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Auditory Habituation in Young and Older Adults: The Verbal Transformation Effect

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In 3 experiments, auditory massed repetition was used to examine age-related differences in habituation by means of the verbal transformation paradigm. Participants heard 10 words (5 high frequency and 5 low frequency), each presented 180 times, and they reported perceived changes in the repeated words (verbal transformations). In these experiments, older adults reported fewer illusory percepts than young adults. Older adults' loss of auditory acuity and slowing of processing, stimulus degradation (in young adults), and instructions biasing the report of these illusory percepts did not account for the fewer illusory percepts reported by the older adults. These findings suggest that older adults' reduced susceptibility to habituation arises from centrally located declines in the transmission of information within the word-recognition pathway. The discussion focuses on the implications that these age-related declines may have on word identification during on-line speech perception.

One of the hallmarks of the human perceptual–cognitive system is that excessive exposure to a stimulus produces habituation, that is, fatigue of the neural structures involved in processing incoming information. The goal of the present study was to examine a type of habituation phenomenon referred to as the *verbal transformation effect* (VTE). Verbal transformations (VTs) are illusory changes that occur as a result of passively listening to a word repeated over and over (Warren, 1961, 1968; Warren & Warren, 1966). These changes involve a variety of alterations of the original auditory percept. For instance, on hearing the word TRESS repeated over and over, listeners report perceiving "dress," "stress," "Joyce," "floris," "florist," and "purse," intermixed with reversals to the original word TRESS.

Of course, the illusory changes that participants report in the VT paradigm are not random disruptions of speech-perception processes. On the contrary, they reflect the way in which information is processed within the word-recognition pathway and a basic but essential function of the operations constituting this pathway, that is, their ability to withdraw processing resources from repetitive noninformative stimuli and direct them to novel information-bearing stimuli (MacKay, 1990). As such, the VT paradigm represents an invaluable technique for understanding how aging may affect the processing of information within the word-recognition pathway. Surprisingly, while there is no shortage of studies that have examined the VT phenomenon in young adults, relatively little research has investigated whether aging weakens or eliminates this habituation-type effect. Indeed, there have been just two studies in this area of inquiry, both of which have provided prima facie evidence that the aged are not as susceptible to the VTE as young adults. For instance, both Yin and MacKay (1992) and Warren (1961) found that older adults reported fewer illusory changes than young adults. Warren, however, also found that older adults experienced fewer fluctuations (transitions) between different percepts, either illusory or veridical (e.g., from "dress" to "pest," from TRESS to "dress," or vice versa), during the repetition treatment, whereas Yin and MacKay found no age differences on this measure of habituation.

In light of these partially conflicting findings, the main goal of the present series of experiments was twofold: (a) to clarify the effects of aging on the VT phenomenon and (b) to understand the probable source(s) of these effects. To this end, the VT paradigm served as a means for investigating age-related changes in habituation along the sensory–perceptual pathway that subserves word recognition in the auditory domain. Because activation models provide a viable conceptualization of this fatigue-type phenomenon, we now turn to a brief description of activation models and how they may account for age-related differences in the VTE.

VTE Within an Activation Framework

In general, activation models postulate that word recognition occurs via the activation of units hierarchically organized into different representational levels, from those symbolizing sublexical information (syllables, vowels, consonants, and phonological features) to those representing lexical (word) information. In activation models, the presentation of a spoken word produces a pattern of activation across this hierarchical structure, and the level of activation of the sublexical and lexical units within this structure is determined by the degree to which they match the incoming signal (Elman, 1989; Elman & McClelland, 1986; Mackay, Wulf, Yin, & Abrams, 1993; McClelland & Elman, 1986). Word recognition is assumed to rely on the level of activation of a particular unit relative to all the other units. Accordingly, a spoken word such as TRESS activates its target lexical unit and to a lesser extent neighboring units that share with the former some phonetic properties (e.g., dress, stress, etc.). The recognition of TRESS occurs when the level of activation of the lexical unit that represents TRESS exceeds the level of activation of neighboring units.

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In activation models (see MacKay, 1990; MacKay et al., 1993), VTs are conceptualized as the result of a type of habituation that involves a temporary decrement in the activation level of the lexical unit that originally represented the best match for the incoming auditory signal (TRESS). The decrement in the activation level of the original percept (TRESS) results in other sublexical–lexical units related to TRESS gaining relative strength. In a word-recognition system where activation levels are relative in nature, the most strongly activated unit at a given time becomes the listeners' percept. Thus, listeners, who continue to be exposed to the auditory signal originally perceived as TRESS, now experience auditory illusions, such as "dress," "stress," "Joyce," "floris," "florist," and "purse." Listeners also experience reversal to the original percept when TRESS regains its original strength because of either (a) the habituation of other sublexical–lexical units or (b) a weakening of the habituation effect on TRESS when these other units become activated.

If the VTE involves a repetition-induced decrement in the activation level of preexisting representational units, what is the source of this effect? The VTE may be the result of a temporary impairment in the uptake of sensory information that is due to fatigue of the neural structures subserving the translation of an acoustic signal into an auditory percept. Independent evidence for the existence of a bottom–up type of fatigue-induced effect is provided by two converging sets of results. First, habituation of auditory percepts can occur in the absence of lexical habituation as demonstrated by McDowd and Filion (1992), who reported that several repetitions of pure tones induced a reduction of the skin conductance orienting response (SCOR), and by Skinner (1936), who found that repeating indistinct vowels over and over produced in listeners the experience of hearing words. Second, acoustic repetition is necessary for the occurrence of habituation at the lexical and semantic levels of processing. Pilotti, Antrobus, and Duff (1997) found that varying the acoustic characteristics of the repetitions of a spoken word, thereby eliminating acoustic repetition while preserving lexical and semantic repetition, prevented the occurrence of another habituation-type phenomenon known as semantic satiation in young adults.

If the VTE is simply the result of auditory habituation, then it is reasonable to expect age differences in this phenomenon to arise from differences at the early sensory–perceptual levels of processing in which acoustic signals are translated into auditory percepts. There are at least two possible sources of age-related changes at the early sensory–perceptual levels of processing: loss of auditory acuity (Humes & Roberts, 1990; Willott, 1991) and slowing in the uptake of sensory information in the aged (Stine, Wingfield, & Poon, 1986; Wingfield, Poon, Lombardi, & Lowe, 1985). Both hearing loss and slowing would reduce the amount of information from the periphery that reaches a lexical unit every time a word is repeated, thereby weakening lexical habituation in the aged. Therefore, in Experiment 1, we examined the effects of age-related hearing loss and slowing on the VT phenomenon. In Experiment 2, we further examined the possible contribution of peripheral impairments to the VTE by exposing young adults to degraded stimuli. The goal was to assess whether experimentally induced peripheral impairments in young adults could mimic older adults' performance in the VT paradigm. Finally, in Experiment 3, we examined whether older adults' reduced susceptibility to the VTE, reported in earlier studies, could also be the result of age-group differences in the willingness to report illusory percepts.

Experiment 1: The Effects of Hearing Loss and Repetition Rate on VTs

Experiment 1 examined age-related differences in habituation by means of the VT paradigm. In this paradigm, participants hear a word repeated over and over (TRESS) and report changes (VTs) in the repeated word. These changes are scored in terms of numbers of *new forms* and numbers of *transitions,* both of which serve as a measure of habituation (Warren, 1961). New forms are the illusory percepts (e.g., "dress") reported during the habituation treatment. Transitions are all the possible ways in which percepts change during the habituation period, such as changes between different new forms (from "dress" to "pest"), changes from the veridical percept to a new form (from TRESS to "dress"), and reversals from new forms to the original percept (from "dress" to TRESS).

The main goals of this experiment were to replicate the earlier findings of age-related differences in the VTE (Warren, 1961; Yin & MacKay, 1992) and to identify the possible sources of these age differences. Warren (1961) and Yin and MacKay (1992) reported that the aged are less susceptible to the VTE than young adults. They failed, however, to report any direct measure of auditory acuity. Thus, it is possible that hearing loss in the aged could be responsible for the observed differences in VTs. In Experiment 1, we measured hearing acuity in young and older adults (pure-tone air-conduction thresholds), and then we statistically removed the effect of this variable on the reports of VTs. If loss of auditory acuity makes older adults less susceptible to auditory massed repetition, then statistically removing the effect of this variable would eliminate the age-group difference.

In Experiment 1, we also examined whether age-related slowing in the uptake of sensory information, apart from hearing loss, is responsible for any age-related difference in the VTE. To this end, we used two repetition rates: fast (100-ms interstimulus interval [ISI]) and slow (500-ms ISI). Warren (1961) and Yin and MacKay (1992) did not examine whether repetition rate modulates older adults' reports of VTs. However, it is reasonable to assume that a longer delay between consecutive repetitions of a word would give older adults more opportunities to process each repetition, thereby increasing the amount of information reaching the lexical unit that corresponds to the repeated word every time the word is repeated. As a result, if age-related slowing in the uptake of sensory information is responsible for older adults' fewer reports of VTs, older adults would benefit from a slower repetition rate (i.e., they would perceive more illusory changes).

The third issue addressed in Experiment 1 was whether, apart from hearing loss and slowing of processing, age-related differences in the VTE can be attributed to changes in the integrity of the lexical units undergoing habituation in the aged. Several language-processing studies have reported that, in perceptual tasks such as naming and lexical decision, older adults usually show word-frequency effects in the same direction as those displayed by young adults (see Allen, Madden, Weber, & Groth, 1993; Balota & Ferraro, 1993, 1996; Spieler & Balota, 2000). In the VT literature, however, word-frequency effects have not been examined closely. In the present study, we were interested in word-frequency effects as symptomatic of lexical integrity in the aged. We predicted that if habituation of a lexical unit via the VT paradigm is indeed a reduction in the activation level of that unit (baseline plus additional activation resulting from the first repetition of the word), high-frequency words' higher baseline levels should make them less susceptible to habituation than low-frequency words in both age groups. To test this prediction, we selected stimulus words of either low or high frequency but with the same neighborhood size to avoid confounding frequency with neighborhood density (the number of words differing by one phoneme from the stimulus word; Goldinger, Luce, & Pisoni, 1989). In fact, there is evidence suggesting that the VT phenomenon is influenced by the neighborhood size of the stimulus words. For instance, with word frequency held constant, Yin and MacKay (1992) found that words with a dense neighborhood elicited more new forms than those with a sparse neighborhood in both young and older adults.

Method

Participants. Forty-eight young and 48 older adults participated in the experiment (24 in each repetition rate condition: 100 and 500 ms). The mean age of young adults was 20.1 (17–29), and the mean age of older adults was 75.0 (63–87). The young adults were Washington University undergraduate students who participated in the experiment for course credit. The older adults were community members from the Aging and Development Subject Pool who were paid for participating in the experiment. Young and older participants reported themselves as being in good health for their age, and none wore a hearing aid. All participants were given the vocabulary subtest of the Wechsler Adult Intelligence Scale—Revised (Wechsler, 1981). The mean score of young adults was 52.8, and the mean score of older adults was 51.9. The two groups did not reliably differ on vocabulary scores, $t(94) < 1$.

Prior to the experimental session, pure-tone air-conduction thresholds for octave frequencies between 250 and 4000 Hz were obtained from the participants. The average thresholds (dB HL) for the better ear, that is, the ear with the least average loss, are reported in Table 1. All the young participants had absolute thresholds less than 25 dB HL for octave frequencies from 250 to 4000 Hz. As shown in Table 1, although the auditory acuity of older participants was more variable across all the selected frequencies, the vast majority had thresholds exceeding 25 dB HL for high frequencies.

Stimuli and apparatus. The stimuli in this experiment consisted of 10 monosyllabic words, 5 high frequency (M = 600; range = 269–895) and 5 low frequency (M = 2; range = 2–5; Francis & Kucera, 1982), with a lexical density of 20 (i.e., the number of words, neighbors, differing by one phoneme from the target word; see Goldinger et al., 1989; Nusbaum, Pisoni, & Davis, 1984). The stimuli (M duration = 534 ms), spoken by a middle-aged male talker, were digitized at a 20 kHz sampling rate and their RMS (root-mean square) amplitude levels were digitally equated. Four independent raters (two young and two older adults) correctly identified all the stimuli prior to experimental implementation.

Procedure. The experiment took place in a sound-attenuated room. Each trial began with a 500-Hz, 500-ms tone, followed 500 ms later by a word repeated 180 times. Either a 500-ms or 100-ms silent ISI separated each repetition of a word. Participants initiated any given trial by pressing the *enter* key on the computer keyboard. Trials were randomized separately for each participant. All the words were presented monaurally to the better ear of each participant over headphones (Sennheiser, HD 250) at 80 dB sound-pressure level (note that the VTE is not sensitive to monaural vs. binaural listening conditions; see Warren, 1961).

Participants were instructed to say aloud the word they heard at the beginning of each trial and then report any change they perceived, such as new forms and transitions (see Taylor & Henning, 1963; Warren, 1961). They received a one-word practice trial at the beginning of the experiment. Participants' responses were recorded by means of a tape recorder. It is important to note here that the groups of either young or older adults assigned to the two repetition rate conditions of the present experiment did not differ reliably in any of the demographic measures discussed above.

Results

Earlier studies have included in their analyses the data of trials in which listeners incorrectly reported the word at the beginning of the repetition sequence (Warren, 1961; Yin & MacKay, 1992). However, we thought that for a test involving age differences to be meaningful, young and older adults not only should be presented

Table 1
Experiments 1–3: Average Thresholds (dB HL) and Standard Deviations of Young and Older Participants' Better Ear for Octave Frequencies From 250 to 4000 Hz

	250 Hz		500 Hz		1,000 Hz		2,000 Hz		4,000 Hz	
Age groups	Threshold	*SD*	Threshold	*SD*	Threshold	*SD*	Threshold	*SD*	Threshold	*SD*
Experiment 1										
Young adults	4.1	11.0	0.9	6.0	−1.4	8.5	2.0	2.9	4.1	6.6
Older adults	16.0	14.1	18.9	17.4	16.8	17.6	27.9	18.7	47.3	22.2
Exceeded 25 dB HL[a]	7		13		11		25		36	
Experiment 2										
Young adults	9.7	3.6	9.7	3.6	6.4	3.8	6.7	3.8	5.3	5.0
Older adults	11.7	9.9	9.1	12.4	7.8	7.8	19.2	14.6	36.2	18.2
Exceeded 25 dB HL[a]	0		0		0		6		12	
Experiment 3										
Young adults	11.6	4.8	13.1	4.4	8.8	6.3	6.5	6.1	4.6	6.7
Older adults	19.9	9.1	21.1	10.0	20.4	11.2	26.8	15.3	40.1	17.1
Exceeded 25 dB HL[a]	8		9		7		16		28	

[a] The number of older adults whose thresholds exceeded 25 dB HL for each of these frequencies.

with the same stimulus material but also should perceive that stimulus material as being the same at the beginning of each trial. Therefore, we excluded trials in which participants misperceived the stimulus words at the beginning of the habituation period to evaluate age differences in the VTE uncontaminated by differences in stimulus material. These exclusions accounted for 9.6% of the young adults' trials (the veridical form was never reported on 2.3% of these trials) and 14.2% of the older adults' trials (the veridical form was never reported on 8.1% of these trials). Note that the inclusion of these data would not have changed the overall pattern of results observed with the subset of data that we have selected.

The mean number of new forms (number of illusory changes) and the mean number of transitions (number of possible ways in which a percept may change, including new forms and reversals to the veridical percept) reported by young and older adults are presented in Figure 1. There are four major points to note from Figure 1: First, older adults reported fewer new forms than young adults. Second, older adults compared with young adults also reported fewer transitions for high-frequency but not for low-frequency words. Interestingly, the analyses reported below indicated that age-related differences in auditory acuity did not account for older adults' fewer reports of new forms but only for their fewer reports of transitions. Third, as expected, low-frequency words produced more new forms and transitions than high-frequency words in both age groups. Fourth, the fast repetition rate slightly increased the number of transitions but not the number of new forms in both age groups.

These observations were supported by a 2 (age) × 2 (repetition rate) × 2 (word frequency) mixed-factor analysis of variance (ANOVA) followed by an analysis of covariance with hearing level as the covariate. Because young and older adults' thresholds differed the most in the high-frequency range, we used the thresholds averaged across the high frequencies reported in Table 1 (2,000 and 4,000) as a restricted measure of participants' hearing levels.[1] Note that all the differences reported here and in the subsequent experiments are significant at the $p < .05$ level unless otherwise indicated.

Number of new forms. Older adults reported fewer illusory changes than young adults, $F(1, 92) = 31.63$, $MSE = 2.21$. This age difference remained significant when the effect of auditory acuity was statistically removed. In both age groups, low-frequency words induced more illusory changes than high-frequency words, $F(1, 92) = 14.15$, $MSE = 0.52$ (the effect of rate and interactions, $Fs < 1.9$). Interestingly, although repetition rate did not reliably interact with the other factors, a separate analysis of the effect of word frequency at each repetition rate showed that the fast repetition rate eliminated the effect of word frequency in young adults, slow: $t(23) = 2.03$; fast: $t < 1$. In contrast, the effect of word frequency remained unaltered by repetition rate in older adults, slow: $t(23) = 3.05$; fast: $t(23) = 3.08$.

Number of transitions. Although no significant age differences were observed in number of transitions, $F(1, 92) = 2.09$, a separate analysis for high- and low-frequency words showed a reliable age difference for high-frequency words, $F(1, 92) = 4.53$, $MSE = 125.67$, but not for low-frequency words ($F < 1$). The age-related difference in number of transitions for high-frequency words, however, was no longer significant when the effect of hearing acuity was removed. That is, the lower auditory acuity of the aged accounted for the fewer transitions reported by this group to high-frequency words. In both age groups, low-frequency words produced more transitions than high-frequency words, $F(1, 92) = 13.82$, $MSE = 85.70$. The effect of repetition rate (500-ms ISI and 100-ms ISI) was marginally significant, $F(1, 92) = 3.35$, $p = .07$, $MSE = 293.15$, with a trend in the direction of more transitions in the faster repetition rate condition (all the other effects and interactions, $Fs < 1$).

Discussion

Several aspects of Experiment 1 are noteworthy. First, older adults were less susceptible to the VTE than young adults. They reported fewer new forms for both high- and low-frequency words and reliably fewer transitions for high-frequency words. Second, older adults' weak susceptibility to massed repetition could not be entirely accounted for by age-related losses in auditory acuity (at least as indicated by the persistence of an age-group difference after the removal of the effect of hearing level on new forms). Third, slowing in the uptake of sensory information in the aged did not account for the age differences in new forms. It is interesting that the marginally significant effect of repetition rate on number of transitions was not in the direction predicted by the slowing account. According to this account, a slower repetition rate should increase the number of VTs in older adults. In our experiment, however, slowing the repetition rate slightly decreased the number of transitions in both age groups. Fourth, the word-frequency effects observed on new forms and transitions indicated that aging preserves the strength of the word units in the mental lexicon.

The age differences in new forms observed in the present experiment are consistent with earlier findings showing that older adults report considerably fewer illusory percepts than young adults (Warren, 1961; Yin & MacKay, 1992). Similarly, the age differences in transitions observed in this experiment replicate Warren's finding, albeit for only high-frequency words. Interestingly, our finding that loss of auditory acuity does not account for the age differences in new forms observed in Experiment 1 also supports Warren's claim that stimulus degradation induced by hearing loss cannot explain older adults' reduced susceptibility to auditory massed repetition. Warren's claim is based on the finding that although young adults exposed to degraded stimuli, such as words masked by noise, display a decrement in VTs, this decrement is not as profound as the one displayed by the aged (1961, 1968). It is noteworthy to point out that Warren's argument relies on the assumption that the reduced intelligibility produced by older adults' hearing loss is directly comparable to the perceptual effects of stimulus degradation on young adults. However, masking noise, an experimentally induced form of degradation, adds to the speech-signal-irrelevant information, whereas hearing loss, an endogenous form of degradation, depletes the speech signal of information relevant to word identification (e.g., generally high-frequency information). These two forms of stimulus degradation are qualitatively different except for the fact that they both reduce

[1] We also used the thresholds averaged across all the frequencies reported in Table 1 as a covariate. We found that using this broader measure of hearing level did not produce a pattern of results different from that observed with the thresholds averaged across the high frequencies only.

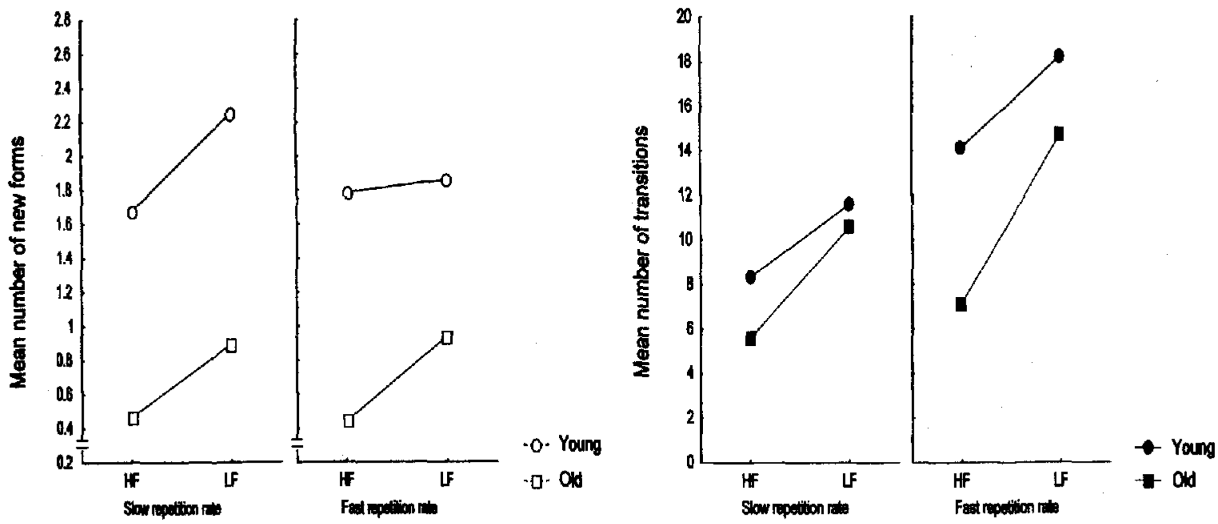

Figure 1. Experiment 1: Mean number of new forms and transitions (reversals) as a function of age (young and old), word frequency (HF = high frequency, and LF = low frequency), and repetition rate (fast and slow).

the intelligibility of speech signals (Hirsh, Reynolds, & Joseph, 1954). The results of Experiment 1 suggest that they are also functionally different. Indeed, in Experiment 1, we found that older adults' lower auditory acuity accounted for only their fewer reports of transitions to high-frequency words. In contrast, Warren found that masking noise reduced young adults' reports of both transitions and new forms. Nevertheless, if one accepts Warren's notion that the reduced intelligibility produced by masking noise is comparable to the perceptual effects of hearing loss, then the decrement in VTs observed by Warren in the young participants exposed to degraded stimuli suggests that reduced intelligibility plays a role in lexical habituation. Experiment 2 examined this notion by exposing young participants to degraded stimuli.

Experiment 2: The Effect of Stimulus Degradation on VTs in Young Adults

Although loss of auditory acuity in the aged did not account for the age differences in new forms observed in Experiment 1, we thought that statistically removing the contribution of age-related differences in auditory acuity was only an indirect means of evaluating the role of peripheral impairments. Therefore, we directly tested the peripheral account of age-related differences in lexical habituation by presenting young adults with the words of Experiment 1 low-pass filtered at 1.5 kHz. We then compared their reports with those of the older participants of Experiment 1 who displayed losses of auditory acuity above 1 kHz. The choice of low-pass filtering was motivated by the need of an experimentally induced form of degradation that would mimic hearing loss in the aged. Low-pass filtering deleted from our stimulus material the acoustic information that the older adults of our sample were less likely to perceive (high-frequency information), thereby creating in young adults peripheral impairments that roughly approximated those of older adults. It was hypothesized that if loss of auditory acuity in the aged plays any role in lexical habituation, the age differences in VTs encountered in Experiment 1 would be eliminated or minimized by exposing young participants to degraded stimuli.

Method

Participants. Eighteen young adults participated in the experiment. Their mean vocabulary score was 55.6, and their mean age was 21.4 (19–25). Twenty-four additional young adults who participated in the 500-ms condition of Experiment 1 served as the comparison group for examining the effects of stimulus degradation on young participants (note that this subsample of young adults did not differ in demographics from the entire sample of young adults used in Experiment 1). The 18 older adults in the 500-ms condition of Experiment 1, who had normal hearing acuity for octave frequencies from 250 to 1000 Hz but thresholds exceeding 25 dB HL for frequencies above 1000 Hz, served as the comparison group for examining age differences (see Table 1).

Stimuli and procedure. The stimulus words used in Experiment 1 were low-pass filtered at 1.5 kHz using a commercial signal-processing program. With the exception of stimulus degradation, the experimental procedure was identical to the one used in the 500-ms condition of Experiment 1.

Results

The main purpose of this experiment was to examine the contribution of stimulus degradation to the habituation of lexical units in young adults and assess whether it reproduced the effects of hearing loss in the aged. As in Experiment 1, the data of trials in which listeners misperceived the word at the beginning of the repetition sequence were eliminated from the analyses. These data accounted for 33.3% of the young adults' trials in the degradation condition (the veridical form was never reported on 14.4% of these trials), 9.2% of the young adults' trials in the nondegradation condition (the veridical form was never reported on 1.7% of these trials), and 14.4% of the older adults' trials (the veridical form was never reported on 9.4% of these trials).

The mean number of new forms and the mean number of transitions reported by young adults exposed to degraded stimuli and by young and older adults exposed to nondegraded stimuli are presented in Figure 2. There are two major points to note from Figure 2: First, contrary to what would be expected with masking noise, our experimentally induced form of degradation did not decrease the young adults' reports of new forms and transitions to the level observed in older adults. Interestingly, compared with young and older adults exposed to nondegraded stimuli, there was a trend in the opposite direction (i.e., stimulus degradation actually increased the VTE). Second, stimulus degradation preserved the word-frequency effect observed with intact stimuli on new forms but weakened it on number of transitions. These observations were supported by two separate analyses: First, a 2 (degradation) × 2 (word frequency) mixed-factor ANOVA examined whether stimulus degradation affected performance in young adults. Second, a 2 (age) × 2 (word frequency) mixed-factor ANOVA assessed whether stimulus degradation reduced the age differences observed in Experiment 1.

Does stimulus degradation affect habituation in young adults? The analyses of the young adults' data (degradation vs. nondegradation) indicated that the reports of new forms and transitions were not reliably different between the two groups, $F(1, 40) < 1$, and $F(1, 40) = 1.26$, respectively. As expected, both groups reported more new forms for low-frequency than high-frequency words, $F(1, 40) = 8.11$, $MSE = 0.77$. The word-frequency effect on transitions was marginally significant, $F(1, 40) = 3.40$, $p = .07$, $MSE = 30.31$. No reliable interaction was observed on either dependent measure ($Fs < 1$).

Does stimulus degradation reproduce the effects of hearing loss? Young adults exposed to degraded stimuli reported more new forms than older adults exposed to intact stimuli, $F(1, 34) = 18.49$, $MSE = 2.05$. Although young adults reported more transitions than older adults, there was no reliable age effect ($F = 1.54$). Both groups reported more new forms for low-frequency than high-frequency words, $F(1, 34) = 12.37$, $p = .001$, $MSE = 4.55$. The word-frequency effect on number of transitions was not significant but in the expected direction ($F = 2.06$). No reliable interaction was observed on either dependent measure ($Fs < 1$). It is interesting that when the reports of young adults exposed to intact stimuli were compared with those of the older adults selected for this experiment (who had losses in auditory acuity limited to high-frequency information), older adults still reported reliably fewer new forms but not transitions than young adults, $F(1, 40) = 10.14$, $MSE = 2.74$, and $F < 1$, respectively.

Discussion

Several aspects of Experiment 2 are noteworthy. First, stimulus degradation did not produce any reliable effect on the number of new forms and transitions reported by young adults. Warren (1961, 1968) found that stimulus degradation (masking noise) reduced the number of VTs experienced by young adults. It is interesting that our experimentally induced form of degradation produced a trend in the opposite direction. Of course, one may argue that low-pass filtering does not reduce the intelligibility of the signal as much as hearing loss or masking noise, but the data on misperceptions at the beginning of the repetition treatment suggest that this is not the case. In fact, these data show that our experimentally induced form of stimulus degradation, whose effects were assumed to be roughly similar to those produced by peripheral impairments, successfully induced in young adults word-identification difficulties that were even larger than those experienced by the aged. Second, Warren found that presenting young adults with stimuli masked by noise did not eliminate the age differences in the reports of VTs observed without degradation. Similarly, we found that older adults reported fewer new forms than young adults exposed to degraded stimuli even if their losses in auditory acuity roughly matched the missing portions of the degraded stimuli (high frequencies). Third, we found no reliable age differences in the reports of transitions. In Experiment 1, we observed only weak age differences in transitions, which were eliminated when the effect of hearing acuity was statistically removed. Therefore, it is not surprising that the older adults of this experiment, who displayed losses in auditory acuity restricted to high-frequency information, reported as many transitions as the young adults exposed to intact stimuli. Fourth,

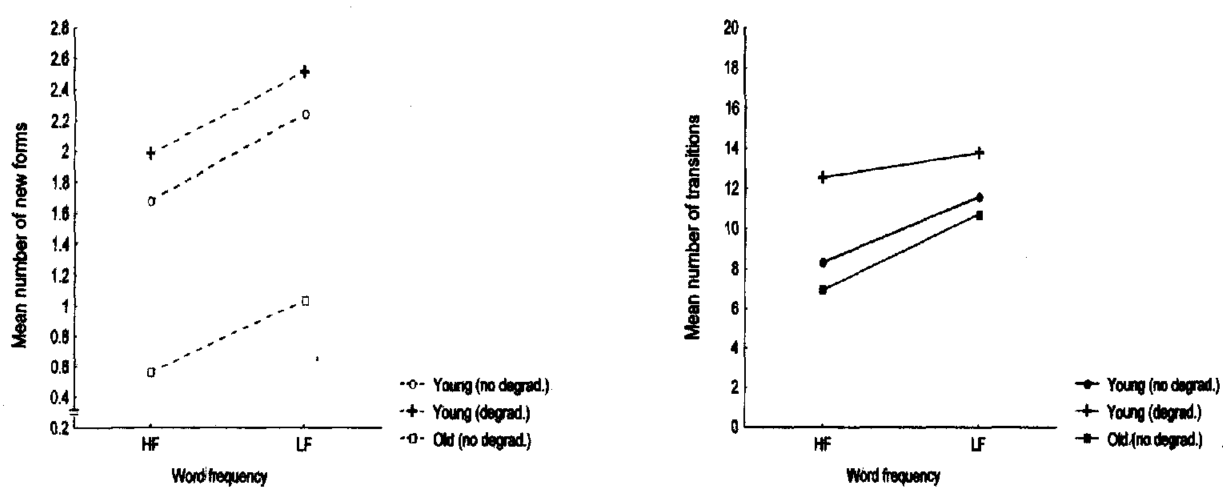

Figure 2. Experiment 2: Mean number of new forms and transitions as a function of age, word frequency (HF = high frequency, and LF = low frequency), and stimulus degradation (young adults only). Degrad. = degradation.

stimulus degradation in young adults preserved the word-frequency effects on new forms observed with no degradation. Similarly, older adults with losses of auditory acuity limited to high-frequency information displayed word-frequency effects on new forms as the older adults of Experiment 1, who exhibited a wider range of losses.

One possible explanation for these findings is that new forms and transitions reflect different aspects of lexical processing during the habituation period. The reports of new forms may be thought of as an index of the number of neighboring lexical units that receive some activation during the repetition period. Of course, if the reports of new forms are a measure of the amount of activation that spreads across these units (i.e., pattern of activation), the age differences of Experiments 1 and 2 suggest that aging decreases the amount of information that transfers from one lexical unit to related units, thereby restricting the pool of candidates available for lexical activation (new forms) during the habituation period (Burke, MacKay, Worthley, & Wade, 1991; MacKay et al., 1993; Yin & MacKay, 1992). Note that although older adults' decrements in spreading of activation (transmission deficits) do not appear to be induced by peripheral losses, these decrements may not be functionally independent of such losses. On the contrary, centrally located transmission deficits in the aged may be conceptualized as an adaptive response to the perceptual ambiguity produced by degraded acoustic signals but only in the sense that having fewer lexical candidates may aid older adults' word identification (selection).

If new forms are a measure of the number of units that become activated at some point during the habituation period, the overall number of changes (transitions) may be thought of as an index of how much information continues to spread across the pool of previously activated units. The minimal or null age differences in transitions observed in Experiments 1 and 2 suggest that the activation of new forms strengthens the connections between the units that have become activated at some point during the habituation period (including the unit corresponding to the veridical stimulus), thereby counteracting the effects of transmission deficits in the aged. It is interesting that three sets of findings suggest that the flow of activation among these units may be to a certain extent modulated by the amount of information that can be gathered from the periphery. First, in Experiment 1, statistically removing the effect of auditory acuity on transitions eliminated the already weak age differences observed on this dependent measure. Second, in Experiment 2, empirically restricting hearing loss in the aged to high-frequency information made young and older adults' reports of transitions virtually equivalent. Third, in Experiment 2, presenting young adults with degraded stimuli weakened the effects of word frequency on their reports of transitions.

Although the notion of centrally located transmission deficits is a reasonable account for our findings of age differences in new forms, there is an alternative explanation that Experiment 3 addressed. That is, it is possible that the age-related differences observed in Experiments 1 and 2 were due to response-criterion differences. Specifically, older adults might have been simply less willing to report illusory changes than young adults because of the cultural stereotypes regarding loss of auditory acuity in the aged. This explanation implies that older adults habituate as well as young adults but their criterion to respond is different. Our findings of robust age differences in new forms and of weaker age differences in transitions support this notion of response bias. That is, older adults might be more careful in reporting an illusory change, but once they have reported it, they have no difficulty indicating that it changed again. It is noteworthy to point out that this explanation conflicts with the behavioral expression of surprise that older adults displayed during debriefing in Experiment 1 when they were told that the changes they heard were produced by their perceptual system. However, because subjective reports at the end of an experimental session may not be as reliable as the results of an experimental manipulation, in Experiment 3, we tested the response-criterion explanation on a group of young and older adults by changing the VT instructions.

Experiment 3: The Effect of Instructions on VTs in Older Adults

The notion of response bias is not novel to the VT literature. It is embedded in the standard VT instructions first devised by Warren and has been the concern of other researchers. Warren (1968, p. 265) argued that "the very fact that the subject is required to continue to listen to the stimulus suggests that there is a reason for listening (i.e., that the stimulus might change)." What is really a concern here is not the existence of VTs (anyone exposed to a massively repeated spoken word hears these changes) but the extent to which group differences are produced by a person's willingness to report changes. Natsoulas (1967) directly addressed this issue by modifying the instructions given to two separate groups of participants. One group was informed that changes were actually occurring in the recording (external attribution), whereas the other group was told that the same word was repeated over and over and changes were produced by the perceptual system (internal attribution). Participants given the opportunity to attribute the changes to an external source reported more transformations than those who were aware of the true nature of these changes.

Experiment 3 examined whether older adults' fewer reports of new forms found in the earlier experiments resulted from age-related differences in response criterion. Young and older adults were instructed that their task was to detect and report real changes occurring during each word trial. Specifically, the difference between the standard instructions of Experiments 1 and 2 and the biasing instructions of the present experiment is that the former required participants to listen carefully to what was being presented to them via headphones and report any change in what the voice seemed to be saying (nonbiasing instructions), whereas the latter encouraged participants to attribute any perceived change to the recording.

Method

Participants. Thirty-six older adults and 34 young adults participated in the experiment. Their mean vocabulary scores were 53.3 and 51.9, respectively ($t = 1$). Older adults' mean age was 74.5 (67–86), and young adults' mean age was 19.2 (16–23). Table 1 reports hearing acuity measures.

Stimuli and procedure. The words used in Experiment 1 constituted the stimulus material. The same procedure used in the 500-ms condition of Experiment 1 was used here with the exception of the biasing instructions.

Results and Discussion

The mean number of new forms and the mean number of transitions reported by young and older adults are presented in

Figure 3. As in the earlier experiments, we excluded trials in which participants misperceived the stimulus words at the beginning of the habituation period to evaluate age differences in the VTE uncontaminated by differences in stimulus material. These exclusions accounted for 15% of the older adults' trials (the veridical form was never reported on 6.9% of these trials) and 8% of the young adults' trials (the veridical form was never reported on 1% of these trials).

There are three major points to note from Figure 3: First, older adults still reported fewer new forms than young adults. Second, older adults did not reliably report fewer transitions than young adults (albeit a trend in this direction was observed). Third, the new instructions eliminated the word-frequency effects observed in Experiment 1 with the standard instructions.

These observations were supported by a 2 (age) $\times$ 2 (word frequency) mixed-factor ANOVA conducted on the new form and transition data, separately. The analysis of the new form data yielded a main effect of age, $F(1, 68) = 37.08$, $MSE = 2.42$, indicating that older adults reported reliably fewer illusory changes than young adults (other $Fs < 2.6$). This age difference remained significant after the effect of auditory acuity was statistically removed. Even if older adults reported numerically fewer transitions than young adults, the analysis of the transition data yielded only a marginally significant effect of age, $F(1, 68) = 3.13$, $p = .08$, $MSE = 380.61$ (other $Fs < 1.2$), which, of course, did not improve with the removal of the contribution of hearing acuity.

It is interesting that instructions encouraging participants to report illusory changes did not eliminate the age differences in new forms observed in the earlier experiments, suggesting that older adults' declines in lexical habituation are not due to differences in bias. Of course, another interesting finding of this experiment is that the biasing instructions eliminated the word-frequency effects observed in the earlier experiments in both young and older adults while preserving the age differences in the reports of new forms. Note that this finding does not challenge the conclusion that we made earlier that the word-frequency effects observed in both young and older adults exposed to standard instructions (Experiments 1 and 2) are symptomatic of lexical integrity in the aged. In fact, in Experiment 3, the biasing instructions eliminated word-frequency effects by favoring the reports of illusory changes for high-frequency words in both young and older adults. The absence of word-frequency effects in this experiment, however, cautions against interpreting the word-frequency effects observed in Experiments 1 and 2 as being the exclusive byproduct of the automatic functioning of the mental lexicon. Because the liberal response criterion made both young and older adults more sensitive to such changes, it is reasonable to conclude that aging preserves not only the integrity of the lexical units but also the influence of external factors (instructions) on participants' use of lexical information.

General Discussion

The results of the experiments presented here can be summarized in three main points. First, older adults reported fewer illusory percepts (new forms) than young adults. Second, stimulus degradation (in the form of either hearing loss in older adults or low-pass filtering in young adults), slowing in the uptake of sensory information, and response bias did not account for this age difference in lexical habituation. Third, word frequency modulated the reports of illusory changes in both young and older adults.

The present series of experiments provides prima facie evidence for a model of habituation in the auditory domain in which any repetition-induced fatigue of lexical units is dependent on the preexisting levels of activation of these units (as exemplified by word-frequency measures). The word-frequency effects observed in our experiments suggest that aging preserves the integrity of the lexical units that constitute the mental lexicon (see also Balota & Duchek, 1988; Spieler & Balota, 2000). The reliable age differences in new forms observed in our experiments, however, indicate that aging modulates lexical processes, that is, the patterns of activation in the mental lexicon induced by incoming speech signals. Specifically, older adults' fewer reports of new forms suggest that aging restricts the pool of candidates available for

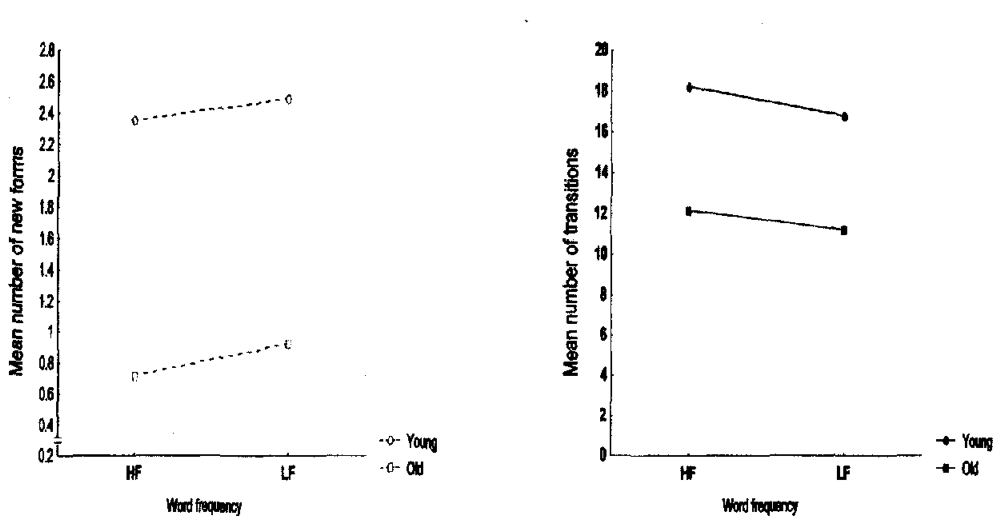

Figure 3. Experiment 3: Mean number of new forms and transitions as a function of age and word frequency (HF = high frequency, and LF = low frequency).

word identification, whereas the weak age differences in transitions indicate that aging has only a minimal effect on the flow of activation among these units once they become activated. Of course, a restriction of the pool of candidates available for word recognition in older adults may be an adaptive solution to their peripheral impairments. Indeed, older adults' peripheral impairments prevent them from gathering from the speech signals as much information as young adults, thereby increasing older adults' difficulties in selecting lexical units that represent the best match for the incoming signals. A reduction in the transmission of information among lexical units restricts the pool of candidates available for word identification, and thus it may facilitate the selection process.

Of course, the age differences in new forms observed in our experiments suggest that aging, by modulating the patterns of activation within the mental lexicon, also affects participants' ability to withdraw processing resources from repetitive noninformative stimuli and direct them to novel information-bearing stimuli (MacKay, 1990). Given that the ability to allocate processing resources to information-bearing stimuli is a primary property of an efficient processing system (Cowan, 1988), older adults' weakened susceptibility to habituation may impair their ability to process information during on-line speech perception. Specifically, if older adults are less efficient in withdrawing resources to already processed items, these items will continue taking up resources that would otherwise be devoted to novel items, weakening the processing of the latter (see Balota & Black, 1997, for similar arguments from a visual semantic satiation paradigm). Further evidence in support of this claim is found in studies of selective attention, in which older adults' impairments in processing relevant information are generally related to their difficulties in excluding from attention task-irrelevant stimuli (Barr & Giambra, 1990; Gopher & Kahneman, 1971).

It is interesting that although our findings indicate that the massed repetition of a spoken word modulates the patterns of activation within the mental lexicon, whether the lexical habituation effects observed in our study are also the result of habituation at earlier stages of processing (auditory), as suggested by Pilotti et al. (1997), is a matter for future research. Indeed, in our experiments, the repetitions of any given word were physically identical, and this may have induced habituation at the auditory level to be carried onto the next levels of the word-recognition pathway. One thing that our study clearly indicates, however, is that when physical identity is preserved across the different repetitions of a word, peripheral impairments are unlikely to be an important contributor of age differences in lexical habituation.

References

Allen, P. A., Madden, D. J., Weber, T. A., & Groth, K. E. (1993). Influence of age and processing state on visual word recognition. *Psychology and Aging, 8,* 274–282.

Balota, D. A., & Black, S. (1997). Semantic satiation in healthy young and older adults. *Memory and Cognition, 25,* 190–202.

Balota, D. A., & Duchek, J. M. (1988). Age-related differences in lexical access, spreading activation, and simple pronunciation. *Psychology and Aging, 3,* 84–93.

Balota, D. A., & Ferraro, R. (1993). A dissociation of frequency and regularity of pronunciation performance across young adults, older adults, and individuals with senile dementia of the Alzheimer type. *Journal of Memory and Language, 32,* 573–592.

Balota, D. A., & Ferraro, R. (1996). Lexical, sublexical, and implicit memory processes in healthy young adults and healthy older adults and in individuals with dementia of the Alzheimer type. *Neuropsychology, 10,* 82–95.

Barr, R. A., & Giambra, L. M. (1990). Age-related decrement in auditory selective attention. *Psychology and Aging, 5,* 597–599.

Burke, D. M., MacKay, D. G., Worthley, J. S., & Wade, E. (1991). On the tip of the tongue: Why do word finding failures increase with age? *Journal of Memory and Language, 36,* 542–579.

Cowan (1988). Evolving conceptions of memory storage, selective attention, and their mutual constraints within the human information-processing system. *Psychological Bulletin, 104,* 163–191.

Elman, J. L. (1989). Connectionist approaches to acoustic/phonetic processing. In W. D. Marslen-Wilson (Ed.), *Lexical representation and process* (pp. 227–260). Cambridge, MA: MIT Press.

Elman, J. L., & McClelland, J. L. (1986). Exploiting lawful variability in the speech waveform. In J. S. Perkell & D. H. Klatt (Eds.), *Invariance and variability in speech processing* (pp. 360–385). Hillsdale, NJ: Erlbaum.

Francis, W., & Kucera, M. (1982). *Frequency analysis of English usage: Lexicon and grammar.* Boston: Houghton Mifflin.

Goldinger, S. D., Luce, P. A., & Pisoni, D. B. (1989). Priming lexical neighbors of spoken words: Effects of competition and inhibition. *Journal of Memory and Language, 28,* 501–518.

Gopher, D., & Kahneman, D. (1971). Individual differences in attention and the prediction of flight criteria. *Perceptual and motor skills, 33,* 1335–1342.

Hirsh, I. J., Reynolds, G., & Joseph, M. (1954). Intelligibility of different speech materials. *Journal of the Acoustical Society of America, 26,* 530–538.

Humes, L. E., & Roberts, L. (1990). Speech-recognition difficulties of the hearing-impaired elderly: The contribution of audibility. *Journal of Speech and Hearing Research, 33,* 726–735.

MacKay, D. G. (1990). Perception, action, and awareness: A three-body problem. In O. Neumann & W. Prinz (Eds.), *Relations between perception and action* (pp. 269–303). Berlin: Springer-Verlag.

MacKay, D. G., Wulf, G., Yin, C., & Abrams, L. (1993). Relations between word perception and production: New theory and data on the verbal transformation effect. *Journal of Memory and Language, 32,* 624–646.

McClelland, J. L., & Elman, J. L. (1986). The TRACE model of speech perception. *Cognitive Psychology, 18,* 1–86.

McDowd, J. M., & Filion, D. L. (1992). Aging, selective attention, and inhibitory processes: A psychophysiological approach. *Psychology and Aging, 7,* 65–71.

Natsoulas, T. (1967). What are perceptual reports about? *Psychological Bulletin, 67,* 249–272.

Nusbaum, H. C., Pisoni, D. B., & Davis, C. K. (1984). *Sizing up the Hoosier mental lexicon: Measuring the familiarity of 20,000 words.* (Research on Speech Perception, Progress Report No. 10, pp. 357–371). Bloomington, IN: Indiana University Press.

Pilotti, M., Antrobus, J. S., & Duff, M. (1997). The effect of presemantic acoustic adaptation on semantic "satiation." *Memory and Cognition, 25,* 305–312.

Skinner, B. F. (1936). The verbal summator and a method for the study of latent speech. *Journal of Psychology, 2,* 71–107.

Spieler, D. H., & Balota, D. A. (2000). Factors influencing word naming in younger and older adults. *Psychology and Aging, 15,* 225–231.

Stine, E. L., Wingfield, A., & Poon, L. W. (1986). How much and how fast: Rapid processing of spoken language in later adulthood. *Psychology and Aging, 1,* 303–311.

Taylor, M. M., & Henning, G. B. (1963). Verbal transformations and an effect of intructional bias on perception. *Canadian Journal of Psychology, 17,* 210–223.

Warren, R. M. (1961). Illusory changes in repeated words: Differences between young adults and the aged. *The American Journal of Psychology, 74,* 506–516.

Warren, R. M. (1968). Verbal transformation effect and auditory perceptual mechanisms. *Psychological Bulletin, 70,* 261–270.

Warren, R. M., & Warren, R. P. (1966). A comparison of speech perception in childhood, maturity, and old age by means of the verbal transformation effect. *Journal of Verbal Learning and Verbal Behavior, 5,* 142–146.

Wechsler, D. (1981). *Manual for the Wechsler Adult Intelligent Scale—Revised.* New York: Psychological Corporation.

Willott, J. F. (1991). *Aging and the auditory system.* San Diego, CA: Singular Publishing Group.

Wingfield, A., Poon, L. W., Lombardi, L., & Lowe, D. (1985). Speed of processing in normal aging: Effects of speech rate, linguistic structure, and processing time. *Journal of Gerontology, 40,* 579–585.

Yin, C., & MacKay, D. G. (1992, March). *Auditory illusions and aging: Transmission of priming in the verbal transformation paradigm.* Poster presented at the Cognitive Aging Conference, Atlanta.

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