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THE EFFECT OF AGING ON REACTION TIME IN AUDITORY DETECTION AND DISCRIMINATION TASKS

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ABSTRACT

This research investigated the effect of aging on sensory information processing and decision-making. Detection thresholds in quiet and in noise and temporal acuity, and their associated choice reaction times were measured in two groups of normal-hearing subjects, differing in age. All three psychophysical tasks utilized a four-interval forced-choice procedure. The results indicated that there were no differences in duration discrimination or choice reaction time as a function of aging. However, the variability in choice reaction times was significantly greater for the older group, signifying greater heterogeneity in the time for decision-making. Erroneous responses generally took longer to make than correct responses. For the younger group, the erroneous response time increased with task complexity.

SOMMAIRE

Cette étude s'intéresse à l'effet de l'âge sur le traitement de l'information sensorielle et la prise de décision. Les seuils d'audition dans le silence et dans le bruit, l'acuité temporelle ainsi que les temps de réaction associés ont été mesurés chez deux groupes de sujets d'âges variés et dont l'audition était normale. La procédure de choix forcés à quatre intervalles a été utilisée pour les trois tâches psychoacoustiques. Les résultats démontrent qu'il n'y a pas de différence significative en fonction de l'âge pour les épreuves de discrimination de la durée ou pour le temps de réaction. La variabilité dans le temps de réaction était toutefois significativement plus grande dans le groupe plus âgé, ce qui indique une plus grande hétérogenéité dans le temps requis pour une prise de décision. Les reponses incorrectes étaient en general plus longues à venir que les réponses correctes. Pour le groupe de jeunes sujets, le temps de réponse incorrecte augmentait avec la complexité de la tâche.

1. INTRODUCTION

Both sensory information processing and decision-making are affected by aging. In the former category, a well documented finding is the deterioration of temporal acuity. Herman, Warren and Wagener (1977), for example, found that the interaural time delay required by older subjects for sound lateralization was twice that observed for younger subjects. In contrast, there were no differences in the minimum interaural intensity required by the two groups. Similar time-related difficulties have been demonstrated in animal models for free-field sound localization (e.g., Harrison, 1981; Brown, 1984). This decline in sensitivity to the temporal parameter is neither related to hearing loss nor confined to differences in stimulus input to the two ears. Abel, Krever and Alberti (1990) found significantly increased duration difference limens with aging in a diotic listening experiment. As well, a number of investigators have reported a marked decline in speech intelligibility as early as 40 years, when the stimulus materials are degraded by temporal interruption or reverberation (e.g., Bergman, Blumenfeld et al., 1976; Bergman, 1980).

There is evidence that these stimulus processing decrements have a neuroanatomical basis. Age-related degenerative changes have been documented throughout the auditory pathway. These include hair cell damage in the cochlea with nerve deterioration (Johnsson and Hawkins, 1972), neuron loss in the brainstem (Casey and Feldman, 1982), ganglion cell degeneration, including a change in the shape and a decrease in the number and size of cells in the ventral cochlear and superior olivary nuclei, inferior colliculus and medial geniculate (Kirikae, Sato and Shitara, 1964), and a loss of neurons in the superior temporal region of the cortex (Chandler and Grantham, 1991).

There are also data to support the contention that difficulties observed with aging reflect changes in cognitive function, particularly selective attention and decision-making. Attentional deficits have been demonstrated in vigilance experiments. In a watch-keeping task, Surwillo and Quilter (1964) found that subjects over the age of 60 years responded to fewer targets than younger subjects, and showed a greater decline in performance over time. Signal detection studies have shown that individuals aged 60 to 80 years adopt a more cautious criterion than those aged 21 to 35 years, suggesting that they require stronger evidence before making a decision (Craik, 1969; see also Rees and Botwinick, 1971; Potash and Jones, 1977). However, Gordon-Salant (1986) has argued that response bias is task-dependent. In her experiments on word recognition in noise, elderly subjects adopted a less conservative criterion. The explanation given for the difference in outcome was increasing confidence in the accuracy of one's own responses with aging but greater cautiousness in relation to externally controlled events.

Historically, reaction time has been used as an index of cognition, specifically to estimate the time taken for each of the stages that occur between the presentation of a stimulus and response (Donders, 1869; Smith, 1968). *Simple reaction time* (e.g., key tap to tone onset) is comprised of the times for the cortical registration of a particular event and response execution. *Choice reaction time,* which is obtained by requiring a different response for each of a number of possible stimuli, adds the times for stimulus identification and choice. These two stages represent intervening cognitive events. Both simple and choice reaction times increase significantly after the fourth or fifth decade of life. According to Welford (1980), this increase reflects changes in performance strategy rather than a deterioration in sense organ or motor function.

2. RATIONALE

The present experiment was conducted to investigate the effect of aging on measures of sensation and choice reaction time for different psychophysical tasks. The tasks investigated included signal detection in quiet (Det/Q), signal detection in noise (Det/N), and duration discrimination (Discrim). In all three, a four-interval forced-choice paradigm with four response alternatives was used, requiring subjects to compare auditory stimulus events presented across a series of listening intervals (pure tone vs quiet, pure tone in noise vs noise alone, and long vs short duration for a one-third octave noise band).

It could be argued that within a restricted age group, the three tasks should yield the same reaction time because they require the same degree of choice. A finding of increasingly longer reaction times for discrimination as compared with detection would suggest that the level of complexity in decision-making (i.e., a comparative judgement vs. the detection of an event) is an important factor. Previous studies support the conclusion that the effect of task complexity on choice reaction time will interact with aging (Cohen and Faulkner, 1983). So that the age-related effect of a possible distractor on performance could be assessed, a continuous noise background of moderate intensity was introduced in the second detection task. Published data also indicate that temporal acuity, as measured by the difference limen for stimulus duration, will decline with age, even when hearing remains normal (see above).

In all three tasks, the stimulus frequency was 4000 Hz, based on our previous findings of age-related high-frequency decrements in both frequency and duration discrimination (Abel, Krever and Alberti, 1990). For the detection tasks, the stimulus duration was 300 ms (including a rise/decay time of 50 ms). For the discrimination task, the standard duration was 220 ms (including a rise/decay time of 10 ms). These values were sufficiently long to preclude the effect of temporal integration which would change the detection threshold, and possibly provide a loudness cue in duration discrimination (Garner, 1947; Green, Birdsall and Tanner, 1957). A one-third octave noise band was used in preference to a pure tone for duration discrimination, in order to avoid possible spectral changes (and thus a pitch cue) which might be confounded with a change in duration.

3. METHODS AND MATERIALS

3.1 Subjects

Two groups of 15 subjects with screened normal hearing, aged 20-30 (young) and 50-60 (old) years, were tested. Potential candidates in these two age groups were rejected if their hearing thresholds at 4000 Hz exceeded 20 and 40 dB SPL, respectively. The difference in the hearing criterion reflected an allowance for presbycusis (Brant and Fozard, 1990). All subjects were volunteers who had responded to advertisements posted in selected locations at the University of Toronto and Mount Sinai Hospital. Although several had previously participated in psychoacoustic experiments, none were familiar with the protocols of the present study. Upon completion of the experiment, subjects were paid $15 for their services and were reimbursed for public transit or parking expenses.

3.2 Apparatus

The experiment was carried out in a double-walled IAC booth. The ambient noise levels were less than the maximum allowable levels for headphone testing specified in ANSI Standard S3.1-1977. The pure-tone and one-third octave band stimuli used for the experiment were generated respectively by means of a Hewlett-Packard Multifunction Synthesizer (Model 8904A) and Bruel & Kjaer Noise Generator (Type 1405), in conjunction with a Bruel & Kjaer Band Pass Filter (Type 1617). A Coulbourn Instruments Modular System was used to control the stimulus selection and fine adjustment of stimulus level, duration and envelope shaping. The output of this system was fed to a Hewlett-Packard manual range attenuator (Model 350D) and Rotel integrated stereo amplifier (Model RA-1412) for presentation to the subject binaurally (and diotically) over a Telephonics matched headset (TDH-49P). The system was controllable from an AST Premium 286 personal computer (Model 140X) via the use of IEEE-488 and Lablinc interfaces, and digital I/O lines. The intensities of the two types of stimulus were calibrated at the earphone by means of a Bruel & Kjaer artificial ear (Type 4153). Subjects responded using a custom designed handheld response box which comprised a set of five LEDs to cue events on a trial and four microswitches for responding. The latter were accurate to within 1 ms.

3.3 Procedure

3.3.1 Detection

The detection thresholds for both the quiet and noise background conditions were measured using a four-interval forced-choice procedure. On each trial the subject was presented a 1/2-sec warning light followed in succession by four listening intervals of 300 ms duration, separated by pauses of 300 ms. These events were cued by a horizontal array of five LEDs on the response box. The pure-tone stimulus was presented in one of the four listening intervals, the choice randomly determined. The subject was instructed to depress the response key corresponding to the LED that was coincident with the stimulus, as soon as the last LED in the series was extinguished. In the noise background condition, white noise at an intensity of 54 dB SPL was continuously present throughout the trial block.

The intensity of the stimulus was varied across blocks of 32 trials, so as to generate a psychometric function with the proportion of correct responses, P(C), ranging from 0.25 (chance) to 1.00 (perfect) performance. The detection threshold, defined as that intensity yielding P(C) equal to 0.625, was interpolated using a straight line visual best fit to the data points obtained for the various blocks. A minimum of two points was considered sufficient, as long as one value of P(C) was between 0.30 and 0.625, and the other was between 0.625 and 0.90. In practice, three to four blocks were required to satisfy this condition.

3.3.2 Discrimination

The paradigm used for the duration discrimination task was similar to that for detection. On each forced-choice trial, four one-third octave noise band stimuli were presented, three standards and one comparison, whose duration exceeded the standard by Δt ms. The subject was required to choose the listening interval that coincided with the longest of the four auditory events. Across blocks of 32 trials, the value of Δt was varied so as to generate a psychometric function with P(C) ranging between 0.25 and 1.00. The discrimination threshold, defined as that Δt for which P(C) was 0.625, was interpolated from a visual fit to the data points obtained for the blocks presented. The requirement for two data points within different ranges of P(C) was the same as that specified for detection.

3.3.3 Choice Reaction Time

The correct and incorrect reaction times associated with the detection and discrimination thresholds were obtained by plotting the proportion of correct responses against the median reaction time (correct and incorrect) for each block of trials obtained within subject for the various tasks. Straight lines were then fit by eye to these reaction time psychometric functions. The correct and incorrect reaction times associated with P(C) = 0.625 were then interpolated to give the values of reaction time at threshold. Median reaction times for each trial block were used in preference to means based on the reported observation of skewness in reaction time distributions (Moody, 1970; and Abel, Rajan and Giguère, 1990).

3.3.4 Instructions and Practice

For both the detection and discrimination paradigms, subjects were instructed to respond as quickly as they could, without sacrificing accuracy, and to guess on each trial, if uncertain. The entire experiment was replicated twice in each subject, so that the effect of practice could be determined for the various measures. In approximately half the subjects in each group, the two replications were conducted within the same session which lasted approximately one and a half hours, and in half, the replications were conducted during two different sessions of approximately 45 min, separated by no more than one week. This allowed an evaluation of the possible dissipation of practice over time. For the first replication, the detection in quiet task was always presented first, followed by the detection in noise and duration discrimination tasks in random order. For the second replication, the order of the three tasks was counter-balanced across subjects within groups.

4. RESULTS

The median detection and discrimination thresholds for the three tasks are presented in Table 1 for each of the four group by replication (Rep) conditions. Table 2 and Figure 1 show the median reaction times for the two response types (Resp), correct and error, corresponding to these threshold measurements. In the figure, the data points for the three tasks have been joined for each of the four replication by response type conditions to aid visual comparison. The slopes of the lines have no theoretical significance. All medians, for both threshold and reaction time, are based on 15 observations. Since there were no statistically significant differences for second replications held on the same or different days, the data for the two subgroups in the second replication were collapsed.

Nested analyses of variance (ANOVA) were applied to the threshold data for each of the three tasks to assess the effects of age (between groups) and replication (within groups), and to the reaction time data to assess the effects of age (between groups) and task, replication and response type (within groups). Because of the differences in the dispersion of scores across conditions, particularly for the reaction time data, a rank transformation was applied to each of the four data sets prior to statistical analysis (Conover and Iman, 1981).

4.1 Thresholds

Age was a significant main effect for the detection threshold measured both in quiet and in noise ($F=39.71$, $p<0.001$, $df=1$ and $F=16.24$, $p<0.001$, $df=1$, respectively). This outcome was expected given the difference in the hearing selection criterion for the two groups. In spite of the difference, the thresholds in quiet for both groups, i.e., 9 and 19 dB SPL (see Table 1, replication 2), were within the range of normal hearing for young listeners (Yantis, 1985). The median detection thresholds in noise, 37 and 38 dB SPL, were similar for the two groups. Given that the white noise masker was 54 dB SPL, the signal to noise ratio for threshold detection was approximately -16 dB, a value close to that reported previously (e.g., Green, 1976). Neither the threshold in quiet or in noise changed significantly with replication.

In contrast, the duration discrimination threshold, Δt, did decrease significantly with replication ($F=101.30$, $p<0.05$, $df=1$) but was not affected by age. As shown in Table 1, this practice effect was evident only for the older of the two groups, although the interaction of age and replication did not reach statistical significance ($F=3.46$, $p<0.10$, $df=1,28$). The observed values of 45 to 52 ms for the four group by replication conditions were close to those documented in the literature for unpracticed normal hearing subjects for a standard duration of 300 ms (Thompson and Abel, 1992) but somewhat larger than those for practiced listeners (Abel, 1972).

4.2 Reaction Time

4.2.1 Medians

The ANOVA on the reaction time data indicated that there were significant main effects of task ($F=12.31$, $p<0.001$, $df=2$), replication ($F=26.25$, $p<0.001$, $df=1$) and response type ($F=106.68$, $p<0.001$, $df=1$); a significant two-way interaction of task by response type ($F=3.63$, $p<0.05$, $df=2,56$); and a significant three-way interaction of task by replication by response type ($F=4.05$, $p<0.05$, $df=2,56$). Age was not significant either as a main effect or in interaction with the other three variables.

Post hoc pairwise comparisons of ranked reaction times for the three *tasks* indicated that there were significant differences only for the erroneous responses made by the younger group. In the first replication, the error reaction time was significantly less for detection in noise than for duration discrimination. Since the detection in quiet task was always presented first in this replication, its relatively greater reaction time compared with detection in noise may have been due to lack of familiarity. In the second replication, the error reaction time for detection in quiet was significantly less by 160 ms than that observed for duration discrimination, with the outcome for detection in noise falling between.

With respect to the *replication* effect, post hoc comparisons showed that there were significant decrements in reaction time with practice only for the erroneous responses made in detection in quiet. This outcome (approximately 125 ms) was significant for both groups and was likely due again to the non-random order of tasks in the first replication. Generally, erroneous responses took longer to make than correct responses. *Response type* was a significant factor for the younger group in both replications of duration discrimination, and for the older group in both replications of detection in quiet and duration discrimination, and in the second replication of detection in noise.

A separate nested ANOVA of the differences between correct and erroneous reaction times, calculated within subject for combinations of task and replication, indicated that task, group by task and group by task by replication were statistically significant factors ($F=6.41$, $p<0.01$, $df=2,56$; $F=5.33$, $p<0.01$, $df=2,56$; and $F=3.66$, $p<0.05$, $df=2,56$, respectively). Post hoc pairwise comparisons indicated that after practice (i.e., in the second replication), the older group showed a significantly greater difference than the younger for detection in quiet (150 msec vs 40 msec). For the younger subjects, the difference observed for duration discrimination was greater than that for detection in quiet (130 msec vs 40 msec) with the result for detection in noise (90 msec) falling midway between the two (see Table 3).

4.2.2 Variance

A statistical analysis was also conducted to determine the effect of age on the range of choice reaction times. Variance ratios (i.e., the ratio of the square of the standard deviations) were computed for the reaction time scores observed for the two groups in each task by replication by response type condition. Significant F-ratios (one-tailed test) were obtained in the first replication for the error reaction time in duration discrimination ($F=3.58$, $p<0.025$, $df=14,14$), and in the second replication for correct and error reaction times in detection in quiet ($F=2.55$, $p<0.05$, $df=14,14$ and $F=12.12$, $p<0.001$, $df=14,14$), the error reaction time for detection in noise ($F=4.69$, $p<0.01$, $df=14,14$) and the correct and error reaction times for duration discrimination ($F=11.31$, $p<0.001$, $df=14,14$ and $F=5.71$, $p<0.01$, $df=14,14$).

5. DISCUSSION

The purpose of this experiment was to further explore the previously reported detrimental effect of aging on auditory temporal information processing. The index of temporal processing chosen was the minimum perceptible change in stimulus duration. Choice reaction times (correct and error) were measured in order to determine the relative importance of decision-making, in comparison with sensory function. Detection thresholds in quiet and in noise and their associated reaction times were also obtained to determine whether the effect of aging was specific to temporal acuity or more pervasive in perception.

The results showed that aging did not affect duration discrimination. Although the minimum perceptible change was relatively longer for the older than the younger subjects in the first replication, the performance of the two groups was virtually identical after practice. Observed age-related differences in the detection thresholds could be accounted for by the admission criteria. These findings lead to the conclusion that aging, in the range studied, does not affect sensory function.

Age was also not a significant factor for choice reaction time, neither as a main effect nor in interaction with task, replication or response type. However, in both replications the difference in the time taken to make a correct and an erroneous response was greater for the older subjects, although this was only significant in the detection in quiet task. Age also significantly affected the variance in the time taken to respond. Even after practice, the correct and error reaction times in detection in quiet and duration discrimination, and the error reaction time in detection in noise covered a broader range in the older group. These outcomes suggest that regardless of task, there is greater heterogeneity in the difficulty of decision-making for the older compared with the younger subjects.

A question raised at the outset was whether choice reaction time would be the same for the three tasks since a common methodology was used. The results indicated that task was an important determinant of the time taken for erroneous judgements. For the younger group, after practice errors in duration discrimination took approximately 150 ms longer to make than errors in either of the two detection tasks. For the three tasks, the differences between erroneous and correct reaction times were 40, 90 and 130 ms, respectively. The difference of 40 msec for detection in quiet was similar to the value reported by Abel, Rajan and Giguère (1990) for well-practiced young adults. Thus, the nature of the judgement, rather than the degree of choice was the important determinant of performance.

In a series of papers, Surwillo has presented evidence of a positive correlation between the period of the alpha rhythm of EEG activity and reaction time (Surwillo, 1961; 1963; 1964). Such data are supportive of the notion that brainwave cycles provide a unit of time for the programming of events by the central nervous system (see, for example, Bishop, 1936; Stroud, 1955). According to Surwillo's findings, the period of the alpha cycle will increase with age, and his contention is that this slowing of brain activity is responsible for the progressively longer decision reaction times observed with aging.

The data for practiced young adults in the present study are supportive of the concept of a central clock. The time to make an erroneous response added approximately the equivalent of the alpha half cycle, i.e., 50 ms. This difference was incremented by multiples of 50 ms for each of detection in noise and duration discrimination. The trend was not evident for the older listeners. After practice, the differences between the two response type reaction times were 150 ms for both detection in quiet and duration discrimination and 110 ms for detection in noise, values which were not significantly different. There was also significantly greater variance in the reaction time data of the older listeners. Surwillo's theory might attribute this outcome to greater heterogeneity of the alpha cycle with aging.

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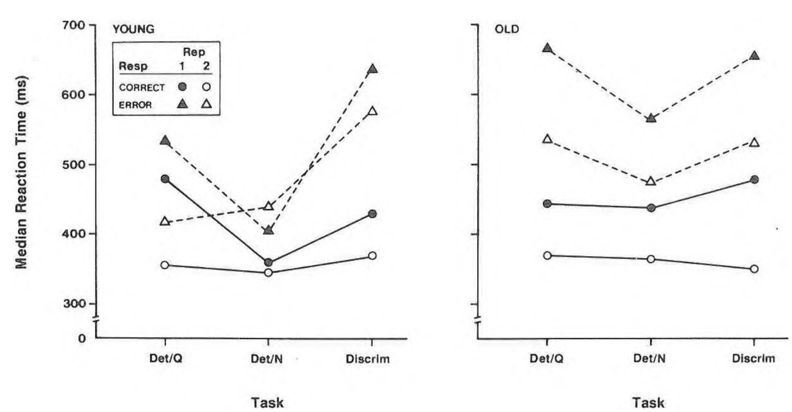

Figure 1. The Effect of Aging, Task and Replication on the Median Reaction Time for Correct and Erroneous Responses

Table 1. The Effect of Aging and Replication on the Detection and Discrimination Thresholds

Group	Rep	Det/Q	Det/N	Discrim
			TASK	
Young	1	8.0 ± 3.3*	37.0 ± 1.1*	46.0 ± 6.8+
	2	9.0 ± 2.5	37.0 ± 0.7	48.0 ± 6.9
Old	1	21.0 ± 5.4	38.0 ± 1.1	52.0 ± 7.3
	2	19.0 ± 4.6	38.0 ± 1.1	45.0 ± 10.4

*Median (dB SPL) ± 1 avg. dev.
+Median (msec) ± 1 avg. dev.

Table 2. The Effect of Aging, Task and Replication on Reaction Time

Group	Resp	Rep	Det/Q	Det/N	Discrim
				TASK	
Young	Correct	1	480 ± 116*	360 ± 103	430 ± 105
		2	355 ± 85	345 ± 85	370 ± 85
	Error	1	535 ± 219	405 ± 227	640 ± 233
		2	420 ± 114	440 ± 129	580 ± 136
Old	Correct	1	445 ± 132	440 ± 106	480 ± 119
		2	370 ± 122	365 ± 74	350 ± 183
	Error	1	670 ± 245	570 ± 186	660 ± 363
		2	540 ± 360	480 ± 248	540 ± 312

*Median (msec) ± 1 avg. dev.

Table 3. The Effect of Aging, Task and Replication on the Difference in Reaction Time for Correct and Erroneous Responses

Group	Rep	Det/Q	Det/N	Discrim
			TASK	
Young	1	95 ± 129*	70 ± 134	130 ± 183
	2	40 ± 79	90 ± 62	130 ± 92
Old	1	280 ± 136	80 ± 124	180 ± 273
	2	150 ± 240	110 ± 212	150 ± 229

*Median Difference (msec) ± 1 avg. dev.

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