

Supplemental Materials 1. IRT Model Assessment

The following text and Supplemental Figures S1 and S2 are from the companion article: Fergadiotis, Kellough, & Hula, "Item response theory modeling of the Philadelphia Naming Test," *JSLHR*, doi:10.1044/2015_JSLHR-L-14-0249. Please see the companion article for the complete dimensionality and IRT model analysis and discussion.

Dimensionality

To assess the dimensionality of the PNT, we fitted the dichotomous (correct vs. incorrect) response data for all 251 participants to a unidimensional confirmatory item-level factor model using NOHARM 4.0 (Fraser & McDonald, 1988). We examined three indices of model fit: the root-mean-square of residuals, Tanaka goodness of fit, and an approximate chi-square statistic (X^2_{GD} ; De Champlain & Gessaroli, 1998). The root-mean-square of residuals is an indicator of the size of the average residual item covariances, with smaller values indicating better overall fit; a value equal to 4 divided by the square root of the sample size is taken as the criterion below which fit is considered acceptable (de Ayala, 2009). The Tanaka goodness of fit indexes the residual item variances, with values $\geq .90$ indicating acceptable fit and values $\geq .95$ indicating good fit (McDonald, 1999). The approximate chi-square statistic tests the null hypothesis that the residual interitem correlations are equal to zero and is evaluated by a significance test where p values $> .05$ are taken to indicate adequate fit (De Champlain & Gessaroli, 1998).

Results of the confirmatory factor analysis suggested that the one-factor model demonstrated good fit, root-mean-square of residuals = .0101 vs. criterion = .2525, Tanaka goodness of fit = .9840, X^2_{GD} ($df = 15050$) = 8182.055, $p > .99$. The M and SD of the residual correlations were 0.0003 and 0.046, respectively (minimum = -0.22 , maximum = 0.18), with 3.2% taking absolute values > 0.1 . From these results, we concluded that the data satisfied the assumption of unidimensionality.

IRT Model Fit

We tested the 1-PL model assumption of equal item discrimination using the R package ltm version 0.9-9 (Rizopoulos, 2006). We fitted both a 1-PL and a 2-PL model and examined four indicators of relative model fit. We first conducted a likelihood ratio (ΔG^2) significance test of the difference in overall model fit between the 1-PL and 2-PL models (de Ayala, 2009). For this test, a significant result indicates that permitting discrimination to vary by item improves model fit. A nonsignificant result, on the other hand, indicates that the simpler 1-PL model should be retained. It is often the case that models with more parameters demonstrate significantly better model fit, even when the improvement in model fit may not be practically meaningful (de Ayala, 2009). To examine the magnitude of difference in model fit, we used an R^2_{Δ} statistic, which is calculated as the relative reduction in G^2 caused by fitting a more complex model and indicates the increase in proportion of variance accounted for by the 2-PL model relative to the 1-PL model (de Ayala, 2009). We also evaluated the Akaike information criterion (AIC), which takes into account model complexity in addition to goodness of fit, and the Bayesian information criterion (BIC), which is similar to the AIC but carries a larger penalty for model complexity (de Ayala, 2009). We tested the assumption of local independence using Yen's (1984) Q_3 statistic, which is based on interitem residual correlations.

Our final evaluation of model fit was conducted using item-level information-weighted (infit) and outlier-sensitive mean-square (outfit) and standardized fit statistics (Smith, 1991), which are based on the squared standardized differences between the model expectations and the observed responses. . . . Instead of applying fixed cutoffs, we—following Massof (2011)—

compared the distributions of the infit and outfit statistics to their expected distributions: chi-square divided by its degrees of freedom for the meansquare and standard normal for the standardized statistic. [See the companion article for more information on why we chose not to follow published cutoff criteria for the infit and outfit statistics (e.g., Wright & Linacre, 1994).]

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IRT model-fit assessment revealed that the data showed significantly better fit to the 2-PL model than to the 1-PL model, $\Delta G^2 = 384.26$, $df = 174$, $p < .001$. At the same time, the R^2_{Δ} value (.0098) indicated that the 2-PL model provided an improvement in model fit of slightly less than 1%. The AIC favored the 2-PL model ($AIC_{1-PL} = 39,432$, $AIC_{2-PL} = 39,395$), whereas the BIC, which carries a larger penalty for model complexity, indicated better fit for the 1-PL model ($BIC_{1-PL} = 40,052$, $BIC_{2-PL} = 40,629$). Our interpretation of these results is that the 2-PL model showed better fit, but that the improvement relative to the 1-PL model was small.

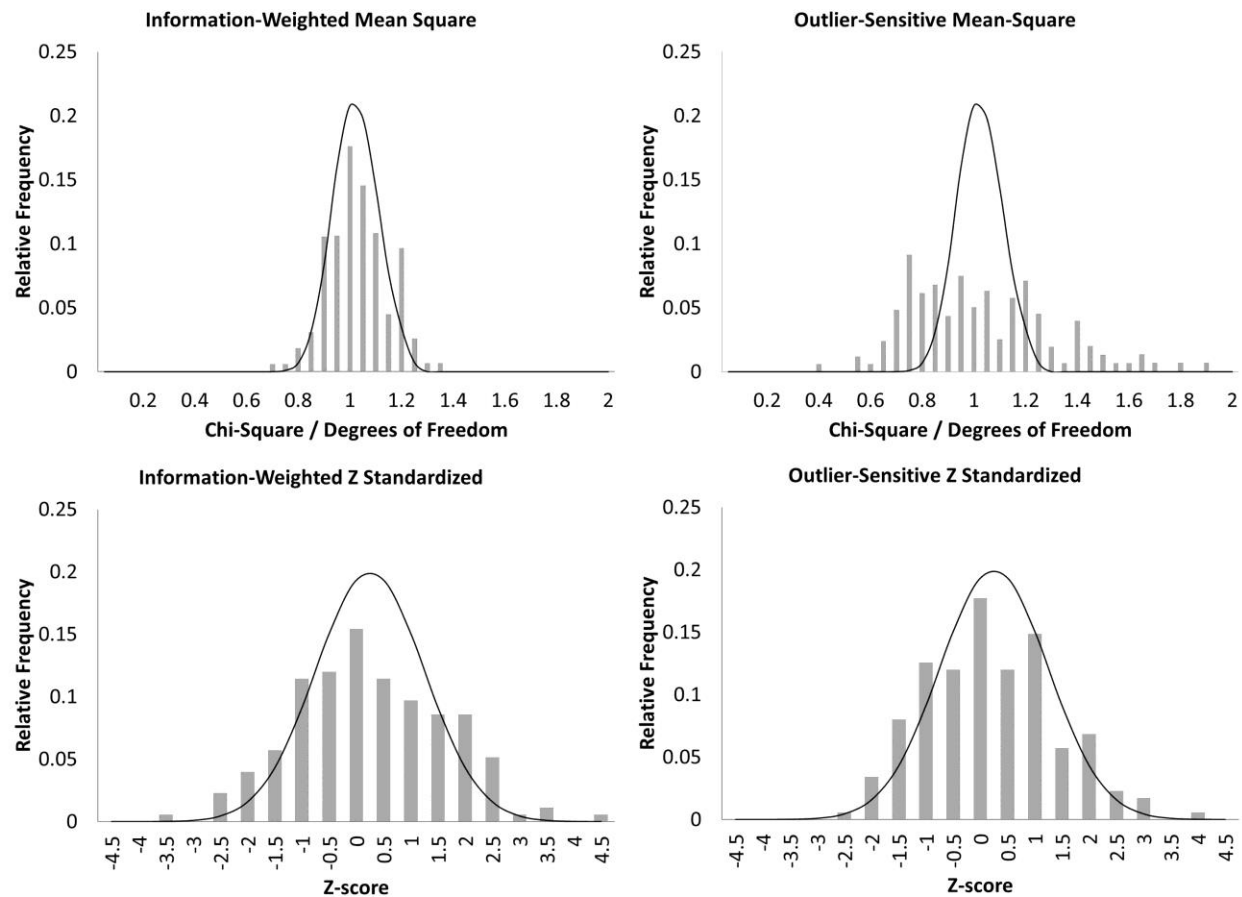
Evaluation of local independence using the Q_3 statistic after fitting the 1-PL model suggested that the data approximated this assumption. Less than 5% of item pairs obtained residual correlations greater than two *SDs* from the mean.

Plots of the item-fit statistics for the 1-PL model, presented in Supplemental Figure S1, suggested that there were differences between the observed and expected distributions. The Kolmogorov–Smirnov test found significant differences between the information-weighted ($p = .028$) and outlier-sensitive ($p < .001$) mean-squares and the expected chi-square distribution divided by its degrees of freedom, and marginally significant differences between the information-weighted ($p = .062$) and outlier-sensitive ($p = .051$) z -standardized values and the expected normal distribution. . . . Plots of the modeled and empirical item characteristic curves for examples of underfitting (with elevated mean-square and standardized fit values), overfitting (with low fit values), and well-fitting (with values close to expectation) items are provided in Supplemental Figure S2.

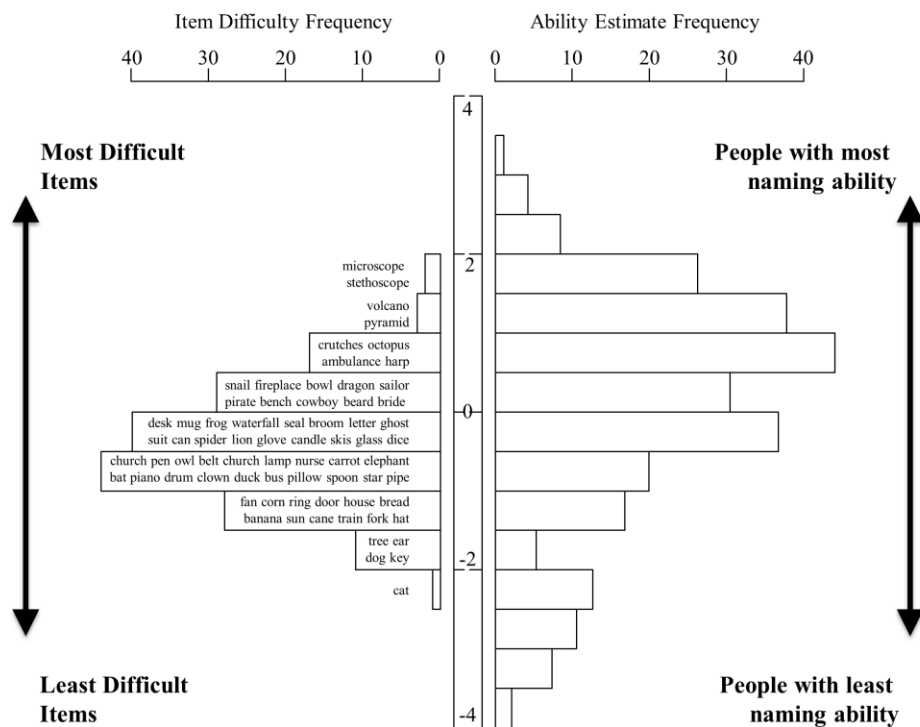
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Because the improvement in fit conferred by the 2-PL model was relatively small and the sample size was not large enough for stable estimation of item discrimination, we proceeded with the 1-PL model without excluding any items.

References

- de Ayala, R. J. (2009). *The theory and practice of item response theory*. New York, NY: Guilford.
- Fraser, C., & McDonald, R. P. (1988). NOHARM: Least squares item factor analysis. *Multivariate Behavioral Research*, 23, 267–269.
- Massof, R. W. (2011). Understanding Rasch and item response theory models: Applications to the estimation and validation of interval latent trait measures from responses to rating scale questionnaires. *Ophthalmic Epidemiology*, 18, 1–19.
- McDonald, R. P. (1999). *Test theory: A unified treatment*. Mahwah, NJ: Lawrence Erlbaum.
- Rizopoulos, D. (2006). ltm: an R package for latent variable modeling and item response theory analyses. *Journal of Statistical Software*, 17(5), 1–25.
- Smith, R. M. (1991). The distributional properties of Rasch item fit statistics. *Educational and Psychological Measurement*, 51, 541–565.
- Wright, B. D., & Linacre, J. M. (1994). Reasonable mean-square fit values. *Rasch Measurement Transactions*, 8, 370.



Supplemental Figure S1. Relative frequency plots of one-parameter logistic model item-fit statistics and their expected distributions. The histogram bars in each plot represent the observed fit values, and the curves represent the expected distributions. For the upper plots, the expectation is a chi-square divided by its degrees of freedom ($df = 250$); for the lower plots, it is a standard normal distribution.



Supplemental Figure S2. Map of items and persons showing selected item content. The figure orders the difficulty of the items on the left side and the level of naming ability of the participants on the right side. Items at the bottom of the scale are easiest to name. Participants with the least naming ability are at the bottom of the scale and are expected to have difficulty even with the easiest items.

Supplemental Table S1. Item parameter and fit estimates, based on the full sample of 251 individuals with aphasia. Items are sorted in ascending order of difficulty.

Item	Item Difficulty	Standard Error	Discrimination	Information-Weighted Mean Square	Information-Weighted Z	Outlier-Sensitive Mean Square	Outlier-Sensitive Z
cat	-2.008	0.178	1.258	1.24	1.6	1.62	1.47
ear	-1.932	0.175	1.258	1.24	1.64	1.7	1.67
key	-1.825	0.17	1.258	0.69	-2.56	0.38	-2.22
baby	-1.72	0.166	1.258	1.22	1.63	1.54	1.5
bed	-1.687	0.165	1.258	0.96	-0.26	0.63	-1.2
hand	-1.687	0.165	1.258	0.81	-1.56	0.75	-0.71
dog	-1.686	0.165	1.258	1.15	1.16	1.35	1.06
eye	-1.686	0.165	1.258	1.26	1.89	1.28	0.89
nose	-1.686	0.165	1.258	0.97	-0.18	1.25	0.82
tree	-1.587	0.162	1.258	0.84	-1.34	0.52	-1.78
fish	-1.555	0.161	1.258	0.89	-0.89	0.95	-0.07
book	-1.525	0.16	1.258	1.16	1.28	1.87	2.42
shoe	-1.494	0.159	1.258	1.18	1.44	1.18	0.69
pie	-1.493	0.159	1.258	1.01	0.11	1.12	0.49
bone	-1.463	0.158	1.258	1.09	0.73	0.88	-0.35
hat	-1.463	0.158	1.258	1.04	0.35	0.84	-0.49
apple	-1.462	0.158	1.258	0.89	-0.93	0.68	-1.15
heart	-1.462	0.158	1.258	0.96	-0.29	0.69	-1.11
ball	-1.433	0.157	1.258	1.19	1.53	1.37	1.26
man	-1.403	0.156	1.258	1.2	1.61	1.25	0.92
hammer	-1.314	0.153	1.258	1.19	1.62	1.02	0.15
king	-1.314	0.153	1.258	1.03	0.32	0.85	-0.52
door	-1.286	0.152	1.258	1.09	0.79	1.11	0.5
horse	-1.286	0.152	1.258	0.85	-1.33	0.73	-1.04

ring	-1.286	0.152	1.258	0.88	-1.08	0.92	-0.22
balloon	-1.23	0.15	1.258	1.01	0.15	0.96	-0.06
corn	-1.23	0.15	1.258	1.05	0.5	1.17	0.71
fan	-1.23	0.15	1.258	0.75	-2.45	0.52	-2.25
pig	-1.202	0.15	1.258	0.91	-0.79	0.81	-0.73
banana	-1.148	0.148	1.258	1.02	0.26	1.01	0.12
comb	-1.148	0.148	1.258	1.07	0.66	0.79	-0.86
house	-1.094	0.147	1.258	1.09	0.86	0.95	-0.14
window	-1.094	0.147	1.258	1	0	1.41	1.64
bread	-1.068	0.146	1.258	1.03	0.28	0.99	0.02
sun	-1.068	0.146	1.258	1.18	1.65	1.23	1.01
cane	-1.067	0.146	1.258	0.92	-0.76	0.67	-1.58
football	-1.042	0.145	1.258	1	0.08	0.92	-0.3
train	-1.042	0.145	1.258	1.35	3.04	1.66	2.53
fork	-1.016	0.145	1.258	1.07	0.73	1.21	0.95
snake	-1.016	0.145	1.258	1	-0.01	0.93	-0.24
chair	-0.991	0.144	1.258	1.11	1.06	1.18	0.83
clock	-0.965	0.143	1.258	0.87	-1.35	0.85	-0.67
pencil	-0.965	0.143	1.258	1.06	0.58	1.39	1.69
sock	-0.965	0.143	1.258	0.98	-0.12	0.91	-0.34
whistle	-0.965	0.143	1.258	0.93	-0.7	0.94	-0.21
rope	-0.964	0.143	1.258	0.89	-1.14	0.74	-1.23
cow	-0.915	0.142	1.258	0.99	-0.11	0.89	-0.48
hair	-0.915	0.142	1.258	1.17	1.69	1.24	1.11
nail	-0.915	0.142	1.258	1.03	0.31	0.9	-0.44
basket	-0.914	0.142	1.258	0.89	-1.12	0.82	-0.84
bell	-0.89	0.142	1.258	1.05	0.52	0.96	-0.12
bus	-0.89	0.142	1.258	1.1	1.05	1.16	0.8
monkey	-0.89	0.142	1.258	0.98	-0.22	1.03	0.23

star	-0.89	0.141	1.258	0.93	-0.72	0.73	-1.37
spoon	-0.889	0.141	1.258	0.85	-1.6	0.67	-1.72
grapes	-0.865	0.141	1.258	0.9	-1.05	0.82	-0.86
scissors	-0.865	0.141	1.258	0.94	-0.56	0.8	-0.98
table	-0.865	0.141	1.258	0.88	-1.24	0.71	-1.47
belt	-0.841	0.14	1.258	0.79	-2.29	0.61	-2.17
flower	-0.841	0.14	1.258	0.95	-0.45	1.06	0.37
owl	-0.841	0.14	1.258	0.94	-0.62	0.8	-0.97
pen	-0.841	0.14	1.258	1.09	0.96	1.33	1.54
pillow	-0.841	0.14	1.258	1.04	0.4	1.07	0.42
cake	-0.817	0.14	1.258	0.87	-1.44	0.93	-0.29
turkey	-0.817	0.14	1.258	1.01	0.09	1	0.04
foot	-0.793	0.139	1.258	1.25	2.46	1.39	1.82
duck	-0.746	0.138	1.258	0.99	-0.08	1.03	0.21
goat	-0.746	0.138	1.258	0.84	-1.78	0.79	-1.09
leaf	-0.746	0.138	1.258	0.99	-0.07	0.8	-1.04
pipe	-0.746	0.138	1.258	0.96	-0.39	0.76	-1.29
church	-0.745	0.138	1.258	1.17	1.78	1.43	1.98
knife	-0.745	0.138	1.258	1.04	0.42	1.37	1.75
saw	-0.722	0.138	1.258	0.94	-0.62	0.91	-0.39
queen	-0.699	0.137	1.258	0.96	-0.43	0.81	-0.97
tent	-0.699	0.137	1.258	0.87	-1.5	0.72	-1.56
lamp	-0.676	0.137	1.258	0.91	-0.97	0.77	-1.22
nurse	-0.676	0.137	1.258	0.8	-2.35	0.68	-1.8
clown	-0.653	0.136	1.258	0.81	-2.19	0.71	-1.66
drum	-0.653	0.136	1.258	1.04	0.48	1.12	0.68
pear	-0.63	0.136	1.258	1.12	1.34	1.28	1.42
piano	-0.63	0.136	1.258	1.04	0.5	1.15	0.8
carrot	-0.586	0.135	1.258	0.71	-3.6	0.56	-2.73

elephant	-0.585	0.135	1.258	0.79	-2.5	0.66	-2.04
bat	-0.54	0.134	1.258	1.15	1.64	1.22	1.16
cross	-0.496	0.134	1.258	0.86	-1.7	0.68	-1.9
rake	-0.496	0.134	1.258	1.02	0.27	0.96	-0.17
towel	-0.496	0.134	1.258	0.9	-1.23	0.72	-1.61
bridge	-0.475	0.133	1.258	0.8	-2.45	0.71	-1.69
kite	-0.475	0.133	1.258	0.94	-0.64	0.73	-1.57
kitchen	-0.474	0.133	1.258	1.05	0.64	1.55	2.63
iron	-0.453	0.133	1.258	1.04	0.53	0.92	-0.37
well	-0.453	0.133	1.258	1.04	0.53	0.95	-0.2
hose	-0.431	0.133	1.258	0.9	-1.22	0.83	-0.92
dice	-0.41	0.132	1.258	0.98	-0.22	1.08	0.5
glass	-0.41	0.132	1.258	1.01	0.11	1.26	1.41
skis	-0.41	0.132	1.258	0.86	-1.67	0.7	-1.78
candle	-0.388	0.132	1.258	0.91	-1.05	0.83	-0.93
glove	-0.388	0.132	1.258	0.92	-0.93	0.8	-1.12
lion	-0.388	0.132	1.258	0.99	-0.11	0.97	-0.1
camera	-0.367	0.132	1.258	1.02	0.25	1.04	0.3
ghost	-0.346	0.131	1.258	0.91	-1.16	0.84	-0.86
boot	-0.325	0.131	1.258	1.15	1.79	1.19	1.07
letter	-0.325	0.131	1.258	1.12	1.43	1.37	1.91
broom	-0.283	0.131	1.258	1.08	0.98	1.11	0.67
sandwich	-0.283	0.131	1.258	1.04	0.53	0.99	0.01
vest	-0.283	0.131	1.258	0.89	-1.43	0.73	-1.62
suit	-0.263	0.13	1.258	0.98	-0.19	1.17	0.95
can	-0.242	0.13	1.258	1.11	1.33	1.1	0.59
frog	-0.242	0.13	1.258	0.9	-1.28	0.81	-1.04
spider	-0.242	0.13	1.258	0.86	-1.87	0.73	-1.61
bottle	-0.201	0.13	1.258	1.13	1.59	1.21	1.13

map	-0.201	0.13	1.258	0.98	-0.25	0.79	-1.17
zipper	-0.201	0.13	1.258	1.08	1.04	1.79	3.6
desk	-0.18	0.13	1.258	1.02	0.25	0.9	-0.49
squirrel	-0.16	0.129	1.258	0.93	-0.85	1.04	0.26
camel	-0.14	0.129	1.258	1.14	1.71	1.18	0.98
scarf	-0.12	0.129	1.258	0.92	-1.01	0.87	-0.68
toilet	-0.119	0.129	1.258	1.18	2.2	1.36	1.82
calendar	-0.1	0.129	1.258	0.9	-1.27	0.89	-0.54
wagon	-0.08	0.129	1.258	0.95	-0.69	0.79	-1.16
typewriter	-0.06	0.128	1.258	0.8	-2.77	0.64	-2.15
seal	-0.02	0.128	1.258	0.96	-0.48	0.87	-0.65
strawberries	-0.02	0.128	1.258	0.95	-0.71	0.95	-0.23
waterfall	-0.02	0.128	1.258	1.02	0.27	1.12	0.66
pumpkin	0.02	0.128	1.258	0.89	-1.49	1.19	0.99
mountain	0.04	0.128	1.258	1.08	1.08	1.18	0.93
bowl	0.059	0.128	1.258	1.24	3.1	1.63	2.83
cowboy	0.059	0.128	1.258	1.06	0.77	0.91	-0.44
fireman	0.059	0.128	1.258	1.17	2.2	1.11	0.62
top	0.059	0.128	1.258	1	0.01	1.1	0.58
crown	0.079	0.128	1.258	0.99	-0.12	1	0.06
bride	0.098	0.127	1.258	1.19	2.44	1.46	2.11
anchor	0.118	0.127	1.258	1.08	1.16	1.02	0.19
beard	0.137	0.127	1.258	1.16	2.09	1.17	0.89
bench	0.137	0.127	1.258	1.01	0.11	0.94	-0.24
flashlight	0.137	0.127	1.258	0.89	-1.61	0.77	-1.2
scale	0.137	0.127	1.258	1	0.09	1.11	0.62
butterfly	0.157	0.127	1.258	0.8	-2.94	0.64	-2.01
cannon	0.157	0.127	1.258	1.06	0.8	1.02	0.17
pineapple	0.157	0.127	1.258	0.85	-2.11	0.73	-1.42

sailor	0.157	0.127	1.258	0.99	-0.18	0.92	-0.34
closet	0.176	0.127	1.258	0.98	-0.21	0.79	-1.05
vase	0.176	0.127	1.258	1.17	2.29	1.4	1.83
snail	0.273	0.127	1.258	0.9	-1.41	0.76	-1.2
pirate	0.311	0.127	1.258	0.99	-0.16	1	0.05
saddle	0.311	0.127	1.258	0.81	-2.84	0.67	-1.71
mustache	0.33	0.127	1.258	0.97	-0.44	0.83	-0.78
tractor	0.368	0.127	1.258	0.96	-0.55	1.13	0.67
wig	0.388	0.127	1.258	1.32	4.23	1.48	2.01
fireplace	0.407	0.127	1.258	0.98	-0.32	0.86	-0.63
chimney	0.426	0.127	1.258	1.09	1.24	1.21	0.96
dragon	0.445	0.127	1.258	1.09	1.35	1.02	0.16
ruler	0.483	0.127	1.258	1.04	0.54	0.95	-0.15
celery	0.521	0.127	1.258	0.96	-0.55	0.82	-0.78
harp	0.522	0.127	1.258	1.09	1.31	1.4	1.66
helicopter	0.522	0.127	1.258	1.04	0.54	0.99	0.02
zebra	0.54	0.127	1.258	0.95	-0.75	0.95	-0.13
garage	0.541	0.127	1.258	1.16	2.26	1.08	0.42
skull	0.579	0.128	1.258	1.16	2.24	1.13	0.63
van	0.579	0.128	1.258	1.07	1.06	0.92	-0.28
eskimo	0.598	0.128	1.258	0.99	-0.09	1.02	0.18
plant	0.636	0.128	1.258	1.19	2.59	1.58	2.19
slippers	0.637	0.128	1.258	0.99	-0.11	0.95	-0.12
thermometer	0.637	0.128	1.258	0.9	-1.53	0.74	-1.12
necklace	0.695	0.128	1.258	0.88	-1.85	0.72	-1.22
crutches	0.714	0.129	1.258	0.94	-0.89	0.9	-0.36
ambulance	0.772	0.129	1.258	1.15	2.07	1.44	1.65
cheerleaders	0.772	0.129	1.258	0.88	-1.78	0.74	-1.09
octopus	0.772	0.129	1.258	0.99	-0.06	1	0.1

dinosaur	0.989	0.132	1.258	1.13	1.85	1.23	0.86
binoculars	1.029	0.133	1.258	0.96	−0.52	0.75	−0.89
pyramid	1.049	0.133	1.258	0.93	−1.05	0.87	−0.4
volcano	1.07	0.133	1.258	0.98	−0.26	0.97	−0.01
microscope	1.772	0.153	1.258	0.92	−0.85	0.78	−0.56
stethoscope	1.88	0.157	1.258	0.79	−2.2	1.18	0.59
