Inhibition and Facilitation in Auditory Comprehension Across the Lifespan

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Abstract

The relationship between activation and inhibition in word comprehension was examined in younger and older adults by using a novel Picture Identification / Negative Priming paradigm. Picture identification results showed increased interference from similar-sounding competitor words in older (compared to younger) adults. Subsequent priming probe results yielded reduced competitor inhibition with increased target word facilitation in older (compared to younger) adults. Findings suggest a link between activation and inhibition in younger adults and age-related changes in word selection mechanisms, with increased compensatory target facilitation accompanying decline in inhibitory control. Implications for models of word recognition are discussed.

Keywords: Inhibition; facilitation; negative priming; auditory word recognition; cognitive aging.

Introduction

A number of distributed and connectionist models formalize mechanisms of auditory word recognition (e.g., Marslen-Wilson, 1987; McClelland & Elman, 1986). These models posit that words are identified from the speech stream via parallel activation of multiple similar-sounding candidates, where target words are selected once sufficient acoustic information becomes available. In addition, some models, such as McClelland and Elman's (1986) *TRACE Model,* posit that lexical-level lateral inhibition between competing word candidates contributes to target word selection. Indeed, inhibitory control has been experimentally shown to contribute to comprehension (Gernsbacher, 1990; Swinney, 1979). While it is intuitive that activation and inhibition mechanisms interact, few accounts specify the nature of this interaction. Since abilities of inhibitory control decline with age (Comalli, Wapner, & Werner, 1962; Hasher & Zacks, 1988), one way to examine the interaction between inhibition and activation is to study their magnitude during comprehension in younger vs. older adults.

In older adults, decline in inhibitory control has been linked to decline in auditory comprehension abilities (e.g., Sommers & Danielson, 1999; Taylor et al., 2005). However, it is likely that, as inhibitory control abilities decline, older adults employ compensatory strategies to maintain performance. For example, it is possible that, as inhibitory control becomes less efficient, target activation to a higher threshold becomes necessary for successful word selection. Therefore, we reasoned that the relationship between inhibition and activation during word recognition would dynamically change with age. In an auditory word identification task, participants identified the picture of a target word (*cab*) from among a picture of a similar-sounding competitor (*cat*) and pictures of two neutral filler words (*bus, ant*). Immediately following each picture identification trial, participants completed a priming trial, where residual target activation and competitor inhibition were probed. Younger adults were predicted to inhibit competitors and efficiently identify target words. In contrast, older adults were predicted to show greater target-competitor interference, less competitor inhibition, and increased target activation at the time of word selection.

Methods

Participants

Thirty English-native *younger* monolingual adults (M_{age} = 21.4, *SD* = 3.9; 4 males) and 28 English-native *older* monolingual adults (M_{age} = 73.3, *SD* = 10.3) were recruited. Participants were administered the *Language Experience and Proficiency Questionnaire* (Marian, Blumenfeld, & Kaushanskaya, 2007) and a number of standardized linguistic and cognitive tasks (see Table 1). Younger and older adults were matched on the percentage of time they were currently exposed to their native English (as opposed to foreign languages), on expressive vocabulary knowledge (as measured by the standard score on the *Peabody Picture Vocabulary Test-III*), on nonverbal IQ (as measured by the *Wechsler Abbreviated Scale of Intelligence*), and on digit span performance (as measured by the *Comprehensive Test of Phonological Processing*), $p > .05$.

Task

The paradigm included two types of trials, which were presented in alternating order (see Figure 1). *Word Recognition / Picture Identification* trials were presented first and indexed activation of target and competitor words, relative to control words, during word recognition. *Priming Probe* trials were presented next and indexed inhibition of preceding competitor words and facilitation of preceding

Table 1: Linguistic and cognitive characteristics of younger and older adult participants. Standard Deviations in parentheses.

	Younger group (n = 30)	Older group (n = 28)	Group differences (t-test)
Age (in years)	21.4 (3.9)	73.3 (10.3)	t (56) = -24.96, p < .05
Vocabulary (*PPVT-III*)	116.6 (11.6)	122.0 (14.7)	t (56) = -1.50, p > .05
Current percentage use of English	98.1 (2.7)	98.2 (4.5)	t (56) = -0.10, p > .05
Nonverbal IQ (*WASI*)	110.5 (11.9)	113.6 (16.7)	t (56) = -0.81 , p > .05
Digit Span (*CTOPP*)	17.5 (2.1)	16.5 (2.9)	t (56) = 1.47 , p > .05

target words, relative to control words. *Priming Probe* trials immediately followed *Word Recognition* trials, and contained grey asterisks that occurred in the locations previously occupied by pictures of competitor, filler, or target words.

On *Word Recognition* trials, if longer reaction times and /or lower accuracy rates were found during identification of target pictures in the presence of competitor words than in their absence, it would be concluded that the competitor word interfered during target selection. On *Priming Probe* trials, if identification latencies for priming probes in locations preceded by competitor pictures would exceed identification latencies for priming probes in locations preceded by filler pictures, then it would be concluded that the competitor-location was inhibited, suggesting prior inhibition of the competitor word. If filler probe identification latencies would exceed target probe identification latencies, then it would be concluded that target words were facilitated. Together, competitor interference / inhibition and target facilitation were indexed.

Study Design

The study design included two components. First, to examine interference of similar-sounding competitor words during auditory comprehension, reaction times and accuracy rates were compared for trials with and without competitors in a 2 x 2 ANOVA, with trial type (competitors, no competitors) as a within-subjects factor and group (younger, older) as a between-subjects factor.

Second, to examine subsequent inhibition of competitor words, and facilitation/activation of target words, identification latencies of competitor-, target-, and filler-probes were compared in a 3 x 2 ANOVA, with priming probe type (competitor probe, target probe, filler probe) as a within-subjects factor, and with group (younger, older) as a between-subjects factor. Three dependent measures were collected: (1) target-word picture identification times, (2) target-word picture identification accuracies, and (3) identification times of priming probes that immediately followed each picture identification trial.

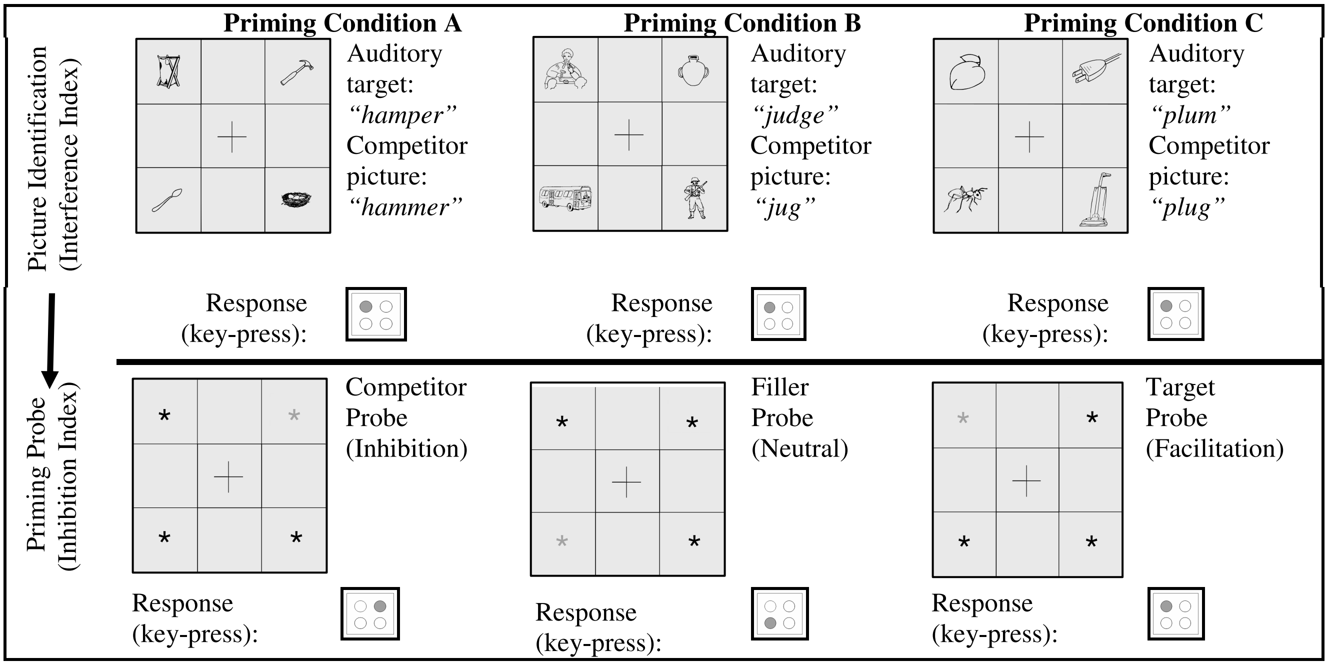

Figure 1: The Picture Identification / Negative Priming paradigm. To probe interference of similar-sounding words, participants heard words and identified corresponding pictures in the presence of phonological competitors (top panel). To probe word inhibition and facilitation, picture identification trials were followed by priming probe trials (bottom panel) that probed inhibition / facilitation of competitor items (Condition A: grey asterisks appeared in locations previously occupied by competitor pictures), filler items (Condition B: grey asterisks appeared in locations previously occupied by filler pictures), and target items (Condition C: grey asterisks appeared in locations previously occupied by target pictures).

Materials

For *Picture Identification Trials,* stimulus displays included four pictures and a central fixation cross (see Figure 1, top row). The four pictures in each display included (1) a target-word picture, (2) a competitor- or filler word picture, and (3, 4) two filler word pictures. A total of 234 Picture Identification trials were presented. In one third of all trials (n = 78), target words were paired with competitor words that overlapped phonologically. For example, when the target word was *cab*, the competitor word was *cat.*

The ratio of competitor- to filler trials was 1:2 in order to minimize awareness of phonological overlap, and to maximize competition effects (Botvinick et al., 2001; Green, 1998; Henik, Bibi, Yanai, & Tzelgov, 1997). In the remaining two thirds of Picture Identification trials (i.e., filler trials, n = 156), target words were paired with three neutral filler words. Target-competitor pairs were chosen to have high phonological overlap. This overlap consisted of at least 2 word-initial shared phonemes. Phonological overlap was also measured in terms of duration of acoustic overlap by a native speaker of English, and averaged 279.4 msec (SE = 20.8) across target-competitor pairs. Based on findings by Dahan, Magnusson, and Tanenhaus (2001) and using the CELEX word frequency database (Baayen, Piepenbrock, et al., 1995), competitors were selected to be of higher word frequency (M = 91.9, SE = 16.9) than targets (M = 15.7, SE = 2.3), t (154) = 4.5, p <.001, since high-frequency words would yield more competition with targets.

Auditory stimuli in the form of single words were presented concurrently with picture displays. Recordings of auditory stimuli were made in a sound-proof booth (44,100 Hz, 16 bits) by a female native speaker of American English, using a Marantz Solid State recorder. During the experimental session, the name of the target picture was presented 500 msec after the onset of the picture display. Picture stimuli were selected from Blumenfeld and Marian (2007), the *International Picture Naming Database* (Székely et al., 2004), the *IMSI Master Clips* database, and the *Alta Vista* search engine. Pictures were black line-drawings, and were manipulated in Photoshop so that pictures appearing within the same display were similar in terms of salience and line thickness. Positioning of target and competitor pictures in display quadrants I-IV was counterbalanced across conditions.

To match picture identification trials to the three types of priming probe trials (target probes, competitor probes, and filler probes), the 78 picture identification trials with competitors were divided into three lists of 26 stimuli. Across these three lists, stimuli were matched for target frequencies, F (2, 75) = 0.2, p > .5, and competitor frequencies, F (2, 75) = 0.2, p > .5. Finally, the three lists were balanced for duration of phonological overlap between targets and competitors, F (2, 75) = 0.02, p > .5.

For *Priming Probe Trials*, the purpose was to index extent of inhibition of competitors on preceding Picture Identification trials via *negative* location priming (e.g., Simone et al., 2006), and extent of facilitation of targets on preceding Picture Identification trials via *positive* location priming. After each Picture Identification trial, a Priming Probe trial was presented. One of the four quadrants on the visual display contained a grey asterisk, and the remaining three quadrants contained a black asterisk. Asterisks were presented in each of the four quadrants because behavioral evidence suggests that negative priming effects are reduced if response competition is not maintained during priming probe trials (May, Kane, & Hasher, 1995). Three types of priming probe trials were employed: (1) *filler probe trials,* (2) *competitor probe trials,* and (3) *target probe trials*. On *filler probe trials*, the grey asterisk occurred in the same quadrant location as a *filler* trial on the preceding Picture Identification trial. Since filler objects on Picture Identification trials were likely to be minimally attended to and minimally inhibited, response latencies on filler probe trials should reflect minimal facilitation or inhibition, and acted as a *baseline*. On the *competitor probe trials*, the grey asterisk occurred in the same quadrant location as the *competitor* in the previous Picture Identification trial. Since competitor objects on Picture Identification trials were likely to be only briefly and partially attended to and then inhibited, response latencies on competitor probe trials would reflect location inhibition, and would therefore be delayed relative to filler probe trials. Finally, on the *target probe trials*, the grey asterisk occurred in the same quadrant location as the *target* on the preceding Picture Identification trial. Since target objects on Picture Identification trials were likely to be maximally attended to and fully activated, response latencies on target probe trials would reflect location facilitation, and would therefore be shorter relative to filler probe and competitor probe trials.

All filler Picture Identification trials were followed by "dummy" priming probe trials that had grey asterisks assigned to each quadrant an equal number of times. Of the 234 Priming Probe trials, 26 trials were filler probe trials, 26 trials were competitor probe trials, 26 trials were target probe trials, and 156 trials were dummy trials. In order to reduce effects due to stimulus characteristics, pairings between the 26 filler probe, competitor probe, and target probe trials and the three lists of Word Recognition trials were counterbalanced across participants so that each set of Word Recognition trials was paired with each type of Priming Probe trial an equal number of times.

Data Coding

Only trials with correctly identified target pictures were included in reaction time analyses. On Picture Identification trials, trials with reaction times that exceeded 3 Standard Deviations from the participants' mean were excluded for that participant. When picture identification trials were removed from analyses due to incorrect responses or reaction time outliers, corresponding priming probe trials were also omitted from analyses. Finally, priming probe response latencies that exceeded 3 standard deviations from the participants' mean were also excluded.

Results

Word Interference across the Lifespan (indexed by Picture Identification / Word Recognition Trials)

Accuracy rates and reaction times of target word identification were analyzed using 2 x 2 ANOVAs, with trial type (competitor trial, filler trial) as a within-subjects variable and group (younger, older) as a between-subjects variable. For accuracy rates, results yielded a main effect of trial type, with more correct responses for filler trials (M = 98.1%, SE = 0.6%) than for competitor trials (M = 94.7%. SE = 0.4%), F (1, 56) = 58.2, $p < .001$, $\eta_p^2 = 0.5$, and a main effect of group, with more correct responses for younger adults (M = 97.4%, SE = 0.6%) than for older adults (M = 95.3%, SE = 0.6%), F (1, 56) = 6.1, $p < .05$, $\eta_p^2 = 0.1$. No interaction was found between trial type and group, F (1, 56) = 0.4, $p > .5$, $\eta_p^2 = 0.006$.

For participants' response latencies, results yielded a main effect of trial type, with faster responses for filler trials (M = 2052.4 msec , SE = 36.2 msec) than for competitor trials (M = 2237.4 msec. SE = 49.7 msec), F (1, 56) = 121.8 , $p < .001$, $\eta_p^2 = 0.7$, and a main effect of group, with faster responses for younger adults (M = 1936.5 msec, SE = 59.3 msec), than for older adults (M = 2353.3 msec, SE = 61.4 msec), F (1, 56) = 23.9, $p < .001$, $\eta_p^2 = 0.3$. In addition, an interaction was found between trial type and group, F (1, 56) = 12.6, $p = .001$, $\eta_p^2 = 0.2$, with younger adults showing a smaller response latency difference between filler and competitor trials (125.5 msec, t (29) = 8.4, $p < .001$, Cohen's $d = 0.5$) than older adults (244.3 msec, t (27) = 7.9, $p < .001$, Cohen's $d = 0.6$), suggesting greater interference of similar-sounding words in older adults (see Figure 2).

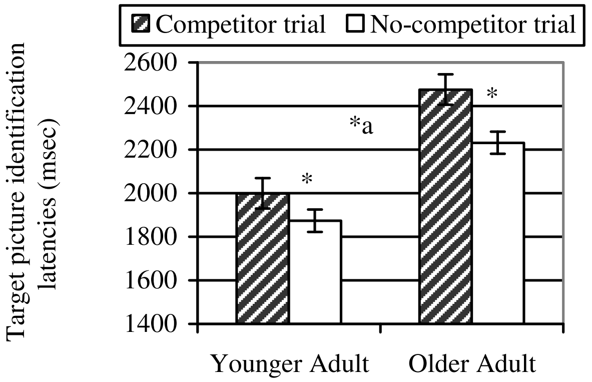

Figure 2: Target identification latencies for younger and older adults in competitor and no-competitor conditions, $p < .001$ (*a indicates an interaction *and* a main effect).

Word Inhibition and Facilitation across the Lifespan (indexed by Priming Probe Trials)

Response latencies on target, competitor, and filler priming probe trials were analyzed using a 3 x 2 ANOVA, with trial type (target, competitor, filler) as a within-subjects variable and with group (younger, older) as a between-subjects variable. Results yielded a main effect of trial type, F (1, 56) = 83.1, $p < .001$, $\eta_p^2 = 0.6$, with response latencies to probes in target position (M = 575.4 msec, SE = 17.2 msec) shorter than latencies to probes in filler positions (M = 640.5 msec, SE = 20.1 msec). In addition, a main effect of group was found, F (1, 56) = 55.8, $p < .001$, $\eta_p^2 = 0.5$, with younger adults (M = 483.2 msec, SE = 25.8 msec) showing shorter response latencies than older adults (M = 760.4 msec, SE = 26.7 msec). Finally an interaction was found between trial type and group, F (1, 56) = 18.3, $p < .001$, $\eta_p^2 = 0.3$.

A follow-up 2 x 2 ANOVA with trial type (target, filler) as a within-subjects variable and group (younger, older) as a between-subjects variable yielded an interaction between trial type and group, F (1, 56) = 21.9, $p < .001$, $\eta_p^2 = 0.3$. Follow-up t-tests suggested larger differences between target and filler probe identification latencies for older adults (103.4 msec, t (27) = 6.4, $p < .001$, Cohen's $d = 0.5$) than younger adults (26.9 msec, t (29) = 5.5, $p < .001$, Cohen's $d = 0.4$).

A 2 x 2 ANOVA with trial type (competitor, filler) as a within-subjects variable and group (younger, older) as a between-subjects variable yielded an interaction between trial type and group, F (1, 56) = 6.1, $p < .05$, $\eta_p^2 = 0.1$, with younger adults showing longer identification times (M = 505.4 msec, SE = 14.3 msec) for competitor probes than filler probes (M = 485.5 msec, SE = 12.9 msec), t (29) = -4.3, $p < .001$, and older adults showing no difference between competitor (M = 793.6 msec, SE = 37.5 msec) and filler probes (M = 795.6, SE = 39.2), t (27) = 0.3, $p > .5$.

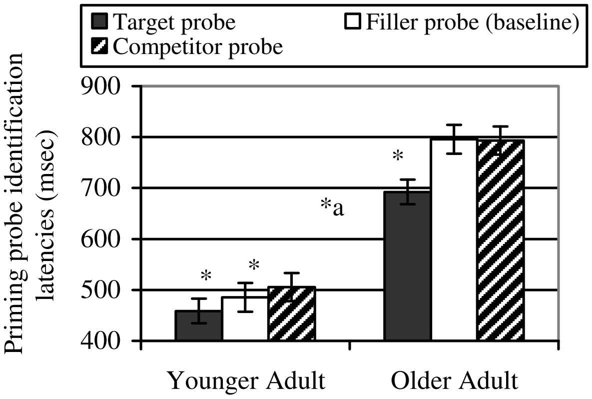

Figure 3: Priming probe identification latencies for younger and older adults in target, filler (baseline) and competitor conditions, $p < .001$ (*a indicates an interaction *and* a main effect).

Discussion

The present study shows that both accuracy rates and response latencies in word comprehension decline with age. In addition, older adults show more interference from similar-sounding competitor words than younger adults. Consistent with these word recognition findings, evidence from the present study's priming component suggests that inhibition-/activation-based mechanisms of word selection undergo change with age. The previously-established decline of inhibitory control with age (Comalli, Wapner, & Werner, 1962) is reflected in reduced competitor inhibition effects in older adults. In addition, older adults show a greater reliance on target word activation for word selection, which is reflected in higher target facilitation levels at the time of word selection.

The consequences of age-related decline in inhibitory control for word comprehension may be twofold. First, less efficient lateral inhibition of competitor words may result in prolonged competition between multiple word candidates (i.e., greater interference). Second, it has been suggested that less efficient inhibitory control results in an accumulation of irrelevant information in working memory, therefore rendering the processing system *overall* less efficient (i.e., causing general slowing, Van der Linden et al., 1999). It is possible that aging individuals find compensation strategies to counteract these two sources of lower efficiency. Specifically, they may let activation of the target word accrue beyond a higher threshold, where it can be correctly identified from multiple candidates. Therefore, as inhibitory control mechanisms decline with age, target word facilitation beyond the activation level of similar-sounding competitors may become the predominant mechanism of auditory word identification.

To further examine the relationship between inhibition and activation in younger and older adults, we conducted correlation analyses comparing younger and older participants' degrees of target activation and competitor inhibition. We found that positive priming (target facilitation) and negative priming (competitor inhibition) are closely related in younger adults (r = 0.6, p = .001), with stronger competitor inhibition associated with reduced target activation at the time of word selection, and weaker competitor inhibition associated with greater target activation. This correlation between competitor inhibition and target facilitation in younger adults provides support for the idea that inhibition and activation mechanisms are tightly linked, with robust competitor inhibition necessitating less target activation for successful selection. However, when the same correlation analysis was conducted for *older* adults, we found that competitor inhibition and target facilitation effects may become less associated with age (r = .3, p = .1). This finding suggests that, in older adults, inhibition and activation mechanisms may no longer operate in tandem.

While the present findings suggest more reliance on word activation (instead of inhibition) with aging, it is important to recall that young adults also resolve ambiguity via facilitation of relevant information. Notably, Egner et al. (2005) conducted a neuroimaging study that showed amplified activation in the visual cortex during incongruent trials on a visual Stroop task. This finding is consistent with target facilitation effects in young adults. The *greater* target facilitation in older adults, relative to the absence of inhibition, points to a gradual shift from a dual-mechanism (activation-inhibition) in younger adults to a single mechanism (activation) in older adults. Findings of decreased reliance on competitor *inhibition* in older adults' word identification are consistent with Comalli, Wapner, and Werner (1962)'s findings that interference on the Stroop task increased significantly in individuals aged 65-80. Findings of increased reliance on target *facilitation* are consistent with Spieler, Balota, and Faust (1996)'s findings that facilitation effects on the Stroop task *maintain* with age.

Current models of auditory word recognition do not specify the effects of aging on cognitive change in the linguistic system. Future models may allow for such dynamic changes over time. Specifically, parameters such as activation thresholds and lateral inhibition strength may be dynamically adjusted to simulate changes in auditory word recognition with aging. It is expected that a combination of experimental approaches and cognitive modeling will be most useful in further elucidating cognitive and linguistic aspects of aging.

As a methodology to examine mechanisms of word comprehension, the Picture Identification / Negative Priming paradigm introduced in the present study is unique in that it allows for independent measurements of interference *and* inhibition / activation during auditory word identification. The location-based negative priming paradigm has characteristics that make it particularly suitable for use in older adults. First, behavioral findings suggest that (in contrast to identity-based negative priming effects, Tipper, 1985), location-based negative priming effects are *not* sensitive to age[1] (Connelly & Hasher, 1993). This finding suggests that any age-differences found using the Picture Identification / Negative Priming paradigm can be ascribed to inhibition at the *word level.*[2] Secondly, the task is relatively easy, and requires minimal motor coordination and task demands. In sum, coupling of the interference measure with a more direct measure of previous inhibition (negative priming) and facilitation (positive priming) strengthens the conclusion that, in addition to generalized cognitive slowing, a weakened inhibitory mechanism is likely to contribute to changing patterns of target selection during auditory word comprehension in older adults.

Conclusions

Findings of the present study suggest that, in younger adults, activation and inhibition mechanisms are tightly

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[1] While spatial negative priming relies on a dorsal path, with activation in occipital and parietal cortices, non-spatial negative priming relies on a ventral path, with activation in occipital and fusiform cortices (May et al., 1995).

[2] While it can not be ruled out that decreased negative priming in older adults is due to longer picture identification times, this interpretation is unlikely given that longer picture identification times are associated with longer negative priming times in both younger (r = .8, p < .0001) and older (r = .7, p < .0001) monolinguals. Consistently, prior research suggests that negative priming effects can last up to 8 seconds (May et al., 1995).

linked during auditory word comprehension in a dual-mechanism context. With aging, it appears that inhibitory mechanisms become less involved in auditory comprehension, with greater reliance on an activation mechanism. This age-related change in word comprehension likely reflects a quantitative change (stronger target facilitation with decreasing competitor inhibition) rather than a change towards a qualitatively different mechanism. Cognitive and computational models of word recognition are needed to reflect the dynamic interplay between activation and inhibition mechanisms across the lifespan.

Acknowledgments

This project was supported by a John and Lucille Clarke Dissertation Scholarship and seed funds at San Diego State University to the first author, and NSF grant # BC-0418495 to the last author. Thanks go to Margarita Kaushanskaya, members of the *Bilingualism and Psycholinguistics Laboratory* at Northwestern University, and members of the *Bilingualism and Cognition Laboratory* at San Diego State University for helpful discussions of this work.

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