Suggested for 2012

Title: Validity of an Eye-Tracking Method for Capturing Auditory-Visual Cross-Format Semantic Priming

Abstract

Semantic priming studies have great potential to improve understanding of lexical processing in people with aphasia. Traditional priming response tasks, such as lexical decision, cued shadowing, and naming, and techniques based on fMRI and ERPs, entail potential confounds that are especially critical in aphasia. Eye-tracking may help reduce such confounds. The validity of an eye-tracking method to capture semantic priming effects in an auditory-visual cross-format priming context was tested in adults without neurological disorders. Traditional priming responses were used for stimulus validation. Results support a pool of valid measures and protocol effectiveness. Further research including people with aphasia is warranted.

Introduction

Importance of Studying Priming

Priming methods are used by wide range of researchers to study language comprehension, lexical organization, syntax, and cognitive processes such as memory, learning, and attention. Semantic priming effects are the most robust, reliably observed, and well established of psycholinguistic priming effects (Balota & Duchek, 1988; Balota, 1994; McNamara, 2005; Tabossi, 1996). Semantic priming studies have great potential to improve understanding of the nature of comprehension and lexical processing challenges in people with aphasia (Hagoort, 1993; Milberg, Blumstein, & Dworetzky, 1987).

Problems and Confounds in Current Methods of Priming Research and the Need for Alternative Methods

The most common response tasks used in priming studies have been lexical decision, cued shadowing, and naming. These tasks require participants to understand instructions, make metalinguistic decisions, and use spoken or limb-motor actions, all of which introduce potential confounds when assessing people with neurological impairments, who may have problems with comprehension, learning, memory, attention, speech, and limb-motor control. Therefore, the validity of traditional priming tasks in assessing individuals with aphasia may be questioned. Neuroimaging (PET and fMRI) and event-related potential (ERP) techniques have been implemented to study priming. However, neuroimaging entails high sensitivity to physical movements, and hemodynamic changes measured occur over time intervals longer than real-time priming effects. ERPs are highly sensitive to acoustic and electrical disturbances, and participant movement, which may confound results (Picton, Bentin, Berg, Donchin, & Hillyard, 2000).

Eye-tracking methods offer hope for alternative priming research methods. First, the impact of several task-related problems inherent to traditional priming methods is avoided. Second, allowance for spontaneous eye movement rather than intentional or planned motor responses allows valid testing of participants with varied forms of apraxia, including ocular motor apraxia and apraxia of speech. Third, even individuals with severe neurological disorders tend to have the requisite intact saccadic movement and fixation abilities (Leigh & Zee, 1983).

In a recent study, Odekar, Hallowell, Kruse, Moates, and Lee (2009) demonstrated the validity of an eye-tracking method to study semantic priming effects of isolated words in a visual cross-format priming context using a written word-picture method in individuals without neurological problems. Given the effectiveness of that method, and given that in traditional priming experiments, auditory primes lead to stronger effects than the same words presented visually, we reasoned that an auditory-visual cross-format method could also be used to index priming effects.

Purpose

The purpose of this study was to validate an eye-tracking method for capturing semantic priming effects in an auditory-visual cross-format context. Results may have important implications for future priming studies in individuals with and without neurological disorders.

Procedure

Participants

Eighty adult native speakers of American English (age 21 to 30) were recruited for two experiments (40 for each). Participants with a history of any neurological impairment or learning disability were excluded. All passed screenings for hearing, near and peripheral vision, ocular motor functions, and visual attention.

Method

First, a traditional semantic priming experiment (picture naming) was conducted to test prime-target pairs for priming effects based on verbal response times. Each trial consisted of an auditory word prime, followed by a picture. In the related condition, the prime word was semantically related to the target image. In the unrelated condition, the prime word was unrelated to the image. Naming reactions times (see Table 1) were used to determine qualifying stimulus pairs for the second experiment entailing eye-tracking.

In the second experiment, each trial consisted of a spoken prime word, plus a visual display containing one image highly associated with the auditory prime (target) and two images unrelated to the prime (see Figure 1), shown for four seconds. Eye-tracking measures are summarized in Table 2. A threshold of 100 milliseconds and tolerance of 6 degrees horizontally and 4 degrees vertically were used to determine eye fixations (Hallowell & Lansing, 2004; Manor & Gordon, 2003).

Results

1. Do fixation duration measures on targets capture semantic (associative) priming effects?

   Results are shown in Tables 3 and 4. For all measures, in the related condition, a significantly greater allocation of all fixation duration measures was observed for targets as compared to non-target foils. Fixation duration measures were significantly greater in the related condition compared to the unrelated condition.

2. Can the latency of fixation (LF) for the stimulus areas capture semantic associative priming effects?

   Results are shown in Tables 5 and 6 and Figure 2. The mean LF was significantly shorter for targets compared to non-target foils in the related condition. The mean LF was significantly shorter for target items in related compared to the unrelated condition.

3. Are the eye-tracking dependent measures related to the reaction time (picture naming) measures recorded during the traditional priming task?

   Correlation results for differences between related and unrelated conditions according to each of the eye-tracking measures were compared to differences in traditional priming (naming) reaction times are given in Table 7. There was no significant relationship between eye-tracking and traditional priming RT measures.

Discussion

As predicted, semantic priming effects were successfully captured using all of the fixation duration measures (PFD, MFD, and FPFD). The pattern of preferential allocation of fixations to target items in related compared to unrelated conditions was similar. Also as predicted, there were significantly shorter latencies of fixation on target items in the related compared to the unrelated condition. These findings are consistent with previous studies demonstrating that latency to target fixation is shorter for semantically related items compared to unrelated foils (De Graef et al., 1990; Hallowell, Wertz, & Kruse, 2002; Henderson et al., 1999; Heuer & Hallowell, 2009; Odekar et al., 2009). Results support the validity of using eye-tracking results to index semantic priming.

The lack of a statistically significant correlation between traditional and eye-tracking measures may be due to the fact that the automatic activation of concepts induced by a prime word decays after 400 ms (Lupker, 1984) such that the strength of the overall priming effect depends on the continued maintenance of activated concepts in the controlled processing phase. In the present study the priming effects were measured at a single SOA of 400 ms, so it was not possible to identify priming effects that may have occurred at different SOAs. Another possibility for the lack of correlation between the two methods is that the traditional priming method is based on reaction time and does not capture a truly online response; evidence from ERP studies suggest that the online lexical retrieval is not accurately reflected by RT measures, as it is speed limited (Rossel, Price, & Nobre, 2003).

Implications and Future Directions

This study validates an eye-tracking method to capture semantic priming effects in an auditory-visual cross-format context. Regardless of which dependent measures were used, semantic priming effects were captured using the eye-tracking method. A validated pool of measures and a testing protocol are available for future studies. Further testing of psychometric properties of eye-tracking measures in priming contexts is needed. Experimentation with adults with aphasia and related disorders is warranted, given (a) the great relevance of priming to understanding of aphasia and (b) the myriad benefits of eye-tracking in terms of reducing potentially confounding factors inherent in other priming methods.

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Tables

Table 1

Naming reaction time results from traditional semantic priming (picture naming)

Trial	Target	Related	Unrelated	Related RT	Unrelated RT	T	*Df*	*p*
1	anchor	ship	Wool	916.71	966.42	-0.78	30	.441
2*	arrow	left	Autumn	723.26	802.71	-3.00	30	.005
3	axe	wood	Toast	740.10	847.69	-2.99	28	.006
4	baby carriage	baby	Drummer	752.17	1091.90	-3.61	28	.001
5	ball	bounce	Smell	617.03	778.78	-4.44	31	.000
6*	basket	baseball	God	679.00	875.47	-5.49	31	.000
7	bat	picnic	Write	571.47	815.41	-5.28	31	.000
8	bed	sleep	Love	651.97	957.19	-5.82	31	.000
9	bell	ring	Turn	829.50	905.28	-1.61	31	.118
10	belt	pants	Milk	801.10	812.90	-0.60	30	.556
11	bicycle	ride	Smoke	767.06	829.84	-2.15	31	.040
12*	book	read	Halloween	676.72	879.94	-6.29	31	.000
13	bow	tie	Picnic	893.29	1044.19	-2.33	20	.031
14*	bowl	cereal	Hat	731.03	890.74	-4.86	30	.000
15	broom	sweep	Lion	789.24	1016.17	-1.97	28	.059
16*	brush	hair	Nuts	763.28	999.93	-5.67	28	.000
17	bus	school	Spoon	788.11	947.19	-4.13	26	.000
18	butterfly	wings	Stop	762.74	765.29	-0.11	30	.917
19*	cake	birthday	Feet	737.06	840.10	-2.67	30	.012
20	camel	hump	Measure	888.90	995.47	-2.34	29	.026
21	cannon	war	Pepper	813.10	1029.58	-4.52	30	.000
22	carrot	rabbit	Baseball	810.06	820.42	-0.41	30	.685
23	chair	sit	Salad	877.90	908.03	-0.86	30	.397
24*	church	god	Sew	767.61	991.16	-4.52	30	.000
25	clock	time	Cook	733.59	942.44	-3.35	31	.002
26	clown	scary	Night	851.06	856.29	-0.13	30	.896
27	coat	warm	Bounce	907.80	1027.28	-1.46	24	.158
28	corn	cob	Slow	882.93	1049.21	-2.26	28	.031
29	cow	milk	Rain	862.90	1179.68	-3.82	30	.001
30*	crown	king	Ring	760.65	973.77	-5.30	30	.000
31*	dog	bark	Tall	651.16	879.34	-5.21	31	.000
32*	door	open	Jeans	831.56	1075.56	-3.98	31	.000
33	door knob	turn	Baby	1002.50	1023.83	-0.48	29	.634
34*	drum	drummer	Sting	782.75	947.19	-4.06	31	.000
35	duck	quack	Left	576.13	957.94	-6.58	30	.000
36	ear	hear	Light	753.23	774.35	-0.50	30	.621

37	elephant	big	Oink	820.07	1024.70	-5.36	26	.000
38	envelope	letter	Home	848.77	836.17	0.23	29	.820
39	eye	see	Play	656.03	767.42	-3.24	30	.003
40	fence	white	Hoot	844.69	834.56	0.33	31	.742
41	finger	point	Set	781.10	844.87	-1.31	30	.199
42	flag	America	Ball	702.62	958.93	-4.74	28	.000
43	fork	spoon	Chair	802.80	851.37	-0.69	29	.495
44	garbage can	trash	Feathers	903.65	1079.23	-2.57	30	.016
45	giraffe	tall	Pants	902.79	982.07	-1.13	27	.267
46	glasses	eyes	Iron	769.20	739.43	1.28	29	.211
47	glove	hand	Fruit	947.07	866.79	1.68	28	.105
48	gorilla	monkey	Tie	775.73	912.53	-1.38	29	.177
49	grapes	fruit	Key	773.34	852.56	-3.52	31	.001
50	guitar	music	Watch	834.37	882.30	-1.20	29	.241
51	gun	bullet	Thread	854.03	815.30	0.30	29	.764
52	hammer	nail	Rabbit	868.09	802.53	2.44	31	.021
53	hand	finger	Quack	872.15	802.37	1.20	26	.243
54	hanger	clothes	Snow	765.32	795.13	-0.88	30	.383
55	hat	head	Flowers	851.59	881.03	-0.58	31	.563
56	heart	love	Point	672.00	807.09	-2.95	31	.006
57	house	home	Bow	861.23	812.77	1.07	25	.293
58	ironing board	iron	Jump	777.11	851.61	-1.55	27	.133
59	kangaroo	jump	Wine	762.13	846.73	-4.11	29	.000
60	kettle	tea	Hump	1016.32	1019.00	-0.05	24	.964
61	kite	fly	Pan	781.63	808.31	-0.97	31	.342
62*	ladder	climb	Monkey	695.13	889.34	-4.20	31	.000
63	lamp	light	Ocean	884.04	869.64	0.27	27	.791
64	leaf	autumn	King	710.15	844.96	-3.15	25	.004
65	lemon	sour	Time	841.50	814.88	0.63	31	.535
66	leopard	spots	Hammer	970.14	1058.29	-1.40	20	.176
67	lips	kiss	Nail	685.52	807.87	-3.63	30	.001
68	lock	key	Water	828.97	959.58	-2.95	30	.006
69	mitten	glove	Sweep	976.28	774.28	2.19	24	.038
70	moon	night	Teeth	878.84	783.58	2.81	30	.009
71	necklace	pearls	Hear	672.00	818.10	-3.55	30	.001
72	nose	smell	Climb	629.45	762.55	-3.54	30	.001
73	onion	cry	Clothes	1013.96	862.11	2.14	26	.042
74	owl	hoot	Hand	705.78	823.50	-2.51	31	.018
75*	paintbrush	paint	Ride	792.72	988.44	-3.50	17	.003
76	pants	jeans	See	806.97	766.97	0.92	29	.366
77	peacock	feathers	America	843.21	1144.93	-1.69	28	.102
78	pencil	write	Fly	796.48	752.29	1.62	30	.116
79*	pig	oink	Read	649.54	894.58	-4.62	25	.000

80	pipe	smoke	Bark	832.61	847.68	-0.61	30	.545
81	pliers	tool	Cob	964.91	1090.17	-1.73	22	.097
82	pumpkin	Halloween	Cry	843.93	879.50	-0.62	29	.543
83	refrigerator	food	Letter	832.42	842.39	-0.39	30	.702
84	rhinoceros	horns	Ship	767.61	870.96	-2.62	27	.014
85	ring	marriage	Stripes	792.44	910.56	-2.97	31	.006
86	rocking chair	grandma	Sour	875.03	976.48	-2.12	28	.043
87	ruler	measure	Head	840.80	853.07	-0.25	29	.801
88	scissors	cut	Big	818.81	1106.58	-1.14	30	.264
89	sea horse	ocean	Spin	1065.59	1050.93	0.16	28	.872
90*	sheep	wool	Sit	796.70	980.30	-3.61	26	.001
91	shoe	feet	Eggs	819.61	845.65	-0.65	30	.520
92	skunk	stink	Kiss	691.12	924.52	-5.47	24	.000
93	sled	snow	Music	967.70	998.33	-0.76	29	.455
94	snail	slow	Red	876.56	886.72	-0.21	31	.833
95	spoon	fork	Sleep	809.03	883.48	-1.67	28	.105
96	squirrel	nuts	Fork	976.53	911.03	0.78	29	.440
97	swing	set	Horns	1014.07	1066.30	-0.93	26	.359
98	table	chair	Stink	990.13	920.00	1.46	30	.156
99	television	watch	Butter	906.84	932.77	-0.64	30	.525
100	tennis racket	ball	Spots	951.40	1094.30	-2.61	19	.017
101	tie	neck	Wood	810.00	854.47	-1.20	29	.241
102	tiger	lion	Tea	1132.35	1026.61	1.02	22	.320
103	toaster	toast	Eyes	887.83	1160.10	-2.71	28	.011
104	tomato	red	White	1006.39	1090.58	-1.23	30	.230
105	toothbrush	teeth	Warm	834.43	932.65	-2.32	22	.030
106	top	spin	on/off	833.75	1194.54	-3.90	23	.001
107	umbrella	rain	Pearls	847.61	903.23	-1.58	30	.124
108*	vase	flowers	Birthday	831.50	990.38	-3.70	31	.001
109	violin	play	Bullet	1096.72	1313.11	-2.50	17	.023
110	watermelon	seeds	Marriage	842.94	876.29	-0.80	30	.430
111	well	water	Finger	943.10	1021.26	-1.31	30	.200
112	whistle	bow	Open	986.00	833.25	2.84	27	.008
113	windmill	wind	Bolt	929.27	1218.27	-2.43	25	.023
114	wineglass	wine	School	716.17	1015.10	-6.71	28	.000
115	zebra	stripes	Glove	903.23	894.68	0.33	30	.744

Note: Alpha = 0.01, * represents items selected for the eye-tracking experiment.

Table 2

Eye-tacking dependent measures used for analysis.

Dependent measure	Definition	References
(a) Proportion of fixation duration	Fixation time not including saccadic transition times allocated to a specific image within display, divided by the total fixation time in the viewing of a stimulus in the display.	(Heuer et al., 2007; Heuer et al., 2009;Hallowell, 1999; Hallowell et al., 2002; Odekar et al., 2009)
(b) Mean fixation duration	The mean fixation duration for all fixations on one image in a display, obtained by dividing total fixation duration on each of the items in the display by the total number of fixations on each item.	(Odekar et al., 2009, p.34; De Graef, Christiaens, & d'Ydewalle, 1990; Henderson, Weeks, & Hollingworth, 1999)
(c) First pass fixation duration	”Time interval between when a viewer first fixates on and first fixates away from an area of interest”. The term “area of interest” corresponds to a specific image within a display.	(Odekar et al., 2009, p.34)
(d) Latency of fixation	The duration of the process of looking anywhere within a display before fixating on a specific area of interest.	(De Graef et al., 1990; Henderson et al., 1999; Odekar et al., 2009)

Table 3

Descriptive Statistics for Fixation Duration Measures on Stimulus Areas

	Related Condition						Unrelated Condition					
	PFD		*MFD*		*FPFD*		*PFD*		*MFD*		*FPFD*	
	4 s	2 s	4 s	2 s	4 s	2 s	4 s	2 s	4 s	2 s	4 s	2 s
M	.67	.60	657.73	473.83	1663.62	810.96	.36	.34	372.20	275.36	743.74	465.79
SD	.18	.13	262.51	70.77	691.26	217.17	.05	.59	48.02	15.12	209.36	86.15

Table 4

Paired Samples t-test Results for Fixation Duration Measures on Stimulus Areas

	Related Condition						Between Conditions					
	PFD		*MFD*		*FPFD*		*PFD*		*MFD*		*FPFD*	
	4 s	2 s	4 s	2 s	4 s	2 s	4 s	2 s	4 s	2 s	4 s	2 s
$t(39)$	11.56	13.19	7.58	17.12	10.17	9.67	10.29	12.15	6.75	17.50	7.99	9.67

Note: Alpha = 0.05, $p < 0.01$

Table 5

Descriptive Statistics for the Latency of Fixation Measure on Stimulus Areas

	Related Condition	Unrelated Condition
M	527.27	685.44
SD	141.58	191.24

Table 6

Paired Samples t-test Results for the Latency of fixation Measure on Stimulus Areas

	Related Condition	Between Conditions
t(39)	3.13	-5.97

Note: Alpha=0.05, $p < 0.01$

Table 7

Correlation Results for the Eye-Tracking Measures and Traditional Priming Reaction Time Measure

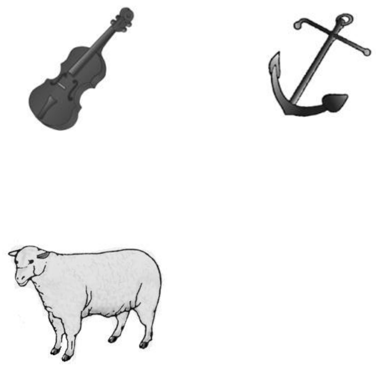
	MDAMFD	*MDPFD*	*MDFPFD*	*MDLF*	*MDRT*
MDAMFD	1	.507*	.635*	.214	-.003
MDPFD		1	.867*	.209	-.215
MDFPFD			1	.293	-.156
MDLF				1	.191
MDRT					1

Note: *Significant at alpha - 0.05

MDAMFD = mean difference of average mean fixation duration for targets across unrelated and related conditions; MDPFD = mean difference of proportion of fixation duration for targets across unrelated and related conditions; MDFPFD = mean difference of first-pass fixation duration across unrelated and related conditions; MDLF = mean difference of latency of fixation duration for targets across unrelated and related conditions; MDRT = mean difference of reaction times in traditional priming experiment across unrelated and related conditions.

Figures

Figure 1



Prime word: Wool

Figure 1. Sample images in a related trial of the eye-tracking experiment.

Figure 2

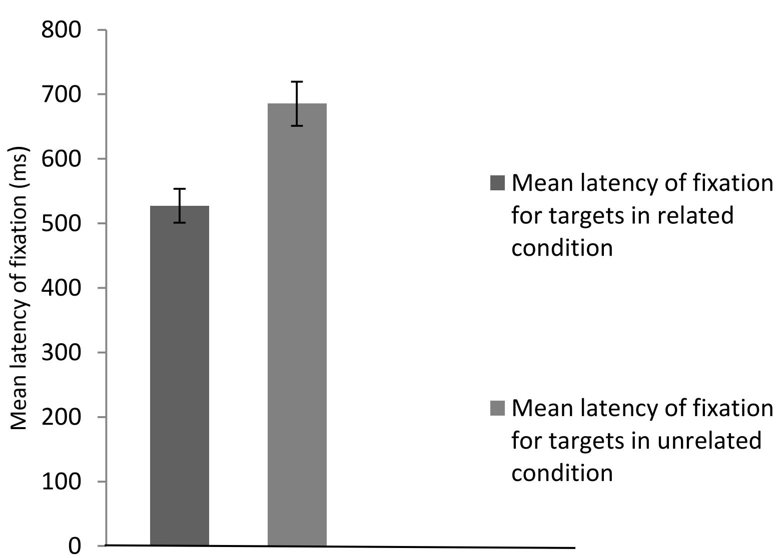


Figure 2. Mean latency of fixation on targets compared to non-target foils in the related condition