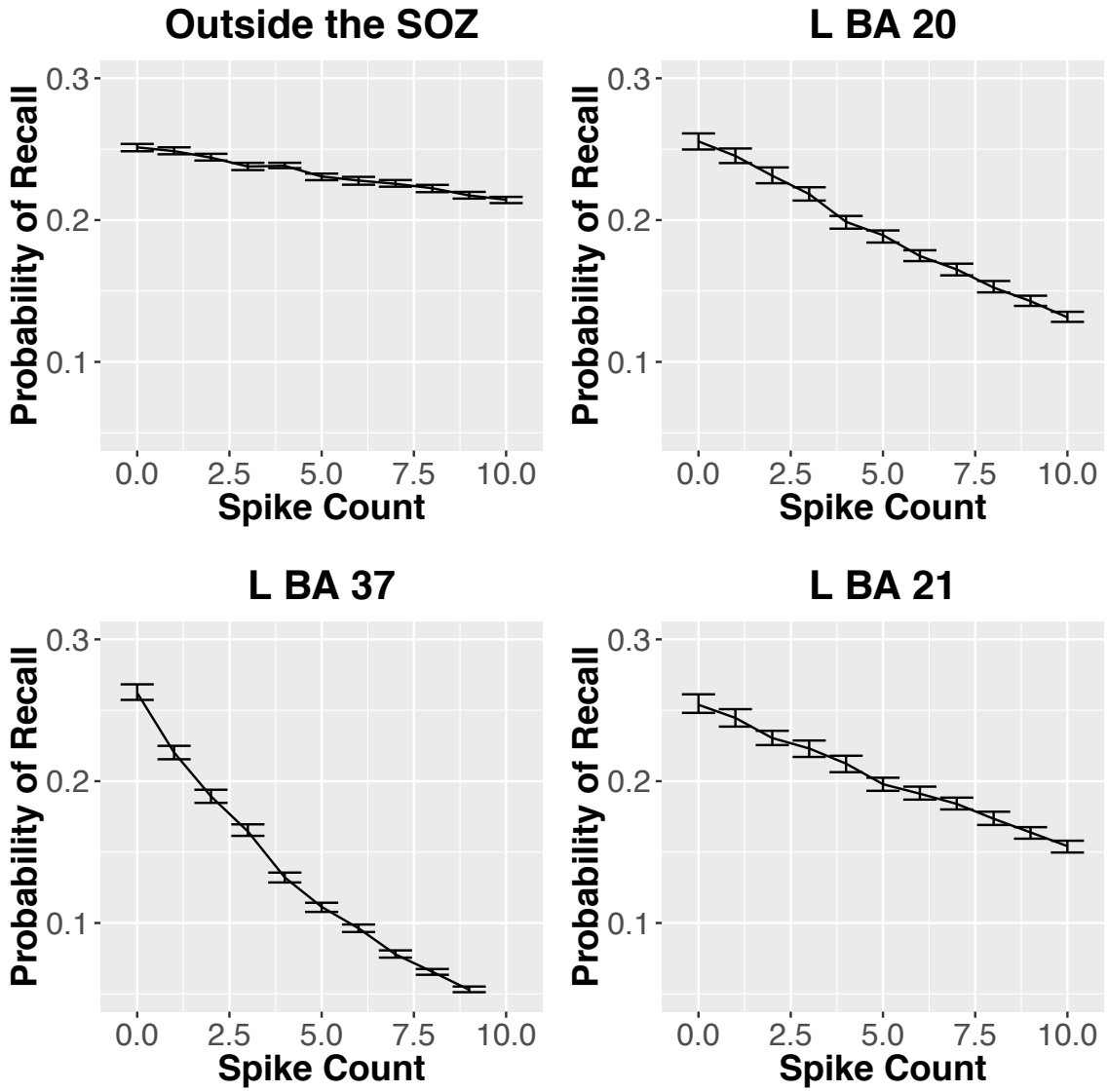
Supplementary Fig. S1. Example of detected spike on ieeg.org interface. Bipolar montage displayed.



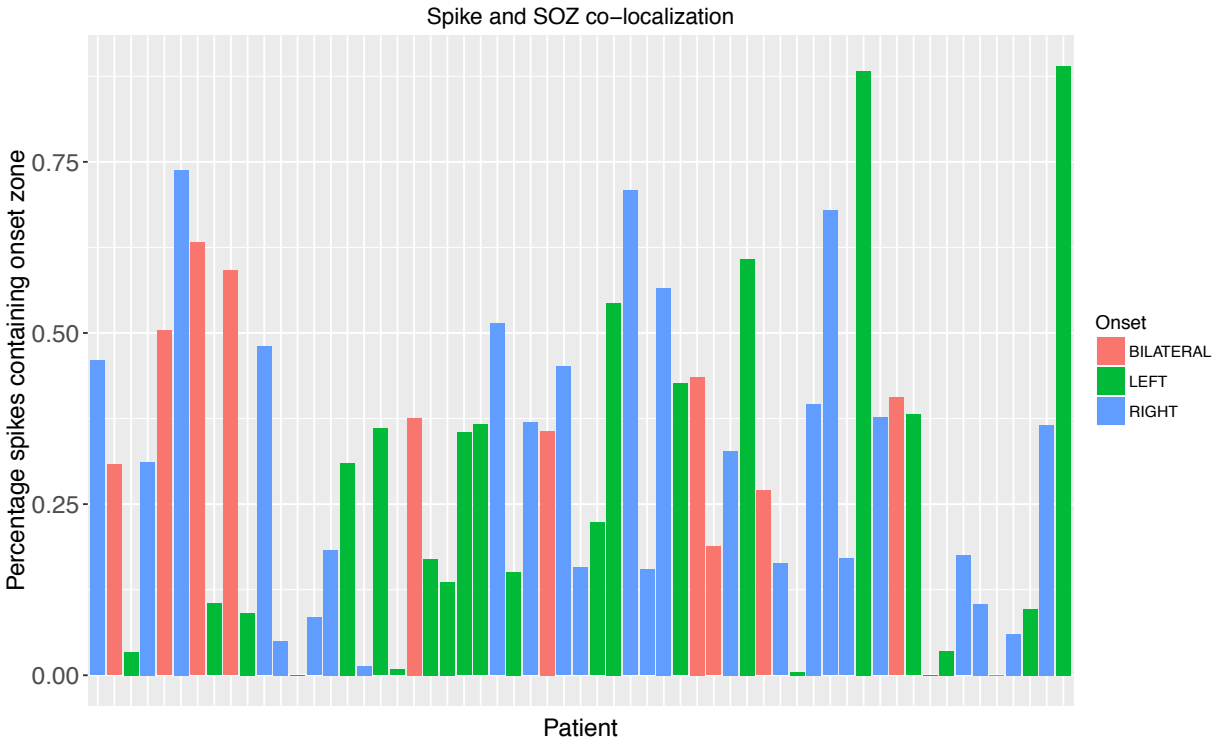
Supplementary Fig. S2. Mean recall percentage by (A) age, (B) sex, and (C) serial word position. Vertical axes represent the mean recall percentage across all plots. (A) Each point represents a patient with sex indicated by color. The horizontal axis indicates age. A best-fit line is plotted with a standard error ribbon. (B) Mean recall by sex; boxplots indicate median, 25th, and 75th percentiles. (C) The horizontal axis indicates the serial word position, where position one is the first word presented in a given trial.



Supplementary Fig. S3. Mean recall percentage versus verbal IQ. Each marker represents a patient for which Verbal IQ was available. A best-fit line is plotted with a standard error ribbon (b = 0.00243, t(40) = 3.133, p = 0.003, $R^2_{\{adj\}} = 0.177$).



Supplementary Fig. S4. Predicted probability of recall per spike during the encoding period. The vertical axis indicates the probability of recall for a given word presentation. The horizontal axis indicates the spike count in a given region for a given word presentation. The predicted probabilities and 95% confidence interval are plotted, which are derived from predictions from 100 bootstrapped samples of 1000 word presentations.



Supplementary Fig. S5. Percent of spikes overriding the seizure onset zone for each patient. Horizontal axis denotes each patient, colored by seizure onset lateralization. The vertical axis denotes the percentage of spikes in all sessions that involve the seizure onset zone.

Supplementary Table S1. Patient demographics and experimental information.

Pt	Hospital	Age	Sex	Lateralization	Onset	Sessions	Mean Recall %
1	HUP	38	M	RIGHT	R Temporal	5	0.23
2	HUP	20	M	BILATERAL	B Temporal	2	0.18
3	HUP	36	M	LEFT	L Temporal	6	0.12
4	HUP	25	M	RIGHT	R Limbic	4	0.23
5	HUP	18	F	BILATERAL	B Limbic, R Temporal	3	0.23
6	HUP	27	F	RIGHT	R Limbic, R Temporal	2	0.23
7	HUP	55	F	BILATERAL	B Limbic	2	0.17
8	HUP	18	M	UNLOCALIZED		3	0.35
9	HUP	38	F	UNLOCALIZED		1	0.20
10	HUP	40	M	LEFT	L Temporal, L Occipital	4	0.30
11	HUP	27	M	BILATERAL	B Temporal	2	0.28
12	HUP	20	M	LEFT	L Frontal	4	0.22
13	HUP	37	M	RIGHT	R Temporal	3	0.25
14	HUP	42	M	RIGHT	R Occipital	2	0.35
15	HUP	30	F	LEFT	L Frontal	3	0.21
16	HUP	40	M	RIGHT	R Frontal	1	0.13
17	TJUH	25	M	UNLOCALIZED		3	0.32
18	TJUH	40	F	RIGHT	R Temporal, R Limbic	4	0.17
19	TJUH	39	M	LEFT	L Limbic	1	0.22
20	TJUH	34	F	RIGHT	R Temporal	10	0.22
21	TJUH	44	M	LEFT	L Temporal	1	0.16
22	TJUH	29	M	LEFT	L Central	1	0.04
23	TJUH	43	M	BILATERAL	B Temporal	4	0.24
24	TJUH	21	M	LEFT	L Frontal	3	0.20
25	TJUH	56	M	LEFT	L Temporal	3	0.17
26	TJUH	57	F	LEFT	L Temporal, L Limbic	3	0.10
27	TJUH	20	M	LEFT	L Frontal	3	0.27
28	TJUH	41	M	RIGHT	R Temporal	2	0.21
29	TJUH	34	F	LEFT	L Temporal	4	0.27
30	TJUH	52	F	RIGHT	R Temporal	1	0.37
31	TJUH	44	M	UNLOCALIZED		3	0.45
32	TJUH	44	F	BILATERAL	B Temporal	4	0.14
33	TJUH	33	M	RIGHT	R Frontal	4	0.32
34	TJUH	23	F	RIGHT	R Temporal	5	0.29
35	TJUH	50	F	UNLOCALIZED		2	0.35
36	TJUH	33	M	LEFT	L Temporal	3	0.38
37	TJUH	44	M	LEFT	L Temporal	4	0.23
38	TJUH	15	M	RIGHT	R Occipital, R Temporal	4	0.46
39	TJUH	23	M	RIGHT	R Temporal, R Frontal	4	0.37

40	TJUH	53	M	RIGHT	R Temporal, R Limbic	2	0.12
41	TJUH	53	M	LEFT	L Temporal	2	0.18
42	TJUH	29	M	BILATERAL	B Temporal	2	0.48
43	TJUH	35	M	BILATERAL	B Temporal	3	0.23
44	TJUH	48	F	RIGHT	R Frontal, R Temporal	8	0.18
45	TJUH	20	F	UNLOCALIZED		15	0.44
46	TJUH	35	M	LEFT	L Temporal, L Frontal	3	0.15
47	TJUH	20	M	BILATERAL	L frontal, R Temporal	9	0.31
48	TJUH	52	F	RIGHT	R Temporal	3	0.26
49	TJUH	26	F	LEFT	L Frontal	3	0.25
50	TJUH	20	F	RIGHT	R Temporal, R Frontal	2	0.30
51	TJUH	31	M	RIGHT	R Temporal, R Frontal	2	0.17
52	TJUH	50	M	UNLOCALIZED		3	0.21
53	TJUH	18	M	RIGHT	R Temporal	3	0.26
54	TJUH	44	F	LEFT	L Temporal	2	0.14
55	TJUH	28	M	RIGHT	R Temporal	3	0.35
56	TJUH	51	M	BILATERAL	B Temporal	5	0.16
57	TJUH	38	M	LEFT	L Temporal	1	0.19
58	TJUH	26	F	LEFT	L Frontal	3	0.12
59	TJUH	56	M	LEFT	L Temporal	2	0.17
60	TJUH	47	M	RIGHT	R Temporal	1	0.28
61	TJUH	26	M	RIGHT	R Frontal	3	0.26
62	TJUH	25	M	RIGHT	R Frontal	1	0.21
63	TJUH	27	M	RIGHT	R Frontal	1	0.23
64	TJUH	20	F	UNLOCALIZED		3	0.42
65	TJUH	55	M	LEFT	L Frontal	1	0.18
66	TJUH	37	F	RIGHT	R Frontal	3	0.34
67	TJUH	57	M	LEFT	L Temporal	2	0.20

Supplementary Table S2. Model construction - Encoding

	Fixed	Random	Testing	$\chi^2(1)$	p
1		Patient	Word order	378.73	<0.001
2	Word order	Patient	Age	9.93	0.0016
3	Word order + Age	Patient	Sex	<0.001	0.99
4	Word order + Age	Patient	Session (Nest)	109.55	<0.001
5	Word order + Age	Patient	Verbal IQ	8.0952	0.004
6	Model: recalled ~ word_order + age + verbal_iq + 1|patient/session				

In each iteration, a null model is compared to an alternative model to test one additional variable through the likelihood ratio test. If the alternative model fits the data better, it is retained. Spike counts are added to the final model (5) and tested in subsequent analyses.

Supplementary Table S3. Regional analysis of patients with right lateralized seizure onset zones.

N	L/R	Region		Odds [95% CI]	$\chi^2(1)$	P (unadj)
21	R	Hippocampus	Hippocampus	0.943 [.879 1.011]	7.49	0.187
25	R	Superior Temporal Gyrus	BA 38	0.988 [.943 1.034]	3.67	0.596
21	R	Superior Temporal Gyrus	BA 22	0.971 [.910 1.035]	3.11	0.683
24	R	Inferior Temporal Gyrus	BA 20	0.970 [.934 1.007]	3.09	0.686
22	R	Fusiform Gyrus	BA 37	1.046 [.989 1.106]	2.68	0.748
28	R	Peristriate cortex	BA 19	0.967 [.904 1.035]	2.32	0.803
28	R	Middle Temporal Gyrus	BA 21	0.982 [.939, 1.028]	1.99	0.851

Regional analysis was performed separately for each region for only right lateralized patients. P values are unadjusted.

Supplementary Table S4. Model construction - Retrieval

	Fixed	Random	Testing	$\chi^2(1)$	p
1		Patient	Word order	384.87	<0.001
2	Word order	Patient	Age	4.23	0.0397
3	Word order + Age	Patient	Sex	3.786	0.1507
4	Word order + Age	Patient	Session (Nest)	566.23	<0.001
5	Word order + Age	Patient	Verbal IQ	0.0575	0.8105
6	Model: retrieved ~ word_order + age + 1|patient/session				

In each iteration, a null model is compared to an alternative model to test one additional variable through the likelihood ratio test. If the alternative model fits the data better, it is retained. Spike counts are added to the final model (5) and tested in subsequent analyses.

Model Details

We model recall success as a binomial distribution represented by parameter π_{ij}, indicating the probability of successful recall on word *i* for subject *j* given our parameters β

$$y|\pi_{ijk} \sim Binomial(1, \pi_{ijk})$$
$$\pi_{ijk} = P(y_{ijk} = 1|\beta)$$

Using maximum likelihood, we estimate β with a logistic generalized linear mixed model . With a logit link function, we predict the log odds as a function of our fixed effects as well as our random effects. We use a nested random effects model to account for variability in baseline recall rates for each person and, within each person, variability between sessions. Below, b_j codes for the mean recall rate for subject j, session *k*, and $a_{k(j)}$ codes for variation in recall rates for each session k within subject j.

$$\log\left(\frac{\pi_{ijk}}{1-\pi_{ijk}}\right) = \beta_1 age_j + \beta_2 verbal_{iq_j} + \beta_2 word_{order_i} + \beta_3 spike_{count_{ijk}} + b_j + a_{k(j)}$$
$$b_j \sim N(0, \sigma^2), a_{k(j)} \sim N(0, \tau_j^2)$$

The GLMM was estimated using R statistical software[1,2]. For better interpretation, odds ($\exp(\beta)$) are reported with 95% confidence intervals calculated with the profile likelihood method, which makes fewer assumptions about normality. For regional analysis, p values are determined using the likelihood ratio test, which compares the difference between likelihood of a null model to an alternative model with the corresponding region.

References

1. Bates D, Maechler M, Bolker B, et al. Package lme4. J Stat Softw. 2015;67:1–91.
2. R Development Core Team. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing Vienna Austria. 2015. p. {ISBN} 3–900051 – 07–0.