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AGE AND SEX PARAMETERS IN PSYCHOMOTOR LEARNING[1]

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Summary.—Quantitative relationships were sought among psychomotor response speed (R), number of practice trials (T), chronological age (A), and biological sex (S) for 600 *Ss* in 30 groups between the ages of 8 and 87 yr. All *Ss* received 320 trials on a Discrimination Reaction Time apparatus. Hull's equation $R = m(1 - e^{-iT}) + c$ was found capable of describing all 30 acquisition curves with an average predictability of 97.98% when the asymptote (m), rate (i), and R-intercept (c) parameters were varied jointly. When m and c were held constant for each sex and only i varied, the average predictability dropped to 64.76%, indicating that rate alone was inadequate to account for variance due to age and sex. Confirming and extending the classical age-performance data, acquisition speeds followed differential trends for both age and sex variation while over-all proficiency was a non-monotonic function of age. There was a rapid growth to a maximum level for females at the age of 16 and for males at 20, then a gradual, non-parallel decline into the seventh decade. Males performed significantly faster than females, and all two-factor interactions were significant. There was no tendency for inter-individual variability to increase with age. We conclude that age and sex are critical parameters in human psychomotor learning and performance. Acquisition curves may be predicted with high accuracy by an exponential equation whose asymptote, rate, and intercept constants jointly reflect inter-individual differences and whose form remains invariant over an extended range. The multiplicative law $R = f(T \times A \times S)$ is proposed for the discrimination-reaction task.

Psychologists interested in the theory of human learning and performance have devoted increasing attention during the past two decades to the role of individual-difference parameters. One specific hypothesis (Hull, 1945) maintains that human-factor differences affect the numerical constants rather than the mathematical forms of behavioral equations (cf. Reynolds & Adams, 1954; Spence, 1956; Adams, 1957; Noble, 1961). This implies that empirical laws of learning obtained inductively as group averages from statistically representative samples are *general* (nomothetic) laws in the sense that, when stratified parametrically into families of curves, no new formal characteristics should emerge in the full range of *particular* (idiographic) traits or abilities.

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Two of the major individual-difference variables affecting human learning and performance are *age* and *sex*. In studies of age researchers generally report a rapid increase in average proficiency from a chronological age of about 8 yr. up to the end of the second decade, then a brief period of relative stability followed by a slow, almost linear decrease in proficiency as the ninth decade is approached (Thorndike, 1928; Hovland, 1951; McGeoch & Irion, 1952; Welford, 1958; Morgan, Cook, Chapanis, & Lund, 1963; Birren, 1964). Cross-sectional sampling techniques applied to a number of learning-performance situations with different populations of *S*s have repeatedly produced this non-monotonic type of age-performance function, although the exact shapes of the curves are contingent upon task characteristics and the dependent variables measured (Koga & Morant, 1923; Jones, 1928; Willoughby, 1929; Miles, 1931; Miles, 1933; Miles, 1935; Ammons, R. B., Alprin, & Ammons, C. H., 1955; Birren & Botwinick, 1955; Braun & Geiselhart, 1959; Botwinick, Robbin, & Brinley, 1960; Shephard, Abbey, & Humphries, 1962).

There is rarely any consistent superiority of one sex over the other except when the task evokes specific motivational or associative processes that are culturally different between the sexes (McGeoch & Irion, 1952). This difference is marked in the area of perceptual-motor skills where males usually excel in tasks which capitalize upon speed or amplitude of response (Jones, 1944; Hunsicker, 1958; Noble, Fuchs, Robel, & Chambers, 1958; Francis & Rarick, 1959). Little of a systematic nature is known about possible interactions among age, sex, and amount of training in determining scores in psychomotor skills.

Our principal objectives in this research were to discover the quantitative relationships between *response speed* (R) as a function of 320 *practice trials* (T) on a discrimination reaction time apparatus, *chronological age* (A) in 15 categories over an 80-yr. range, and *biological sex* (S). The dependent variable, R, is theoretically related to the major independent variable, T, by the familiar exponential equation $R = m(1 - e^{-iT}) + c$, whose form has been rationalized by Hull (1943) and Spence (1956). Constants m, i, and c are empirical, representing the asymptote, rate, and R-intercept parameters, respectively, for each experimental group. Goodness-of-fit tests will be used to evaluate the extent to which the exponential hypothesis remains invariant over differences in the A and S factors as they affect m, i, and c.

Method

Apparatus.—Four units of the USAF Discrimination Reaction Time apparatus, Model D2, described in detail elsewhere (Melton, 1947) were used. As can be seen in Fig. 1, *S*'s task was to snap one of four toggle switches in response to the simultaneous lighting of a pair of red and green signal lamps. The relative position of the red lamp with respect to the green determined which of the four switches was correct. Reinforcing knowledge of results was provided by the offset of the white light.

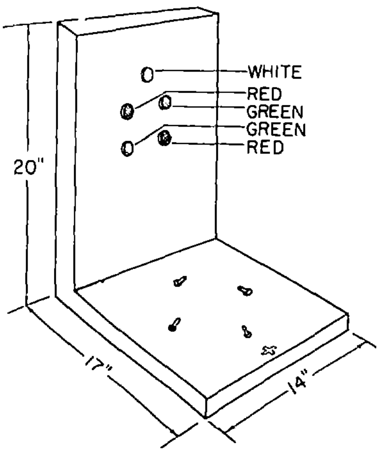

FIG. 1. *S*'s panel of the discrimination reaction time apparatus

A trial was defined as a single 3-sec. stimulus presentation. There was a variable fore-period between stimulus patterns which ranged from .5 sec. to 1.5 sec. and averaged 1 sec. Reaction time was cumulated on .001-min. synchronous clocks and recorded in blocks of 20 trials. The inter-block interval was 40 sec. except between Blocks 4 and 5, Blocks 8 and 9, and Blocks 12 and 13, when it was increased to 80 sec. to allow *E* time to reset the apparatus to the first pattern.

Subjects.—600 persons, ranging in chronological age from 8 to 87 yr. and divided equally between the two sexes, were recruited for the investigation. *Ss*

TABLE 1

CHRONOLOGICAL AGE RANGES AND MEDIAN AGES (A) IN YEARS FOR 30 GROUPS

Males			Females		
Group	Range	*Mdn*	Group	Range	*Mdn*
1	8-9	8.73	16	8-9	8.41
2	10-13	10.50	17	10-13	11.07
3	14-17	16.06	18	15-17	16.14
4	18	18.00	19	18	18.00
5	19	19.00	20	19	19.00
6	20	20.00	21	20	20.00
7	21	21.00	22	21	21.00
8	22-23	22.25	23	22-23	22.73
9	24-25	24.50	24	24-25	24.21
10	26-29	27.50	25	26-30	28.17
11	31-40	35.00	26	31-40	35.50
12	41-50	46.50	27	41-50	46.50
13	51-60	55.00	28	51-60	54.17
14	62-70	67.50	29	61-70	65.25
15	71-84	75.50	30	72-87	76.50

were assigned to 30 experimental groups, each group including 20 males (Groups 1 to 15) or 20 females (Groups 16 to 30). The age of each *S* was recorded in whole years rounded to the nearest birthday. Table 1 shows the chronological age ranges and medians for each group. An effort was made during original selection to have the median ages for the two sexes coincide. Examination of Table 1 reveals close spacing at those age levels where proficiency changes were expected to be greatest, i.e., from 18 to 21 yr.

In addition to psychology students enlisted routinely in classes at Montana State University, *S*s included young adult volunteers from a local high school, a school for nurses, and a business college. Older adults were recruited through the auspices of fraternal orders, civic organizations, women's clubs, associations for retired employees, agencies of the Federal government, and rest homes for the aged. Some children and adolescents were provided by an education class conducted during the University Summer Session; others were obtained through interested friends in the community. No *S*s had had prior experience with the apparatus and all served without remuneration.

Once *S*s had been selected, the only criteria of rejection were: (1) apparatus malfunctions, (2) inability of *S* to understand and comply with instructions, or (3) *S*'s physical impairment in sensory or motor capacities which are directly relevant to discrimination-reaction performance. Although the conventional procedures of recruiting *S*s for developmental studies of this type do not lend themselves to statistical evaluations of the amount of sampling error incurred with respect to variables other than age and sex, it is known that performance differences in psychomotor skills are not highly correlated with educational or occupational levels (Welford, 1958).

Procedure.—In the interest of efficiency and because of the importance of social influences on discrimination-reaction scores (Noble, Fuchs, Robel, & Chambers, 1958; Noble, Chambers, Fuchs, & Robel, 1959; Noble, Fuchs, Walters, & Chambers, 1959), the data were collected from groups of 2 to 4 *S*s at a time. When only 2 *S*s participated, they were positioned next to rather than opposite one another.

All 30 groups received standard USAF instructions, reported verbatim elsewhere (Melton, 1947; Noble, Alcock, & Frye, 1959). The instructions, accompanied by 4 demonstration trials, placed equal emphasis upon speed and accuracy. *E* corrected any *S* who deviated from the standard operating procedure and encouraged to greater effort those who appeared to be poorly motivated. Following the instructions, *S*s received 6 familiarization trials, then 320 training trials grouped into 16 blocks of 20 trials each. Except for the convenience of 8-yr.- and 9-yr.-old children in Groups 1 and 16, who were allowed to stand while performing, all *S*s were seated in front of the apparatus. They used the preferred (dominant) hand in manipulating the switches throughout the experiment.

Results and Discussion

After transforming the 16 cumulated reaction time (latency) scores for each *S* to reciprocals, the resulting measures of response speed (R) were combined for each group of 20 *S*s. Graphs of the arithmetic means of these R-scores plotted as a function of the 16 successive 20-trial blocks are presented in Fig. 2, with male and female curves of corresponding age groups plotted together.

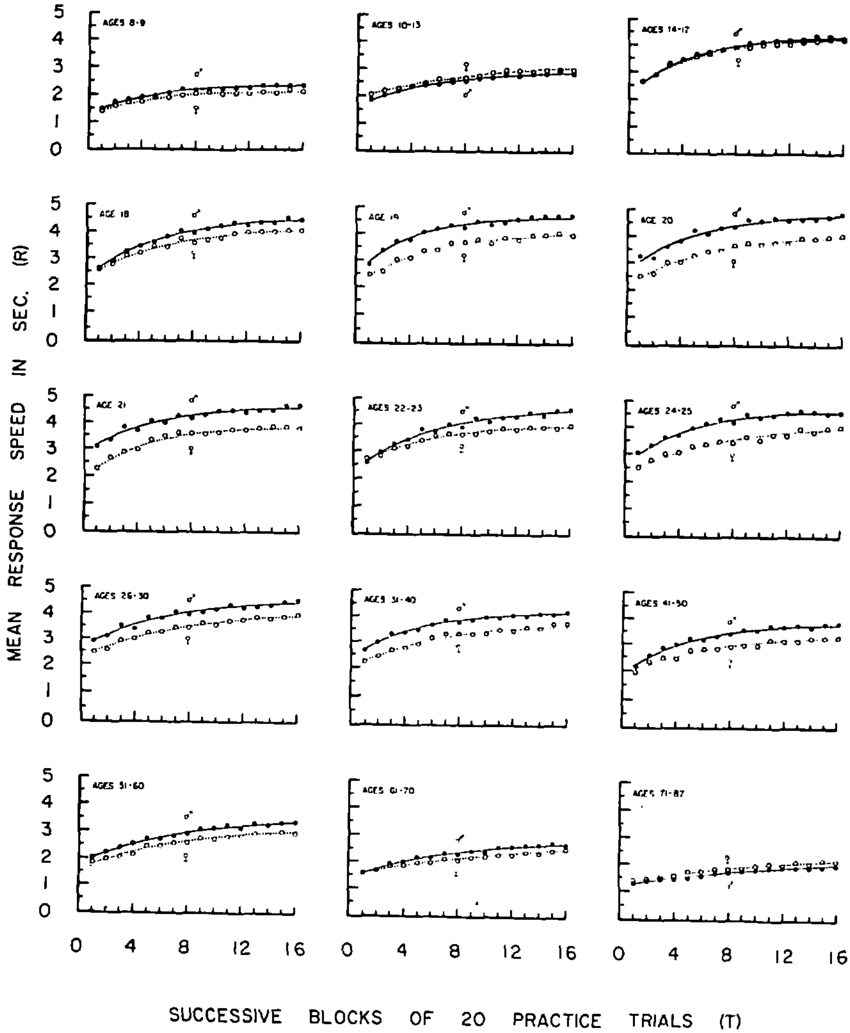

FIG. 2. Response speed (R) as a function of successive practice trials (T) for the 30 experimental groups. Each set of empirical points is based on the data for 20 *S*s, and the theoretical curves are computed from the equation $R = m(1 - e^{-iT}) + c$.

Best-fitting exponential curves were calculated from the equation, $R = m(1 - e^{-iT}) + c$, by allowing the parameters m, i, and c to vary simultaneously in order to satisfy the criterion of minimizing the variance of the residuals, defined as the discrepancies between the empirical (R_e) and theoretical (R_t) scores.[4] As a measure of goodness of fit, an index of determination $d(=100\sigma_t^2/\sigma_e^2)$ was computed for each of the curves in Fig. 2 by a method given in Noble (1957) for response probability curves. The statistic d is analogous to the coefficient of determination in linear regression; it specifies the percentage of variance in the dependent variable (R) which is predicted by the exponential equation. These goodness-of-fit indexes, recorded in Table 2 along with the asymptote,

TABLE 2

PARAMETERS OF ASYMPTOTE (m), RATE (i), AND INTERCEPT (c) FOR 30 ACQUISITION EQUATIONS WITH THEIR COEFFICIENTS OF DETERMINATION (d) EXPRESSED AS PERCENTAGES*

Group	Males				Group	Females			
	m	i	c	d		m	i	c	d
1	1.0884	−.1849	1.3398	98.50	16	.9444	−.2116	1.2308	96.34
2	1.2782	−.1581	1.7016	98.44	17	1.4131	−.1075	1.9028	97.56
3	2.2030	−.2126	2.1770	98.84	18	2.0607	−.1907	2.2817	98.83
4	2.3747	−.1845	2.2209	99.30	19	1.9696	−.1669	2.2382	98.15
5	2.2107	−.2560	2.4225	97.68	20	2.0205	−.1882	2.0618	97.76
6	2.2233	−.1907	2.6929	96.53	21	2.0027	−.1622	2.1592	98.18
7	1.8534	−.1839	2.8207	95.93	22	1.9902	−.2167	1.8993	99.06
8	2.4472	−.1714	2.2215	97.36	23	1.6713	−.1866	2.3648	98.43
9	2.1071	−.2185	2.5529	98.12	24	1.9276	−.1101	2.3775	96.98
10	1.9713	−.1606	2.6224	96.53	25	1.9100	−.1310	2.2567	98.87
11	1.8396	−.2144	2.3201	98.65	26	1.7993	−.1687	1.9364	98.45
12	2.1043	−.1995	1.8288	98.78	27	1.5578	−.1579	1.8232	97.15
13	1.7890	−.1274	1.8059	98.81	28	1.6325	−.1245	1.5978	98.46
14	1.4499	−.1487	1.3598	98.08	29	1.2881	−.0913	1.4586	98.46
15	1.2137	−.0682	1.1836	97.16	30	1.1840	−.0901	1.2308	98.02

*Values of m, i, and c have been rounded to four decimal places.

rate, and intercept parameters, ranged from a low d of 95.93% for Group 7 to a high d of 99.30% for Group 4. Mean predictability for males was 97.91%, for females 98.05%. The grand mean predictability for the 30 curves in the experiment was 97.98%, indicating excellent support for Hull's equation and for the invariance hypothesis.

An alternative analysis of the curves in Fig. 2 was performed to test the

[4]This method of successive approximations was programmed for the IBM 1620 Computer in collaboration with Prof. John A. Peterson, Director of the Montana State University Computer Center. The constant e has its conventional mathematical value of 2.718 (natural logarithmic system) rather than the special value of 10 (common logarithmic system) which Hull (1943) favored.

simpler hypothesis (Noble, C. E., Noble, J. L., & Alcock, 1958) that merely differences in rate of acquisition (i) might account for the major portions of the response variance associated with the age levels within each sex. Accordingly, for all *S*s of a particular sex we selected the group which had the highest m parameter, then used this value in fitting the curves of the remaining 14 groups. A similar procedure was followed for the lowest c parameter. Thus a maximum m and a minimum c value were taken as constants, with only i allowed to vary in determining the theoretical curves and the resulting values of d. For males the two pairs of fixed values were $m = 2.4472$, $c = 1.1836$; for females $m = 2.0607$, $c = 1.2308$. When these arbitrary parameters were inserted in the above curve-fitting procedure as "floor" and "ceiling" restrictions, the outcome was a very unsatisfactory set of curves. The mean predictability in terms of d value for males dropped to 60.24%, for females to 69.29%; the grand mean was only 64.76%. Thus our attempt to reject the initial hypothesis [that, given constant amounts of practice, $\Delta R = f(m, i, c)$] in favor of the alternative hypothesis [$\Delta R = f(i)$] was unsuccessful.

The second major set of results concerns relationships between over-all proficiency and age for the two sexes. In Fig. 3 are shown the mean total response

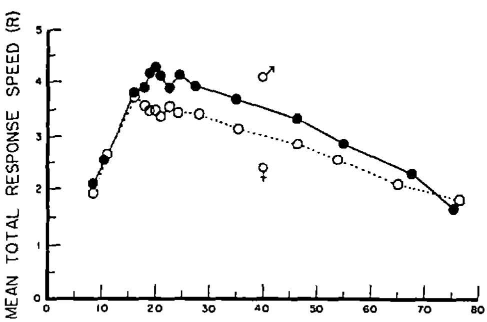

FIG. 3. Mean total response speed (R) as a function of median chronological age (A) for the two sexes (S). Each point is based on the data for 20 *S*s, averaged over the entire practice period.

speed scores (R) earned by each group over the 16 blocks of 20 trials, plotted as a function of median chronological age (A). As we were led to expect from the literature, the classical non-monotonic age-learning function was found, together with a general superiority of males over females in psychomotor speed. In only two age segments (10 to 13 yr. and 71 to 87 yr.) were females faster. The mean speed score of males (Groups 1 to 15) was 3.391 while that of females (Groups 16 to 30) was 3.018, a mean difference in R-units of .373. For both sexes the slope of the pre-maximum or "growth" segment was greater than the post-maximum or "decay" segment.

To determine the significance of the main effects of Trials (T), Age (A), Sex (S), and their interactions, a 16 × 15 × 2 mixed-factorial Type III analysis of variance (Lindquist, 1953) was performed upon the R-scores of Fig. 2 and 3. According to the summary presented in Table 3, all sources of variance except

TABLE 3
ANALYSIS OF VARIANCE OF SPEED SCORES AS A JOINT FUNCTION OF PRACTICE (T), AGE (A), AND SEX (S)

Source	*df*	*MS*	*F*	*P*
Within *Ss*	9000			
Trials (T)	15	106.071	1219.206	<.001
T × S	15	.439	5.045	<.001
T × A	210	.448	5.149	<.001
T × S × A	210	.098	1.126	<.10
Error (*w*)	8550	.087		
Between *Ss*	599			
Sex (S)	1	333.995	71.826	<.001
Age (A)	14	357.700	76.924	<.001
S × A	14	14.053	3.022	<.001
Error (*b*)	570	4.650		
Total	9599			

the three-factor T × A × S interaction were significant ($P < .001$). In addition, the T × A and T × S interactions establish the non-parallelism of the age and sex acquisition curves in Fig. 2; the A × S interaction is consistent with the data of Fig. 3; and the marginal T × A × S interaction ($P < .10$) implies that amount of training may itself interact with the two-factor age-sex interaction.

Referring again to Fig. 3, we observe that the two sexes appear to be quite similar in performance level and rate of growth up to the age of about 16, after which the females begin a fairly linear decline into the 70s. The males continue to improve to the age of 20, after which they, too, undergo a progressive impairment with advancing longevity. A slight curvilinearity in the post-maximum portion of the male curve causes a gradual narrowing of the gap in proficiency between the sexes until, in the seventh decade, the males ($R = 1.68$) finally fall below the level of the females ($R = 1.82$). It is interesting to note that, while there are many pre- and post-maximum correspondences in the two curves where the psychomotor performances of the young and old are statistically equivalent, men and women must attain septuagenarian status before their discrimination-reaction proficiency descends again to the level of childhood.

Two final analyses are shown in Table 4, one in terms of gain scores, the other in terms of variability. Gain scores were measured for each *S* as the difference between his performance on Blocks 1 and 16, as plotted in Fig. 2. A

TABLE 4
GAIN SCORES ($T_{10} - T_1$) AND VARIABILITY MEASURES (σ) FOR THE 30 GROUPS

Males			Females		
Group	$T_{10} - T_1$	σ	Group	$T_{10} - T_1$	σ
1	.861	.487	16	.734	.389
2	.969	.608	17	.953	.510
3	1.604	.586	18	1.726	.481
4	1.844	.484	19	1.496	.514
5	1.659	.478	20	1.489	.345
6	1.590	.488	21	1.523	.514
7	1.555	.459	22	1.534	.601
8	2.015	.378	23	1.281	.366
9	1.534	.491	24	1.497	.549
10	1.640	.504	25	1.490	.429
11	1.534	.513	26	1.386	.601
12	1.636	.669	27	1.323	.613
13	1.364	.686	28	1.139	.699
14	1.124	.672	29	.948	.516
15	.660	.373	30	.780	.402

graph of this portion of Table 4 as a function of age resembles Fig. 3, and is related to the i parameters in Table 2. Variability was computed as the standard deviation of the R-distributions in Fig. 3. It can be seen that there is little support in our data for Welford's (1958) belief in a universal positive relationship between inter-individual variability and chronological age. The product-moment correlation coefficients (r) between σ and A were only .23 for males and .24 for females. Neither r is significantly greater than zero ($P > .05$, $df = 13$).

Our data indicate that the exponential invariance hypothesis relating R to T is tenable over a wide age span and holds for both sexes, with coefficients of determination exceeding 95% in all cases. This provides additional verification of Hull's (1945) original theorem that individual differences affect the numerical constants rather than the mathematical forms of behavior equations. The goodness-of-fit tests make it clear, moreover, that rate of acquisition alone cannot be employed to describe differences in discrimination-reaction performance attributable to variations in age and sex. Asymptote and R-intercept parameters must also be considered. For compound trial-and-error learning, where response probability measures are employed to measure the growth of *Ss'* capabilities to select pre-established responses on cue (Noble, 1957), individual differences seem to influence the rate parameter alone (Noble, C. E., Noble, J. L., & Alcock, 1958). In the development of discrimination-reaction skill, where response-learning is a critical element alongside S-R association formation, not only rate but also initial proficiency, and probably asymptotic level as well, are affected (Adams, 1957); the same is true of rotary-pursuit performance (Reynolds & Adams, 1954). Although an adequate solution is still lacking, we recognize the problem of experimentally isolating the variance components attributable to "ability" and to "capacity" as one of fundamental importance, as Adams (1957) has suggested. To this distinction we now add an emphasis on the need for appropriate analyses of task factors in theorizing about human learning.

With respect to relationships between the acquisition of proficiency and age for the two sexes, the present results confirm the classical findings and extend our knowledge to include a broader principle of age-sex interaction, with amount of training (Fig. 2). The abstract form of this multiplicative law is: $R = f(T \times A \times S)$. But why is $A \times S$ significant? The initial rise in the age-performance curve (Fig. 3) from 8 to 20 yr. for males and from 8 to 16 yr. for females is doubtless a combination of sensorimotor maturation and transfer of (non-specific) training; one might, by experimental manipulation of *S*s' generalized experience in discriminating spatial cues and reacting promptly in selected directions, account for the differential maxima. As for the post-maximal decline, older *S*s are expected to perform less well than are teen-agers on tasks requiring speed in discrimination reaction for a number of reasons which have been reviewed by Welford (1958) and Birren (1964).

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