

# Age effects on duration discrimination with simple and complex stimuli

Peter J. Fitzgibbons

Gallaudet University, Center for Auditory and Speech Sciences, 800 Florida Avenue NE,  
Washington, DC 20002

Sandra Gordon-Salant

University of Maryland, Department of Hearing and Speech Sciences, College Park, Maryland 20742

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This study examined age-related changes in temporal processing by measuring DLs for signal duration using simple and complex stimuli. Previous research has shown that elderly listeners exhibit difficulty discriminating duration changes in simple sounds, suggesting the possibility of age-related changes in central timing mechanisms. The present experiments examined the interactive effects of aging, hearing loss, and stimulus complexity on duration discrimination. Four groups participated: young and elderly listeners with normal hearing, and young and elderly listeners with hearing loss. Duration DLs were measured for 250-ms tone bursts and for silent gaps between tone bursts that were presented either in isolation or embedded as target stimuli within tonal sequences. The tone sequences were composed of five sequential 250-ms components. Stimulus complexity was varied by changing the sequential order of tone frequencies and the location of an embedded target component across listening conditions. Analyses of results revealed the following: Elderly listeners performed more poorly than younger listeners in nearly all stimulus conditions, the effects of stimulus complexity on discrimination were greatest among elderly listeners, and hearing loss had no systematic effect on discrimination performance. © 1995 Acoustical Society of America.

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## INTRODUCTION

This paper describes studies that compared the abilities of young and elderly listeners to discriminate temporal aspects of simple and complex tonal patterns. In recent years several research reports have indicated that elderly listeners may have diminished auditory temporal processing capacity. The evidence for this conclusion comes from different recognition experiments that utilized various forms of temporally degraded speech (Harris and Reitz, 1985; Helfer and Wilber, 1990; Gordon-Salant and Fitzgibbons, 1993), and other tasks that examined listeners' ability to process the order of sounds presented in a rapid temporal sequence (Trainor and Trehub, 1989; Humes and Christopherson, 1991). In addition, measures of backward recognition masking suggest that the speed of perceptual processing may be compromised in elderly listeners (Newman and Spitzer, 1983; Raz *et al.*, 1990; Phillips *et al.*, 1994). By contrast, some basic psychoacoustic estimates of temporal sensitivity measured with simple sounds that involve either the discrimination of amplitude modulation in noise bursts (Takahashi and Bacon, 1992) or the detection of brief temporal gaps in noise and tone bursts (Lutman, 1991; Moore *et al.*, 1992) have not always shown consistent deficits in temporal processing among elderly listeners. Comparisons among these few reports suggest that stimulus complexity and perceptual processing demands are important factors that influence the extent of age-related deficits observed in temporal processing tasks.

The focus of the present investigation was to examine

the effects of listener age and stimulus complexity on measures of temporal sensitivity that involve discrimination of duration increments in tone bursts or silent intervals between tone bursts. Duration discrimination was examined because the perceptual coding of stimulus duration is generally believed to occur within the central nervous system (Creelman, 1962; Abel, 1972a), which is presumed to be the predominant locus of age-related dysfunction and slowed auditory processing (Birren *et al.*, 1980; Salthouse, 1985). Additionally, some recent findings (Fitzgibbons and Gordon-Salant, 1994) reveal that many elderly listeners experience difficulty discriminating changes in the duration of simple tone bursts or silent intervals between pairs of tonal markers. Data collected in this previous study also revealed that hearing loss had little or no influence on discrimination performance for stimuli that were clearly audible. Similar conclusions regarding the effects of age and hearing loss on duration discrimination were reported by Abel *et al.* (1990) for data collected with narrow-band noise bursts. These results for simple sounds may be indicative of diminished accuracy in central timing mechanisms, but it is not clear how the findings generalize to the processing of more complex temporal patterns that describe sounds such as speech or music.

Examination of questions about stimulus complexity is motivated in part by previous discrimination studies conducted with young normal-hearing listeners using a variety of complex tonal sequences (Watson and Kelly, 1981; Watson and Foyle, 1985; Espinoza-Varas and Watson, 1986). Results of these experiments demonstrated that discrimination

TABLE I. Mean pure-tone thresholds and standard deviations (in parentheses) in dB HL for the four subjects groups (YNH=young normal hearing; YHI=young hearing impaired; ENH=elderly normal hearing; EHI=elderly hearing impaired).

Group	Frequency (Hz)				
	250	500	1000	2000	4000
YNH	4.4 (3.9)	1.7 (2.5)	2.2 (4.4)	1.7 (2.5)	5.6 (4.6)
YHI	27.2 (15.4)	32.2 (19.4)	38.3 (18.9)	44.4 (19.4)	56.1 (11.1)
ENH	7.5 (4.6)	7.5 (5.6)	7.0 (7.1)	7.0 (4.6)	13.5 (3.2)
EHI	24.0 (9.7)	25.5 (11.7)	28.5 (13.8)	39.0 (10.8)	52.0 (11.6)

accuracy with complex stimuli can be considerably poorer than that measured for simple sounds presented in isolation. These investigations also revealed that discrimination performance with complex stimuli is influenced strongly by several nonsensory factors, including listener training, degree of stimulus complexity, and listener familiarity and uncertainty regarding stimulus characteristics. The influence of these factors, which presumably reflect central processing limitations, has not been examined in discrimination tasks with elderly listeners. It is anticipated that stimulus complexity effects would be more pronounced in elderly listeners, who are reported to exhibit varying degrees of central processing deficits (Otto and McCandless, 1982; Jerger *et al.*, 1989; Willott, 1991).

The specific goal of the present investigation is to compare duration discrimination performance of young and elderly listeners for stimuli presented in isolation and embedded as components of sequential tonal patterns. Because hearing loss is prevalent among many elderly listeners, another purpose of the experiments is to examine the independent and interactive effects of age and hearing loss in each of several discrimination conditions. This was accomplished by examining groups of listeners who were matched according to age and degree of hearing loss. Testing was also restricted to a high-frequency range that was selected to coincide with regions of maximal hearing threshold elevation in listeners with hearing loss. Duration difference limens (DLs) were measured for tone bursts and silent gaps between tone bursts. Measurement of the DLs for both tones and gaps was conducted because preliminary testing indicated that the two stimulus types may present different levels of difficulty for the simple and complex signal conditions.

## I. METHOD

### A. Subjects

Listeners in the experiments included 40 subjects assigned to four groups with 10 subjects each defined according to age and hearing status. Group 1 included elderly listeners (65–76 years) with normal hearing (pure-tone thresholds  $\leq 15$  dB HL, *re*: ANSI, 1989, 250–4000 Hz). Group 2 consisted of young listeners (20–40 years) with

normal hearing (pure-tone thresholds  $\leq 15$  dB HL, *re*: ANSI, 1989, 250–4000 Hz). Group 3 consisted of elderly listeners (65–76 years) with mild-to-moderate, sloping sensorineural hearing losses. These subjects had a negative history for otologic disease, noise exposure, familial hearing loss, and ototoxicity. The presumed etiology of hearing loss for these subjects was presbycusis. Group 4 included young subjects (20–40 years) with mild-to-moderate, sloping sensorineural hearing losses of hereditary or unknown origin. Each subject in group 4 was matched audiologically to a subject in group 3. Audiometric data for the four subject groups are displayed in Table I. Additionally, each subject had normal tympanograms and acoustic reflex thresholds bilaterally, indicating normal middle-ear function. Each subject also exhibited good general health and passed the Short Portable Mental Status Questionnaire (Pfeiffer, 1975), a screening procedure for cognitive function.

### B. Stimuli

All tonal stimuli for experiments were generated using inverse FFT procedures with a digital signal processing board (Tucker-Davis Technologies AP2) and a 16-bit D/A converter (Tucker Davis Technologies DD1, 20-kHz sampling rate) that was followed by low-pass filtering (Frequency Devices 901F; 6000-Hz cutoff, 90 dB/oct). Tonal duration DLs were measured using a 4-kHz tone burst with a reference duration of 250 ms that included a 240-ms steady-state portion and 5-ms cosine-squared rise–fall envelopes. Gap duration DLs were measured for a reference silent interval of 250 ms inserted between a pair of 250-ms 4-kHz tone bursts. These DLs for the tones and gaps served as baseline performance measures for target stimuli presented in isolation.

The complex stimuli were tone sequences that had an overall duration of 1.25 s and were constructed of five contiguous 250-ms components, each with 5-ms rise–fall characteristics. One component of each tone sequence had a frequency of 4 kHz and served as the embedded target stimulus in conditions that measured tone duration DLs. For other conditions that measured duration DLs for an embedded gap, the 4-kHz tonal component of each sequence was replaced by a silent interval of equal duration. The nontarget tonal

components in each sequence had frequencies that differed across test conditions, with specific values selected from a range of approximately one-third octave centered geometrically about 4 kHz. The frequency range was restricted to insure that tonal components did not span regions of markedly different threshold elevation in the listeners with hearing loss.

Three levels of stimulus complexity with the tone sequences defined the discrimination conditions for the DL measurements with embedded tones or gaps. One condition featured minimal stimulus complexity in which a single tone sequence (3770, 3570, 4000, 4480, 4240 Hz) was arbitrarily selected and presented on each discrimination trial, with the embedded 4-kHz target tone (or gap) always fixed in the third (middle) sequence location. A second condition featured greater stimulus complexity by presenting a different tone sequence on each discrimination trial. For this condition the embedded target component (tone or gap) was also fixed in the third sequence location, but the order of the nontarget components in the range 3570–4480 Hz was randomized across listening trials. The third condition also featured a different random sequence on each trial, but additionally allowed the embedded target component to occur with equal probability in the second, third, or fourth sequence location on each trial.

## C. Procedure

The measurement of duration DLs in each condition was obtained using an adaptive two-interval forced-choice (2IFC) procedure. Each listening trial contained two observation intervals with an interobservation interval of 750 ms. One interval contained the reference 250-ms target stimulus (tone or gap), and the other randomly selected interval contained the corresponding comparison target stimulus that was longer and variable in duration. For conditions with tonal sequences, the reference and comparison sequences of a given listening trial were always identical, except for the longer duration of the embedded target component in the comparison sequence. Additionally, for each condition of stimulus complexity, the subjects were informed about the nature of stimulus variability and the possible sequence locations of the embedded target component. The subjects used a computer keyboard to respond to the trial interval containing the longer target component. The listening intervals of each trial were marked by a visual display that also provided correct-interval feedback to the subjects.

Estimates of all duration DLs were obtained using an adaptive rule for varying the duration of the target stimulus according to the subject's responses on previous trials. The rule stipulated a decrease in target duration following two consecutive correct response trials and an increase in target duration following each incorrect response. The tracking procedure estimated a threshold duration corresponding to 70.7% correct discrimination (Levitt, 1971). Testing was conducted in 65-trial blocks using an initial step size for duration changes of 15 ms that shifted to 2 ms after three reversals in direction for changes in target duration. A threshold estimate was calculated by averaging values of the reversal points associated with the small step-size changes in the

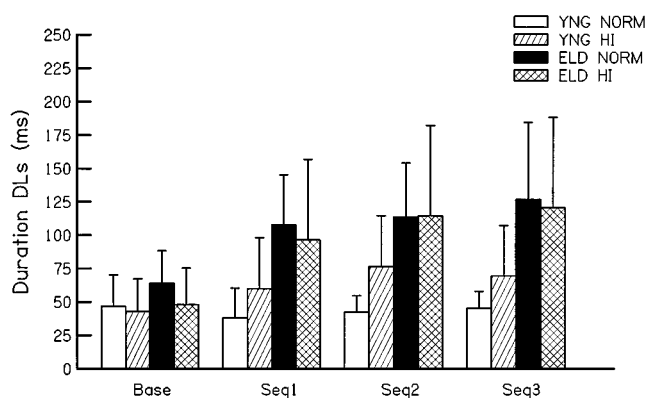


FIG. 1. Duration discrimination of 4-kHz tonal stimuli by four subject groups (young normal-hearing listeners, young hearing-impaired listeners, elderly normal-hearing listeners, and elderly hearing-impaired listeners) in four conditions (BASE=tones in isolation, SEQ1=target tone embedded in a fixed tonal sequence, SEQ2=target tone embedded in a tonal sequence with random frequencies and fixed target location, SEQ3=target tone embedded in a tonal sequence with random frequencies and random target location).

tracking procedure. An average of six threshold estimates was used to determine the duration DL for each subject and condition.

Prior to data collection, each subject received 2 to 3 h of practice in each of the eight discrimination conditions. For most subjects, no significant changes in discrimination performance were observed after five to six trial blocks. A few subjects required up to ten practice blocks before stable performance was observed, but there were no observable differences in the training required of young and elderly subjects.

The subjects were tested individually in a sound-treated booth. The eight discrimination conditions (two baseline measures with simple stimuli and six measures with complex sequences) were tested in a different random order for each subject. Stimulus levels were fixed at 85 dB SPL in order to provide adequate audibility and provide a minimum sensation level of 25–30 dB at 4000 Hz for the listeners with hearing loss. Testing was monaural through an insert earphone (Etymotic ER-3A) that was calibrated in a 2-cm<sup>3</sup> coupler (B&K, DB 0138). Listening was conducted in 2-h sessions at 1-week intervals. Total test time (not including practice sessions) varied across subjects, but averaged approximately 12 h. The subjects were reimbursed for their participation in the experiments.

## II. RESULTS

An initial analysis of variance (ANOVA) conducted on the data from all conditions revealed that the magnitude of the duration DLs for gaps was considerably greater than corresponding DL values for the 4-kHz tones [ $F(1,36)=48.53$ ,  $p<0.01$ ], although there was a significant interaction between gap and sequence effects [ $F(3,108)=3.94$ ,  $p<0.01$ ]. To simplify the examination of age effects, the data were examined separately for the conditions involving the measurement of DLs for tones and gaps. The duration DLs of tones for each condition and group of listeners are presented in Fig. 1. The figure shows group means of the DLs in ms for

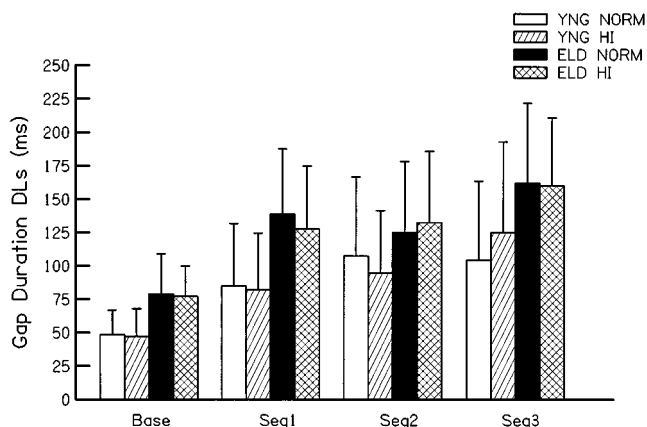


FIG. 2. Gap duration discrimination by four subject groups (young normal-hearing listeners, young hearing-impaired listeners, elderly normal-hearing listeners, and elderly hearing-impaired listeners) in four conditions (BASE=silent interval bounded by two tones, SEQ1=gap embedded in a fixed tonal sequence, SEQ2=gap embedded in a tonal sequence with random frequencies and fixed target location, SEQ3=gap embedded in a tonal sequence with random frequencies and random target location).

the baseline condition (BASE) and the three conditions with tone sequences. These are designated as SEQ1 for the fixed sequences, SEQ2 for the sequences with variable tone order and fixed target location, and SEQ3 for the sequences with variable tone order and random target location.

An ANOVA was performed on the raw data for the tone duration DLs using a repeated-measures design with two between-subjects factors (age and hearing status) and one within-subjects factor (stimulus condition). The ANOVA results revealed significant main effects of stimulus condition [ $F(3,108)=20.14$ ,  $p<0.01$ ] and listener age [ $F(1,36)=18.01$ ,  $p<0.01$ ], and a significant interaction between these two factors [ $F(3,108)=9.03$ ,  $p<0.01$ ]. Subsequent analysis of simple main effects revealed that the duration DLs of the elderly subjects were significantly larger than those of the younger subjects for each of the conditions with complex tone sequences [SEQ1:  $F(1,144)=16.04$ ,  $p<0.01$ ; SEQ2:  $F(1,144)=25.01$ ,  $p<0.01$ ; SEQ3:  $F(1,144)=23.55$ ,  $p<0.01$ ], but not for the baseline condition with the isolated target tone. The duration DLs of the young subjects showed no significant differences across stimulus conditions, but the discrimination performance of the elderly listeners was influenced by stimulus condition [ $F(3,108)=25.10$ ,  $p<0.01$ ]. For these older listeners, a multiple-comparisons analysis (Student–Newman–Keuls) revealed that the duration DLs measured for all tone-sequence conditions were significantly larger than the baseline DLs for isolated tones ( $p<0.05$ ). Although performance differences across the tone-sequence conditions were apparent, these differences failed to reach statistical significance. None of the data analyses revealed significant effects of hearing loss on the duration DLs for young or elderly listeners.

Figure 2 displays the group means for the duration DLs for gaps in each stimulus condition and group of listeners. An ANOVA with the same repeated-measures design was conducted on the raw data for these results. This analysis revealed significant main effects of listener age [ $F(1,36)$

$=10.46$ ,  $p<0.01$ ] and stimulus condition [ $F(3,108)=34.79$ ,  $p<0.01$ ], with no significant effect of hearing loss. There were no significant interactions in this analysis. Multiple-comparisons analysis of the combined data for young and elderly subjects revealed significantly larger duration DLs for all tone-sequence conditions, relative to the baseline values ( $p<0.05$ ). This analysis also indicated that the gap duration DLs for the fixed tone sequences (SEQ1) were smaller than those for the two tone-sequence conditions featuring greater stimulus complexity (SEQ2 and SEQ3) ( $p<0.05$ ). These latter two conditions produced similar results.

### III. DISCUSSION

Results of the discrimination testing indicated performance differences among listeners that differed primarily by age. The discrimination abilities of individual subjects within groups varied considerably, but with a few exceptions for young listeners performance variability was relatively uniform across subject groups for most conditions. The observation of individual differences in duration discrimination is not uncommon and is apparent in the results of studies that examined large groups of minimally trained listeners (Tyler *et al.*, 1982; Abel *et al.*, 1990) and small numbers of extensively trained listeners (Divenyi and Sachs, 1978).

#### A. Baseline measures

For the target stimuli presented in isolation, values of the duration DLs for tones and gaps for the young listeners with normal hearing were equivalent (46.8 and 48.5 ms, respectively), yielding an average Weber fraction of 0.19 for the 250-ms reference durations. Nearly identical results were also observed for the young subjects with hearing loss, who produced an average Weber fraction of 0.18 for the same conditions. The performance of these young subjects was virtually the same as observed previously for tone and gap duration DLs of young listeners for the same reference stimulus durations (Fitzgibbons and Gordon-Salant, 1994). These baseline measures also agree closely with other discrimination data reported for tone and noise signals (Creelman, 1962; Small and Campbell, 1962) or silent gaps (Abel, 1972b), where Weber fractions for duration DLs converge on a value of about 0.2 for reference durations similar in magnitude to that used in this study.

The discrimination performance of the elderly subjects in the baseline conditions was generally poorer than that of the younger listeners. This was particularly the case for gap discrimination, which revealed a Weber fraction of 0.31, a value that was about 65% larger than that observed for the younger listeners. The baseline DLs for tones of these older subjects were mixed, with about one-half of the listeners (mostly from the hearing-loss group) performing like the young listeners, and the other half giving poorer results equivalent to those observed for duration DLs of gaps. Thus most, but not all, of these baseline results are consistent with our earlier reported findings that showed age-related deficits in duration DLs for both tones and gaps. Although many of the smaller tone duration DLs in the present baseline data came from the group of elderly subjects with hearing loss, it is doubtful that sensitivity loss *per se* was a contributing

factor. No consistent effects of hearing loss were observed for most of the data collected from the young and elderly listeners. The results also showed no general differences between duration DLs for tones and gaps for most of the subjects. This outcome differed from the anticipated finding of relatively poorer duration discrimination for gaps compared to tones (Abel, 1972b). However, a different finding emerged for measurements collected with the more complex tone sequences.

## B. Tonal sequences

The duration DLs measured for target stimuli that were embedded as components of the tone sequences revealed some interesting findings, as well as some unexpected trends. The most pronounced of the unexpected outcomes was the relative difficulty of gap duration discrimination. Generally, the DLs for gaps measured with the complex signals averaged 30%–50% larger than corresponding DLs for embedded tones. Although this trend was not evident in the baseline data, it was characteristic of each group of listeners for the complex tone sequences. The effects of stimulus complexity with the tone sequences also differed for the discrimination of embedded tones and gaps.

### 1. Tone discrimination

Discrimination results for tones embedded in sequences differed for young and elderly listeners. For the young subjects, duration DLs were essentially the same in each tone-sequence condition, with values equivalent to those of the baseline condition for isolated tonal stimuli. This outcome was most evident for the young listeners with normal-hearing sensitivity, who produced nearly identical DLs in all conditions, as shown in Fig. 1. The performance of young subjects with hearing loss was somewhat poorer, but these results were also more variable and did not reach a difference of statistical significance. For the elderly listeners the DLs for embedded tones were also equivalent across tone-sequence conditions, but for these data an average Weber fraction of 0.45 reflects a value twice that of the baseline condition, as well as all values calculated for the younger listeners. Thus the older subjects perceived changes in the duration of embedded tones with much greater difficulty than younger listeners. However, like the younger subjects, the elderly listeners did not appear to be differentially affected by variations in stimulus complexity across the tone-sequence conditions.

### 2. Gap discrimination

The duration DLs for embedded gaps were distinguished by their relatively larger values and the changes in magnitude across stimulus conditions. As Fig. 2 shows, the DLs of the elderly listeners were larger than those for the younger listeners in all conditions. The Weber fractions calculated for these older subjects ranged from 0.52 to 0.64 across the tone-sequence conditions. The young subjects also showed elevated DL values, with Weber fractions changing from 0.33 to 0.45 across the tone-sequence conditions. Analysis of data collapsed across subject groups indicated better discrimination performance in the low complexity condition (SEQ1),

relative to the higher complexity sequences. However, this result pertains more to the performance of the young subjects; the older listeners generally found each condition of stimulus complexity to be equivalent in difficulty.

## C. Stimulus complexity effects

The findings generally show that elderly listeners have poorer duration discrimination ability than younger listeners. The performance of elderly listeners also exhibited the greatest effects of stimulus complexity, as evidenced by the magnitude of shifts in DLs from baseline conditions to those with the tonal sequences. This was particularly apparent for the DL shifts associated with embedded tones, which showed minimal effects of stimulus complexity for young listeners and significant effects for the older subjects. For gap discrimination within tone sequences, performance shifts from baseline were substantial for young and elderly listeners, but these, too, were generally greater for the older subjects.

Thus elderly listeners experienced the effects of stimulus complexity for tone and gap discrimination, while the young listeners exhibited similar effects for gap discrimination only. The explanation for this result is not readily apparent. However, it appears from listeners' comments that discrimination of duration changes in embedded tonal components was an easier task than that required for gap discrimination. The reason for this is simply that changes in the durations of embedded tones produced strong perceptual changes in the rhythm of tonal sequences, which could serve as a basis for discrimination. This perceptual cue was also largely independent of the sequence characteristics, which probably accounts for the lack of systematic influence across levels of stimulus complexity that defined the tonal sequence conditions. Perceived rhythmic changes associated with gap increments were less salient, thus allowing factors related to stimulus complexity (frequency randomization and variation in target location) to exert a stronger influence on discrimination performance. The elderly listeners were apparently not able to make use of rhythmic cues to the same extent as younger listeners. This suggestion is consistent with findings reported by Humes and Christopherson (1991) that some of their elderly listeners displayed age-related deficits on a rhythm perception task with tone sequences.

## D. Summary

The present findings provide support for the conclusion that many elderly listeners have diminished temporal processing abilities. For duration discrimination, these age-related processing limitations can be apparent even with relatively simple sounds. The use of more complex sounds for discrimination testing effectively produced exaggerated age-related problems that were not evident from results collected with simpler stimuli. The present experiments used a restricted range of stimulus complexity and thus did not provide an exhaustive investigation of listener uncertainty effects on discrimination performance. Nevertheless, it is clear that factors that act to reduce familiarity and predictability of stimulus characteristics can have an important influence on discrimination of complex sounds. The sources of age-

related limitations in temporal discrimination as examined here are unknown, but seem likely to reside at more central stages of auditory processing. Little information is presently available about the nature of the processing mechanisms involved or the operational characteristics that change with aging.

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