Supplementary methods and results for "Playing 'Duck Duck Goose' with neurons: Change detection through connectivity reduction"

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Supplementary methods and MEG statistical analysis

Angle test of topographic similarity

The experiment was divided into epochs from the first half versus epochs from the second half and the average response patterns of each half were compared to each other within the same condition (e.g., *repeated* first half versus *repeated* second half) to produce a null distribution, and between conditions (e.g., *repeated* first half versus *novel* second half) to produce an alternative distribution. For the angle test of the repetition effect, the epochs were collapsed across the number of prior repetitions. Thus, there were two within condition angle measures per individual (one for *repeated* and one for *novel*) and there were two between condition angle measures per individual (*repeated* first half versus *nonpeated* second half and *repeated* second half versus *novel* first half). The between and within condition comparisons were then averaged separately for each individual and compared across individuals with a dependent samples t-test to determine whether in general the *repeated* and *novel* conditions produced different topographic patterns. This was done separately for the M100, M170, and M400 in response to the category name, the matching category member, and the mismatching category member.

For the angle test across different numbers of prior repetitions broken into thirds, new epochs were calculated that collapsed across the *repeated* and *novel* conditions. The same first half versus second half comparisons were made in an analogous manner, except there were 3 within condition comparisons and 6 between condition comparisons that were averaged prior to the dependent samples t-tests. In the absence of any significant differences in the topographic patterns, the main effects from the projection tests, reported next, are likely due to changes in response magnitude rather than changes in the mixture of underlying neural sources. We note that it is not possible to run an angle test for the interaction between the repetition effect and numbers of prior repetitions because the angle test does not conform to a general linear model. This is because the angle measure necessarily involves pairwise comparisons rather than effects that can be summed for different manipulations. Nevertheless, the absence of any significant topographic differences for the two main effects suggests that in general the same mixture of underlying neural sources was involved in the various experimental conditions.

Projection test of response magnitude

The projection test of response magnitude requires a standard waveform that captures the processes of reading words within the context of the category matching task. This waveform should be relatively uncontaminated by other presentations that might temporally overlap. The waveform produced by the presentation of the category name satisfied these needs. Thus, a standard response for each individual was obtained by averaging responses to all presentations of category names, regardless of condition. For each individual, three different standard responses were determined to capture the M100, M170, and M400. For each condition in response to the category name, the matching category member, and the mismatching category member, the observed M100, M170, or M400 waveform was projected onto the appropriate standard response to yield a measure of response magnitude. This projection normalizes response magnitude and allows comparison across individuals. These projection values were then subjected to a 2 X 3 repeated measures ANOVA examining the repetition effect (*repeated* versus *novel*), the effect of prior repetitions broken into thirds, and the interaction between these two manipulations.

DCM model specification and statistical testing

Previous studies suggest that hierarchical processes mediate reading (Bentin, Mouchetant-Rostaing, Giard, Echallier, & Pernier, 1999), which at least include primary visual cortex (V1) for basic visual analysis (Tarkiainen, Helenius, Hansen, Cornelissen, & Salmelin, 1999), a special fusiform area (visual word form area, VWFA) for abstract orthographic processing (Cohen et al., 2000; Dehaene, Le Clec'H, Poline, Le Bihan, & Cohen, 2002; McCandliss, Cohen, & Dehaene, 2003; Nobre, Allison, & McCarthy, 1994), the middle temporal gyrus (MTG) for lexical/semantic access, and the inferior frontal gyrus (IFG) for semantic contextual integration (Lau, Phillips, & Poeppel, 2008; Vigneau et al., 2006). Because high-level aspects of reading are largely left lateralized (Lau et al., 2008; Vigneau et al., 2006), we included six nodes (left and right V1, left and right VWFA, left MTG and left IFG) in the DCM analysis. Before analyzing the results of a particular DCM model, it is necessary to compare different DCM models that make different connectivity assumptions. There are a vast number of different possible models, but we used prior results to consider only the most plausible subset of models. For instance, there is evidence that backward connections are important for processing contextual information (Garrido et al., 2008; Kiebel, Garrido, Moran, Chen, & Friston, 2009). Furthermore, the involvement of the right VWFA (Cohen et al., 2003) and functional difference between MTG and IFG (Lau et al., 2008) during reading are under debate. Therefore, 24 models were constructed on the basis of three factors. The first factor was vertical bidirectionality (2 levels: either both forward and backward connections or only forward connections). The second factor was the involvement of neural regions (4 levels: all six regions, no RVWFA, no MTG, or no IFG). The third factor was the inclusion of connections between hemispheres (3 levels: bidirectional lateral connections and vertical convergence from right hemisphere onto left lateralized reading areas, vertical convergence from the right hemisphere without bidirectional lateral connections, or bidirectional lateral connections without vertical convergence from the right hemisphere). These three factors were fully crossed to form 24 models (Fig. S1).

Each region of interest (each node in DCM) was modeled as an equivalent current dipole (ECD). Dipole locations were determined using the Montreal Neurological Institute (MNI) space (Table S6). The 24 connectivity models were compared using the category name epochs for each individual collapsed across conditions. The models were fit to each individual and Bayesian model selection was applied at the group level to determine the best model in general for all individuals (Penny, Stephan, Mechelli, & Friston, 2004). Model selection was based on the cumulative posterior log-evidence, $\ln(p(y|m))$. Log-evidence from for each individual was summed and the relative log-evidence of each model was calculated by subtracting the model with the lowest log-evidence, $\ln(p(y|m_i)) - \ln(p(y|m)_{min})$. An evidence ratio, $p(y|m_i)/p(y|m_j)$ exceeding 150 (i.e. a difference of relative log-evidence between two models larger than 5.01), suggests strong evidence (probability greater than 99%) in favor of model i (Penny et al., 2004; Raftery, 1995). The relative log-evidence among all 24 possible models (Fig. S2A) suggested that the best model (model 13) was one that included all 6 regions with only forward vertical connections and with both lateral bidirectional connections and convergence from the right hemisphere (Fig. S2B).

Modulation effects in the different conditions were investigated for the best model (Fig. 2B), separately for the category name, matching category members, and mismatching category members. Random effects linear contrast analyses of the modulation parameters assessed whether connection efficiency differed between the *repeated* and *novel* conditions as a function of the number of prior repetitions broken into thirds. All DCM analyses were carried out using SPM8.

Supplementary results

Supplementary text

Besides the significant linear change for the left VWFA to left MTG connection reported in the text, the repetition effect of the right V1 to right VWFA connection in response to the category name also decreased as a function of the number of prior repetitions [$t(12) = 2.42$, $p = 0.03$]. However, unlike the connection involving the MTG, this connection started from a positive value for the first third (i.e., a greater connection in the *repeated* condition) and merely returned to baseline (no difference between *repeated* and *novel*) by the final third (Table S7). Thus, it is unlikely that this connection caused the M170 and M400 to the category name to decrease in the *repeated* condition as compared to the *novel* condition and it unlikely that this connection caused participants to become slower in the *repeated* condition as compared to the *novel* condition. However, participants were faster to respond in the *repeated* condition for the first third of repetitions and this connection may have been a contributing factor to the short-term facilitation for the *repeated* condition. As seen in Tables S8-9, there were no significant linear effects for any of the connections in response to matching category members or mismatching category member, respectively.

Supplementary tables

Table S1. Angle tests comparing *repeated* and *novel* conditions

	Category name		Matching category member		Mismatching category member	
	$t(12)$	p	$t(12)$	p	$t(12)$	p
M100	-0.79	0.45	0.18	0.86	2.10	0.06
M170	0.95	0.36	1.56	0.15	0.82	0.43
M400	1.78	0.10	-0.72	0.48	1.54	0.15

Table S2. Angle tests comparing different numbers of prior repetitions

	Category name		Matching category member		Mismatching category member	
	$t(12)$	p	$t(12)$	p	$t(12)$	p
M100	0.90	0.38	1.50	0.46	1.09	0.30
M170	1.80	0.10	1.92	0.08	1.56	0.15
M400	0.99	0.34	1.63	0.13	1.75	0.11

Table S3. Projection tests in response to the category name.

	Main effect (*repeated* vs. *novel*)		Main effect (number of prior repetitions)		Interaction	
	$F(1,12)$	p	$F(2,24)$	p	$F(2,24)$	p
M100	0.01	0.93	0.37	0.70	0.27	0.77
M170	6.07	0.03	2.63	0.09	4.33	0.03
M400	3.10	0.10	1.38	0.27	4.35	0.02

Table S4. Projection tests in response to matching category members

	Main effect (*repeated* vs. *novel*)		Main effect (number of prior repetitions)		Interaction	
	$F(1,12)$	p	$F(2,24)$	p	$F(2,24)$	p
M100	0.00	0.98	0.89	0.43	0.76	0.48
M170	0.50	0.49	0.51	0.61	0.63	0.54
M400	0.77	0.40	0.22	0.80	3.74	0.04

Table S5. Projection tests in response to mismatching category members

	Main effect (*repeated* vs. *novel*)		Main effect (number of prior repetitions)		Interaction	
	$F(1,12)$	p	$F(2,24)$	p	$F(2,24)$	p
M100	0.90	0.36	0.54	0.59	0.36	0.70
M170	3.23	0.10	0.88	0.43	0.14	0.87
M400	5.49	0.04	1.42	0.26	0.11	0.90

Table S6. Location of equivalent current dipoles according to MNI space (mm).

Left primary visual cortex (LV1)	-20, -95, -5
Right primary visual cortex (RV1)	20, -95, -5
Left visual word form area (LVWFA)	-48, -56, -18
Right visual word form area (RVWFA)	48,-56, -18
Left middle temporal gyrus (LMTG)	-59, -37, -5
Right middle temporal gyrus (LIFG)	-44, 20, 5

Table S7. Average modulation parameter differences (*repeated* minus *novel*) and linear contrast results in response to category names as a function of prior repetitions. Abbreviation is the same as in Table S6.

	1-3	4-6	7-9	Linear contrast (p values)
LV1 → LVWFA	-0.177	-0.068	-0.019	0.21
RV1 → RVWFA	0.319	-0.052	-0.050	0.03
LVWFA → LMTG	0.030	-0.218	-0.446	0.03
RVWFA → LMTG	-0.239	0.073	-0.133	0.62
LMTG → LIFG	0.027	-0.124	-0.051	0.73

Table S8. Average modulation parameter differences (*repeated* minus *novel*) and linear contrast results in response to matching category members as a function of prior repetitions. Abbreviation is the same as in Table S6.

	1-3	4-6	7-9	Linear contrast (p values)
LV1 → LVWFA	0.185	-0.077	-0.006	0.28
RV1 → RVWFA	-0.090	-0.098	-0.082	0.95
LVWFA → LMTG	-0.313	0.184	-0.182	0.43
RVWFA → LMTG	-0.066	-0.112	-0.076	0.97
LMTG → LIFG	0.034	0.142	0.119	0.65

Table S9. Average modulation parameter differences (*repeated* minus *novel*) and linear contrast results in response to mismatching category members as a function of prior repetitions. Abbreviation is the same as in Table S6.

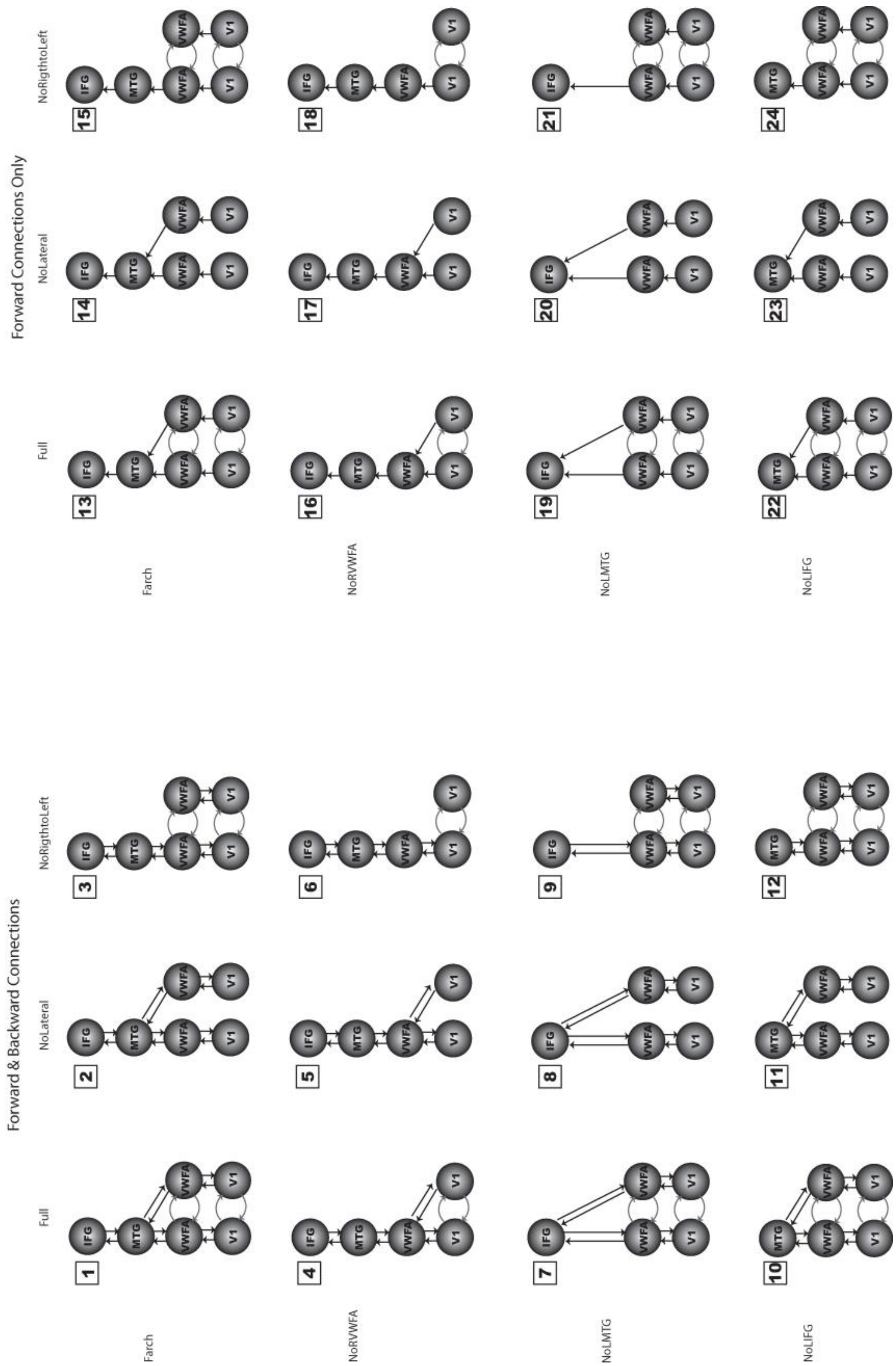
	1-3	4-6	7-9	Linear contrast (p values)
LV1 → LVWFA	-0.123	-0.136	0.124	0.25
RV1 → RVWFA	-0.172	-0.042	0.015	0.25
LVWFA → LMTG	-0.003	0.133	-0.161	0.60
RVWFA → LMTG	0.138	0.013	-0.189	0.08
LMTG → LIFG	-0.069	0.001	-0.043	0.86

Supplementary figure captions

Fig. S1. Twenty-four connectivity models tested with DCM. Acronyms: V1: primary visual cortex; VWFA: visual word form area; MTG: middle temporal gyrus; IFG: inferior frontal gyrus.

Fig. S2. DCM Bayesian model selection results. (A) Relative log-evidence of all 24 models (numbers labeled as in Fig. S1). (B) The posterior probability from model selection.

Fig. S1



Forward & Backward Connections
Forward Connections Only
Full
NoLateral
NoRigthtoLeft
Farch
NoRVWFA
NoLMTG
NoLIFG
IFG
MTG
VWFA
V1
1
2
3
4
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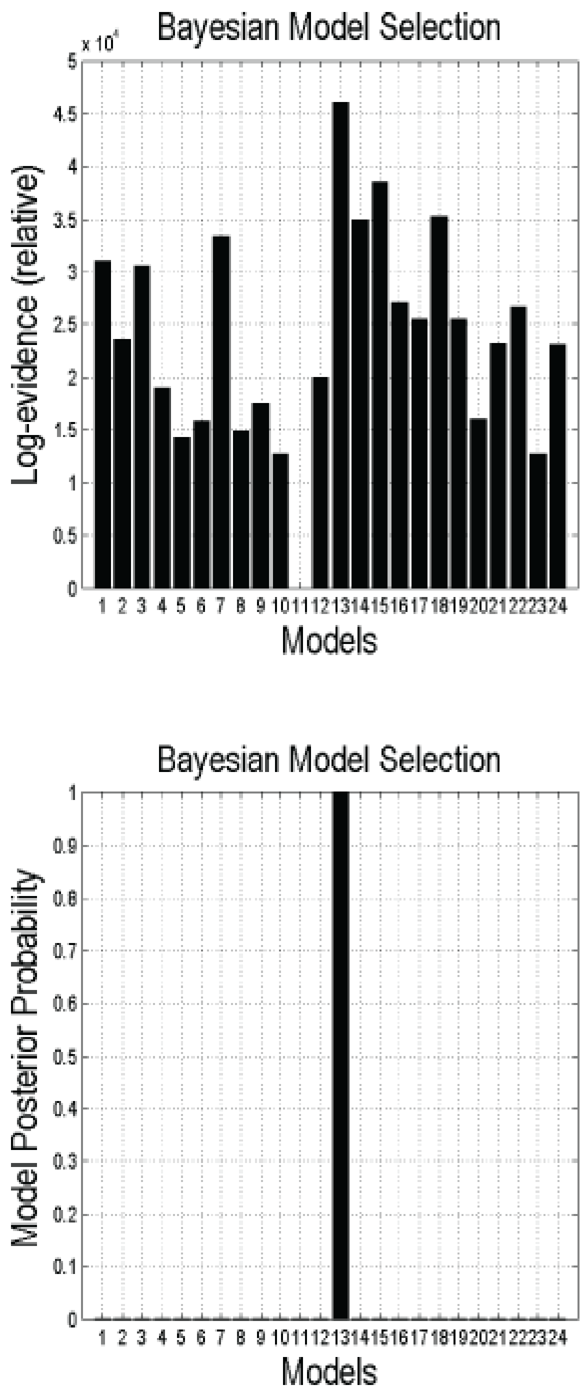
Fig. S2



Bayesian Model Selection
x 10^4
Log-evidence (relative)
Models
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5
Bayesian Model Selection
Model Posterior Probability
Models
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1

Supplementary references

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