

## Online supplement

### **S1: Analysis of aging effects**

In our final analysis comparing Experiments 1 and 2, we found some unexpected differences between the two normal-hearing control groups. Even though each control group was matched in age to its degraded-speech group, the two experiments were not matched for age, and this may have impacted our results. The CI users and NH controls in Experiment 1 had an average age of almost 60 years, whereas the CIS and NS participants were primarily college students, none of whom exceeded age 30. It is important to separate the effects on lexical activation of degraded speech from those of cognitive aging and/or minor age-related hearing loss. While some work on cognitive aging has been conducted in the VWP (Ben-David, Chambers, Daneman, et al., 2011; Revill & Spieler, 2011), this has not examined the specific fine-grained measures used here. Thus, in the next section, we perform two age-based analyses to isolate any differences due to age. First, we examine the effects of aging in NH listeners, comparing the NH control groups from the two experiments above. Second, we assessed the interaction between aging and hearing loss for the participants in Experiment 1.

#### **Effect of Cognitive Aging on NH Listeners**

The same analyses from Experiments 1 and 2 were performed comparing the 26 NH participants in Experiment 1 (mean age: 59.8 years) and the 15 NS participants in Experiment 2 (age range 18-30).

***Mouse clicks (accuracy & reaction time).*** The older and younger NH participants were equally accurate (99.4% and 99.6%, respectively,  $t(39) = -.31$ ,  $p = .76$ ). However, the older participants were slower to click on the named item than the younger ones (1576ms vs. 1278ms,

$t(39) = 4.7, p < .001$ ).

***Time course of fixations.*** Results of t-tests comparing curve fit parameters in older and younger controls are shown in Table S1. In terms of timing, the older NH group was significantly earlier to fixate the rhyme and faster to suppress the cohort and rhyme. In proportion of fixations, the older group had significantly more peak fixations to the target, and marginally more peak fixations to the rhyme and unrelated items.

***Markers of Lexical Processing.***

***Early sensitivity to the signal.*** The older NH participants were somewhat faster to fixate items consistent with the signal, with target/cohort fixations surpassing unrelated fixations marginally earlier (older NH: 203ms; younger NH: 229ms;  $t(33) = 2, p = .055$ ).

***Competitor suppression.*** The two NH control groups began fixating the target more than the cohort at essentially the same time (older NH: 295ms; younger NH: 285ms;  $t(33) = .6, p = .6$ ). The two groups differed marginally in the duration of cohort fixations (older NH: 92ms; younger NH: 57ms;  $t(37) = 1.8, p = .08$ ).

***Degree of consideration.*** Table S2 displays results of 2 (word-type) x 2 (age-group) ANOVAs comparing competitor vs. unrelated across the two groups at both peak and mean RT. Though it is clear that age affected fixations, importantly, it never interacted with word-type. The amount by which a competitor was activated over and above the unrelated item was not affected by age.

## **Discussion**

We found that cognitive aging (including normal age-related hearing loss) does seem to affect the process of lexical access. Older listeners were slower to click on the correct picture,

though they were no less immediate in to begin fixating candidates that match the input and no slower to begin suppressing fixations to competitors than younger listeners. Moreover, older listeners differed in degree of peak target, rhyme and unrelated fixations, as well as in the suppression of fixations to the cohort and rhyme. However, age did not affect the degree of activation of a competitor relative to the unrelated item.

### **Age and Hearing Status**

While these analyses reveal some important age-related differences (and similarities), one final question remains: does aging affect processing differently in severely hearing impaired people than in people who hear at a normal level for their age? That is, do age and hearing impairment interact? If so, comparing our two NH control groups is not sufficient, because hearing loss and aging together may create an interactive effect. To test this, we must examine the effect of aging within the CI population and compare it to the effects of aging within the NH population. Toward this end, we divided the 55 participants from Experiment 1 into two groups: the younger group (12 CI and 14 NH) included participants younger than 60 years of age, and the older group (17 CI and 12 NH) consisted of participants 60 years and older.<sup>6</sup> These groups were analyzed with 2 (hearing-group) x 2 (age-group) ANOVAs to determine whether age interacted with hearing loss. ANOVAs were conducted for each of the curve fit parameters as well as the measurements used to assess timing and degree of fixations (Table S3). Comparison of the two hearing groups (CI vs. NH) was largely similar to what we found with in comparisons with t-

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<sup>6</sup> We chose 60 as our cut-off for a number of reasons. First, the average age in both our participant groups was 60. Second, the literature on cognitive aging often marks the cutoff for “older” groups somewhere between age 60 and 70, with 65 a common cutoff, making 60 a conservative choice. Finally, the prevalence of hearing loss in adults increases with age: in one large epidemiological study, 21 % of adults between the ages of 48 and 59 showed hearing loss, while after the age of 60, rates of hearing loss went up to 44% in the 60s, 66% in the 70s and 90% in the 80s (Cruikshanks, Wiley, Tweed, et al., 1998). We thus expect to see more normal, age-related hearing loss in our NH participants over the age of 60.

tests in Experiment 1. While there were a few significant differences between the younger and older groups (most notably target crossover, and cohort and unrelated offset slopes), the interaction between hearing-group and age-group was not significant for any of the processing measures used in Experiment 1. These results, combined with the results from the cross-experiment comparison, suggest that while there are some differences in lexical processing that can be attributed to aging, these differences do not interact with hearing impairment, nor do they greatly affect our main conclusions.

## **Discussion**

Our comparison of the two NH groups showed some differences, particularly in the overall proportion of fixations at peak and the suppression of competitor fixations. Importantly, age did not interact with the level of competitor activation relative to the unrelated item. When we looked for interactions between hearing loss and aging within the Experiment 1 participants, we found that the two measures essentially do not interact. What is particularly interesting about these results is that the one place in which CI users did not differ from their controls (and the simulation group also did not differ from its controls) was in overall proportion of peak fixations. This seems to be a parameter that is affected by aging, but not by hearing status. In general, though we did find some interesting effects of aging, it does not seem that our comparisons of Experiments 1 and 2 can be explained solely by the difference in age across the two experiments.

## **References**

Ben-David, B., Chambers, C., Daneman, M., Pichora-Fuller, M., Reingold, E., Schneider, B. (2011). Effects of aging and noise on real-time spoken word recognition: Evidence from eye movements. *Journal of Speech, Language, and Hearing Research*, 54, 243-262.

Cruikshanks, K. J., Wiley, T. L., Tweed, T. S., et al. (1998). Prevalence of hearing loss in older adults in Beaver Dam, Wisconsin: The epidemiology of hearing loss study. *American Journal of Epidemiology*, *148*, 879-886.

Revill, K. P., & Spieler, D. H. (2011). The effect of frequency on spoken word recognition in younger and older listeners. *Psychological Aging*.

Table S1

*Parameters Describing the Time Course of Target and Competitor Fixations in the NH (older) and NH (younger) (i.e., Experiment 2's NS) Groups*

	Parameter	M (SD)		df	t <sup>a</sup>	p <sup>b</sup>
		NH (older)	NH (younger)			
Target	Maximum (p[fix]) <sup>c</sup>	.929 (.064)	.879 (.076)	25	2.3	.033
	Crossover (ms) <sup>d</sup>	703 (40)	692 (37)	31	.9	
	Slope ( $\Delta p[\text{fix}]/\text{ms}$ ) <sup>e</sup>	.0019 (.0003)	.0021 (.0004)	26	-1.2	
Cohort	Onset slope (ms) <sup>f</sup>	122 (20)	120 (21)	29	.22	
	Midpoint (ms)	603 (50)	617 (53)	28	-.83	
	Peak height (p[fix])	.18 (.05)	.159 (.049)	26	1.4	
	Offset slope (ms)	199 (54)	175 (30)	39	1.9	.070
	Offset baseline (p[fix])	.006 (.004)	.008 (.007)	-.1	19.3	
Rhyme	Onset slope	107 (18)	123 (37)	18	-1.6	
	Midpoint	563 (50)	608 (67)	23	-2.2	.034
	Peak height	.13 (.04)	.105 (.04)	27	1.8	.085
	Offset slope	226 (42)	194 (49)	26	2.1	.043
	Offset baseline	.008 (.005)	.010 (.009)	21	.3	
Unrelated	Onset slope	110 (29)	116 (24)	34	-.7	
	Midpoint	562 (62)	584 (61)	30	-1.1	
	Peak height	0.119 (0.035)	0.094 (0.039)	24	2.0	.060
	Offset slope	240 (58)	215 (78)	23	1.1	
	Offset baseline	0.006 (0.004)	0.007 (0.008)	20	-0.6	

Notes: <sup>a</sup> T-tests assume unequal variances; <sup>b</sup> P values not shown are  $p > .1$ ; <sup>c</sup> Proportion of total

fixations; <sup>d</sup> Milliseconds; <sup>e</sup> Change in proportion of fixations over time in milliseconds; <sup>f</sup>

Milliseconds: the competitor onset and offset slope measurements correspond to the standard deviation ( $\sigma$ ) or width of a Gaussian and are therefore represented in ms

Table S2

*Measures of Competition in the NH (Older) and NH (Younger) Groups*

	Effect of word type		Effect of age		Interaction	
	F (1,39)	p <sup>a</sup>	F (1,39)	p	F (1,39)	p
Looks at peak cohort	108	< .001	6.7	.014	1.6	
Looks at peak rhyme	38	< .001	6.6	.014	2.0	
Cohort vs. UR at RT	2.6		16.3	< .001	.97	
Rhyme vs. UR at RT	1.6		10.3	.003	.003	

<sup>a</sup> P values not shown are  $p > .1$

Table S3

*Results of 2 (Hearing-Group) x 2 (Age-Group) ANOVAs on Parameters Describing the Time Course of Target and Competitor Fixations and Measures of Principles of Lexical Activation in the NH (Older) and NH (Younger) Groups*

Between-Subjects Factors		Hearing group		Age group		Interaction	
		F <sup>a</sup>	p <sup>b</sup>	F	p	F	p
Target	Target maximum	16.0	< .001	0.006		.09	
	Target crossover	39.5	< .001	10.8	.002	.612	
	Target slope	23.6	< .001	3.8	.058	1.0	
Cohort	Cohort onset slope	10.7	.002	2.2		0.13	
	Cohort midpoint	7.8	.007	0.26		0.04	
	Cohort peak height	0.04		0.29		0.22	
	Cohort offset slope	7.2	.010	8.3	.006	0.03	
	Cohort offset baseline	67.2	< .001	.16		0.01	
Rhyme	Rhyme onset slope	11.3	.001	0.08		.5	
	Rhyme midpoint	8.6	.005	0.3		0.05	
	Rhyme peak height	0.6		3.8	.056	0.1	
	Rhyme offset slope	2.7		1.5		1.3	
	Rhyme offset baseline	19.1	< .001	0.4		0.4	
Unrelated	Unrelated onset slope	2.2	.143	0.3		2.0	
	Unrelated midpoint	5.8	.020	0.2		1.0	
	Unrelated peak height	0.7		2.1		0.1	
	Unrelated offset slope	1.3		7.3	.010	0.9	
	Unrelated offset baseline	39.0	< .001	0.4		0.06	
Timing	Early sensitivity to the signal	15.4	< .001	0.3		0.1	
	Competitor suppression	10.5	.002	1.2		0.04	
	Cohort duration	2.0	.164	0.05		0.2	
Peak Activation	Looks to cohort at cohort peak	0.2		0.3		0.3	
	Looks to unrelated at cohort peak	0.2		1.6		0.28	
	Looks to rhyme at rhyme peak	6.1	.017	6.7	.013	0.08	
	Looks to unrelated at rhyme peak	1.0		1.5		0.02	
Late Activation	Looks to cohort at RT	18.2	< .001	.05		3.5	.068
	Looks to rhyme at RT	61.0	< .001	.04		1.2	
	Looks to unrelated at RT	9.0	.004	.02		0.01	

Notes: <sup>a</sup> For all tests,  $df = (1,51)$ ; <sup>b</sup> P values not shown are  $p > .1$



## **S2. Introduction to individual plots.**

Figures S1-S4 illustrate the wide range of individual variation, especially among the CI users.

The thicker black line indicates the average functions (as shown in Figures 2 and 6). These figures also show why the average function might not capture all the participants' performance, and thus why measures of individual performance were crucial.

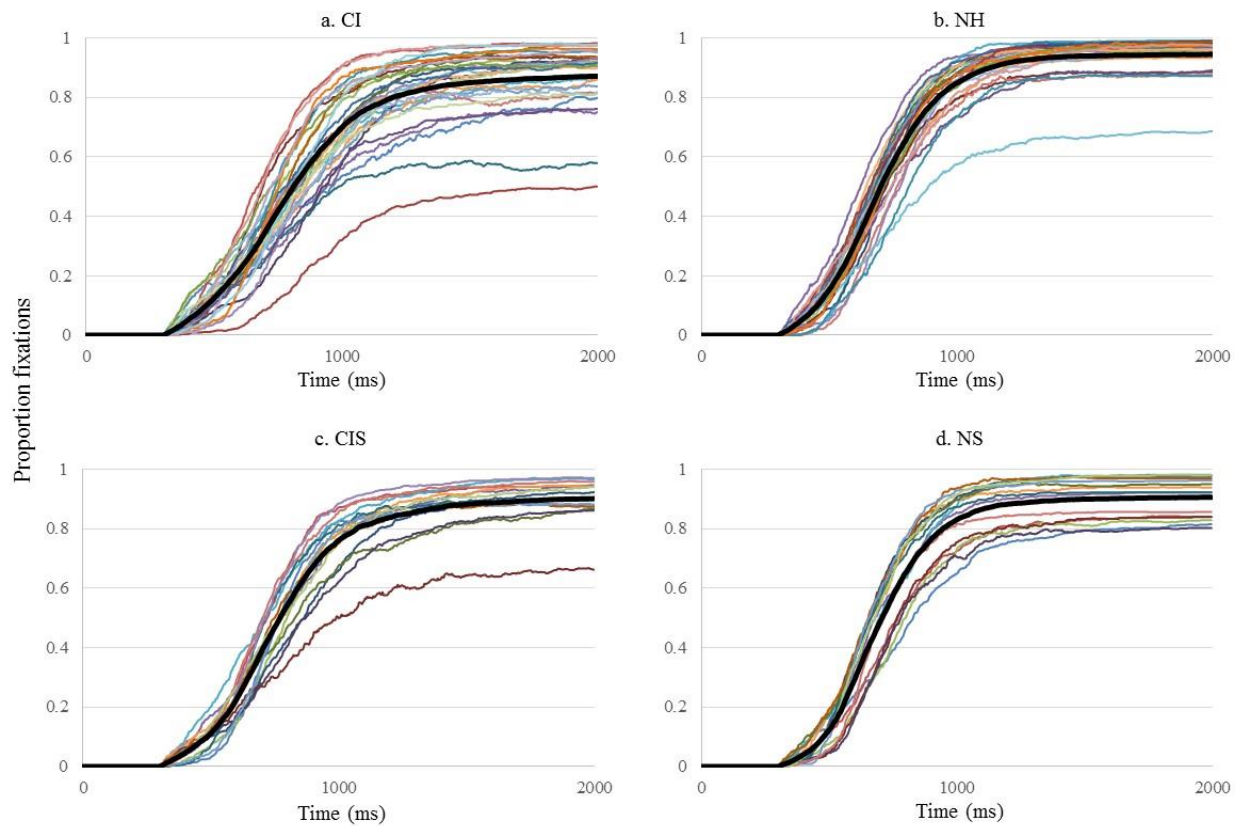


Figure S1. Proportion target fixations by individual A) CI users; B) NH group; C) CIS group; D) NS group. The thicker black line indicates the average.

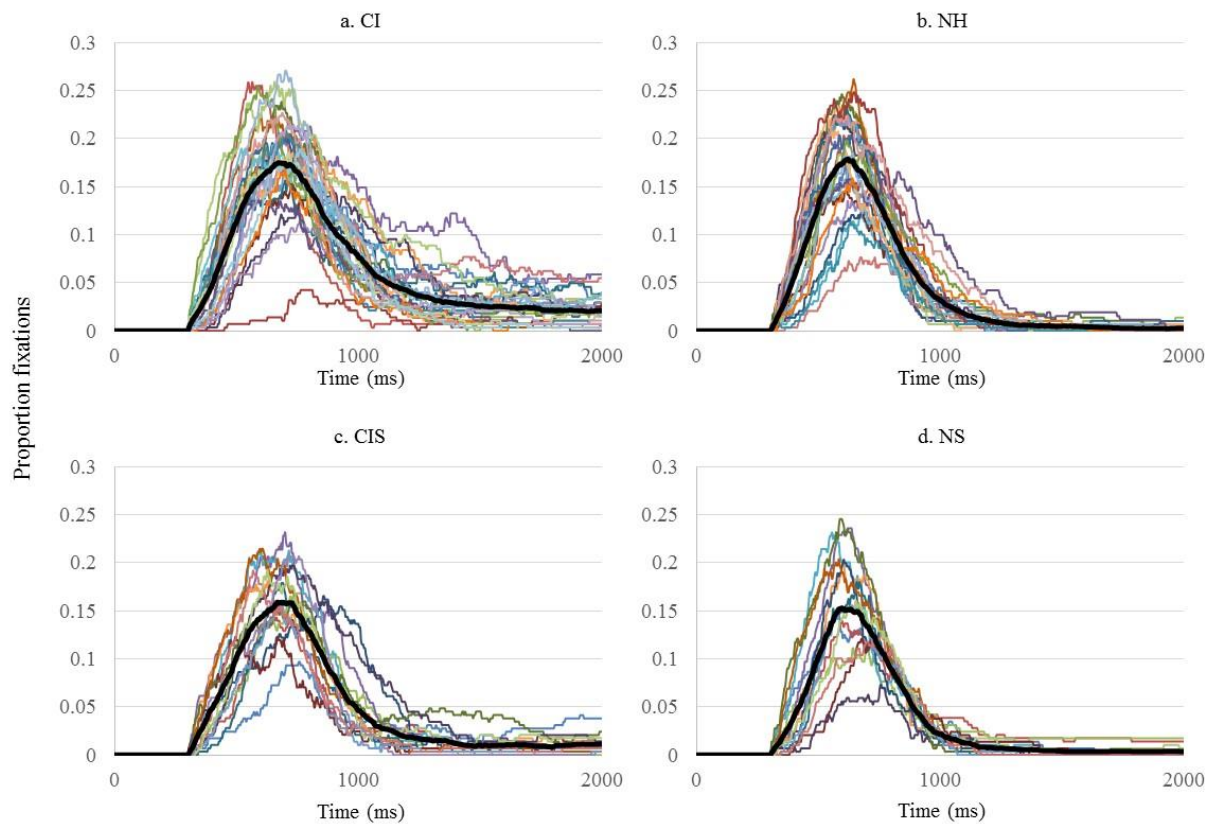


Figure S2. Proportion cohort fixations by individual A) CI users; B) NH group; C) CIS group; D) NS group. The thicker black line indicates the average.

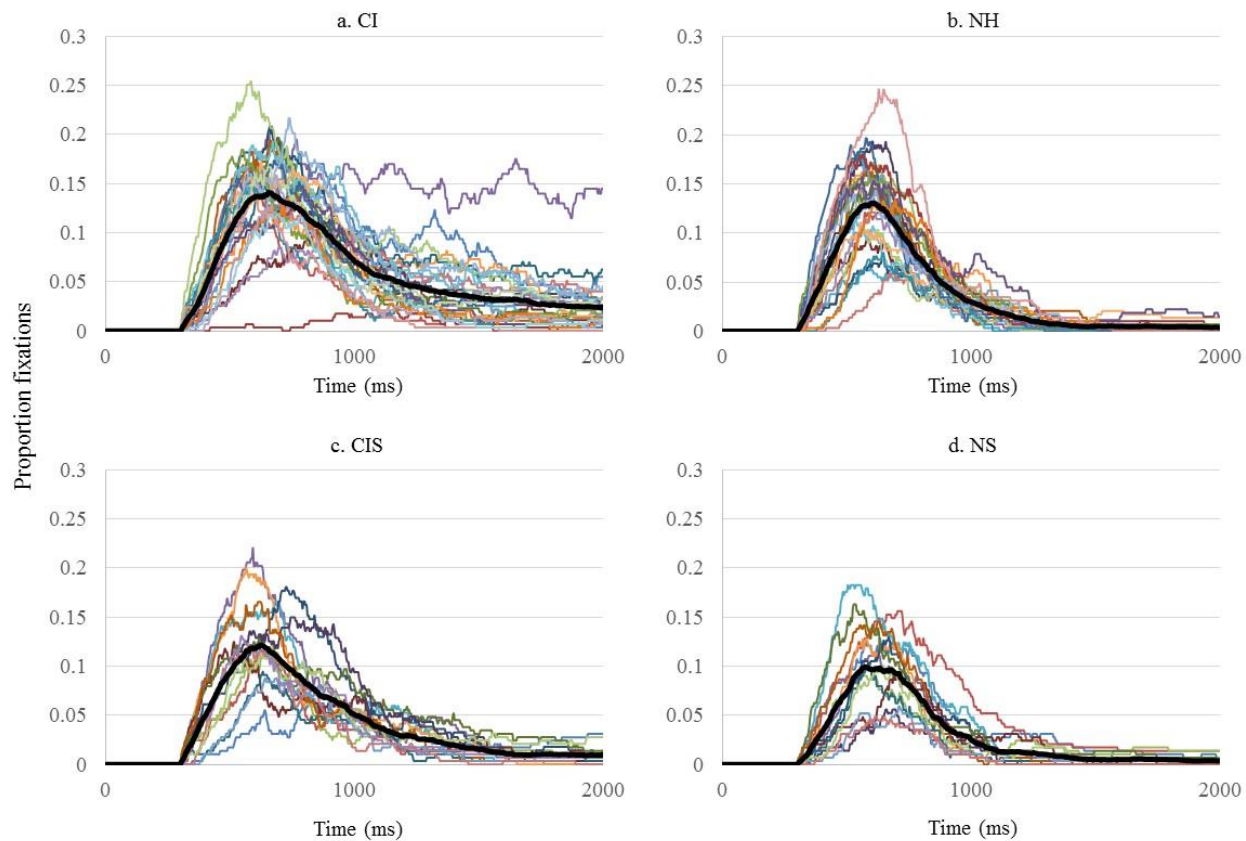


Figure S3. Proportion rhyme fixations by individual A) CI users; B) NH group; C) CIS group; D) NS group. The thicker black line indicates the average.

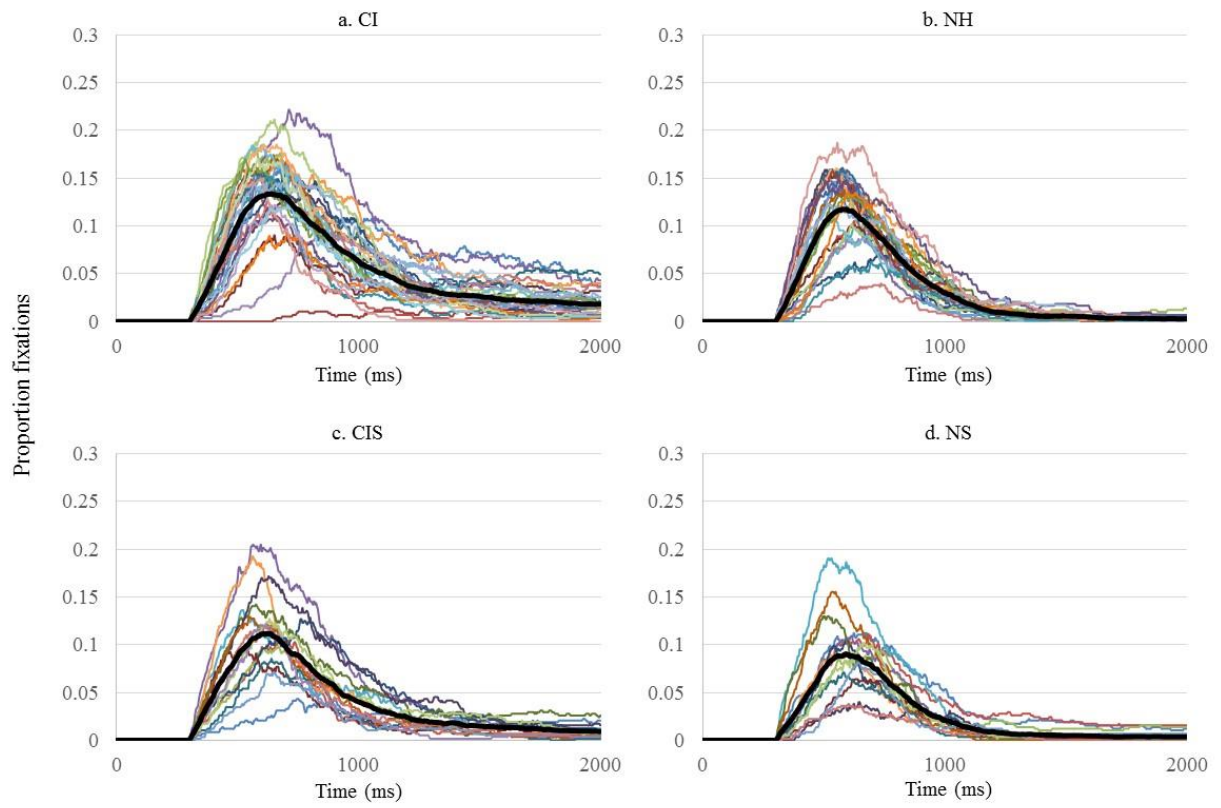


Figure S4. Proportion unrelated fixations by individual A) CI users; B) NH group; C) CIS group; D) NS group. The thicker black line indicates the average.