

Aging and temporal discrimination of brief auditory intervals

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Summary. In a duration-discrimination experiment, young adults (mean age = 25.1), middle-aged adults (mean age = 45.5), and older adults (mean age = 64.6) were presented with two very brief auditorily marked intervals per trial, and their task was to decide which of the two was longer in duration. An adaptive psychophysical procedure was used to determine difference thresholds in relation to a constant standard interval of 50 ms. It was found that duration-discrimination performance was unaffected by age; all three age groups yielded a difference threshold of approximately 17 ms. It was concluded that the ability to discriminate durations of very brief auditory intervals appears to be based on an underlying timing mechanism that does not slow down with advancing adult age.

Introduction

The experimental study of psychological time has many facets. Experimental psychologists interested in psychological time and adult aging have devoted particular attention to two elementary temporal experiences, simultaneity and successiveness on the one hand and the experience of duration on the other. Investigations of simultaneity and successiveness are concerned with the question of how far apart in time two events have to be before they are perceived as two events (successiveness) rather than fused as one event (simultaneity). Investigations of the experience of duration employ a variety of retrospective and prospective techniques, such as verbal estimation of a specified duration or production of a specified duration.

In the area of simultaneity and successiveness, the term *temporal acuity* is used to refer to the smallest inter-stimulus interval (ISI) that leads to a judgment that stimuli are successive. McCroskey (1979, 1984) has claimed that

the temporal acuity of the auditory system begins to decline at about age 50. He introduced the Wichita Auditory Fusion Test (WAFT), in which subjects are confronted with stimuli, each consisting of a pair of tone pulses of 17 ms in duration and separated by an ISI ranging from 0 to 40 ms. The stimuli are presented in two runs, one in ascending order of ISI and the other in descending order of ISI. As the ISI is changed, subjects report whether the stimulus is perceived as one tone or two separate tones. Fusion-threshold estimates are represented by the ISI of the last stimulus perceived as a single tone followed by at least two consecutive two-tone judgments (ascending run) and by the ISI of the first of at least two one-tone judgments following a two-tone judgment (descending run). The auditory fusion point is defined as the mean of these two estimates. McCroskey (1979, 1984) found that temporal resolution improves gradually in childhood, resulting in an auditory fusion point of 4 ms at age 10. The auditory fusion point is stable until age 50, but markedly increases with increasing age thereafter. These age-related changes were attributed to changes in central rather than peripheral auditory processing (McCroskey & Kasten, 1980).

In another study on auditory fusion, Robin and Royer (1989) investigated the relationship between tone duration and ISI. They compared 10 older adult subjects (67–79 years) and 10 younger adult subjects (18–31 years); all subjects had normal pure-tone hearing thresholds. In each trial, subjects were presented with two tones, and were asked to adjust the duration of the first tone until fusion was perceived. It was found, at each ISI tested, that older adults yielded fusion points at greater tone-one durations than did younger adults. Like McCroskey, Robin and Royer concluded that temporal resolution of auditory events is impaired as a consequence of advancing adult age.

In the area of the experience of duration, James (1899) wrote: "The same space of time seems shorter as we grow older—that is, the days, the months, and the years do so; whether the hours do so is doubtful, and the minutes and seconds to all appearance remain about the same" (p. 625). Self-report data support the claim that time seems to pass

more rapidly for older adults than for younger adults (Joubert, 1983, 1984; Lemlich, 1975; Walker, 1977), but empirical studies in which subjects were required to estimate short durations have yielded equivocal results. For example, Surwillo (1964) tested adult subjects from three age groups, with mean ages of 37, 56, and 74 years. He found no age differences in producing durations of 30 s, 60 s, and 180 s. On the other hand, Feifel (1957) asked young and older adults to produce durations of 30, 60, 180, and 300 s, and found that the older adults produced durations approximately 78% as long as those produced by the younger ones.

In another study, Goldstone, Boardman, and Lhamon (1958) asked young and older adults either to count out 30 s, or to judge whether a presented tone was shorter or longer than 1 s in duration. It was found that the counting task yielded age differences like those found by Feifel (1957), indicating that the older adults overestimated the rate of time passage, but the comparison task yielded no age differences. LeBlanc (1969) studied duration estimation of 16-s and 1-min intervals in young, middle-aged, and older adults and found that older adults consistently produced the shortest durations. Although in the 3-minute task the middle-aged adults produced durations intermediate between those of young and older adults, they produced longer durations than the young adults in the 16-s task. In summary, contrary to James's claim about age invariance of the experience of time intervals less than an hour in duration, there is some experimental evidence that time experience does accelerate with advancing adult age, even for durations of the order of seconds or minutes. However, the evidence is by no means conclusive.

Experienced and remembered durations as long as those employed in the above studies have been shown to involve cognitive processing (e.g., Block, 1990). Little is known about the effects of adult aging on perception of time intervals of much briefer duration, in the order of milliseconds. Discrimination of duration of these very brief intervals appears to be based on perceptual rather than on cognitive processing (Michon, 1985; Rammsayer & Lima, 1991). Although McCroskey (1979, 1984) and Robin and Royer (1989) found age deficits in the ability to separate temporally very brief auditory events, the question of whether age deficits also exist in the ability to discriminate the durations of consecutively presented auditory stimuli has not been studied. The purpose of our experiment was therefore to investigate the effects of adult aging on duration discrimination of very brief auditory intervals.

Method

Subjects. Adults from three age groups were tested: each group consisted of 20 male volunteers. The young adult group ranged in age from 20 to 29 years ($M = 25.1$, $SD = 2.3$); the middle-aged adult group ranged in age from 40 to 49 years ($M = 45.5$, $SD = 3.6$); and the older adult group ranged in age from 60 to 78 years ($M = 64.6$, $SD = 4.3$). Subjects were either from Thomas Jefferson University, Philadelphia, PA, or from the University of Giessen, Giessen, Germany. The young adults were graduate or medical-school students, whereas the middle-aged and older adults were faculty members. All subjects were in good health and all

were educationally or professionally active. All of them reported that they had no hearing impairments.

Apparatus and stimuli. The presentation of the intervals and the recording of subjects' responses were controlled by an IBM AT-compatible computer. The stimuli used were empty, auditorily marked intervals. Each interval was marked by a 3-ms onset click and a 3-ms offset click. The clicks were generated by a computer-controlled sound generator. To control for individual differences in hearing sensitivity, the intensity of the clicks was determined individually for each subject. For each subject, the sensation threshold for a 3-ms click was first determined, and an intensity level 50 dB above the individual's threshold was used in the experimental trials (50-dB Sensation Level [SL]). In this way, we ensured that signal levels in relation to sensation threshold were equivalent for all subjects, despite individual differences in sensation thresholds.

Procedure. The stimuli were presented through headphones (Vivanco model SR85). An experimental session consisted of 100 trials, and each trial consisted of two empty intervals: one standard interval 50 ms in duration and one comparison interval. The comparison interval varied in duration from trial to trial depending on the subject's previous responses according to the transformed up-down procedure described by Levitt (1971) which converges on a .707 probability of hits. Some advantages of this procedure as compared to traditional psychophysical methods are its robustness, small-sample reliability, and avoidance of floor and ceiling effects. The duration of the comparison interval changed with a constant step size of 6 ms, except that comparison intervals less than, or equal to, 62 ms in duration changed with a constant step size of 3 ms. The initial value of the comparison interval was 98 ms. The order of presentation for the standard interval and the comparison interval was randomized and balanced, with each interval being presented first in 50% of the trials. Subjects were not informed that there was a constant standard interval involved in every trial. When asked after the experiment if they had been aware of different presentation orders of a constant standard and a variable comparison interval, they reported that they had not.

A subject was seated at a table with a keyboard and a computer monitor in a sound-attenuated room. To initiate a trial, the subject pressed the space bar; the auditory presentation began 900 ms later. The two intervals were presented with an ISI of 900 ms. The subject's task was to decide which of the two intervals was longer and to indicate his decision by pressing one of two designated keys on the keyboard; one key was labeled "first interval longer" and the other was labeled "second interval longer." Instructions to subjects emphasized accuracy; there was no requirement to respond quickly. After each response, visual feedback ("CORRECT" or "FALSE") was displayed. The next trial was started by the subject pressing the space bar again. The experimental trials were preceded by 10 practice trials in which the adaptive procedure was also used.

The purpose of the practice trials was to ensure that subjects understood the instructions and to familiarize them with the stimuli. After the practice trials, subjects were asked whether they had any remaining problems in understanding the procedure; no subject requested additional practice.

As a measure of each individual's performance, mean differences between standard intervals and comparison intervals were computed for every block of 10 trials starting with trials 31–40 (Trial Block 4) and ending with trials 91–100 (Trial Block 10). This resulted in seven difference-threshold values for each subject, one for each trial block starting with the fourth trial block in the experiment. Each value represents an estimate of the individual 70.7%-difference threshold in milliseconds in relation to a standard interval of 50 ms. Thus, better performance on duration discrimination is indicated by smaller values. Data from Trial Blocks 1–3 were not analyzed because the initial stimulus level (i.e., the difference between standard and comparison interval) was far above the threshold range and, furthermore, performance in early trials is generally too variable to yield reliable and valid performance estimates. In previous studies, the placing of initial observations above threshold proved to be the most suitable method for increasing the reliability of threshold estimates.

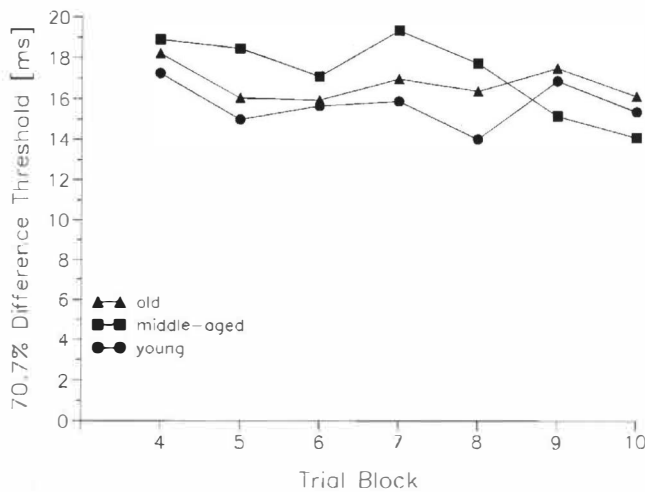


Fig. 1. Mean 70.7%–difference thresholds for each age group as a function of trial block

Results

A two-way analysis of variance with age group (3 levels) as a between-subjects factor and trial block (7 levels) as a within-subjects factor was computed for the difference-threshold values. For the within-subjects effects, the Greenhouse–Geisser correction for heterogeneity of variance was used to determine the appropriate level of significance. The results are presented in Figure 1. Temporal-discrimination performance showed no significant main effect of age group, $F(2,57) = 0.17, p = .84$, no significant main effect of trial block, $F(6,342) = 1.25, p = .29$, and no significant interaction of age group with trial block, $F(12,342) = 0.73, p = .69$. So it is clear that neither age nor practice had any reliable effect on temporal discrimination performance.

Discussion

Duration discrimination of very brief auditory intervals was unaffected by the age of our adult subjects, suggesting a perceptual process that does not deteriorate with advancing age. A cautionary note, however, is that a finding of age invariance in the performance of a task may be due not to a true lack of an age difference, but to insufficient sensitivity of the procedure applied. It must therefore be demonstrated that the null results obtained in this experiment reflect genuinely age-invariant processes and are not the product of an insensitive, noisy psychophysical procedure for threshold estimation. To this end, we computed Cronbach's alpha (e.g., Cronbach, 1990) across the seven threshold estimates based on Trial Block 4 to Trial Block 10 in order to evaluate the reliability of assessment. Reassuringly, the resulting alpha coefficient was very high (.91), indicating that individual differences were highly stable across trials. This high level of internal consistency supports our view that the null results obtained in the present experiment reflect a true age invariance in dura-

tion-discrimination performance rather than insensitivity due to unreliable techniques or instrumentation.

The duration-discrimination-threshold estimates obtained in the current experiment were based on data from 20 subjects in each age group; this sample size is comparable to those that have been successfully used in prior experiments employing similar procedures (Rammsayer, 1990; Rammsayer & Lima, 1991). Rammsayer and Lima (1991) used 16 to 24 subjects per group, and obtained duration-discrimination-threshold estimates not unlike those obtained in the current experiment. It is also important to note that the psychophysical procedure applied in the present experiment is highly sensitive to true individual differences in duration-discrimination performance. In a study on auditory sensory compensation in the blind, for example, this procedure yielded reliable results, indicating duration-discrimination performance in the blind superior to that of the sighted subjects (Rammsayer, 1992). The procedure has also yielded results indicating duration-discrimination-performance differences among psychiatric patients with different diagnoses (Rammsayer, 1990). In this experiment, using the same 50-ms standard interval as in the current experiment, it was found that patients suffering from major depression with melancholia yielded 70.7%–difference thresholds significantly greater than those of schizophrenic patients, whose thresholds were significantly greater than those of dysthymic patients; all three groups yielded significantly greater thresholds than the healthy control group. So it is unlikely that the procedure used in the present experiment was not sufficiently sensitive to detect age-related differences.

To our knowledge, the only other published experiments on adult aging and time perception in the range of milliseconds are those reported by Salthouse, Wright, and Ellis (1979), who used durations ranging from 40 to 1,000 ms. These researchers asked younger adults (aged 18–35 years) and older adults (aged 55–80 years) to judge the duration of a flash of light (Experiment 1) or to judge the duration of the dark interval between two flashes of light (Experiment 2). In both experiments, only one duration was presented per trial, so that the subjects' task was not to perform duration discriminations, but to estimate the magnitude of each duration by marking a line segment on a response sheet. It was found that for both the filled intervals (Experiment 1) and empty intervals (Experiment 2), the functions relating estimated duration and actual duration were virtually identical for younger and older adults. Thus, the results of Salthouse et al. (1979) in the visual domain, using a duration-estimation task, match the results of the current experiment in the auditory domain, using a duration-discrimination task. In both cases, the perception of very brief durations was found to be unaffected by adult aging.

It is unfortunate that so little attention has been paid to perceptual processes that do not show adult age differences. As was noted by Kausler (1982), the usual approach in the experimental study of aging has been to emphasize processes that deteriorate with age and to ignore processes that are unaltered by aging. Perceptual phenomena that have been found to be unaltered by adult aging include size constancy (Leibowitz & Judisch, 1967), the Poggendorff

illusion (Leibowitz & Gwozdecki, 1967), and temporal summation for detection of sine-wave gratings (Sturr, Church, & Taub, 1988). Kausler (1982) asserted the general principle that much of human perception does not change as adults grow older, particularly perceptual functions that are essential for interaction with the environment. It is possible that duration-discrimination performance reflects such an essential function. Performance on duration-discrimination tasks can be explained by the assumption of an internal clock (e.g., Church, 1984; Creelman, 1962; Treisman, 1963; Treisman, Faulkner, Naish, & Brogan, 1990). According to internal-clock models, a pacemaker of some kind generates neural pulses, and the number of pulses relating to a physical time interval is the internal representation of the duration of this interval. The higher the rate of pulses, the finer the temporal resolution of the internal clock, which is equivalent to more accuracy and better performance in duration-discrimination tasks. So our finding that younger, middle-aged, and older adults performed equally well on duration discriminations argues that the internal-clock rate does not change as a function of adult aging.

The lack of an age difference in duration discrimination of very brief auditory intervals may reflect a basic underlying biological timing mechanism that is unaffected by adult aging. Recent research suggests that there is a common timing mechanism that underlies both perception and action. Significant correlations have been observed between timed tapping and duration judgments of brief intervals between auditory events (Keele, Pokorny, Corcos, & Ivry, 1985). It has also been found that subjects can easily synchronize movements with auditory patterns, supporting the notion of a common underlying timing mechanism (Prinz, 1987). A third line of evidence is based on results from dual-task procedures. For example, Klapp (1981) reported that subjects experienced difficulty in producing one rhythmic pattern of finger tapping while simultaneously producing another rhythmic pattern vocally; similar results were reported by Peters (1977). In short, the results of a number of studies suggest the existence of a basic timing mechanism underlying many aspects of both action and perception.

It is widely known that older adults have markedly slower reaction times than younger adults in most perceptual and cognitive tasks, a phenomenon so systematic and pervasive that it has come to be called age-related general slowing (e.g., Lima, Hale, & Myerson, 1991; Salthouse, 1985). However, the fact that older adults tend to have slower reaction times than younger adults does not necessarily imply that the basic timing mechanism has slowed down in the older adults. In fact, although motor timing has been found to correlate with motor speed, perceptual timing has been found to correlate with motor timing, but not with motor speed (Keele, 1987). So it is reasonable to infer that the internal clock that underlies duration discrimination is not likely to be the same mechanism that underlies the age-related slowdown of reaction time found in most cognitive and perceptual tasks. In discussing the implications of their findings of age invariance in estimating very brief visual durations described above, Salthouse et al. (1979) reached a similar conclusion.

The lack of age differences in duration-discrimination thresholds in the present experiment is particularly interesting in light of the age differences in auditory-fusion thresholds reported by McCroskey (1979, 1984) and Robin and Royer (1989). It appears that the physiological mechanism underlying the temporal fusion of brief auditory stimuli is different from the physiological mechanism underlying the duration discrimination of brief auditory intervals; the former mechanism deteriorates with age, but the latter does not. Further evidence for the existence of two distinct mechanisms comes from correlational analyses of data from a study in which 48 healthy adults ranging in age from 19 to 34 were tested on both duration-discrimination and auditory-fusion tasks (Rammsayer, 1989a). Like the present experiment, the duration discrimination task involved auditorily marked empty intervals, with a standard interval of 50-ms duration. The auditory-fusion task was somewhat similar to McCroskey's WAFT, but rather than one ascending run and one descending run, six runs of each type were employed, and thresholds were determined separately for each type of run. To investigate whether one physiological mechanism underlies both duration discrimination of brief auditory intervals and auditory fusion, correlation coefficients were computed. The correlation between duration-discrimination performance and auditory-fusion threshold (ascending runs) was $r = .16$, and that between duration-discrimination performance and auditory-fusion threshold (descending runs) was $r = .11$. Neither correlation was statistically significant, suggesting that different physiological mechanisms underlie duration discrimination and auditory fusion. Converging evidence comes from a pharmacopsychological study. In a placebo-controlled double-blind crossover design, 24 healthy young adults performed both the duration-discrimination task and the auditory-fusion task; the drug being tested was the dopamine antagonist haloperidol (Rammsayer, 1989b). It was found that performance on duration discrimination was significantly impaired under haloperidol, whereas auditory-fusion thresholds were unaffected. Thus, both the correlational evidence and the pharmacopsychological evidence indicate that the physiological mechanism that underlies duration discrimination is independent of the physiological mechanism that underlies auditory fusion. This conclusion is consistent with evidence suggesting that fusion depends primarily on the characteristics of auditory processing and not on the processing of duration per se (Florentine & Buus, 1984; Ison, O'Connor, Bowen, & Bocirnea, 1991).

Our finding that the duration discrimination of short auditory intervals is unimpaired by age may help to elucidate which processes are involved in age-related impairments in speech perception. Temporal constraints are crucial for speech perception, and many cues that are essential for speech perception are of very short duration, such as distinctions based on voice-onset time (VOT) (e.g., Lisker & Abramson, 1967). It has been hypothesized that perceptual difficulties with these short-duration cues may partially explain speech-perception problems observed in older adults. Gengel (1973) reported that impairment in ability to discriminate frequencies of tones is related to impairment in ability to discriminate speech sounds;

furthermore, as the duration of a tone becomes shorter than approximately 150 ms, performance on frequency discrimination decreases progressively. In a recent study using tones ranging from 5 to 500 ms in duration, Cranford and Stream (1991) found that the age-related impairment in frequency discrimination increases as the tones become shorter. In light of our finding of no age-related impairment in discrimination of brief auditory durations, it seems likely that age-related changes in speech perception are mediated by difficulties in discriminating the qualitative aspects of short-duration events (e.g., frequency) rather than by difficulties in processing temporal information per se.

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