A Cross-Sequential Study of Age Changes in Cognitive Behavior[1]

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Abstract

Previous cross-sectional and longitudinal studies of age changes over the adult life span have reported contradictory age gradients. The apparent contradiction was assessed by means of a new research design, called the cross-sequential method, which involves the repeated measurement of members of a cross-sectional sample. The SRA Primary Mental Abilities Test (PMA) and Schaie's Test of Behavioral Rigidity (TBR) were administered to a stratified-random sample of 500 Ss with quotas of 25 men and 25 women in each 5-year age interval from 20 to 70 years. Seven years later all Ss who could be located were contacted and 302 Ss were retested. Significant cross-sectional age changes were found for all variables studied, but longitudinal age changes occurred for all cohorts only for those variables where response speed was of importance. Analysis of the comparative age gradients suggest that age changes over time within a given individual appear to be much smaller than differences between cohorts and that the steep text-book age gradients represent no more than the effects of increased environmental opportunity and/or genetic changes in the species. Further implications with respect to revisions in current thinking on adult age changes are discussed.

[1]Paper presented at the meeting of the Midwestern Psychological Association at St. Louis, Mo. April, 1964.
This investigation was supported by Public Health Service Research grant #HD-00367-02 from the National Institute of Child Health and Human Development. Acknowledgment is made to Betty Bostrom, Margaret Baltes, Robert F. Peterson, Judy Higgins and Pat Sand, who assisted in the testing and data analyses.

One of the pervading problems troubling the developmental psychologist who is interested in studying age changes over the adult life span has been the consistent reporting of contradictory age gradients found as the result of cross-sectional and longitudinal inquiries. Many cross-sectional studies report peak performance in the early twenties or thirties with steep decrement gradients thereafter (cf. Jones & Conrad, 1933; Schaie, 1958). Most longitudinal studies on the other hand report no decrement at all. In fact, slight gains in performance are recorded at least into the mid-fifties (Bayley & Oden, 1955; Owens, 1953). It has been argued that these contradictory findings can be accounted for by systematic sample attrition in the longitudinal studies, which tends to eliminate more Ss of low ability. It is also observed that none of the longitudinal studies have yet reached the sixties and seventies, the age range where the greatest decrement has been noted in the cross-sectional findings (Jones, 1959). The cross-sectional results have also been questioned because of the difficulties in the adequate matching of sub-samples over extensive age ranges (Schaie, 1959a). All these criticisms of both the cross-sectional and the longitudinal method may be well taken. They are unsubtle, however, in that they overlook the methodological problem which is the crux of the difficulty.

It will be shown elsewhere that the conventional cross-sectional and longitudinal methods are simply special cases of a general developmental model (Schaie, 1964). Let us point out here that they can be expected to yield similar age gradients only under very exceptional circumstances. The basis for this statement is the fact that the cross-sectional method compares scores for samples of Ss at different ages who belong to different cohorts (generations) but are measured at the same point in time. Differences between age groups could therefore be a function of actual age differences, or they could be a function of differences between cohorts, or due to both age and cohort differences. In the longitudinal method, one compares scores for a sample of Ss, belonging to the same cohort, measured at different ages, each measure taken at a different point in time. Differences here can therefore be a function of age differences, or of effects of the environment upon the sample over time, or due to both age and time differences. It follows that similar age gradients can be obtained from cross-sectional and longitudinal studies only if age differences are due to maturational phenomena alone, unrelated to any genetic or cultural variation. In most instances therefore, the cross-sectional method will always confound age differences with cohort differences and the longitudinal method will confound age and time differences.

It is possible to handle the above mentioned difficulty by deriving a design which will permit the joint analysis of age, cohort and time differences. In principle, this design would call for the longitudinal study of successive cohorts over the entire age range of interest. Such a design is, of course, not feasible due to the usual attrition problems as well as the limitations of the investigator's own lifespan. An efficient design, can, however, be suggested which will permit a relatively short-term investigation of the problem. The proposed design will be called the cross-sequential method since it involves the sequential analysis of data from two or more cross-sectional studies. To be precise, the requisite design involves the re-examination of a cross-sectional sample after a suitable time interval.[2] This design not only permits the evaluation of cross-sectional age gradients at two points in time, but it also permits the construction of a composite longitudinal age gradient, each section of which will represent the age change for a given cohort over a constant time interval. Since the effect of environmental change will be constant for each age group, it may therefore be argued that differences in such change ought to be due to the effect of maturational variance, and that the composite longitudinal age gradient offers a more proper comparison with the cross-sectional findings than would be given by a conventional longitudinal study.

Procedure

The SRA Primary Mental Abilities Test (PMA), the Test of Behavioral Rigidity (TBR) and a socio-economic status questionnaire were administered to a stratified-random sample of 500 Ss. Subjects were sampled from the membership of a prepaid medical plan with quotas of 25 men and 25 women from each five year age interval from twenty to seventy years of age (Schaie, 1958). Seven years later all Ss who could be located were contacted and 302 Ss were retested with the same instruments. The retested Ss are distributed approximately equal by age, with a slight preponderance of female Ss. Comparison of socio-economic data for the original and attrited sample suggest that the attrition was fairly random and not significantly biased by socio-economic factors.

The analysis of variance was used to test the significance of the age-cohort (cross-sectional) and age-time (longitudinal) differences and their interaction with sex-differences. Results will be reported for the Ss tested on both occasions for variables involving intellectual ability, response tendencies and attitudes. These include in the area of intellectual abilities the variables of Verbal Meaning, Space, Reasoning, Number and Word Fluency. Following the PMA manual (Thurstone & Thurstone, 1949), scores were derived also for a general index of intellectual ability (V + S + 2R + 2N + W) and an index of educational aptitude (2V + R). From the Test of Behavioral Rigidity (Schaie, 1955; 1960), data are reported on the variables of Motor-cognitive Rigidity, Personality-perceptual Rigidity, Psychomotor speed and a scale of Social Responsibility (Gough, McCloskey & Meehl, 1952; Schaie, 1959b). To facilitate comparisons, all scores were transformed into T scores with means of 50 and standard deviations of 10 using as a base the first test administration to a sample of 1000 adult Ss (Schaie & Strother, 1964).

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[2]The repeated measurement aspect is a convenient but not a necessary feature of the cross-sequential method. A cross-sequential study with independent samples on the different measurement occasions will be reported elsewhere (Schaie & Strother, 1964).

Results

The results of the analysis of variance, reported in Table 1, yield cohort differences significant at the .001 level of confidence for all variables except social responsibility.[3] The replicability of cross-sectional sub-sample differences over two administrations for measures of ability and cognitive response style is thereby demonstrated. Quite different findings occur for the analysis of the longitudinal time differences. If the hypothesis of intellectual decrement with age is justified, then one should expect that over a seven year interval, decrement will occur at every adult age level and for every cohort followed over such a period of time. Such overall time differences, however, were found to be significant only for two variables which are primarily measures of response speed and fluency (Verbal Meaning on the PMA and Psychomotor Speed on the TBR) and for the intellectual ability index of which the Verbal Fluency test is a component. It must be concluded therefore, that the cross-sectional differences for all other variables represent differences between generations rather than age changes.

Matters are not quite as straight-forward as they might appear at this point. An account must be rendered for the numerous significant interactions between the time and cohort levels. Such significant interactions imply that there are positive age changes for some cohorts and negative changes for others. Interactions significant at the .001 level of confidence were found for all variables except Space, Word Fluency and Motor-cognitive Rigidity.

Additionally, the analysis of variance revealed significant sex differences for Space and Psychomotor Speed. A significant triple interaction between time, cohort and sex was furthermore found for Number. The latter finding suggests that the shape of the age gradient for Number will differ for men and women.

Test-retest reliability estimates were also obtained from the analyses of variance which, as reported in the last column of Table 1, range from .64 for Motor-cognitive rigidity to .94 for the PMA estimate of intellectual ability.

We must next concern ourselves with the problem of constructing appropriate gradients which will permit comparisons between the cross-sectional and longitudinal findings provided by this study. Tables 2 to 12 report mean scores for each of the eleven variables separately by sex and measurement occasion. The combined means for both sexes are also reported for both times of measurement. These latter data were used to construct the age gradients since none of the sex-time interactions and only one of the sex-time-cohort interactions were found to be significant at or beyond the 1% level of confidence.

The last two columns in Tables 2 to 12 give the predicted mean scores for the youngest group of Ss (Cohort 10) for the age range from 25 to 70 years as obtained from cross-sectional and longitudinal data.

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[3]The social responsibility measure, however, attains cohort differences significant at the .05 level of confidence.

The cross-sectional estimates were obtained by averaging the two mean scores available for each cohort. The longitudinal estimates were obtained by calculating average age changes over a five year interval for each age interval in the range covered. To reduce sampling variability each estimate was based on two cohorts. For example, the longitudinal age change from 25 to 30 was computed by subtracting the mean scores for cohorts 9 and 10 obtained in 1963 from the corresponding mean scores in 1956, and then multiplied by 5/7 to adjust for the disparate time span. A composite longitudinal gradient can then be constructed beginning with the known average base of the cohort. Similar predicted longitudinal gradients could, of course, also be constructed for each of the other cohorts by adding or subtracting the longitudinal age changes from their known base.

Figures 1 to 22 provide graphic representations of the various age gradients. Two sets of gradients are provided for each variable. The first figure in each case presents the two cross-sectional gradients at the two times of measurement. This comparison may be used to identify the age level at which no further increment in test performance occur and/or where decrement begins. Visual comparison is also offered here for relative magnitude of change over time for the various cohorts measured in our study.

The second figure for each variable, however, is of greatest interest as well as theoretical and practical importance. Here we compare the age gradients obtained on the basis of the current performance of individuals at different ages who are members of different cohorts with the estimated longitudinal age gradient for a <u>single</u> cohort. If the cross-sectional age differences for a given variable were a function solely of maturational change, then one would expect the two gradients to coincide. If, on the other hand, cross-sectional differences include the effects of differential environmental opportunity and/or genetic changes in the species, then one would expect discrepancies between the two gradients. Whenever cohort differences are in the positive direction (i.e. Improvement of the species with respect to a given variable) the cross-sectional gradient will have to drop below the longitudinal, since in such case the performance of an older cohort will be below that of a younger even if there is no maturational age change whatever. Conversely, the longitudinal gradient will fall below the cross-sectional for those variables where there is decrement in ability over generations for the population sampled.

In the following paragraphs we shall examine the age gradients for each of the variables included in this study and shall attempt to highlight appropriate inferences to be drawn from these findings.

Verbal Meaning (V). This is the ability to understand ideas expressed in words. It is important in any activity involving the transmission of verbal or written communication. The cross-sectional data place the peak on this ability at age 35, and suggest a decrement from peak age of as much as 1½ population standard deviations. The cross-sequential analysis, however, reveals that actual decrement does not occur for any cohort until age 60. The longitudinal data place the peak age for V at age 55 and indicate that the decrement for the remainder of the range studied is less than half a sigma and that the predicted mean score at age 70 is still above the mean score for age 25. The steep cross-sectional gradient must be attributed to increased level of verbal ability in successive cohorts, presumably due to increasingly favorable environmental experience. It will be noted that the improvement gradient is reaching an asymptote. In fact, cohorts 8 and 9 (born in the late twenties and early nineteen thirties) show a more favorable position than the last cohort. Comparison of the two gradients suggests that age decrement on V within generations is quite mild and probably not seriously disabling until very old age (see Strother, Schaie & Horst, 1957).

Space (S) is the ability to think about objects in two or three dimensions and is important in being able to see the relations of an arrangement of objects in space. Significant sex differences in favor of males occur for this ability. The age gradients, however, maintain the same shape for both sexes and joint analysis seems therefore warranted. The peak age estimated by the cross-sectional gradient for S is at 30 years. The decrement from the peak level to age 70 is approximately 1½ S. D. The cross-sequential analysis shows an ability plateau from approximately 35 to 55 years. The longitudinal data places the actual peak at age 35 but also show that the age changes over the entire range studied are almost trivial and that the miximum age decrement is less than 1/2 S. D. The steep cross-sectional gradient must again be attributed to increasing ability for successive cohorts on S. Here too, an asymptote seems to appear with the last two cohorts showing approximately comparable ability. These results may have important implications for retirement practices involving pilots, draftsmen, engineers and other occupations which require high level of functioning on S. Older members of such professions have in the past compared unfavorably with their younger peers, in the light of these results, not because their ability had declined, but because the younger generation had greater ability to begin with. If an asymptote has been reached, however, the apparent decrement will be lessened or will no longer appear when the present generation will be compared with younger individuals.

Reasoning (R) is the ability to solve logical problems, to foresee consequences and make and carry out plans according to recognizable facts. The peak age for R is estimated at 25 years by the cross-sectional data and the maximum decrement exceeds 1½ standard deviations. The cross-sequential data show continuing increments until age 35 and a plateau until approximately 45. The longitudinal data place the peak age for this ability at 40 years and do not show any substantial decrement until 60. There is a drop of close to 2/3 S. D. from peak age, a longitudinal age change which barely reaches significance at the 5% level of confidence. Differences among generations are again much in excess over the decrement within a given generation. The cohort gradient for R has not yet reached its asymptote but it does show leveling off for the last three cohorts. There is some question whether the time limits imposed in this test are too stringent and it is possible that the longitudinal age gradient might flatten out further in a comparable power test.

Number (N) is the ability to work with figures and to handle simple quantitative problems rapidly and accurately. The cross-sectional data place the peak for N at age 50, with an approximate ½ sigma gain from age 25 and an approximate decrement of 4/5 standard deviations until age 70. Actual gain here occurs until age 65. The longitudinal gradient is considerably flatter than the cross-sectional with the 70 year old level predicted to be above the performance of the 25 year olds. The maximum age decrement at age 70 is less than ¼ sigma and probably of no practical consequence. The cohort gradient here is quite curvilinear and suggests that an ability peak was reached by the generation born in the early twenties with a slight but not statistically significant decline for the subsequent cohorts. There are differences in gradients for men and women, with less decrement for the female Ss.

Word Fluency (W) is the ability to write and talk easily. It is measured by emitting the largest possible number of words beginning with a given letter in a brief period of time. The cross-sectional measures for this attribute place the peak age for W at 35 years and note a decrement of approximately 1 S. D. The cross-sequential analysis, however, notes decrements for every cohort beginning at age 25, at which age the longitudinal analysis would place the peak performance. A highly significant longitudinal age difference is found here which is much in excess of differences between generations. In fact, the longitudinal estimates predict a decrement of 2½ standard deviations within a given cohort. The cohort gradient for this variable is negative and suggests that we are only about to reach a low asymptotic level. What is the explanation for these findings? It may be suggested that Word Fluency is a highly speeded test which requires a quick response and emission of familiar material. It is well known that reaction time increases as a function of age. Word Fluency may therefore perhaps be a better measure of physiological than psychological response capacity. What about the negative cohort gradient? Just as an enriched environment leads to higher ability levels so does it obviate the necessity for physical exertion. The present findings certainly suggest decrement in the fluency and response latency of successive generations. Similar investigations with purer measures of speed and response strength will, of course, be required to confirm this inference.

Index of Intellectual Ability. This index is merely a composite of the five PMA variables weighted approximately inversely to their standard deviations. It should give a reasonable estimate of a person's general level of intellectual functioning. The cross-sectional data place the peak for this global measure at age 35 and yield a decrement gradient in excess of 1½ standard deviations. The cross-sequential study shows increment on this measure until age 35 and decrement for all ages thereafter. The longitudinal gradient for this measure is remarkably similar to the cross-sectional gradient. The absolute maximum decrements are almost alike, but the longitudinal gradient is not quite as steep. It appears that inclusion of Word Fluency, with its steep longitudinal decrements at older ages, has the effect of matching the decrement gradient within generations closely to that between generations for a composite measure of intelligence. The meaning of composite measures of intelligence for developmental studies must therefore be viewed with great caution.

Index of Educational Aptitude. Thurstone (1958) has advocated that the combination 2V + R has been found to be a convenient scholastic aptitude measure which may also be used as a verbal IQ measure similar in meaning to the quotients yielded by tests such as the Otis or Kuhlmann-Anderson. This index does not contain any highly speeded measures and our findings therefore differ markedly from those given for the global index of intelligence. The cross-sectional gradient again attains a peak at age 35 and the maximum decrement amounts to 1½ standard deviations. Actual age changes, however, show increments up to age 55, the peak estimated by the longitudinal data. The maximum decrement for this index is less than ½ sigma, and the estimated level at age 70 is above that found at age 25. The cohort gradient for the index of educational aptitude appears to have reached an asymptote with comparable levels of ability for the last three cohorts. These results have obvious implications for educational policies and points to the ever increasing importance of adult education programs. It moreover suggests that future manpower retraining programs may well be effectively utilized throughout the adult working force without particular age limitations.

Motor-cognitive Rigidity (MCR). This measure indicates the individual's ability to shift from one activity to another. It is a measure of effective adjustment to shifts in familiar patterns and continously changing situational demands. The cross-sectional gradient for MCR peaks at age 25, shows a fairly stable plateau from 30 to 50 years and then declines steeply, with a maximum decrement of 1¼ standard deviations. The cross-sequential study found increments for all cohorts except the next to the oldest group. As a result the estimated longitudinal gradient shows positive acceleration with a peak at age 60 and a virtual plateau until age 70. This variable shows a predicted longitudinal gain in excess of ½ sigma. The cohort gradient is correspondingly steep and has not yet reached an asymptote. We find some difficulty in evaluating these unexpected findings. It is, of course, conceivable that as a result of a life-long practice people do get more proficient and flexible in dealing with the demands of familiar situations. We are somewhat concerned, however, that there may have been some practice effect on this measure which involves somewhat unusual tasks which may have been remembered by the Ss. Another problem is the possibility that more careful administration and scoring might have led to some systematic increase in scores obtained for the second testing. Nevertheless, the results are such that it should at least be concluded that there is no MCR decrement within generations, but that there are highly significant and still ongoing positive shifts in the level of performance on this variable over successive generations.

Personality-perceptual Rigidity (PPR). This measure indicates the individual's ability to adjust readily to new surroundings and change in cognitive and environmental patterns. It is a measure of ability to percieve and adjust to unfamiliar and new patterns and situations. The average cross-sectional peak here is placed at age 25.[4] Maximum decrement for PPR amounts to slightly above 1 standard deviation. The cross-sequential analysis shows decrements beginning with age 35, but there are several reversals, with an increment appearing as late as the next to the oldest cohort. There is no distinct longitudinal peak but instead a peak plateau extending from 30 to 50 years. Maximum decrement is approximately 2/3 sigma, indicating that there is some within generation loss in flexibility in adjusting to unfamiliar patterns. This loss becomes noteworthy only in the late sixties and even seventy is predicted to be only approximately ½ sigma below the status at age 25. The cohort gradient, while significant, is much less steep than for most other variables. It is positively accelerated, however, and has not yet reached its asymptote.

Psychomotor Speed (PS). This measure indicates the individual's rate of emission of familiar cognitive responses. This measure is the other variable in our battery which is highly speeded and the resulting age gradients are consequently quite similar to the ones obtained for the PMA measure of Word Fluency. The cross-sectional gradients peaks at age 30 with a maximum decrement of 1.2 standard deviations. The within generation decrement here is larger than the between generation differences. Decrements over time are noted for every cohort studied. The longitudinal gradient peaks at age 25 and shows a predicted decrement in excess of 2 standard deviations. It appears then that the cross-sectional data on PS underestimate the within generation decrement and that this is another characteristic where the level of ability for the population has declined for successive generations. The inter-generation decrement curve appears to have reached its asymptote since the ability for the last two cohorts are roughly comparable. PS shows sex differences in favor of the female Ss. The age gradients, however, are similar for both sexes.

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[4]This was the only variable for which the peak ages obtained in the cross-sectional gradients differed between the two test occasions. In 1956 the peak appeared in the 31-35 year old group, but the 21-25 year olds obtained the highest mean score in the retest.

Social Responsibility(SR). The final variable to be examined has slightly different characteristics from the remainder of our measures in that it is strictly an attitude scale. This is the only variable for which cohort differences failed to reach the .01 level of confidence in the variance analysis. However, cohort differences were found to be significant at the 5% level, and the cross-sectional gradient peaks at age 55, with an increment of 3/4 sigma from the youngest age and a decrement of ½ sigma until age 70. Increments over time occur for SR for all cohorts until age 55. The longitudinal gradients peaks at ages 50 and 55. Increments and decrements are quite similar to the cross-sectional findings with a somewhat smoother decrement gradient after age 55. We must conclude that the cohort differences for SR are adequately accounted for by maturational changes in attitudes, except for the three oldest cohorts where some shift over generations in favor of more responsible attitudes seems to occur.

Conclusions

The most important conclusion to be drawn from this study consists of the finding that a major portion of the variance attributed to age differences in past cross-sectional studies must properly be assigned to differences in ability between successive generations. Age changes over time within the individual appear to be much smaller than differences between cohorts, and text-book age gradients may represent no more than the effects of increased environmental opportunity and/or genetic improvement in the species. The findings on longitudinal age changes suggest further that levels of functioning attained at maturity may be retained until late in life except where decrement in response strength and latency interferes. The finding that many of the cohort difference curves appear to reach asymptotic levels moreover, suggests many implications for adult education and retirement practices.

There are several serious limitations to the present study. All our estimates are based on two points in time and it is conceivable that we have selected a particularly atypical time span for our study. The only remedy for this problem is, of course, replication over a different time span. The second problem is due to the possible effect of practice on test performance. A seven year span appears long enough to take care of this problem, but it cannot be dismissed as being altogether trivial. Moreover, it is conceivable that the subjects whom we were able to retest do not represent a truly random sample of the original population, a problem implicit in any repeated measurement study. The latter problem is currently being dealt with by repeating the present study with an independent sampling design. A new random sample was drawn and tested in 1963, the results from which will be compared with the entire original 1956 sample. These data will permit estimation of the effects of practice and contribute further information on the validity of our estimated age gradients.

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Table 1. F-ratios from the Analysis of Variance of Cross-sectional and Longitudinal Age Differences[a]

Variable	Cohort Diff.[b] 9 df	Sex Diff. 1 df	Cohort x Sex 9 df	Time Diff.[c] 1 df	Cohort x Time 9 df	Sex x Time 1 df	Cohort x Sex x Time 9 df	r_{tt}
Verbal Meaning	14.20**	2.62	. .	1.68	3.11*	4.86*	. .	.88
Space	13.30**	20.26**	. .	1.56	1.30	. .	. .	.75
Reasoning	20.41**	4.59*	. .	4.03*	3.07*	. .	. .	.93
Number	3.44**	. .	1.33	1.44	3.60**	. .	2.70*	.91
Word Fluency	3.63**	3.41	. .	80.61**	1.79	2.19	. .	.86
Intellectual Ability	13.11**	. .	. .	14.85**	7.30**	. .	1.43	.94
Educational Aptitude	17.76**	3.28	1.23	. .	4.49**	3.94	. .	.92
Motor-Cognitive Rigidity	15.88**	3.24	. .	5.60	. .	. .	. .	.64
Personality Perceptual Rigidity	8.35**	. .	. .	2.67	4.62**	4.96	. .	.85
Psychomotor Speed	10.13**	25.94**	1.45	132.74**	5.31**	. .	1.45	.89
Social Responsibility	2.19	. .	. .	1.55	2.75*	4.40	1.70	.78

[a]The denominator in the first three F-ratios is based on 281 df attributable to the residual mean square for the independent observations and the denominator in the remaining F-ratios is based on 281 df attributable to the residual mean square for the correlated observations.

[b]Usually called "Cross-sectional age differences."

[c]Usually called "Longitudinal age differences."

*Significant at or beyond the .01 level of confidence.

**Significant at or beyond the .001 level of confidence.

Table 2. Mean Scores for Verbal Meaning

Cohort (Age)	Male 1956	Male 1963	Female 1956	Female 1963	Total 1956	Total 1963	Average Cross-Sectional	Average Longi-tudinal
1 (70)	42.1	40.7	44.1	41.4	43.1	41.0	42.1	55.7
2 (65)	42.9	40.6	45.7	41.7	44.3	41.1	42.7	57.6
3 (60)	48.2	47.9	48.5	45.4	48.3	46.6	47.5	59.3
4 (55)	53.4	55.1	47.8	49.3	50.6	52.2	51.4	59.6
5 (50)	50.2	52.1	56.4	53.1	53.3	54.6	53.9	58.6
6 (45)	49.6	51.8	54.2	54.0	51.9	52.9	52.4	57.8
7 (40)	55.0	56.7	55.8	56.4	55.4	56.6	56.0	57.0
8 (35)	55.9	57.5	56.2	57.7	56.1	57.6	56.9	56.0
9 (30)	53.4	54.7	57.7	58.4	55.5	56.6	56.1	55.1
10 (25)	47.3	54.5	54.7	56.3	51.0	55.4	53.2	53.2

Table 3. Mean Scores for Space

Cohort (Age)	Male 1956	Male 1963	Female 1956	Female 1963	Total 1956	Total 1963	Average Cross-Sectional	Average Longi-tudinal
1 (70)	44.9	40.3	40.3	39.9	42.6	40.1	41.3	53.5
2 (65)	47.2	44.8	43.1	39.8	45.2	42.3	43.7	55.4
3 (60)	53.7	51.0	42.2	42.8	48.0	46.9	47.4	56.8
4 (55)	49.5	47.7	44.3	46.3	46.9	47.0	46.9	57.1
5 (50)	50.7	48.7	51.1	50.5	50.9	49.6	50.3	56.7
6 (45)	51.2	51.8	46.6	48.3	49.0	50.1	49.5	56.7
7 (40)	53.6	53.1	49.9	49.4	51.7	50.8	51.3	56.6
8 (35)	56.4	57.3	52.4	50.5	54.4	53.9	54.2	57.1
9 (30)	57.5	58.9	56.1	56.1	56.8	57.5	57.2	56.6
10 (25)	58.0	58.7	51.7	54.4	54.8	56.6	55.7	55.7

Table 4. Mean Scores for Reasoning

Cohort (Age)	Male 1956	Male 1963	Female 1956	Female 1963	Total 1956	Total 1963	Average Cross-Sectional	Average Longi-tudinal
1 (70)	39.9	37.8	43.0	39.9	41.5	38.9	40.2	53.4
2 (65)	41.6	39.8	44.5	41.2	43.0	40.5	41.8	55.2
3 (60)	47.5	44.4	46.6	45.5	47.0	45.0	46.1	56.9
4 (55)	50.6	49.9	47.6	47.3	49.3	48.1	49.9	58.1
5 (50)	49.5	49.4	54.8	53.7	52.2	51.5	51.9	58.4
6 (45)	52.0	52.0	52.5	51.5	52.2	51.8	52.0	59.1
7 (40)	51.5	49.7	52.5	54.2	52.0	52.0	51.9	59.3
8 (35)	54.0	56.2	57.2	58.0	55.6	57.1	56.3	58.7
9 (30)	56.1	55.9	56.5	58.6	56.3	57.3	56.8	57.9
10 (25)	54.5	55.4	58.2	60.0	56.4	57.7	57.0	57.0

Table 5. Mean Scores for Number

Cohort (Age)	Male 1956	Male 1963	Female 1956	Female 1963	Total 1956	Total 1963	Average Cross-Sectional	Average Longi-tudinal
1 (70)	45.7	43.3	48.0	45.5	46.9	44.4	45.6	50.5
2 (65)	47.1	44.5	45.2	43.3	46.2	43.9	45.0	52.2
3 (60)	49.5	48.5	48.0	48.9	48.7	48.7	48.7	53.0
4 (55)	51.5	52.0	50.7	49.7	51.1	50.8	51.0	53.1
5 (50)	54.1	53.0	53.5	54.4	53.8	53.7	53.8	53.2
6 (45)	55.0	55.7	47.1	48.8	51.0	52.3	51.7	52.8
7 (40)	51.7	54.3	53.2	52.4	52.4	53.4	52.9	52.0
8 (35)	54.9	54.5	48.2	51.7	51.5	53.1	52.3	51.1
9 (30)	49.2	50.5	51.3	51.7	50.2	51.1	50.6	50.3
10 (25)	42.6	51.3	49.7	50.0	46.2	50.6	48.4	48.4

Table 6. Mean Scores for Word Fluency

Cohort (Age)	Male 1956	Male 1963	Female 1956	Female 1963	Total 1956	Total 1963	Average Cross-Sectional	Average Longi-tudinal
1 (70)	47.4	42.0	46.1	41.3	46.8	41.7	44.2	25.6
2 (65)	50.1	43.6	51.1	43.8	50.6	43.7	47.2	29.9
3 (60)	52.1	48.7	51.0	42.0	51.6	47.6	49.6	33.8
4 (55)	53.4	48.1	53.4	49.9	53.4	49.0	51.2	36.8
5 (50)	50.4	47.9	59.7	55.1	55.1	51.5	53.3	39.6
6 (45)	51.2	49.1	56.4	52.7	53.8	50.9	52.4	41.9
7 (40)	53.4	48.8	55.1	52.5	54.3	50.7	52.5	44.2
8 (35)	55.8	52.3	58.6	51.4	57.2	51.9	54.5	47.4
9 (30)	51.9	50.6	53.5	52.3	52.7	49.9	52.1	49.8
10 (25)	48.3	51.1	54.3	49.2	51.3	49.9	50.7	50.7

Table 7. Mean Scores for Intellectual Ability

Cohort (Age)	Male 1956	Male 1963	Female 1956	Female 1963	Total 1956	Total 1963	Average Cross-Sectional	Average Longi-tudinal
1 (70)	42.3	38.2	43.3	39.6	42.8	38.9	40.8	40.8
2 (65)	44.6	40.5	44.6	39.7	44.6	40.1	42.4	45.5
3 (60)	50.7	47.4	46.9	45.1	48.8	46.3	47.3	49.9
4 (55)	52.0	50.6	48.9	48.0	50.5	49.3	49.9	51.2
5 (50)	52.4	50.7	56.6	55.8	54.5	53.3	53.9	52.0
6 (45)	53.9	53.4	50.3	51.1	53.6	50.7	52.2	53.5
7 (40)	53.7	53.4	55.1	53.8	54.4	53.6	54.0	54.8
8 (35)	57.0	57.1	55.1	55.4	56.0	56.2	56.1	55.0
9 (30)	54.0	54.7	55.7	56.5	54.9	55.6	55.2	54.5
10 (25)	49.3	54.9	54.4	54.7	51.9	54.8	53.3	53.3

Table 8. Mean Scores for Educational Aptitude

Cohort (Age)	Male 1956	Male 1963	Female 1956	Female 1963	Total 1956	Total 1963	Average Cross-Sectional	Average Longitudinal
1 (70)	41.9	40.2	44.1	40.9	43.0	40.5	41.8	55.4
2 (65)	42.9	40.9	45.7	41.8	44.3	41.4	42.8	57.3
3 (60)	48.3	47.3	48.3	45.7	48.3	46.3	47.4	59.0
4 (55)	53.0	53.8	48.0	49.1	50.5	51.5	51.0	59.4
5 (50)	50.3	51.6	56.2	56.2	53.3	53.9	53.6	58.8
6 (45)	50.4	52.1	54.0	53.6	52.2	52.9	52.5	58.3
7 (40)	54.4	55.2	54.9	56.1	54.7	55.6	51.4	57.8
8 (35)	55.5	57.4	56.7	58.0	56.1	57.7	56.9	56.8
9 (30)	54.3	55.2	57.6	58.7	55.9	57.0	56.4	55.9
10 (25)	49.8	54.6	55.8	57.4	52.8	56.0	54.4	54.4

Table 9. Mean Scores for Motor Cognitive Rigidity

Cohort (Age)	Male 1956	Male 1963	Female 1956	Female 1963	Total 1956	Total 1963	Average Cross-Sectional	Average Longitudinal
1 (70)	43.5	47.4	42.9	41.9	43.2	44.6	43.9	64.0
2 (65)	46.5	45.8	48.2	45.6	47.9	45.7	46.5	64.1
3 (60)	47.3	49.3	48.4	48.7	47.8	49.0	48.4	64.2
4 (55)	52.4	55.2	46.9	51.4	49.7	53.3	51.5	62.5
5 (50)	51.9	53.4	53.7	54.9	52.8	54.2	53.5	60.7
6 (45)	53.4	55.0	51.1	52.7	52.3	53.9	53.1	59.7
7 (40)	51.3	56.3	49.9	54.7	50.6	55.5	53.1	57.4
8 (35)	53.5	54.9	53.9	53.3	53.7	54.1	53.9	55.5
9 (30)	54.5	53.8	54.2	52.2	54.4	53.0	53.7	55.7
10 (25)	56.0	57.3	56.6	55.1	56.3	56.2	56.3	56.3

Table 10. Mean Scores for Personality-Perceptual Rigidity

Cohort (Age)	Male 1956	Male 1963	Female 1956	Female 1963	Total 1956	Total 1963	Average Cross-Sectional	Average Longi-tudinal
1 (70)	46.6	43.3	45.3	44.1	45.9	43.7	44.8	49.6
2 (65)	46.6	43.7	48.4	45.3	42.5	44.5	46.0	51.5
3 (60)	49.9	44.0	49.0	46.7	49.5	45.4	47.5	54.0
4 (55)	49.0	47.8	49.0	47.8	49.0	47.8	48.4	55.9
5 (50)	51.1	50.0	53.5	52.5	52.3	51.3	51.8	56.8
6 (45)	48.1	49.1	49.2	52.1	48.7	50.6	49.6	56.8
7 (40)	55.1	52.3	50.5	52.3	52.8	52.3	52.4	56.3
8 (35)	55.7	54.3	53.5	53.4	54.6	53.9	54.3	56.8
9 (30)	53.9	55.4	54.3	54.4	54.1	54.9	54.5	56.9
10 (25)	52.1	57.8	53.9	56.7	53.0	57.3	55.1	55.1

Table 11. Mean Scores for Psychomotor Speed

Cohort (Age)	Male 1956	Male 1963	Female 1956	Female 1963	Total 1956	Total 1963	Average Cross-Sectional	Average Longi-tudinal
1 (70)	44.5	36.5	46.2	40.3	45.3	38.4	41.9	28.7
2 (65)	42.9	37.2	49.0	42.0	45.9	39.6	42.8	33.4
3 (60)	47.0	42.8	50.2	44.6	48.6	43.7	46.2	37.6
4 (55)	51.8	47.9	50.9	44.6	51.4	46.3	48.8	41.2
5 (50)	49.4	45.6	55.6	51.5	52.5	48.6	50.5	44.2
6 (45)	51.8	49.1	51.7	51.6	51.8	50.3	51.0	46.1
7 (40)	53.6	44.9	56.3	53.2	54.9	49.1	52.0	48.7
8 (35)	48.6	49.1	54.2	52.9	51.4	51.0	51.2	51.0
9 (30)	49.8	49.4	59.0	57.4	54.4	53.4	53.9	51.5
10 (25)	49.8	48.1	57.2	55.0	53.5	51.6	52.5	52.5

Table 12. Mean Scores for Social Responsibility

Cohort (Age)	Male 1956	Male 1963	Female 1956	Female 1963	Total 1956	Total 1963	Average Cross-Sectional	Average Longitudinal
1 (70)	49.1	50.7	52.3	52.6	50.7	51.6	51.2	51.3
2 (65)	54.3	51.8	53.4	47.7	53.8	49.7	51.8	52.4
3 (60)	51.3	46.2	51.4	50.7	51.3	48.4	49.9	54.9
4 (55)	56.1	58.5	55.7	54.2	55.9	56.3	56.1	55.8
5 (50)	54.3	55.3	55.4	53.9	54.9	54.6	54.7	55.8
6 (45)	49.5	55.4	52.0	54.7	50.8	55.1	52.9	54.3
7 (40)	52.7	55.5	49.9	52.2	51.3	53.9	52.6	51.8
8 (35)	47.7	49.0	50.9	50.2	49.3	49.6	49.5	50.8
9 (30)	49.6	50.7	50.7	52.0	50.1	51.3	50.7	50.3
10 (25)	43.8	52.3	49.2	48.4	46.5	50.4	48.4	48.4

CROSS-SECTIONAL AGE GRADIENTS Verbal Meaning

Figure 1

ESTIMATED AGE GRADIENTS Verbal Meaning

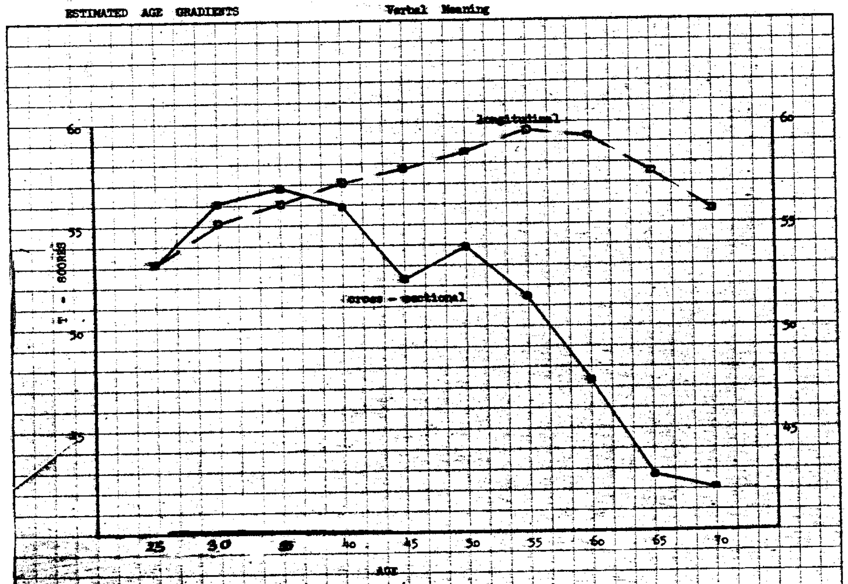

Figure 2

Cross-Sectional AGE GRADIENTS Space

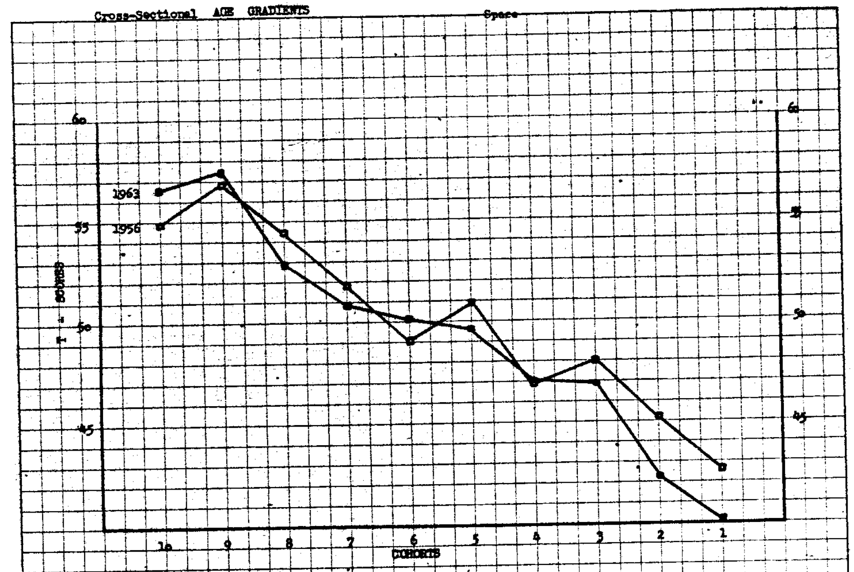

Figure 3

ESTIMATED AGE GRADIENTS Space

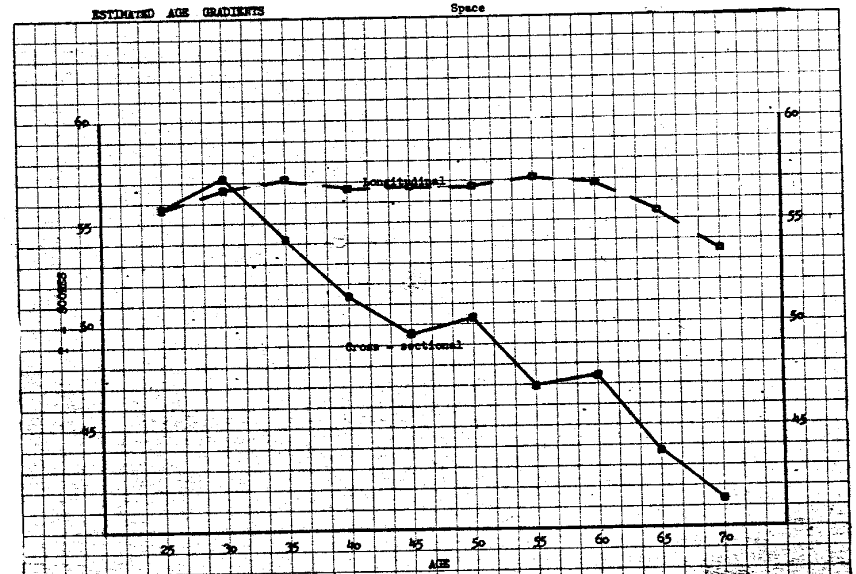

Figure 4

CROSS-SECTIONAL AGE GRADIENTS Reasoning

Figure 5

CROSS-SECTIONAL AGE GRADIENTS Number

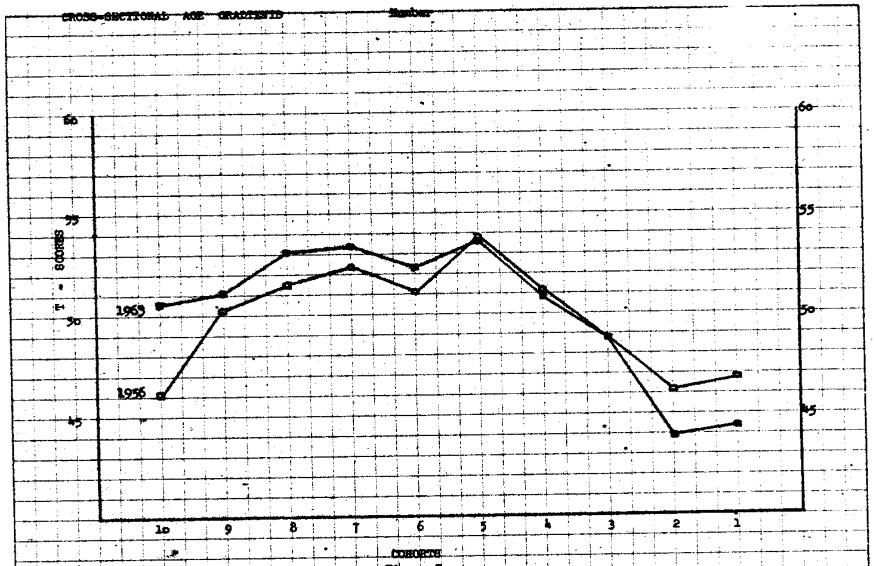

Figure 7

ESTIMATED AGE GRADIENTS Reasoning

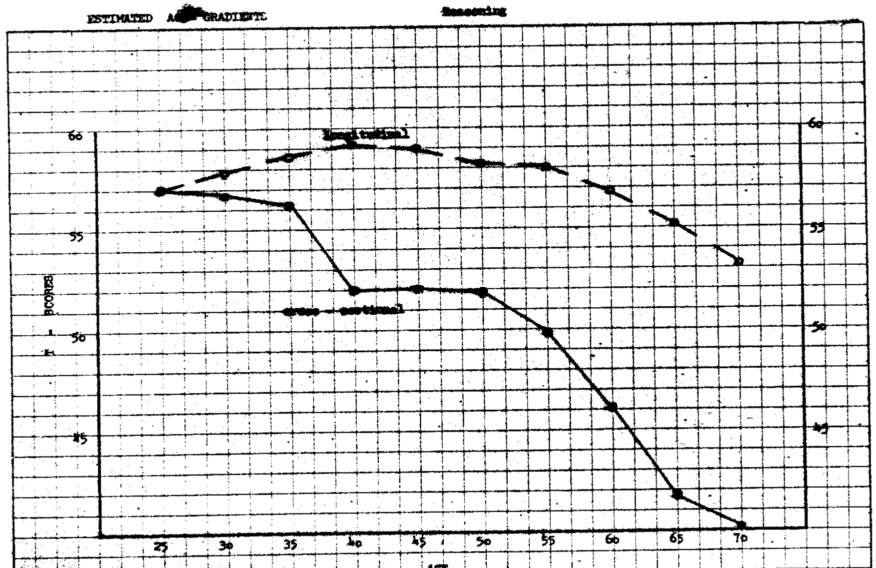

Figure 6

ESTIMATED AGE GRADIENTS Number

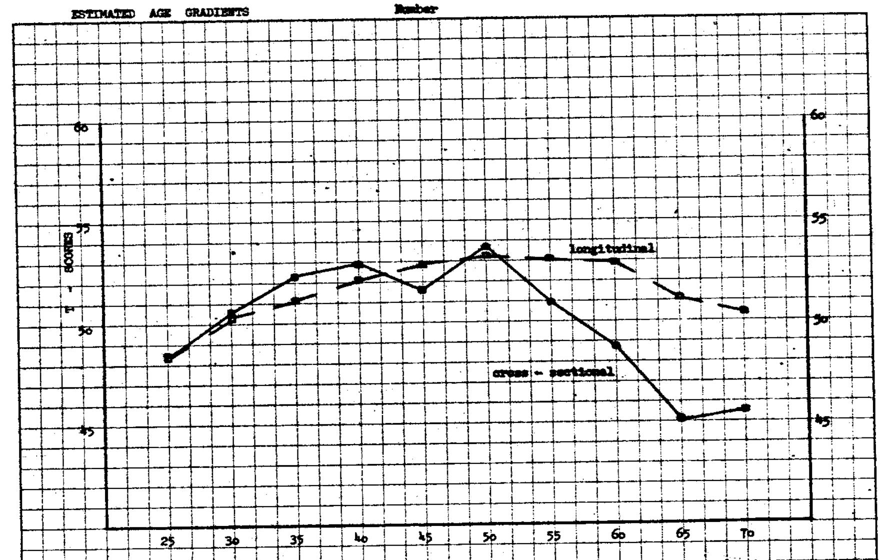

Figure 8

Figure 9

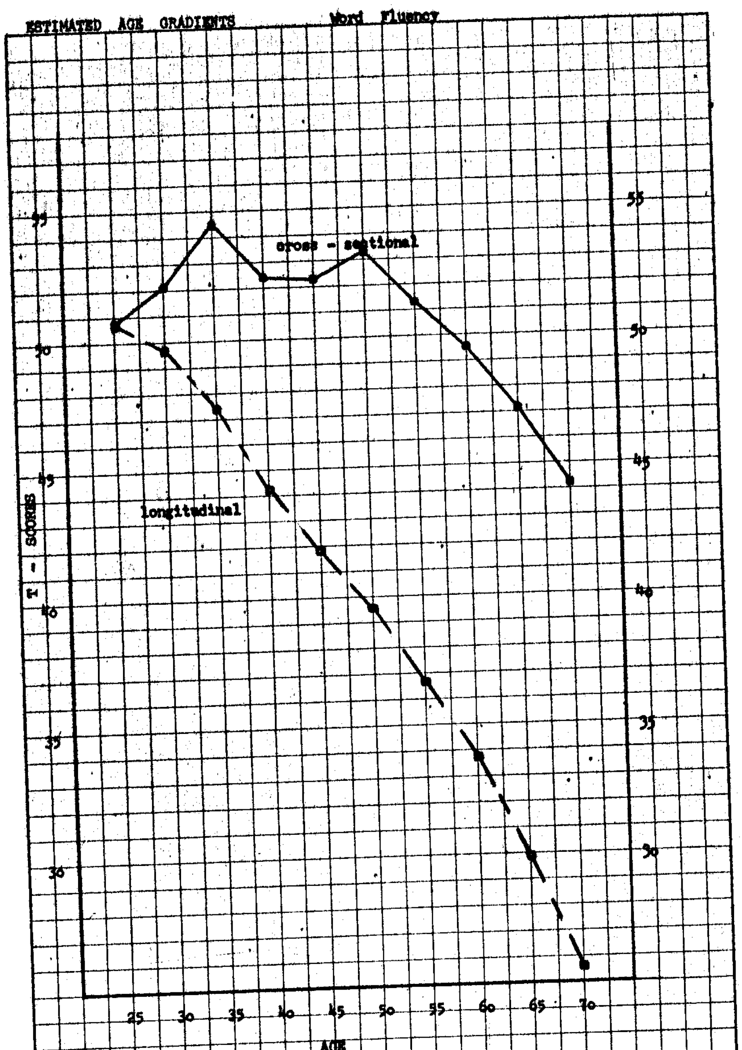

Figure 10

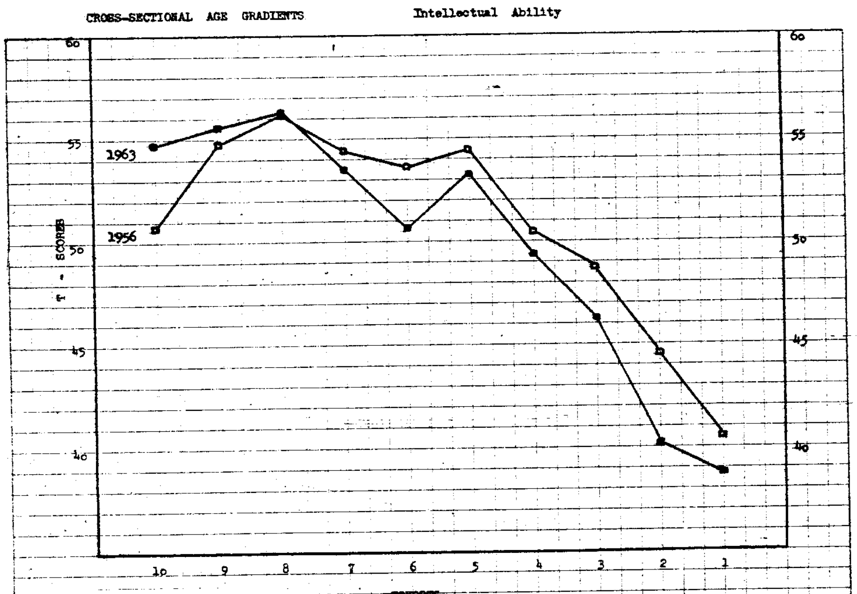

Figure 11

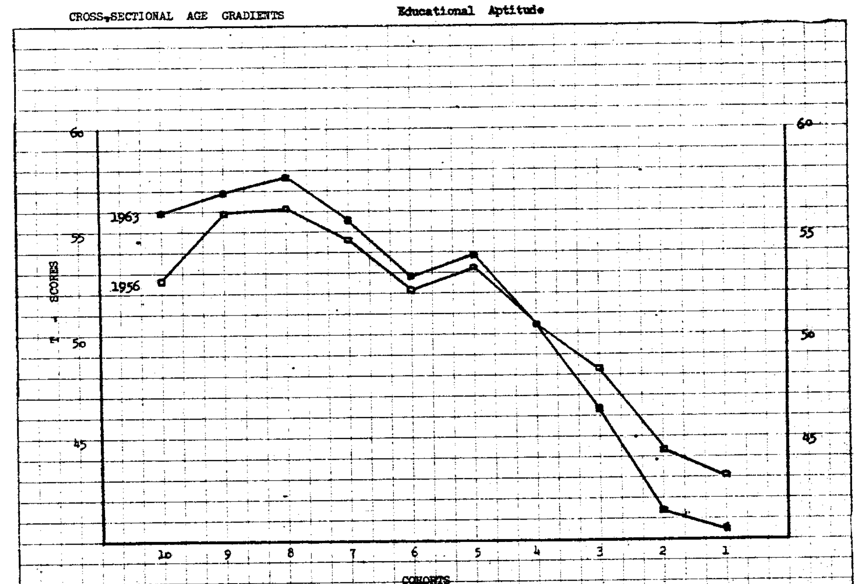

Figure 13

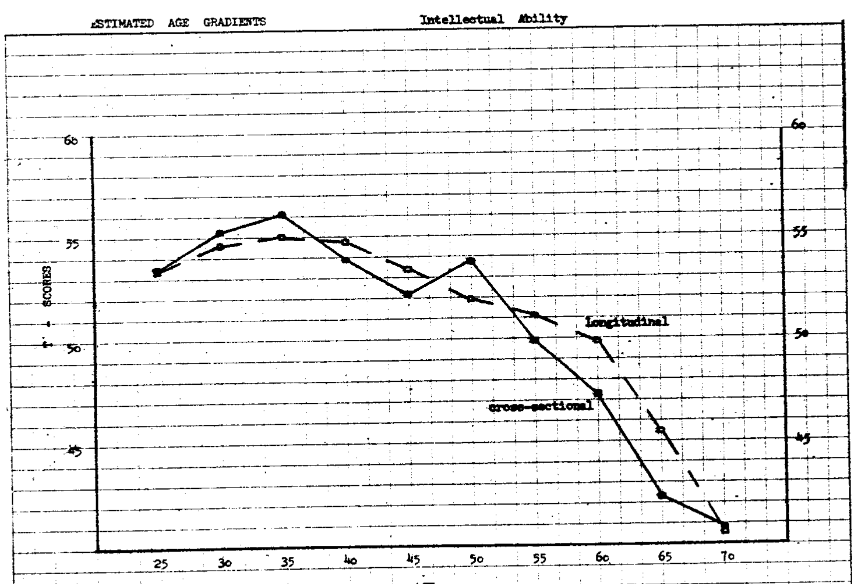

Figure 12

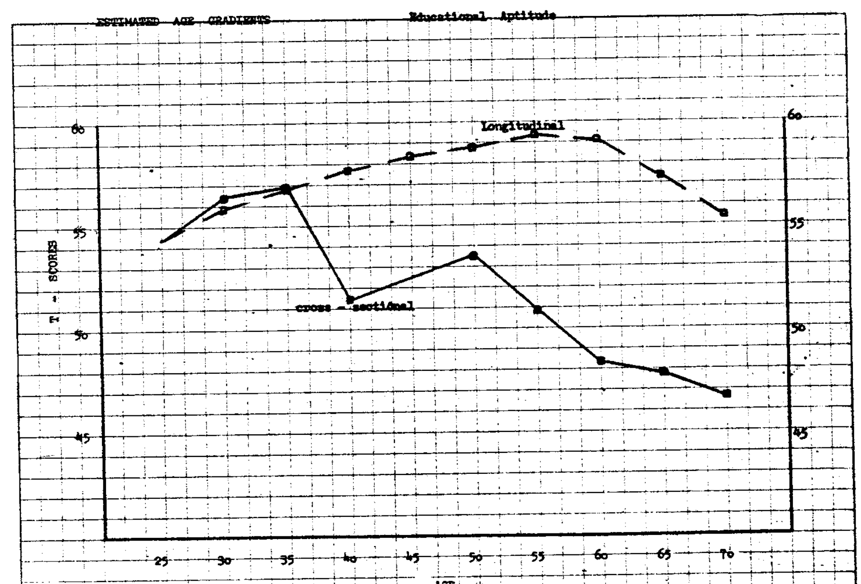

Figure 14

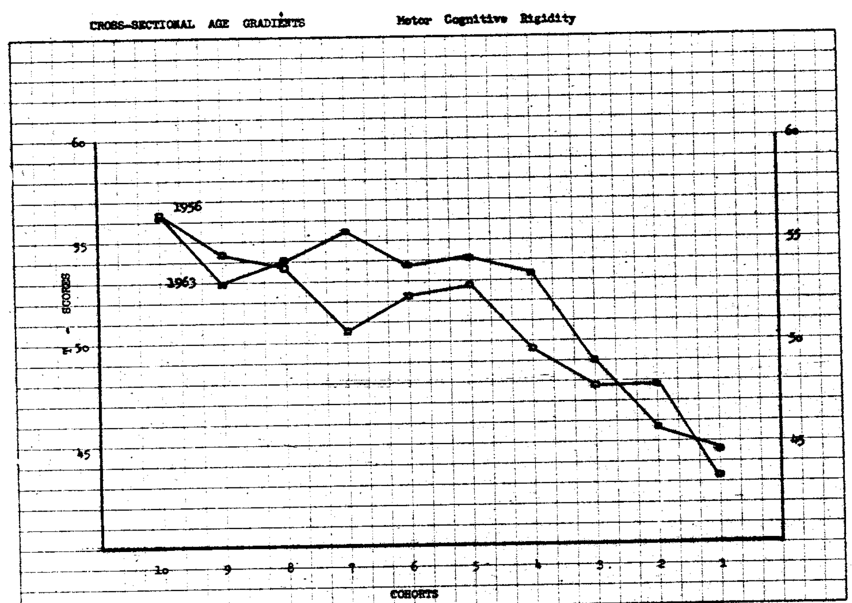

Figure 15

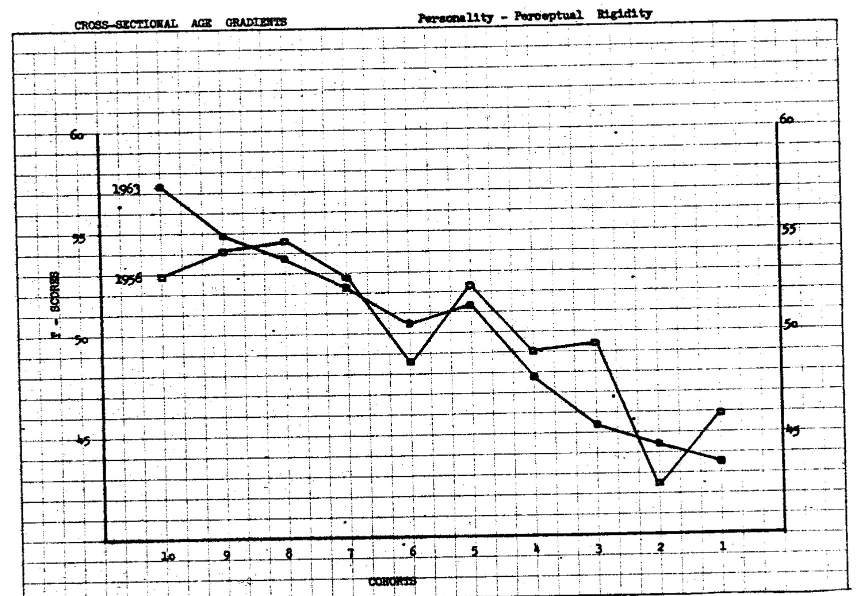

Figure 17

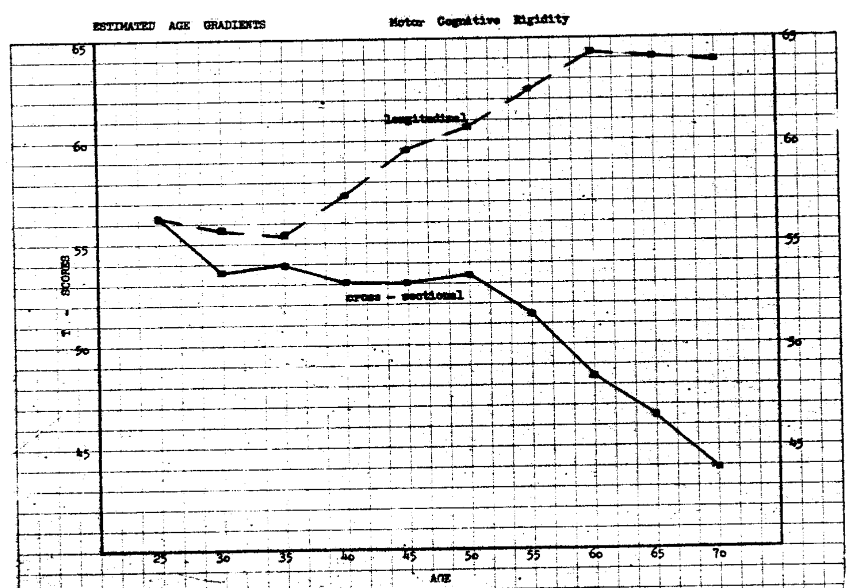

Figure 16

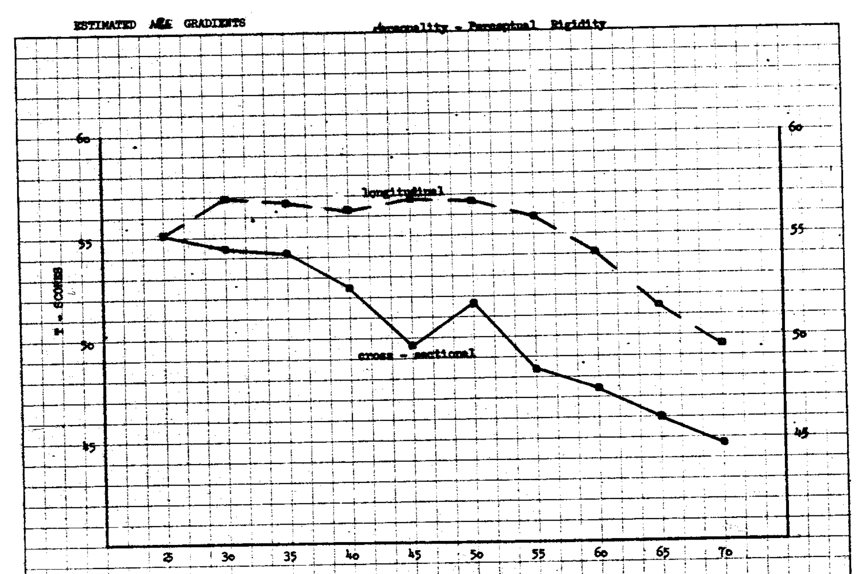

Figure 18

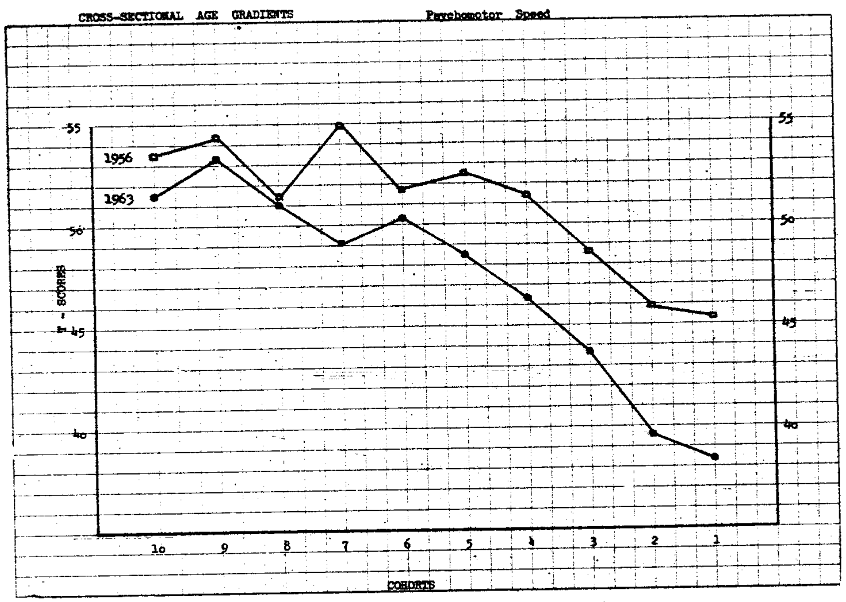

Figure 19

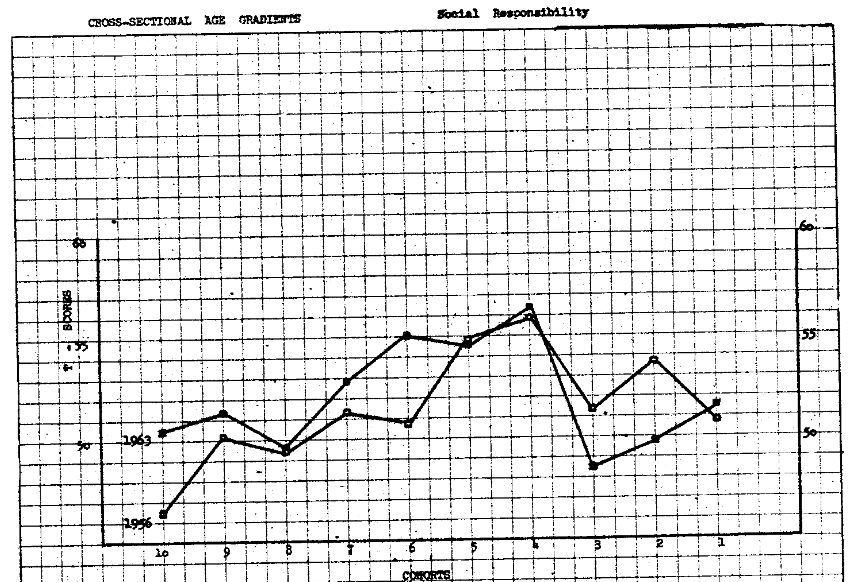

Figure 21

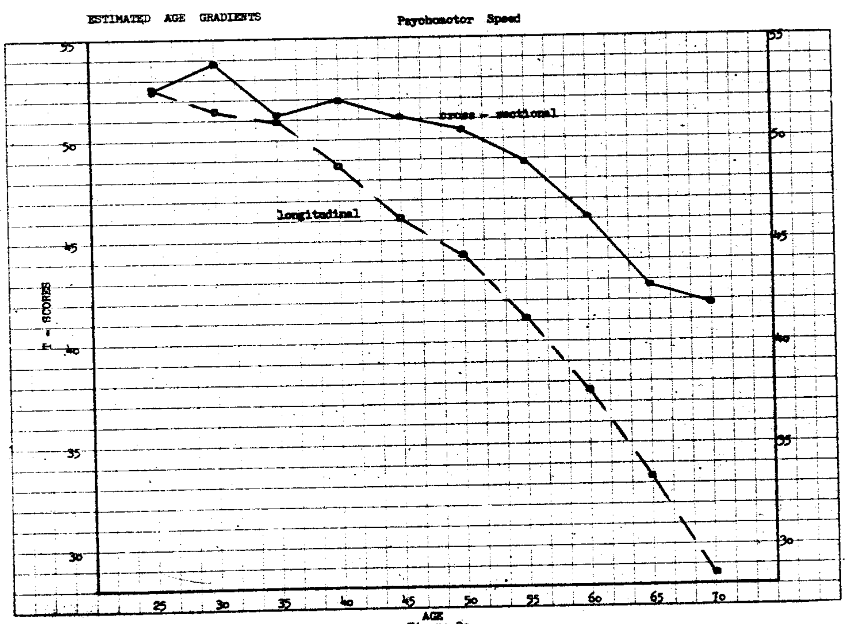

Figure 20

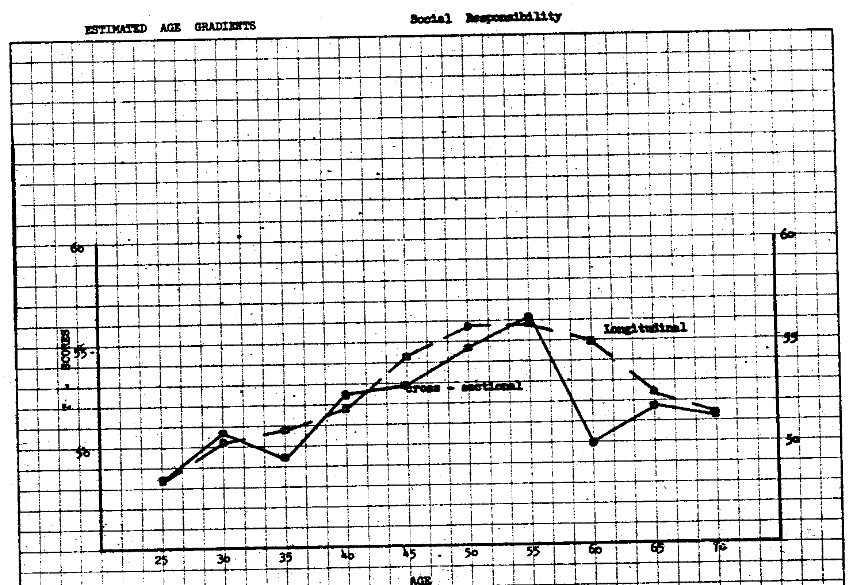

Figure 22