Journal of Gerontology: PSYCHOLOGICAL SCIENCES
1997, Vol. 52B, No. 6, P319–P328

Frequency Discrimination vs Frequency Estimation: Adult Age Differences and the Effect of Divided Attention

Sharon A. Mutter and Kelly M. Goedert

Western Kentucky University.

In this experiment we explored age differences in frequency judgment. Young and older adults studied words occurring from one to six times under divided or focused attention and then completed either a frequency discrimination or a frequency estimation test for these items. Divided attention led to poorer performance on both frequency judgment tests, suggesting that distraction during the encoding of target events results in less optimal encoding of the information that is necessary for any type of frequency judgment. Contrary to the notion that older adults encode this information more superficially than young adults, older adults were as sensitive as young adults to relative differences in the frequency of target words, and distraction did not magnify age differences for either type of frequency judgment task. On the other hand, older adults were less accurate in assigning an absolute numerical value to the frequency of the target words. Altogether, the results are consistent with the idea that the encoding and/or retrieval processes required for accurate numerical estimation of frequency suffer a larger age-related decline than do those required for accurate discrimination of relative frequency.

A NUMBER of years ago, Hasher and Zacks (1979) published an influential paper suggesting that processing the frequency of occurrence of events develops early and remains intact into old age. Since then, several studies have compared young and older adults' performance on frequency judgment tasks (e.g., Attig & Hasher, 1980; Ellis, Palmer, & Reeves, 1988; Freund & Witte, 1986; Hasher & Zacks, 1979, Exp. 2; Kausler, Lichty, & Hakami, 1984; Kausler & Puckett, 1980; Kausler, Salthouse, & Saults, 1987; Kausler, Wright, & Hakami, 1981; Sanders, Wise, Liddle, & Murphy, 1990; Tweedy & Vakil, 1988; Warren & Mitchell, 1980; Wiggs, Martin, & Howard, 1994), but their findings have not consistently supported the notion that frequency judgment is unaffected by age. One reason for this lack of consistency could be that, with few exceptions (e.g., di Pellegrino, Nichelli, & Faglioni, 1988; Wiggs, 1993; Wiggs et al., 1994), earlier studies focused on older adults' ability to encode frequency information and did not systematically examine their ability to retrieve and use this information. In the present experiment, we explored age differences in both the encoding and retrieval of information for frequency judgment by manipulating attentional demands during the initial presentation of events and comparing young and older adults' performance on frequency judgment tests with different retrieval requirements.

Age differences in frequency judgment are typically studied using either a frequency estimation task or a frequency discrimination test. A frequency estimation is made by indicating how many times a single event has occurred, whereas a frequency discrimination is made by indicating which of two events occurred most (or least) frequently. The way frequency information is used in the two tests varies, and there may also be differences in the way this information is retrieved. Although some recent evidence suggests that an actual numerical value representing frequency of occurrence can be encoded and retrieved (Jonides & Jones, 1992), the prevailing view is that frequency information is derived or inferred from the multiple memory traces of repeated events (Hintzman, 1988). According to multiple trace theory, an item on a frequency test serves to cue the retrieval of general memory information that varies based on the number of encoded traces for that item. The mechanism that captures this variation is the magnitude of a familiarity signal called the echo intensity. In frequency discrimination, retrieved familiarity information for paired target items is directly compared and the member with the highest (or lowest) relative familiarity is chosen (Hintzman & Hartry, 1990). In frequency estimation, a numerical estimate of absolute frequency must be determined either by the application of a set of criterion values to the general familiarity information (Hintzman, 1988) or by further retrieval and enumeration of individual memory traces (Begg, Maxwell, Mitterer, & Hams, 1986).

Consistent with this view of the differing retrieval processes in the two types of frequency judgments, it has been suggested that frequency discrimination bears some resemblance to recognition memory, whereas frequency estimation is more similar to recall memory (Sanders et al., 1990). Research has shown that older adults are at a greater disadvantage than young adults on recall than on recognition (for a review, see Kausler, 1994), and there is some evidence that this age-related difference may extend to frequency judgment. Specifically, frequency estimation is almost always associated with a modest age-related decline in performance (di Pellegrino et al., 1988; Ellis et al., 1988, Exp. 1; Freund & Witte, 1986, Exps. 1 & 2; Hasher & Zacks, 1979, Exp. 2; Tweedy & Vakil, 1988; Warren & Mitchell, 1980; Wiggs et al., 1994, Exp. 1), whereas frequency discrimination is sometimes associated with age differences (Kausler et al., 1981, 1984, 1987; Wiggs, 1993; Wiggs et al., 1994, Exp. 2) and is sometimes not (Attig & Hasher, 1990; di Pellegrino et al., 1988; Kausler & Puckett, 1980; Sanders et al., 1990; Wiggs, 1993, Exp. 1). These findings suggest that older adults may perform more or less proficiently depending on the retrieval demands of the frequency judgment task. However, there is considerable procedural variation both across and within these studies, and it is possible that differences in older adults' performance for the two types of frequency judgment tests are due to this variation and not to differences in the ability to retrieve and use frequency information. We addressed this issue in the present experiment by keeping stimulus materials and encoding procedures constant and examining young and older adults' performance for both frequency estimation and frequency discrimination. We expected that age differences would be more likely to occur for frequency estimation, which depends on accurate retrieval and enumeration of individual memory traces (Begg et al., 1986), than for frequency discrimination, which can be based on the retrieval and comparison of general familiarity information (Hintzman, 1988; Hintzman & Hartry, 1990).

We also addressed the question of whether age affects the ability to encode frequency-of-occurrence information. Research with young adults suggests that manipulations that enhance the quality of the encoded information for events improve frequency judgment and those that degrade the quality of this information lead to poorer judgment performance (e.g., Begg et al., 1986; Hintzman, 1988; Jonides & Naveh-Benjamin, 1987; Maki & Ostby, 1987; Naveh-Benjamin & Jonides, 1986; Sanders, Gonzalez, Murphy, Liddle, & Vitina, 1987). Several researchers have suggested that because of diminished attentional resources, older adults encode events superficially (Eysenck, 1974) or less distinctively (Rabinowitz, Craik, & Ackerman, 1982). It might be expected, therefore, that this qualitative difference in encoding would be reflected in frequency judgment. However, evidence for age-related deficits in encoding of frequency information has been mixed. The fact that the overall accuracy of older adults' frequency judgments is sometimes lower than that of young adults (e.g., di Pellegrino et al., 1988; Ellis et al., 1988; Freund & Witte, 1986; Hasher & Zacks, 1979; Kausler et al., 1984, 1987; Tweedy & Vakil, 1988; Warren & Mitchell, 1980) tends to support the possibility of an age-related deficit in encoding, but other findings are not consistent with this idea. For example, Kausler et al. (1981) reasoned that performing a distracting case monitoring task would exacerbate any age-related difficulties in encoding of target words and that this effect would be revealed in differential reductions in frequency discrimination for young and older participants. Contrary to this idea, they found that while both age and distraction during encoding were associated with a reduction in discrimination accuracy, distraction did not lead to differential effects in the performance of the two age groups.

Although the Kausler et al. (1981) results provide little support for the idea that age leads to changes in the ability to encode frequency information, two other factors may have contributed to the absence of the Age × Attention interaction in this study. First, although the case monitoring task apparently did burden the attentional resources of the two age groups, it may not have been difficult enough to reduce the resources of the older adults to the point at which differential effects would be revealed. Attentional focus was never diverted away from the target items because both studying and case monitoring involved these items. Moreover, maintaining letter case information in working memory from trial to trial may not be particularly difficult. In the present experiment, we examined the effect of distraction during encoding on frequency judgment by requiring young and older participants to perform a cumulative addition task while studying for a general test of memory (cf. Naveh-Benjamin & Jonides, 1986). This task has a number of advantages over the case monitoring task. First, it fully engages both the processing and storage aspects of working memory (e.g., Baddeley & Hitch, 1974) because participants must divide their attention between reading the current target item and maintaining and updating a numerical count. Second, the task discourages encoding of direct numerical frequency information for target items (e.g., Jonides & Jones, 1992), and participants may therefore be more likely to rely on the encoded memory traces of these items to make their frequency judgments. In line with earlier predictions (i.e., Kausler et al., 1981), if distraction produces greater disruption in older adults' ability to encode target items than in young adults' ability to encode these items, then concurrent performance of the cumulative addition task should have a more detrimental effect on our older participants' frequency judgment performance.

A second reason why Kausler et al. (1981) did not observe differential costs of divided attention for young and old adults could be that the frequency discrimination test used in their study was insensitive to subtle changes in encoding processes. Although both frequency discrimination and estimation benefit from more effective encoding (Begg et al., 1986; Jonides & Naveh-Benjamin, 1987; Maki & Ostby, 1987; Naveh-Benjamin & Jonides, 1986), the frequency estimation test, which requires retrieval and enumeration of individual memory traces, may show more sensitivity to age differences in encoding processes (Sanders et al., 1990). Thus, greater divided attention costs for older adults may be revealed in frequency estimation performance, even when a similar age difference is not present for frequency discrimination.

Method

Participants and Design

Eighty-nine young adults were recruited from psychology classes and were given course credit for their participation; 87 older adults were recruited from the community and were paid for their participation. It was necessary to replace 17 of the young adults and 13 of the older adults due to equipment problems (9 young, 2 older), failure to follow instructions (1 young, 4 older), or failure to perform the divided attention task correctly (7 young, 8 older). The ages of the remaining 72 young participants (23 males, 49 females) ranged from 17 to 29 and the ages of the remaining 72 older participants (27 males, 45 females) ranged from 60 to 87. Additional data on participant characteristics [Age, Education, Wechsler Adult Intelligence Scale-Revised (WAIS-R, Wechsler, 1981) Vocabulary, Information, Digit Span Backwards, and Digit Symbol subtest scores] are presented in Table 1. None of the participants had histories of neurological or psychiatric illness, and none were taking medications known to affect cognitive functioning. All reported that they were in good health.

Within each age group, 18 participants were randomly assigned to each of the four Attention (divided vs focused) × Test Type (frequency discrimination vs frequency estimation) conditions. An additional within-subjects variable was associated with each type of frequency test: For frequency discrimination, this variable was the difference in presentation frequency between paired target words (1 vs 2 vs 3), and for frequency estimation it was the presentation frequency for individual target words (0 vs 1 vs 2 vs 3 vs 4 vs 5 vs 6). Counterbalancing procedures for the frequency discrimination test necessitated the preparation of six different study lists. Each list was given to three participants within a condition.

Materials

Study lists were constructed in the following way. Nouns with a length of 5 to 7 letters and a background frequency ranging from 100 to 200 occurrences per million were selected from the Francis and Kucera (1982) analysis of word frequency in English usage. Forty-eight words were randomly selected from this pool to serve as target items and another 20 words were selected to serve as practice items and primacy and recency buffers. The 48 target words were assigned to sets corresponding to the seven presentation frequencies represented in the study list. Six words were assigned to the Frequency 0 set, 8 to the Frequency 1 set, 10 to the Frequency 2 set, 12 to the Frequency 3 set, 6 to the Frequency 4 set, 4 to the Frequency 5 set, and 2 to the Frequency 6 set. (The number of items in each set was determined by the structure of the word pairs in the frequency discrimination test.) Six different study lists were constructed by rotating target words through these sets so that each word was presented at four of the seven presentation frequencies. Practice words and primacy buffers occupied the first 10 positions of each list, target words occupied the middle 120 positions, and recency buffers occupied the last 10 positions. Target words were assigned to their positions in a study list by successively partitioning these positions into sixths, fifths, fourths, thirds, and halves and assigning items from the Frequency 6, 5, 4, 3, and 2 sets, respectively, to the positions in each portion. Items in the Frequency 1 set were assigned to the remaining positions. Position assignments were made randomly with the restriction that there could be no fewer than five intervening items between each presentation of a target word.

Frequency discrimination and frequency estimation tests were constructed for each of the six study lists. The frequency discrimination tests consisted of a total of 24 target word pairs representing two test items for each of four word pair combinations at each of three levels of frequency difference. A word pair was composed of a least frequent or base item and a most frequent item. The base item in a pair was presented from one to three times in the study list, and the most frequent item in a pair was presented from one to six times in the study list. The presentation frequencies of base words and most frequent words in Frequency Difference 1 pairs were either 0:1, 1:2, 2:3, or 3:4, respectively; in Frequency Difference 2 pairs, they were 0:2, 1:3, 2:4, or 3:5, respectively; and in the Frequency Difference 3 pairs, they were 0:3, 1:4, 2:5, or 3:6, respectively. Across the six frequency discrimination test lists, target words were combined in such a way that each served equally often as the least frequent and most frequent word in a pair and also served equally often in pairs representing each of the three levels of frequency difference. In each of these tests, the least frequent word was presented in the first posi-

Table 1. Participant Characteristics

	Divided Attention		Focused Attention	
	Young	Older	Young	Older
Frequency Discrimination				
Age (years)	21.11 (3.35)	68.33 (5.31)	21.61 (2.79)	70.00 (6.75)
Education (years)	14.00 (2.06)	14.61 (1.91)	14.39 (1.54)	13.89 (1.37)
Vocabulary[a]	42.06 (5.51)	55.11 (7.30)	46.61 (5.71)	48.72 (10.14)
Information[a]	17.17 (2.97)	23.11 (3.12)	19.83 (4.62)	20.33 (3.81)
Digit Span[a,b]	7.06 (1.87)	7.00 (1.94)	7.27 (2.02)	6.22 (1.11)
Digit Symbol[a]	68.11 (15.58)	48.83 (8.37)	69.78 (11.42)	40.00 (12.77)
Frequency Estimation				
Age	20.67 (2.57)	68.72 (6.90)	21.56 (2.50)	72.83 (6.78)
Education	13.44 (1.34)	15.29 (3.56)	14.28 (1.56)	14.61 (1.75)
Vocabulary[a]	43.00 (6.84)	55.94 (6.81)	45.61 (7.62)	50.17 (8.49)
Information[a]	16.94 (4.49)	22.67 (2.74)	19.22 (5.27)	20.44 (3.05)
Digit Span[a,b]	7.00 (1.68)	6.44 (1.98)	7.94 (2.58)	6.44 (2.01)
Digit Symbol[a]	73.28 (9.86)	50.11 (11.38)	70.44 (10.56)	42.89 (10.41)

Note: Standard deviations are in parentheses.
[a]Subtests of the WAIS-R (Wechsler, 1981).
[b]Backward Digit Span only.

tion for half of the pairs, and the most frequent word was presented in this position for the remaining half of the pairs. The frequency estimation test lists were constructed by separating the 24 word pairs in each of the frequency discrimination tests and rearranging these items into 48-item lists.

Procedure

Participants were tested individually or in pairs in a session lasting approximately 1 hour. After completing consent procedures and a questionnaire on health status and biographical information, participants began the study phase. The procedure for this phase varied depending on the condition to which the participant had been assigned. Participants in the focused attention condition saw a series of words projected on a screen at the rate of one word every 5 seconds. They were told that some of the words would appear more than once and that their memory for the words would be tested. The nature of the memory test was not specified. Participants in the divided attention condition saw the same series of words and received the same instructions concerning word repetition and the memory test, but they also performed a cumulative addition task while studying the words. They were told that attending to the study list and performing the addition task were equally important. For the cumulative addition task, participants were given the number 1847 just prior to study list presentation and were instructed to start from this number and count forward by two each time the word on the screen changed. They were not allowed to write down the intermediate results of their calculations, and they were reminded that they must keep these results in mind to update the count accurately as the screen changed.

After study list presentation, there was a 5-minute retention interval during which the experimenter queried the divided attention participants about the cumulative addition task and engaged the focused attention participants in conversation. At the end of this interval, the participants completed either a frequency discrimination or a frequency estimation test. For both types of frequency test, the participants were told that their test booklets contained study list words and words that had not been presented before, and that the words in the study list had been presented from one to six times. For the frequency discrimination test, participants circled the word in each pair that occurred most frequently in the study list; for the frequency estimation test, they indicated how many times each word had appeared in the study list. After finishing the frequency judgment test, participants completed the WAIS-R (Wechsler, 1981) Vocabulary, Information, Backward Digit Span, and Digit Symbol subtests.

Results

Analyses were conducted on intelligence measures [WAIS-R (Wechsler, 1981) Information, Vocabulary, Backward Digit Span, and Digit Symbol subtest scores] and on frequency discrimination and estimation data. All effects reported as significant reached a criterion of $p \leq .05$. Strength of association was measured by partial η^2.

Cumulative Addition Task

Most of the participants indicated that they thought the counting task was difficult, and several indicated that they knew they had lost count during the presentation, but continued to add 2 to the number they thought was correct. Two young participants and one older participant indicated that they simply stopped counting during the task. To ensure that participants who did not perform the divided attention task correctly were not included in the sample, we replaced anyone who missed the correct count by more than 100. Of the remaining participants, 10 of the 36 younger adults and 6 of the 36 older adults reported the correct total. Altogether, 94% of the young participants (34) and 100% of the older participants (36) reported a final value that missed the actual total by 50 or less.

Intelligence Measures

To assess the degree of consistency in the intelligence measures across the six Age × Attention × Test Type conditions, a multivariate analysis of variance (MANOVA) was conducted on WAIS-R (Wechsler, 1981) Information, Vocabulary, Backward Digit Span, and Digit Symbol scores. These data are presented in Table 1. Age was the only significant main effect, $F(5,132) = 57.25$ (all others, $F < 1.00$). Follow-up univariate tests of the age effect indicated that young participants' scores were higher than older participants' scores on the Backward Digit Span, $F(1,136) = 6.02$, $MSe = 3.74$, $\eta^2 = .04$, and Digit Symbol, $F(1,136) = 163.41$, $MSe = 131.64$, $\eta^2 = .55$, subtests, but older participants' scores were higher than young participants' scores on the Vocabulary, $F(1,136) = 43.40$, $MSe = 55.33$, $\eta^2 = .24$ and Information, $F(1,136) = 27.03$, $MSe = 14.92$, $\eta^2 = .17$, subtests.

The only significant interaction effect was that between age and attention, $F(5,132) = 6.32$ (all others, $F < 1.00$). Follow-up univariate tests for each individual difference variable indicated that this interaction occurred for Vocabulary, $F(1,136) = 15.20$, $MSe = 55.33$, $\eta^2 = .10$, Information, $F(1,136) = 14.91$, $MSe = 14.92$, $\eta^2 = .10$, and Digit Symbol scores, $F(1,136) = 4.87$, $MSe = 131.64$, $\eta^2 = .03$. In each case, older adults in the divided attention condition performed better than older adults in the focused attention condition, whereas young adults in the focused attention condition performed similar to or somewhat better than young adults in the divided attention condition (see Appendix, Note 1).

Older adults typically outperform young adults on measures of crystallized intelligence that reflect the use of well-learned, general knowledge (e.g., Vocabulary and Information); however, they perform more poorly than young adults on measures of fluid intelligence that reflect speed of processing and the operation of working memory (e.g., Digit Symbol and Digit Span, respectively). Our findings are consistent with these typical age-related differences in intelligence measures. Interestingly, prior research has shown that measures of both crystallized and fluid intelligence covary with frequency discrimination performance for young adults, but not for older adults (Kausler & Puckett, 1980). We therefore examined the correlations between our participants' WAIS-R (Wechsler, 1981) subtest scores and their performance on the frequency discrimination and estimation tests. Further details concerning these analyses are provided in the sections below.

Frequency Discrimination

Frequency discrimination performance was evaluated using the proportions of correct responses for each of the three frequency difference conditions (see Appendix, Note 2). For each participant, the proportion correct for the Frequency Difference 1 condition was computed by averaging the scores for target word pairs with presentation frequencies of 0:1, 1:2, 2:3, and 3:4; for the Frequency Difference 2 condition, it was computed by averaging the scores of pairs with frequencies of 0:2, 1:3, 2:4, and 3:5; and for the Frequency Difference 3 condition, it was computed by averaging the scores of pairs with frequencies of 0:3, 1:4, 2:5, and 3:6. The mean proportions of correct responses partitioned by age, attention, and frequency difference are shown in Table 2.

A 2 (Age) × 2 (Attention) × 3 (Frequency Difference) ANOVA revealed that although older participants were somewhat less accurate than young participants in discriminating the frequencies of items in the test pairs, this difference was not significant, $F(1,68) = 2.35$, $MSe = .05$, $\eta^2 = .03$. Discrimination accuracy was lower in the divided attention condition than in the focused attention condition, $F(1,68) = 12.04$, $MSe = .05$, $\eta^2 = .15$, and the extent of the decline in performance associated with divided attention was similar for participants in both age groups, $F(1,68) < 1.00$, $MSe = .05$, $\eta^2 = .00$. Discrimination accuracy increased as frequency difference increased, $F(2,136) = 15.90$, $MSe = .02$, $\eta^2 = .19$, and this effect did not vary as a function of age or attention (all tests, $F < 1.00$).

Correlations between average proportion correct and the various intelligence measures collapsed across the two attention conditions are presented in Table 3. The young participants' frequency discrimination performance was positively correlated with WAIS-R (Wechsler, 1981) Information and Vocabulary scores. Thus, for young adults, higher scores on the tests of general knowledge were associated with better frequency discrimination performance. However, there were no significant correlations between the older participants' judgment performance and any of the intelligence measures. These findings partially replicate those reported by Kausler and Puckett (1980). When the Vocabulary score was entered as a covariate in a 2 (Age) × 2 (Attention) × 3 (Frequency Difference) ANCOVA, there was no change in the pattern of results. However, when the Information score was entered as a covariate, a main effect of age emerged, $F(1,67) = 4.41$, $MSe = .05$, $\eta^2 = .04$. Evidently, overall frequency discrimination accuracy was mediated by factors related to the participants' level of general knowledge. When age-related variance associated with this measure was controlled (i.e., the young adults' disadvantage was eliminated), an age difference was revealed.

Table 2. Mean Proportions Correct in Frequency Discrimination

	Frequency Difference			
	One	Two	Three	*M*
Divided Attention				
Young	.59 (.18)	.68 (.18)	.74 (.14)	.67
Older	.56 (.22)	.60 (.15)	.69 (.19)	.62
M	.58	.64	.71	
Focused Attention				
Young	.65 (.16)	.81 (.13)	.83 (.15)	.77
Older	.65 (.26)	.75 (.17)	.78 (.18)	.73
M	.65	.78	.81	

Note: Standard deviations are in parentheses.

Table 3. Correlations Between Frequency Test Measures and Intelligence Scores

	Vocabulary[a]	Information[a]	Digit Span[a,b]	Digit Symbol[a]
	Frequency Discrimination-Average Proportion Correct			
Young	.43**	.57**	.01	−.04
Older	−.23	−.16	−.06	−.13
	Frequency Estimation-Average Unsigned Deviation			
Young	−.34*	−.14	−.39*	.09
Older	.14	.22	−.42**	−.16
	Frequency Estimation-Slope			
Young	.34*	.12	.41**	.03
Older	−.13	−.15	.37*	.13
	Frequency Estimation-Rank-Order Correlation			
Young	.30	.08	.37*	.06
Older	−.13	−.19	.29	.08

Note: Average proportion correct is proportion correct collapsed across the three levels of frequency difference; average unsigned deviation is unsigned deviation collapsed across the seven levels of actual frequency.

[a]Subtests of the WAIS-R (Wechsler, 1981).

[b]Backward Digit Span only.

*$p < .05$; **$p < .01$.

Frequency Estimation

Analyses were performed on three measures computed from each participant's estimation data (see Brown, 1995, for further description of these measures). The mean unsigned deviation of estimated frequency from presentation frequency (i.e., |Estimated – Presentation Frequency|) for each level of presentation frequency provided information on the degree of overall error in the participant's estimates. The slope of the line relating estimated frequency to presentation frequency provided a measure of whether errors were due to the tendency to overestimate or underestimate event frequencies. And finally, the rank-order correlation between estimated frequency and presentation frequency measured the level of relative accuracy in estimation, that is, how sensitive the participant's estimates were to differences in presentation frequency irrespective of errors in response magnitude. Mean estimated frequency by presentation frequency for the four Age × Attention conditions is shown in Figure 1; mean unsigned deviations are shown in Table 4, and mean slopes and rank-order correlations for these four conditions are shown in Table 5.

Unsigned deviation. — Older participants' frequency estimations for study list items deviated more from presentation frequency than did young participants' estimations, $F(1,68) = 5.18$, $MSe = .78$, $\eta^2 = .07$, reflecting estimation errors of greater magnitude for older participants. In addition, differences in the magnitude of estimation error for the two age groups were greatest at the higher frequencies, $F(6,408) = 2.91$, $MSe = .43$, $\eta^2 = .04$. Divided attention during encoding produced higher levels of error than did focused attention, $F(1,68) = 22.92$, $MSe = .78$, $\eta^2 = .25$, and the magnitude of estimation error increased as presentation frequency increased, $F(6,408) = 110.49$, $MSe = .43$, $\eta^2 = .62$. The increase in error associated with presentation frequency was greater for participants in the divided attention condition than for those in the focused attention condition, $F(6,408) = 3.51$, $MSe = .43$, $\eta^2 = .05$. However, increasing age did not enhance the detrimental effects of attention on estimation error (all tests, $F < 1.00$).

Correlations between average unsigned deviation (mean unsigned deviation collapsed across presentation frequency) and intelligence scores collapsed across the two attention conditions are presented in Table 3. There was a significant negative correlation between average unsigned deviation and Vocabulary for the young participants, and there were significant negative correlations between average unsigned deviation and Backward Digit Span for both age groups. Entering Vocabulary as a covariate in a 2 (Age) × 2 (Attention) × 7 (Presentation Frequency) ANCOVA for the unsigned deviation scores did not change the original pattern of findings, but

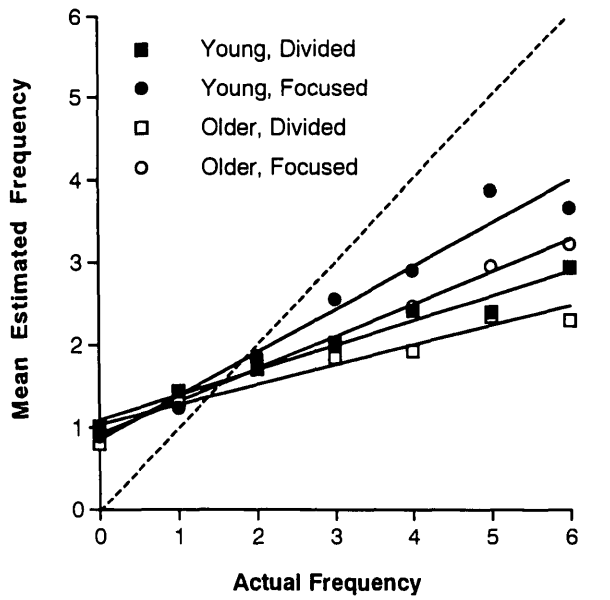

Figure 1. Mean estimated frequencies for young and older participants in the divided and focused attention conditions. Solid lines represent the best linear fit for the means, and the dashed line represents accurate frequency estimation.

Table 4. Mean Unsigned Deviations for Frequency Estimation at Each Level of Actual Frequency

	Young	Older	*M*
Divided Attention			
Zero	1.00 (.62)	.80 (.63)	.90
One	.99 (.50)	.92 (.44)	.95
Two	1.05 (.33)	1.19 (.27)	1.12
Three	1.43 (.33)	1.51 (.45)	1.47
Four	1.77 (.48)	2.31 (.54)	2.04
Five	2.57 (.75)	2.74 (.90)	2.65
Six	3.11 (1.16)	3.69 (1.35)	3.40
M	1.70	1.88	
Focused Attention			
Zero	.79 (.65)	.72 (.42)	.75
One	.83 (.43)	.84 (.48)	.83
Two	.98 (.48)	.87 (.35)	.92
Three	1.23 (.39)	1.24 (.30)	1.23
Four	1.55 (.56)	1.77 (.40)	1.66
Five	1.57 (.71)	2.32 (.74)	1.94
Six	2.33 (1.31)	2.79 (1.33)	2.56
M	1.33	1.51	

Note: Standard deviations are in parentheses.

Table 5. Mean Slopes and Rank-Order Correlations for Frequency Estimation

	Young	Older	*M*
Slope			
Divided attention	.32 (.15)	.25 (.16)	.28
Focused attention	.56 (.22)	.40 (.17)	.48
M	.44	.32	
Rank-Order Correlation			
Divided attention	.41 (.16)	.36 (.15)	.38
Focused attention	.58 (.18)	.52 (.14)	.55
M	.49	.44	

Note: Standard deviations are in parentheses.

entering Backward Digit Span as a covariate reduced the age difference observed in the original analysis, $F(1,67) = 2.27$, $MSe = .09$, $\eta^2 = .03$. Thus, factors related to performance on this test of working memory mediated errors in frequency estimation. Higher Backward Digit Span scores were associated with lower estimation errors, and statistically eliminating the age-related variance associated with this measure reduced age differences in estimation error.

Slope. — The mean frequency estimates shown in Figure 1 indicate that participants underestimated presentation frequency regardless of age or attentional condition. This tendency to underestimate frequency is also reflected by mean slope scores for the four conditions that were under 1.00. Older participants' slopes were lower on average than those of young participants, $F(1,68) = 7.46$, $MSe = .03$, $\eta^2 = .10$, showing that the rate of increase in estimated frequency with increasing presentation frequency was lower for older participants. This difference suggests that the age differences in overall estimation error were due to a greater tendency on the part of the older participants to underestimate frequency at the higher presentation frequencies. Across the two age groups, the rate of increase in estimated frequency was lower when attention was divided during study list presentation than when it was focused, $F(1,68) = 21.56$, $MSe = .03$, $\eta^2 = .24$, and the magnitude of underestimation following divided attention did not change with increasing age, $F(1,68) = 1.23$, $MSe = .04$, $\eta^2 = .02$.

Correlations between slope and intelligence scores collapsed across the attention conditions are presented in Table 3. There was a positive correlation between slope and Vocabulary for the young participants, as well as positive correlations between slope and Backward Digit Span for both age groups. Entering Vocabulary as a covariate in a 2 (Age) $\times$ 2 (Attention) ANCOVA did not change the original pattern of findings. However, when Backward Digit Span was entered as a covariate, the effect of age observed in the original analysis was reduced, $F(1,67) = 4.06$, $MSe = .03$, $\eta^2 = .06$. Thus, in agreement with the previous findings for the unsigned deviation data, factors related to working memory performance mediated the degree of underestimation in frequency estimation performance; that is, the higher this performance, the faster the rate of increase in frequency estimation over presentation frequency. When variance associated with differences in the two age groups on this measure was removed (i.e., young participants' advantage was eliminated), age differences in the magnitude of frequency estimations were reduced.

Rank-order correlation. — Rank-order correlations between estimated frequency and presentation frequency did not differ for the two age groups, $F(1,68) = 2.18$, $MSe = .03$, $\eta^2 = .03$, showing that young and older adults were equally sensitive to relative differences in the frequency of the target events. However, participants in the divided attention condition were less sensitive to these differences than participants in the focused attention condition, $F(1,68) = 18.68$, $MSe = .03$, $\eta^2 = .22$, and increasing age did not magnify the detrimental effect of divided attention on sensitivity to differences in presentation frequencies, $F(1,68) < 1.00$.

Correlations between rank-order correlation and intelligence scores collapsed across the attention conditions are presented in Table 3. There was a significant positive correlation between rank-order correlation scores and Backward Digit Span for the young adults, but the relationship between these two measures was only marginally significant for the older adults ($p \leq .08$). Entering Backward Digit Span as a covariate in a 2 (Age) $\times$ 2 (Attention) ANCOVA for the rank-order correlations did not change the original pattern of results. Thus, although higher Backward Digit Span scores were associated with greater sensitivity to differences in the presentation frequencies of target events, statistically removing variation associated with age-related differences in this measure of working memory had little effect on the outcome of the analysis for the frequency sensitivity measure.

Discussion

This experiment has produced four main findings that are relevant to the issue of age differences in frequency judgment. First, old age did not magnify the detrimental effect of distraction on performance for either frequency discrimination or frequency estimation. Second, there were no age differences in frequency discrimination, but older adults' frequency estimation performance was less accurate than that of young adults. Third, the pattern of effects for age and distraction varied across the different measures of frequency judgment. Specifically, distraction during encoding reduced both discrimination accuracy and the rank-order correlation between estimated frequency and presentation frequency; however, there were no age differences in these measures. On the other hand, both distraction and old age led to higher levels of overall error in frequency estimation and to a greater tendency to underestimate frequency at the higher presentation frequencies. Thus, distraction was associated with reductions in both sensitivity to relative frequency and accuracy of estimation, whereas age was associated only with reduced accuracy of estimation. Finally, for young adults, higher WAIS-R (Wechsler, 1981) Information scores were associated with better frequency discrimination, and statistically equalizing performance for the two age groups on this measure of general knowledge produced an age difference in discrimination accuracy. In contrast, for both young and older adults, higher Backward Digit span scores were associated with lower absolute error of estimation and less underestimation of frequency. Statistically equalizing the two age groups' performance on this measure of working memory reduced age differences in both absolute error and degree of underestimation.

The present results are consistent with earlier findings (e.g., Kausler et al., 1981; Maki & Ostby, 1987; Naveh-Benjamin & Jonides, 1986; Sanders et al., 1987), showing that distraction has a detrimental effect on frequency judgment performance. The finding that distraction was associated with both decreased sensitivity to relative differences in presentation frequency and increased errors from underestimation of frequency suggests that target events in this condition were encoded in a very superficial way. However, the question of greatest interest to us was whether distraction during encoding would produce greater disruption in the frequency judgments of older adults than in those of young adults.

Kausler and his colleagues (Kausler et al., 1981) found that monitoring the letter case of words studied for an expected memory or frequency test did not produce a greater degree of disruption in older adults' frequency discrimination performance. We thought that the case monitoring task might not differentially tax the attentional resources of the older participants and predicted that a more difficult cumulative addition secondary task would produce greater costs in older adults' frequency judgment. We also predicted that this effect would be stronger for frequency estimation than frequency discrimination. However, the present results offer little support for these predictions — no matter how we measured frequency judgment, divided attention during presentation did not have a differentially greater effect on older adults' performance. Our results thus support and extend the Kausler et al. (1981) findings.

Although the high cost of distraction during encoding was clear in both frequency discrimination and frequency estimation, old age was associated with a decline only in frequency estimation. Older adults had a greater magnitude of absolute error in their estimations, and their lower slopes indicated that this was due to a tendency to underestimate frequency when presentation frequency was high. Given the difficulty our older adults had in estimating how often very frequent events occurred, it is possible that they might also have shown a decline in frequency discrimination if we had tested word pairs from the upper range of frequencies requiring the most difficult discriminations (i.e., 4:5, 5:6). Although we cannot completely rule out this possibility, three pieces of evidence argue against the idea that older adults are less sensitive to relative frequency differences for very frequent events. First, Attig and Hasher (1980) compared young and older adults' frequency discrimination performance for the word pairs in question, and their results indicated that discriminating between very frequent words was equally difficult for the two groups. Second, in the present study the Weber's law function for the frequency discrimination data was the same regardless of age; i.e., discrimination accuracy decreased to a similar degree for young and older adults as the base frequency of word pairs increased and the frequency difference decreased. Finally, an age-related difference was not observed in our measure of sensitivity to relative frequency in estimation performance (i.e., the rank-order correlation between estimated and presentation frequency), despite the fact that the ordering of the frequencies for the very frequent words contributed to this measure. Therefore, in line with earlier suggestions by Hasher and her colleagues (Attig & Hasher, 1980; Hasher & Zacks, 1979), we offer the tentative conclusion that older adults are as sensitive to the relative frequencies of target events as young adults whether sensitivity is measured by frequency estimation or frequency discrimination.

If older adults remain sensitive to relative frequency differences, why do they make more absolute errors of estimation and underestimate frequency to a greater degree than young adults? Hasher & Zacks (1979) dismissed evidence of an age difference in estimation accuracy by suggesting that it simply reflects a conservative response bias. However, knowledge of the distribution of frequency values for events is as critical to the accuracy of frequency estimation as knowledge of the relative differences in frequency among these events (Brown & Siegler, 1993). Moreover, other researchers who have observed older adults' tendency to underuse the higher frequencies in their estimation (Tweedy & Vakil, 1988) have suggested that this could reflect a memory deficit. We suspect that this is so, but suggest that this deficit may be limited to either the ability to encode a distinctive trace for each repetition of an event or to the ability to retrieve each of these traces.

Before discussing possible age-related changes in memory that could lead older adults to underestimate higher event frequencies, two other factors that might be responsible for this outcome must be considered. First, it could be argued that older adults simply do not use the higher frequencies because they are less likely to acquire information on the upper endpoint of the range of these frequencies. However, even if our older participants did not learn the range of frequencies during presentation, they knew it before the estimation test because participants in both age groups were explicitly reminded that items on the test had been presented from zero to six times and that they should use this range of frequencies in making their estimations. Moreover, nearly identical numbers of young (26) and older (23) participants used the highest frequency response at least once during the estimation test. Second, it might be argued that our participants were using a counting strategy during encoding and that the older ones were more likely to lose count at the higher frequencies. Although it is possible that some participants counted occurrences it is unlikely that they were doing so because (1) they were unaware that their memory for frequency would be tested, (2) counting is a cognitively demanding activity (Hintzman, 1988; Jonides & Naveh-Benjamin, 1987), and (3) the cumulative addition task performed in the divided attention condition would effectively prevent counting. Finally, both young and older participants underestimated frequency despite the fact that they knew the range of frequencies before the test. Brown (1995) has shown that when the range of frequencies is known, underestimation is indicative of the retrieval and enumeration of individual memory traces to obtain frequency estimates.

Turning now to the age-related changes in memory that could account for our findings, we propose that, under most circumstances, older adults are proficient at encoding and retrieving the information that allows them to judge relative frequency, but they are less proficient at encoding or retrieving the information that allows them to determine the exact number of times an event occurs. It has been suggested that older adults encode events in the "same old way" from one occurrence to the next (Rabinowitz et al., 1982). Proponents of this view do not believe that older adults encode superficial or shallow representations of events (cf. Eysenck, 1974); rather, they argue that their ability to encode general semantic information is preserved, while their ability to encode a distinctive, contextually specific representation declines (Craik & Jennings, 1992). Thus, one explanation for the present findings is that there is little or no change in older adults' ability to discriminate the frequency of repeated events, because their memory for the general semantic attributes of these events remains intact; however, their ability to accurately estimate the frequency of repeated events declines because they are less likely to encode or retrieve the contextual detail that makes each repetition of these events distinctive in memory.

A considerable amount of research indicates that there is little age-related change in memory for the general semantic attributes of to-be-remembered single events (for a review, see Light, 1991). The present results are consistent with the idea that older adults also encode these attributes for repeated events effectively. As a result, information on variations in the familiarity or echo intensity of these events (i.e., Hintzman, 1988) is present in memory and can be used to evaluate relative frequency differences. On the other hand, retrieval and enumeration of each presentation of the same nominal event may ultimately depend on whether one has encoded or can retrieve enough contextual information to distinguish the various memory traces for that event (Begg et al., 1986). Any age-related decline in contextual memory would thus impair older adults' ability to estimate frequency.

Prior studies have consistently shown that older adults have disproportionately poorer memory for the temporal, spatial, and perceptual context of to-be-remembered events than for the events themselves (for reviews, see Craik & Jennings, 1992, and Light, 1991), and they are more likely to forget the source of an event rather than the event itself (e.g., McIntyre & Craik, 1987). More recent findings suggest that older adults encode nonsemantic contextual attributes, but they have difficulty retrieving this information when deliberate recollection is required (cf. Light, La Voie, Valencia-Laver, Albertson Owens, & Mead, 1992). On the other hand, memory for semantic context may remain largely intact across the life span except under difficult encoding conditions (Craik & Jennings, 1992). For example, studies of age differences in encoding specificity have indicated that older adults benefit as much as young adults from matching encoding and retrieval contexts (Park, Puglisi, Smith, & Dudley, 1987), except when attention has been divided at encoding (Puglisi, Park, Smith, & Dudley, 1988) or when target items must be integrated with weak or semantically unrelated contexts (Hess, 1984; Rabinowitz et al., 1982). In the present experiment, the unrelated words that preceded and followed target words provided only a weak semantic context for these words. Thus, our older adults may not have encoded enough semantic and nonsemantic contextual information to make the memory trace of each target word repetition distinctive. Alternatively, they may have encoded this information, but could not use it to gain access to each trace of a repeated word. Failure to encode or retrieve context would inevitably lead to difficulties in retrieving and counting these memory traces to obtain a numerical estimation of frequency (see also, Begg et al., 1986; Jonides & Naveh-Benjamin, 1987).

Our correlational data also seem to be consistent with this view. For young adults, frequency discrimination performance covaried with level of general knowledge, whereas for both young and older adults, frequency estimation accuracy covaried with working memory ability. As is commonly observed, our older adults displayed greater general knowledge than our young adults, but poorer working memory. When the difference in general knowledge for the two age groups was eliminated statistically, an age difference emerged on the frequency discrimination task. Greater general knowledge may lead to more effective semantic processing of events (Craik & Jennings, 1992), and the older adults' advantage in this area relative to young adults could serve to minimize age-related differences in frequency discrimination. This may also explain why older adults' discrimination accuracy is lower when novel, nonverbal target items are used (Wiggs, 1993; Wiggs et al, 1994, Exp. 2); when target words are thought to be irrelevant (Kausler et al., 1984); and when young adults have especially high verbal intelligence scores (Kausler et al., 1981). In each of these cases, the young adults may have processed the semantic attributes of target events more effectively or thoroughly than the older adults. In contrast to these findings, removing the age difference in working memory resulted in the reduction of age differences in frequency estimation accuracy. Although the role of working memory in encoding and retrieval is not well specified (Craik & Jennings, 1992), intact working memory may be necessary for effective encoding and retrieval of the contextual information that enhances frequency estimation performance. Interestingly, poor memory for context has also been linked to age-related declines in frontal lobe functioning (Craik, Morris, Morris, & Loewen, 1990), and a recent study by Smith (1996) has shown that individuals with frontal lobectomies perform more poorly on a frequency estimation task than normal controls. Findings such as these point to the need for further research on the relationship between frequency judgment and individual differences in basic cognitive and neuropsychological functioning.

In summary, the results of this experiment suggest that older adults process the repetitions of events in such a way that variations in the familiarity of these events are preserved, but they do not encode or are unable to retrieve enough contextual information to distinguish among the memory traces generated for each repetition. Hence, there are often no age differences in sensitivity to the relative frequencies of repeated events, but older adults are consistently less accurate at estimating the absolute number of times these events occur. One important implication of these results is that probing older adults' memories for the absolute frequency of everyday events may produce an inaccurate picture of how often these events actually occur. A more accurate representation may be obtained by structuring questions in such a way that older adults can make good use of their sensitivity to the relative frequency differences among these events.

ACKNOWLEDGMENTS

This research was supported by National Institute on Aging Grant AG-10047 and by a Western Kentucky University Summer Research Fellowship to the first author.

We thank Sue Lindsey and Emily Patterson for their assistance in data collection and analysis.

Address correspondence and requests for reprints to Sharon A. Mutter, Department of Psychology, Western Kentucky University, Bowling Green, KY 42101. E-mail: sharon.mutter@wku.edu

REFERENCES

Attig, M., & Hasher, L. (1980). The processing of frequency of occurrence information by adults. *Journal of Gerontology, 35,* 66–69.

Baddeley, A. D., & Hitch, G. (1974). Working memory. In G. H. Bower

(Ed.), *The psychology of learning and motivation* (Vol. 8, pp. 47–90). New York: Academic Press.
Begg, I., Maxwell, D., Mitterer, J. O., & Harris, G. (1986). Estimates of frequency: Attribute or attribution? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 12,* 496–508.
Brown, N. R. (1995). Estimation strategies and the judgment of frequency. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21,* 1539–1553.
Brown, N. R., & Siegler, R. S. (1993). Metrics and mappings: A framework for understanding real-world quantitative estimation. *Psychological Review, 100,* 511–534.
Craik, F. I. M., & Jennings, J. M. (1992). Human memory. In F. I. M. Craik & T. A. Salthouse (Eds.), *The handbook of aging and cognition* (pp. 51–110). Hillsdale, NJ: Erlbaum.
Craik, F. I. M., Morris, L. W., Morris, R. G., & Loewen, E. R. (1990). Aging, source amnesia, and frontal lobe functioning. *Psychology and Aging, 5,* 148-151.
di Pellegrino, G., Nichelli, P., & Faglioni, P. (1988). Frequency and recognition judgment by young and elderly adults. *Neuropsychologia, 26,* 765–768.
Ellis, N. R., Palmer, R. L., & Reeves, C. L. (1988). Developmental and intellectual differences in frequency processing. *Developmental Psychology, 24,* 38–45.
Eysenck, M. W. (1974). Age differences in incidental learning. *Developmental Psychology, 10,* 936–941.
Francis, W. N., & Kucera, H. (1982). *Frequency analysis of English usage: Lexicon and grammar.* Boston, MA: Houghton Mifflin.
Freund, J. S., & Witte, K. L. (1986). Recognition and frequency judgments in young and elderly adults. *American Journal of Psychology, 99,* 81–102.
Greene, R. L. (1986). Effects of intentionality and strategy on memory for frequency. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 12,* 489–495.
Hasher, L., & Zacks, R. T. (1979). Automatic and effortful processes in memory. *Journal of Experimental Psychology: General, 108,* 356–388.
Hess, T. M. (1984). Effects of semantically related and unrelated contexts on recognition memory of different-aged adults. *Journal of Gerontology, 39,* 444–451.
Hintzman, D. L. (1988). Judgments of frequency and recognition in a multiple-trace memory model. *Psychological Review, 95,* 528–551.
Hintzman, D. L., & Hartry, A. L. (1990). Commensurability in memory for frequency. *Journal of Memory and Language, 29,* 501–523.
Jonides, J., & Jones, C. (1992). Direct coding for frequency of occurrence. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 18,* 368–378.
Jonides, J., & Naveh-Benjamin, M. (1987). Estimating frequency of occurrence. *Journal of Experimental Psychology, 13,* 230–240.
Kausler, D. H. (1994). *Learning and memory in normal aging.* San Diego, CA: Academic Press.
Kausler, D. H., Lichty, W., & Hakami, M. K. (1984). Frequency judgments for distractor items in a short-term memory task: Instructional variation and adult age differences. *Journal of Verbal Learning and Verbal Behavior 23,* 660–668.
Kausler, D. H., & Puckett, M. (1980). Frequency judgments and correlated cognitive abilities in young and elderly adults. *Journal of Gerontology, 35,* 376–382.
Kausler, D. H., Salthouse, T. A., & Saults, J. S. (1987). Frequency-of-occurrence memory over the adult lifespan. *Experimental Aging Research 13,* 159–161.
Kausler, D. H., Wright, R. E., & Hakami, M. K. (1981). Variation in task complexity and adult age differences in frequency-of-occurrence judgments. *Bulletin of the Psychonomic Society, 18,* 195–197.
Light, L. L. (1991). Memory and aging: Four hypotheses in search of data. *Annual Review of Psychology, 42,* 333–376.
Light, L. L., La Voie, D., Valencia-Laver, D., Albertson Owens, D. A., & Mead, G. (1992). Direct and indirect measures of memory for modality in young and older adults. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 18,* 1284–1297.
Maki, R. H., & Ostby, R. S. (1987). Effects of level of processing and rehearsal on frequency judgments. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 13,* 151–163.
McIntyre, J. S., & Craik, F. I. M. (1987). Age differences in memory for item and source information. *Canadian Journal of Psychology, 41,* 175–192.
Naveh-Benjamin, M., & Jonides, J. (1986). On the automaticity of frequency coding: Effects of competing task load, encoding strategy, and intention. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 12,* 378–386.
Park, D. C., Puglisi, J. T., Smith, A. D., & Dudley, W. N. (1987). Cue utilization and encoding specificity in picture recognition by older adults. *Journal of Gerontology, 42,* 423–425.
Puglisi, J. T., Park, D. C., Smith, A. D., & Dudley, W. N. (1988). Age difference in encoding specificity. *Journal of Gerontology: Psychological Sciences, 43,* P145–P150.
Rabinowitz, J. C., Craik, F. I. M., & Ackerman, B. P. (1982). A processing resource account of age differences in recall. *Canadian Journal of Psychology, 36,* 325–344.
Sanders, R. E., Gonzalez, E. G., Murphy, M. D., Liddle, C. L., & Vitina, J. R. (1987). Frequency of occurrence and the criteria for automatic processing. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 13,* 241–250.
Sanders, R. E., Wise, J. L., Liddle, C. L, & Murphy, M. D. (1990). Adult age comparisons in the processing of event frequency information. *Psychology and Aging, 5,* 172–177.
Smith, M. L. (1996). Recall of frequency of occurrence of self-generated and examiner-provided words after frontal lobectomy. *Neuropsychologia, 34,* 553–563.
Tweedy, J. R., & Vakil, E. (1988). Evaluating evidence for automaticity in frequency of occurrence judgments: A bias for bias? *Journal of Clinical and Experimental Neuropsychology, 10,* 664–674.
Warren, L. R., & Mitchell, S. A. (1980). Age differences in judging the frequency of events. *Developmental Psychology, 16,* 116–120.
Wechsler, D. (1981). *A manual for the Wechsler Adult Intelligence Scale–Revised.* New York: Psychological Corp.
Wiggs, C. L. (1993). Aging and memory for frequency of occurrence of novel, visual stimuli: Direct and indirect measures. *Psychology and Aging, 8,* 400–410.
Wiggs, C. L., Martin, A., & Howard, D. V. (1994). Direct and indirect measures of frequency monitoring in young and elderly adults. *Aging and Cognition, 1,* 247–259.

Received August 5, 1996
Accepted May 19, 1997

Appendix

Notes

1. The relatively higher intelligence scores of older adults assigned to the divided attention condition raised two issues of concern. First, we wondered whether eliminating older participants who did not perform the divided attention task correctly might have inadvertently led to the elimination of individuals with lower intellectual ability from this condition. We found, however, that the mean WAIS-R scores of the eliminated participants were almost identical to those left in the sample. Our second concern was that this pattern of results for the intelligence scores would compromise the outcomes of the tests of the Age × Attention interaction in our frequency discrimination and estimation data. However, this did not happen — the reported outcomes of these tests remained unchanged after we reanalyzed both sets of data using ANCOVA with the intelligence measures as covariates.

2. A 2 (Age) × 2 (Attention) × 3 (Base Frequency) × 3 (Frequency Difference) ANOVA performed on the full set of 24 discrimination accuracy scores indicated that these data conform to what would be predicted by Weber's Law. Specifically, discrimination accuracy decreased as base frequency increased, $F(3,204) = 9.22$, $MSe = .09$, $\eta^2 = .12$, and increased as frequency difference increased, $F(2,136) = 15.94$, $MSe = .10$, $\eta^2 = .19$. There was no interaction between base frequency and frequency difference, nor were there any interactions between these two variables and age or attention (all $Fs \leq 1.50$). Thus, the Weber's Law function for these data was the same regardless of age or attention.