Acta Psychologica 26 (1967) 107–129; © *North-Holland Publishing Co. Amsterdam*

AGE DIFFERENCES IN FLUID AND CRYSTALLIZED INTELLIGENCE

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ABSTRACT

The general purpose of this study was to describe differences in intellectual functioning associated with aging in adulthood. Estimates of broad factors identified as fluid intelligence, crystallized intelligence, general visualization, speediness, carefulness and fluency were obtained by combining scores on several tests found to define these factors in previous research. A sample of 297 subjects was divived into five age groupings: 14–17 year-olds, 18–20 year-olds, 21–28 year-olds, 29–39 year-olds and 40–61 year-olds. Analyses of variance and covariance were carried out on these factors and age groupings, using sex and education, as well as the factors themselves, as covariates. These analyses revealed that:

(a) The mean level of fluid intelligence was systematically higher for younger adults (relative to older adults),
(b) The mean level of crystallized intelligence was systematically higher for older adults (relative to younger adults),
(c) The mean for the general visualization function was highest for the grouping of 21–28 year-olds and the means systematically dropped off on either side of the high value,
(d) No systematic age trends were discernible for the general speediness, carefulness and fluency factors.

These results provided support for the theory of fluid and crystallized intelligence.

1. PURPOSES

This is one of several studies aimed at demonstrating that the theory of fluid and crystallized intelligence (CATTELL, R. B., 1941, 1950, 1957a, 1963; HORN, J. L., 1965a; HORN and CATTELL, R. B., 1966a; 1966b) provides a useful framwork within which to integrate existing knowledge about human abilities. This theory appears to be particularly applicable in the study of relationships between aging in adulthood and changes in intellectual performances.

In a previous study (HORN, J. L. and R. B. CATTELL, 1966b) it was shown that when primary mental ability factors (after FRENCH, EKSTROM and PRICE, 1963) are grouped according to their patterns of loadings on second-order factors (HORN, J. L., 1965a; HORN, J. L. and CATTELL, R. B., 1966a), then analyses between adult age groupings extending from the 'mid-teens' (14–17) to 'over forty' (40–61) indicate consistent differences favoring the young on primaries that are relatively pure makers for fluid intelligence (Gf), consistent differences favoring the older adults on primaries which define crystallized intelligence (Gc) most purely and variable age-trend curves for primaries having variance divided roughly equally between Gf and Gc. These results are highly encouraging for the general fluid crystallized theory, but they leave some questions unanswered and they fail to bring out certain details of the relationships between intellectual performance and aging. For example, the question of the influence of educational and sex differences on the results was not answered and the analyses did not clearly show the extent to which the age-trend curves could be altered by statistically controlling the variance measured in generel speediness and visualization factors. The present study was designed to help resolve issues of this kind.

2. THEORETICAL BASIS FOR THIS STUDY

For readers not yet familiar with the most recent expressions of the theory of fluid and crystallized intelligence some outline of this is necessary to put the present investigation in context.

In broad terms the Gf–Gc theory is an attempt to integrate evidence converging from some five kinds of studies of intellectual performance, viz., studies dealing with: (1) the effects of brain damage on abilities, particularly the differential effects associated with early (in development) as compared with late brain damage; (2) the relationships between test scores and opportunities to acquire knowledge; (3) the construction of intelligence tests which will be more nearly fair for all persons regardless of their social class of origin; (4) the factor structure among sets of tests said to measure various aspects of intelligence and; (5) the changes in intellectual performances associated with aging, both in childhood and in adulthood. The principal conclusion deriving from analysis of the evidence in these various areas is that intellectual abilities are organized at a general level into two general intelligences, viz., fluid intelligence and crystallized intelligence. These represent the operation of somewhat different – i.e. independent – influences in development. On the one hand there are those influences which directly affect the physiological structure upon which intellectual processes must be constructed – influences operating through the agencies of heredity and injury: these are most accurately reflected in measures of fluid intelligence. And on the other hand there are those influences which affect physiological structure only indirectly through agencies of learnings, acculturation, etc.: crystallized intelligence is the most direct resultant of individual differences in these influences.

For the reader who prefers concrete, operational definitions of concepts, table 1 gives the actual variables found to define Gf and Gc in a recent and comprehensive study of factor structure among primary mental abilities (HORN, J. L., 1965a). Here it can be seen that Gf is defined by tasks such as:

(a) Letter grouping and series from the primary factor I,[1] Inductive reasoning,
(b) Figure classifications, Topology and Matrices from the primary factor CFR, Figural relations,
(c) Common word analogies of CMR, Semantic relations,
(d) Nonsense equations and paired associates memory of Ma, Associative memory.

These tasks call for a capacity to perceive relations and educe correlates, as SPEARMAN (1927) defined these functions; they indicate ability to maintain span of immediate awareness; they involve concept formation and attainment, reasoning and abstracting. That is, in general, the tasks which define Gf require intelligence as this concept is usually defined. But it will be noted that the problem materials of these tasks are not such that emphasis in measurement is placed upon individual differences in education or acculturation, broadly conceived. For example, the Letter Series task requires only knowledge of the

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[1] The abbreviations and other labels for ability are those commonly used in the U.S.A. Readers not familiar with this jargon should consult FRENCH, et al. (1963) and GUILFORD (1959).

TABLE 1

Oblique structure among a broad sample of primary mental ability factors; after HORN, (1965a).

Primary factor symbol and name *		Second-order factors and loading **					
		Gf	Gc	Gv	Gs	C	F
I	Inductive reasoning	50		28			
CFR	Figural relations	46		43			
Ma	Associative memory	32					
ISp	Intellectual speed	40				—21	
IL	Intellectual level	51					
R	General reasoning	23	30				
CMR	Semantic relations	33	50				20
Rs	Formal reasoning	34	40				
N	Number facility	24	29		34		
V	Verbal comprehension		69				26
Mk	Mechanical knowledge		48	25			
EMS	Experiential evaluation		43		23		
Fi	Ideational fluency		25		25		42
Fa	Associational fluency		35				60
S	Spatial orientation			50			—20
Vz	Visualization			58			
Cs	Speed of closure	21		36			
Cf	Flexibility of closure			48			
DFT	Figural adaptive flexibility			40			
P	Perceptual speed				48		
Sc	Speed copying				63		
Pf	Productive flexibility		—23		46		
C	Carefulness					60	

* After FRENCH *et al.* (1963) and GUILFORD (1959).

** Factor loadings below .20 and decimal points have been omitted in order to achieve maximum clarity of presentation.

order of the English alphabet. When used with adults who are products of the American educational system, this knowledge is available to virtually all people tested: the conventional order of listing alphabet characters is about as much over-learned by ditch diggers as by college professors. The figural materials of the Topology test (CATTELL, R. B., 1957b) on the other hand, are about as novel for college professors as they are for ditch diggers. The problem materials of the tests which define Gf are in these senses relatively culture fair – i.e. about equally novel or equally common for all persons tested in a properly designed study aimed at demonstrating the Gf and Gc functions.

It will be noted that the tasks which define Gc are also of a kind commonly said to indicate intelligence -- e.g.,

(a) Vocabulary and general information from the primary factor V, Verbal comprehension,
(b) Syllogistic reasoning and inferences from Rs, Formal reasoning,
(c) Social situations from EMS, Experiential evaluation,
(d) Arithmetic reasoning and destinations from from R, General reasoning,
(e) Ideas and things from Fi, Ideational fluency, etc.

In these tasks, however, the perception of relations, education of correlates, reasoning etc., required for problem solution must usually be premised on absorption of what can be termed the 'collective intelligence of a culture'. For example, in an analogy item like this one:

Hippocrates–Galen: Aeschylus – Greece Euripides Pericles Zeno (modeled on the items of the well known Concept Mastery Test which Terman used in his follow-up studies of the gifted) perception of relations is required for solution, to be sure, but individual differences in reaching solution are also due to awareness of a rather esoteric aspect of Western culture. A person who can solve quite complex problems of the kind which define Gf can easily fail even very simple analogy problems of this sort simply because he lacks information. But perhaps a better example illustrating that Gc is a kind of intelligence and yet distinct from Gf is to be found in the use of what CATTELL (1963) has described as 'generalized solution instruments' or 'aids'. The idea of differentiation in the calculus of Newton and Liebnitz is an example of an *aid*. Differentiation enables the person who has mastered it to solve many problems he would otherwise not be able to solve. It thus provides a distinct advantage in problem-solving to the person who has acquired a particular element from the collective intelligence of his culture. And an individual may use this aid, and behave more intelligently by virtue of this use, even when he is incapable of creating the concept of differentiation himself!

Crystallized intelligence indicates the extent to which one has appropriated the collective intelligence of his culture for his own use. In part, of course, this is dependent upon that person's fluid intelligence, for he must have the basic capacity to appropriate that which at one time must have been novel for him. But to a large extent the factors which enable one to come into contact with this culture, and to learn as a result of such contact, are independent of level of fluid intelligence. Not only are the factors which indicate opportunity somewhat independent of Gf, but also many non-intellectual factors of the person himself are thus independent and yet may determine the attainment represented in Gc – factors such as the person's motivations (e.g., what HAYES (1962) has cogently described as 'experience producing drives'), his characteristic level of personality integration, his vitality, etc. And since Gc is largely a function of experience, aging throughout life – not only in childhood – will tend to be associated with its increase. Thus it can be seen that Gc, through development, can become quite independent of Gf.

It will be noted that table 1 shows four general factors in addition to Gf and Gc. These, according to our theory, represent functions which are not basically intellectual, as such, but which produce variance on necessarily fallible measures of intelligence.

Gv is a general visualization function producing some variance on all intellectual tasks which involve imaging the way objects may change in appearance as they move in space, maintaining orientation whith respect to objects in space, keeping spatial configurations in mind, finding the Gestalt among disparate parts in a visual field, maintaining flexibility concerning other possible structurings of elements in space, etc. It is interesting that many putative tests of intelligence are constructed of spatial materials and thus require visualization. And, of course, we must recognize the importance of vision in the development of intelligence. But in part this emphasis on spatial materials in intelligence tests is fortuitous. As SPEARMAN (1927) pointed out some years ago, there is probably no necessary reason to emphasize use of any particular kind of problem material in measures of intelligence. Many, if not all, of the problems presently phrased, as it were, in spatial symbols might be phrased in auditory symbols. And if this emphasis were present in a set of ability measurements, a general audition factor, analogous to general visualization, would obtrude and produce variance additional to that on the Gf or Gc functions. It's in this sense that Gv is said to account in part for individual differences in measures of intelligence and yet not itself indicate intelligence.

The Gs factor picks up variance from most speeded ability tests and in this sense represents a function determining the rate at which ability problems are solved. This function is largely independent of those indicating the level of complexity one reaches in problem solving, as represented in the Gf and Gc factors. But beyond this, the nature of the Gs function is not clear. It would seem to stem either from a test-taking effortfulness or from a more physiologically-based capacity, but the research which would provide for a clear distinction between these, and possibly other, interpretations has yet to be done. Meanwhile it is recognized as merely a speediness function which produces some variance on intellectual tasks but which is not an essential aspect of the functioning of intelligence, as such.

Carefulness, C, originally defined by FRUCHTER (1950, 1953), is a dimension of unwillingness to give an incorrect answer to ability-test problems. Here again the essential nature of the function is obscure. Logically, it would appear to be the inverse of the speediness function described above, but in fact the two factors have been quite independent in the research upon which their definition is based (FRUCHTER, 1953; HORN, 1965a; HOWIE, 1962). In the present study it is treated primarily as a factor which needs to be statistically controlled because it represents a non-intellectual influence in performances on intelligence tests.

The F function pervades the fluency primary factors. It is perhaps rather surprising that this general dimension should be independent of the general speediness and carefulness factors described above, and yet it was so defined in our previous research. It would appear to involve, principally, a process of quickly bringing concept labels – i.e., mainly words – from a long-term storage unit into immediate awareness. This, in turn, could represent either the size of store of concept labels – something that could be expected to increase with aging – or the degree of short-circuiting of pathways from storage centers to immediate awareness. And, of course, it could represent an interrelation of these two kinds of function. In this study we probably cannot get far toward deciding between these alternative explanations, but because the F factor produces variance on several primaries – particularly those defining Gc – it will be useful to keep track of it, as it were, in covariance analysis.

Now, then, the general theory is that fluid intelligence increases throughout childhood and into young adulthood, but then levels off and eventually declines, whereas crystallized increases thoughout almost the entire period of development, from childhood to late maturity. The reasons for these predictions are numerous and intertwined in a complex manner (see HORN, 1965a, for a fuller treatment), but in general terms they may be summarized as follows:

(1) The neural and other physiological structures upon which intellectual functioning is based mature by growth and increase in complexity until the late teens or early twenties, at which time they reach their full growth and complexity. This maturation is reflected directly in an increase in Gf, for although the development of Gf is a function of learning, the particular learning here involved is mainly dependent upon the adequacy of the physiological structure which supports learning. This maturation is reflected also, though indirectly, in an increase in Gc, because the development of Gc is based in part on the development of Gf and on the same physiological structures which support learning in general.

(2) Injuries to the structures which support intellectual functioning occur throughout life and are irreversible. These injuries are usually so small and few in number during the course of a perceptible time span that they are not noticed, either subjectively by the person himself or by others. Moreover, in childhood the effects of such injuries on intellectual performances are masked by the larger effects resulting from neural growth, learning and other development in this period. But such injuries accumulate nevertheless and have a long-term limiting influence on the development of intelligence. Again, as in the case of maturational influences, this influence is felt most directly in the development of Gf and somewhat more indirectly in the development of Gc. In adulthood, when the masking influences referred to above cease to be potent, the effects of accumulation of neural damage become more evident in intellectual behavior. Hence, because fluid intelligence is most sensitively dependent upon the functioning of the physiological structures which support intellectual behavior, there will tend to be a decline in Gf with aging in adulthood, this reflecting a gradual degeneration of structure due to accumulation of irreversible injuries.

(3) Large injuries to the structures which support intellectual functioning will have occurred more frequently in the population of older people than in the population of younger people. This is likely simply because injury results from exposure in living and older persons would have had more such exposure. It means that, analogous to the accumulation with aging of small injuries within a particular person, there is

an accumulation of large injuries within a sample of people. And because the effects of these larger injuries are also manifested most sensitively in Gf, the mean Gf level for older adults will in general be lower than the mean Gf level for younger adults.

It should be noted at this point that when considered in terms of cross-sectional data (1) and (2) are alternative explanations for the same outcome: a lower Gf mean for older subjects as compared with younger subjects. Comparisons of results from cross-sectional and longitudinal studies can provide a basis for choice between these two or, what is perhaps more reasonable (since both may point to valid phenomena), a basis for estimating the relative potency of the two kinds of influence.

(4) In the human, particularly, but in all organisms to some extent, some learning occurs incidentally, without much effort being expended either on the part of the individual or on the part of those who would educate him. It is this learning which is manifested primarily in Gf, although, as noted, Gc is constructed on top of this learning. But some – perhaps much – learning occurs less incidentally, particularly in the formal agencies for acculturation such as the school. A kind of intensive acculturation can occur and this is likely to be particularly intensive during childhood, when the principal work of the young person is seen to be that of acquiring enough of the knowledge of the culture to be able to maintain it. And since the acquisition resulting from this acculturation is shown mainly in Gc, crystallized intelligence increases at a rapid rate in childhood. But the work of preparing people to maintain a culture is never done; adults learn in their attempts to pass knowledge on to the young; and there are numerous inducements and incentives which encourage adults to acquire more and more of the collective intelligence of their culture. Hence, insofar as various acculturation influences continue to operate throughout adulthood, Gc can increase with aging.

Just as apparent decline in Gf (when seen in the averages provided in cross-sectional studies) can be due either to an accumulation with aging of small decrements in all people, to an age-correlated increase in frequency of large decrements in some people, or to both of these, so, too, an apparent increase with age of Gc can be due either to small increases by all (or most), to large increases by some or to both of these factors.

The principal hypotheses of this study are thus implied. As suggested in our descriptions of factors above, Gv, Gs, C and F were included in the study mainly to provide a basis for statistical control of the potentially distorting influences represented by these factors. However, for reasons similar to those outlined in (1) and (2) above, it was predicted that Gv and possibly Gs and F would decline with age in adulthood, whereas for reasons that are too vague to dignify by specifying them as a hypothesis (but see HORN, 1965a and HORN and CATTELL, 1966a), it was thought that C would increase with age.

TABLE 2

Second-Order factor estimates

Factor estimated	Symbol	Test scores combined to obtain estimates
1. 'Pure' fluid intelligence	Gf_p	Letter grouping, [illegible]ure series, topology, matrices, figure classification
2. 'Overall' fluid	Gf_o	Gf_p plus number series, Nufferno speed and level, common word analogies, arithmetical reasoning, match arrangements, paired related words, nonsense equations, careful letter series, careful figure classification
3. 'Pure' crystallized intelligence	Gc_p	Vocabulary, general information, social situations, abstruse word analogies
4. 'Overall' crystallized intelligence	Gc_o	Gc_p plus arithmetical reasoning, common word analogies, mechanical information tool identification, inferences, controlled association, ideas, mixed arithmetic
5. General visualization	Gv	Cards, figures, form boards, match arrangements, street gestalt, designs, backward reading
6. Clerical speed	Gsc	Forward writing, forward printing, unusual writing, matching letters, matching numbers, rapid cancellation
7. General speed (with intellectual components)	Gs	Gsc plus nufferno speed, reading speed
8. General verbal fluency	F	Controlled associations, things round, ideas
9. General carefulness	C	Carefulness on: letter series, figure classification, estimates, dividing, fractions
10. Omnibus intelligence	G	Gf_p, Gc_p, Gv, F, number series, nufferno speed and level, arithmetical reasoning, paired related words, nonsense equations, mechanical information, tool identification, false premises, inferences, mixed arithmetic

3. Operational definition of crucial variables

The factors described in previous sections were estimated by adding together standard scores on several tests. The tests and combinations used are shown in table 2.

Two estimates of each of the two major intelligence factors – Gf and Gc – were obtained, a 'pure' measure and an 'overall' measure. The 'pure' measure was obtained by combining standard scores on the tests which previous analyses (Horn, 1965a) had shown to have substantial loading (i.e., always over .30, usually over .40) on the factor in question (Gf or Gc) and *no loading above .25 on any other factor.* The less 'pure' but more general 'overall' measure was obtained by summing standard scores on all tests which had loadings above .35 on the factor in question, regardless of the test's loading on other factors.

The reason for this distinction between a 'pure' and 'overall' estimates of a factor is perhaps more intuitive than rational. In studies of the characteristics of factor scores (Horn, 1964, 1965b; Horn and Miller, 1966) it has seemed that the simple structure concept of a factor is best represented by combining only those variables which fall into one factor alone – and no other – or by very carefully ensuring that extraneous factor influences are cancelled out by combining high-loaded variables having opposite signs in their loadings on extraneous, unwanted factors. The practice of using all variables to estimate a factor, as in the so-called 'exact' methods, appears to result in the introduction of 'noise' – i.e., random influences – from variables falling in the hyperplane of the factor. The conditions required to achieve the best (in all of several senses) estimate of a factor are difficult to specify and therefore more difficult to impose, but the 'pure' estimate obtained here would appear to more nearly achieve the desired end than the so-called 'overall' estimate. Actually, our hypothesis was that both kinds of estimate would yield much the same results but that the 'pure' estimate would provide a somewhat more accurate description of the predicted age differences.

Estimates of Gv, Gs, C and F were obtained by combining no less than three – and usually more than five – tests having correlations greater than .3 with the factor in question Two estimates of Gs were obtained. In one, any test which would be said to involve intelligence to a noteworthy degree was excluded, whereas in the other estimate all tests measuring the Gs function were included.

The reason for the omnibus intelligence measure will be made evident below, after the basic results have been described.

4. The sample

The measurements indicated in table 2 were obtained from a sample of 297 older teenagers and adults drawn from Stateville, Pontiac and Dwight State Prisons in Illinois, The Illinois Soldiers' and Sailors' Children's School, Canon City State Penitentiary in Colorado and the Colorado State Employment Office in Denver.[2] All subjects were volunteers. They were offered information about their performances as an inducement for giving their time and doing their best. Of the 297 subjects, 215 were males.

The age range was 14 to 61 years, but there was only one fourteen-year-old, two persons aged 61 and one each aged 56, 55 and 52, the bulk of the sample thus being between 15 and 51. For purposes of analysis the sample was divided into five age categories, viz., (1) 'adolescents': 46 subjects 14 to 17 years of age inclusive, (2) 'late adolescents': 51 subjects between 18 and 20 years, (3) 'young adults': 81 subjects between 21 and 28 years, (4) 'adults': 73 subjects between 29 and 39 years, and (5) 'mature adults': 46 subjects between 40 and 61 years inclusive. This breakdown was made to provide groups wherein N was large enough to yield stable statistics and with the aim of representing theoretically interesting phases in intellectual developmen from late childhood into adulthood. Thus, for example, because it is widely held that intellectual development reaches a peak in late adolescence, the sample in the age range from 14 to 20 was divided into the 'adolescents' and 'late adolescents' groups.

5. Results

In table 3 results are presented for analyses with the factors and age groupings described in previous sections. The units of measurement for the various factors are arbitrary – i.e., as noted above, test scores

[2] For aid in securing this sample special thanks are due to Julia Bates, Staff Psychologist at the Illinois Soldiers' and Sailors' Children's School; Arthur V. Huffman, State of Illinois Criminologist; Wilson Meeks, Chairman of the Classification Board at Stateville Prison; Stow E. Syman, Sociologist at Pontiac Prison; Bernard Robinson, Sociologist at Dwight Prison; George Levy, Senior Psychologist at the Colorado State Penitentiary; and David J. Wilson, of the Denver Department of Welfare.

were converted to standard score form (made positive, with mean 100 and standard deviation 10) and added with unity nominal weight, so the unit of measurement for a factor depends upon the number of scores combined and their intercorrelations (see HORN, 1964). An asterisk in one of the columns under 'covariates' indicates that the particular variable at the head of the column was covaried out. If no asterisk appears in a given row, no covariates were involved and the *F*-value at the right is for an analysis of variance on the listed means. In some of the analyses on Gf estimates the 14 to 17-year-olds group was omitted. This was done because the mean for this group was lower than the means for the 18–20 and 21–28 year-olds groups and, in view of the hypotheses here under consideration, it seemed desirable to avoid (if possible) any implication that this fact was responsible for the significance of the overall *F*. Depending upon the number of covariates and groups included, the degrees of freedom vary from 3 and 240 to 4 and 292. For these degrees of freedom an *F* in the neighborhood [4] of 3.38 to 3.87 is significant at the .01 level, one between approximately [4] 3.79 and 4.32 is significant at the .005 level and one between approximately [4] 4.74 and 5.61 is significant at the .001 level. To give some indication not only of the significance of difference between means but also of the degree of association between age and the ability dimensions, the correlation ratios (see COHEN, 1965) have been entered in the column at the far right in table 3. For those who prefer to use these values when thinking about the significance of differences, we may note that with the degrees of freedom here at hand a η above about .20 is significant at the .01 level and one above about .25 is significant at the .001 level. With these boundaries and conditions in mind, let us examine the results of table 3 in detail.

First, as regards fluid ability, notice that the differences favoring the young are significant in all analyses, both those in which the Gf-pure measurements were involved and those which utilized the Gf-overall measurements. These differences remain significant after removal of the linear effects associated with the various covariates and when the grouping for the youngest people has been excluded. Indeed, the data suggest that the influences represented by the covariates tend to obscure the basic relationship showing decline in Gf with aging: when sex and education differences are covaried out in the analyses of Gf-pure

[4] That is, the Fs are estimated by linear interpolation in Central F tables such as those provided by GRAYBILL, 1961.

TABLE 3

Summary of results from analyses of variance and analyses covariance

Dependent variable	Covariate(s): variable(s) statistically controlled									Means or adjusted means for different age groups						
	Sex	Educ	Gsc	Gs	Gv	C	F	Gfp	Gcp	14–17	18–20	21–28	29–39	40–61	F-Value	η
Gf-Pure										6046	6170	6093	5886	5760	8.91	.33
Gf-Pure											6170	6093	5886	5760	10.66	.34
Gf-Pure	*									6072	6157	6090	5886	5752	9.13	.33
Gf-Pure		*								6172	6182	6091	5848	5682	15.21	.42
Gf-Pure			*							6089	6165	6064	5888	5771	9.41	.33
Gf-Pure				*						6091	6156	6060	5893	5779	9.06	.33
Gf-Pure					*					6170	6095	5998	5886	5887	9.69	.34
Gf-Pure	*	*								6210	6167	6087	5846	5669	16.52	.43
Gf-Pure	*	*									6195	6119	5879	5697	17.39	.42
Gf-Pure	*	*	*							6217	6146	6063	5860	5708	14.37	.41
Gf-Pure	*	*	*								6177	6097	5892	5734	13.87	.38
Gf-Pure	*	*		*						6207	6148	6059	5867	5714	14.11	.40
Gf-Pure	*	*		*							6176	6090	5897	5739	13.76	.38
Gf-Pure	*	*	*		*					6236	6106	6001	5865	5837	14.45	.41
Gf-Pure	*	*	*		*						6140	6037	5901	5870	9.07	.32
Gf-Pure	*	*	*		*	*				6267	6102	6002	5853	5829	17.74	.45
Gf-Pure	*	*	*		*	*					6141	6046	5892	5867	10.87	.34
Gf-Pure	*	*	*		*	*	*			6265	6104	6004	5851	5827	17.78	.45
Gf-Pure	*	*	*		*	*	*				6143	6047	5890	5865	10.85	.34
Gf-Pure	*	*	*		*	*	*		*	6327	6140	6030	5814	5736	26.00	.52
Gf-Pure	*	*	*		*	*	*		*		6187	6081	5867	5793	17.36	.42
Gf-Overall										5774	6328	6195	5895	5627	5.54	.27
Gf-Overall											6328	6195	5895	5627	5.93	.26
Gf-Overall	*	*								6182	6326	6182	5796	5400	9.80	.34
Gf-Overall	*	*									6394	6258	5875	5472	12.12	.37
Gf-Overall	*	*	*							6197	6278	6126	5827	5488	7.53	.30
Gf-Overall	*	*	*								6356	6211	5904	5554	9.13	.32
Gf-Overall	*	*		*						6174	6279	6113	5845	5507	7.34	.35
Gf-Overall	*	*		*							6351	6191	5919	5571	8.90	.31
Gf-Overall	*	*	*		*					6283	6191	5993	5837	5767	4.83	.25
Gf-Overall	*	*	*		*						6277	6084	5922	5839	4.33	.22
Gf-Overall	*	*	*		*	*				6353	6174	5996	5791	5737	8.81	.33
Gf-Overall	*	*	*		*	*					6283	6116	5889	5828	6.88	.28
Gf-Overall	*	*	*		*	*	*			6344	6190	6009	5779	5725	9.36	.34
Gf-Overall	*	*	*		*	*	*				6299	6129	5874	5810	7.96	.30
Gf-Overall	*	*	*		*	*	*		*	6517	6292	6082	5675	5470	22.25	.49
Gf-Overall	*	*	*		*	*	*		*		6422	6222	5810	5609	19.02	.44
Gc-Pure										3688	3912	3948	4138	4272	34.16	.56
Gc-Pure	*									3714	3899	3946	4138	4264	32.45	.55
Gc-Pure		*								3787	3922	3947	4108	4211	19.09	.46
Gc-Pure			*							3712	3909	3932	4139	4278	36.43	.58
Gc-Pure				*						3711	3904	3931	4141	4282	37.85	.59
Gc-Pure	*	*								3824	3907	3944	4107	4199	17.72	.44
Gc-Pure	*	*	*							3826	3898	3933	4112	4215	20.18	.47
Gc-Pure	*	*		*						3822	3998	3931	4116	4219	21.59	.48

Gc-Pure	*	*	*				*			3816	3915	3946	4099	4205	19.94	.47
Gc-Pure	*	*	*			*	*			3832	3912	3945	4093	4262	18.87	.46
Gc-Pure	*	*	*		*	*	*			3835	3901	3928	4096	4233	24.04	.50
Gc-Pure	*	*	*		*	*	*	*		3774	3877	3927	4129	4277	32.82	.56
Gc-Overall										1283	1940	1964	2249	2416	19.49	.46
Gc-Overall	*	*								1683	1912	1948	2166	2208	5.76	.27
Gc-Overall	*	*	*							1993	1880	1910	2187	2268	7.98	.32
Gc-Overall	*	*		*						1677	1882	1903	2198	2277	9.04	.33
Gc-Overall	*	*	*				*			1655	1940	1956	2140	2232	8.70	.33
Gc-Overall	*	*	*			*	*			1710	1930	1954	2118	2226	7.29	.30
Gc-Overall	*	*	*		*	*	*			1716	1901	1909	2127	2318	11.31	.37
Gc-Overall	*	*	*		*	*	*	*		1539	1831	1905	2223	2430	25.17	.51
G Omnibus										0064	1311	1276	1087	0852	5.18	.26
G Omnibus	*									0260	1214	1257	1089	0801	3.59	.22
G Omnibus	*	*								0914	1264	1241	0904	0408	3.17	.21
G Omnibus	*	*						*		0249	0734	0961	1372	1430	14.78	.41
G Omnibus	*	*							*	2003	2023	1857	0873	0013	28.08	.54
G Omnibus	*	*	*							0950	1151	1112	0976	0617	1.34	.13
G Omnibus	*	*		*						0896	1158	1089	1013	0647	1.36	.14
G Omnibus	*	*			*					1027	0984	0854	0996	1153	0.89	.11
G Omnibus	*	*	*				*			0975	1069	0923	0932	1089	0.59	.09
G Omnibus	*	*	*		*	*	*			1058	1058	0926	0897	1067	0.75	.10
G Omnibus	*	*	*		*	*	*	*		0525	0846	0913	1188	1405	14.81	.41
G Omnibus	*	*	*		*	*	*		*	1431	1278	1084	0673	0519	15.81	.43
G Omnibus	*	*	*		*	*	*	*	*	0898	1047	1031	0969	0940	1.44	.14
Gv-Visual										6794	7118	7150	6996	6788	7.77	.30
Gv-Visual	*	*								6953	7099	7142	6967	6701	8.13	.32
Gv-Visual	*	*	*							6963	7066	7105	6987	6770	5.48	.26
Gv-Visual	*	*		*						6948	7071	7102	6996	6773	5.70	.27
Gv-Visual	*	*	*					*		6813	6964	7060	7081	6968	5.58	.27
Gsc-Clerical										4897	5039	5068	4988	4940	2.27	.17
Gsc-Clerical	*	*								4978	5059	5068	4958	4883	2.93	.17
Gs-All										6876	7034	7086	6978	6945	1.95	.16
Gs-All	*	*								7007	7058	7085	6934	6858	2.73	.19
C-Careful										4844	5015	5001	5058	5032	3.97	.23
C-Careful	*									4838	5017	5001	5058	5034	4.11	.23
C-Careful		*								4875	5018	5000	5049	5013	2.23	.17
C-Careful	*	*								4869	5020	5001	5049	5015	2.31	.16
F-Fluency										2960	2968	2986	3040	3028	1.21	.13
F-Fluency	*									2964	2966	2985	3040	3027	1.17	.13
F-Fluency		*								3014	2973	2984	3024	2995	0.46	.08

N.B. Although results in these tables are listed to only 4 places, the calculations (done on a Burroughs 5500 computer) carried 11 or 12 digits throughout.[3]

[3] We are grateful to W. H. Eichelberger for help in developing computerprograms and to L. G. Humphreys for guidance on theoretical points of the analyses used here.

measurements, the adjusted means show a clear monotonic negative relationship between aging and ability, and the F-value, indicating significance, increases. The negative relationship and significant F remain when other co-variates are added. Most crucially, perhaps, the relationship remains and the differences continue to be highly significant even when the 'pure' estimate of the crystallized function is included as a covariate. Thus, the tenor of these results is clear: when seen in averages for performances of many people at each age level, fluid intelligence declines with age in adulthood and this decline is not ascribable to decline in other functions – notably general speediness and visualization – nor is it due to obtained sampling differences in education and sex.

The findings for crystallized intelligence are no less clear. Here the differences favor the older subjects. These remain significant when variance associated with other factors is partialled in covariance analysis. The correlation ratio drops notably – from .55 to .46 – when educational differences are partialled, but even in this case the basic form of the relationship is not altered and the differences between means remain highly significant. And the same can be said when the variance associated with the 'pure' estimate of fluid intelligence is removed. Hence again the tenor of the results is clear: on the average, older adults perform better than younger adults in tasks depending primarily on crystallized intelligence, and the differences favoring the older subjects are not ascribable to obtained differences in education, sex, fluency, carefulness, speediness, visualization and fluid intelligence.

The measure referred to as 'omnibus intelligence' in tables 2 and 3 may be likened to the measure obtained with many popular tests of intelligence, such as the Stanford–Binet, Army Alpha, Otis, Lorge–Thorndike and Wechsler scales, for in these scales, as here, a single score is obtained by adding together scores on several rather diverse kinds of subtests, each accepted as measuring a valid aspect of intelligence. The logical, empirical justification for this practice is the well-confirmed fact of positive manifold among the intercorrelations for ability tests. But according to the theory presented in this paper, this fact is not sufficient to support the contention (albeit implicit) that a functional unity is represented by the measure thus obtained. Specifically, we argue that the measurements obtained in this manner do *not* represent a functional unity with respect to aging in adulthood. Subtests which intercorrelate positively (and are widely accepted as measuring some aspect of intelligence) may require mainly fluid intelligence – which declines with age in adulthood – mainly crystallized intelligence – which increases with age – or one or the other – i.e., a test may allow for use of alternative mechanisms, either Gf or Gc. And the mixtures of subtests in different omnibus tests vary. Hence, depending upon the mixture of subtests and the Gf–Gc composition of the subtests, a measure of omnibus intelligence may show virtually any relationship between aging and change in intelligence.

The omnibus measure obtained in this study was designed to help illustrate these points. It will be noted that it is based upon a wide range of tests said to involve intelligence in some acceptable sense of this word. In looking at the means for different age groupings for this variable, we are viewing the kind of result obtained in many studies of age changes in general intelligence. It is thus particularly interesting that the results obtained here are consistent with those found in several earlier studies. Thus, for example, if the mean differences are considered before sex and education have been statistically controlled, there is suggestion of a very slight decline in intelligence beginning in the late twenties or early thirties – an interpretation suggested by investigations like those of BARNES (1943), BAYLEY (1957, 1955), FREEMAN and FLORY (1932), HUNTER (1942), and others (see JONES, 1940). But if variance associated with speediness is partialled, the differences for the adjusted means turn out to be *not* significant, an outcome that agrees with LORGE's (1936) early hypothesis and results and with GHISELLI's (1957) more recent findings. And the differences between adjusted means remain insignificant when, additionally, education, general fluency, general visualization, etc., are covaried out. But if the variance of the omnibus measure is forced to reflect more surely the differences in fluid intelligence, by covarying out the component measured with Gc-pure, the differences favoring the young are found to be significant: this outcome agrees with results shown in the FOULDS and RAVEN (1948) and RAVEN (1948) studies, employing the fluid measurements given by the Matrices subtest, and it agrees with the results found by CORSINI and FASSETT (1953), COHEN (1957), RIEGEL (1958), and WECHSLER (1944) using the fluid measurements obtained with the so-called 'performance' subtests of the Wechsler scales. However, if the component measured by the Gf-pure score is partialled out, thus forcing the variance of the residual to reflect primarily differences in crystallized intelligence, then again the differences between age groupings are found to be significant, but this time the differences favor the older subjects. This finding agrees with results reported in the BAYLEY and ODEN (1955), BRADWAY and THOMPSON (1962) and OWENS (1953), studies wherein were used Gc-saturated measures like the Concept Mastery, Otis and Stanford–Binet.

The results for the other second-order factors may be dealt with more quickly, since they are not of principal concern in this study.

It is interesting, in view of what is known about the structural bases for visual processes (see WEISS, 1959), that the findings here obtained for general visualization suggest that this function improves through the twenties and declines somewhat thereafter. This relationship needs to be studied more intensively.

The differences shown in the analyses of variance on the carefulness function would appear to reflect mainly influences associated with formal education, for when education is partialled in covariance analyses, the differences for the adjusted means prove to be insignificant. Similarly, no clear aging trends are discernible for the Gs and F factors. These outcomes are consistent with findings from our previous study (HORN and CATTELL, 1966b) in which it was found that age differences in speediness, carefulness and fluency related most directly to the residual Gf or Gc variance of the primary factors. But, again, these are matters calling for more intensive study in researches specifically designed to provide for test of the several alternative hypotheses.

6. DISCUSSION

A particularly noteworthy outcome of this study is that it has shown intelligence to both increase and decrease with age – depending upon the definition of intelligence adopted, fluid or crystallized! This allows us to make sense out of seemingly contradictory results from past research. For whereas several studies have shown that intelligence declines with age in adulthood, others have shown that it increases and still others have shown that it remains more or less constant. But the findings of this study suggest that the apparent contradictions are reflections of the fact that varying mixtures of the fluid and crystallized functions were measured in these earlier investigations. When Gf was prominent, decline was noted; when Gc predominated, increase was found and when the two were nearly evenly mixed (and extraneous factors were controlled), neither increase nor decrease was recorded.

Our results illustrate an essential fallacy implicit in the construction of omnibus measures of intelligence. This fallacy is found in the assumption (perhaps often implicit) that positive manifold among intercorrelations for a set of tests necessarily indicates a functional unity. Here it has been shown that some measures which correlate positively nevertheless have quite different relationships to aging. Just because there is a sense in which various tests can be said to require intelligence, just because these tests are positively intercorrelated, just because older children perform better than younger children on these tests and just because these tests have positive correlations with practical criteria said to involve intelligence, it does not follow that the measure obtained by adding scores from these various tests is valid for the purpose for which it is intended. The resulting omnibus score is analogous to a chemical mixture, whereas it would seem that the more useful scientific measure should be analogous to a chemical compound. To be sure, mixtures are often needed: in practical predictions, for example, where both Gf and Gc are apt to have stable beta weights. But the scientist needs to know the composition of his mixtures in terms of the compounds and elements which go into them. The suggestion from this research is that it is particularly worthwhile to recognize the Gf and Gc compounds in the mixtures provided by omnibus, so-called general intelligence tests, and it is probably useful to remain aware of the fact that these mixtures also usually contain traces of the Gv, Gs, and F and C compounds.

The results and theory presented here are in basic agreement with HUMPHREYS' (1962) and MCNEMAR'S (1964) criticisms of the trend in recent years towards proliferation, by factor analytic study, of so-called 'primary mental abilities'. If only slightly different tasks are used to identify a factor – in the limiting case, merely parallel forms of the same test – then that factor is little more than a swollen specific, not an important factor in scientific discourse. However, our position here obviously does not agree with McNemar's implicit argument that general (omnibus) intelligence is the construct of principal scientific value. The combination of Gf and Gc achieved in omnibus intelligence tests will usually give higher predictions of practical criteria than either Gf or Gc used alone. But an understanding of such predictions, and the ability to change procedures in the light of new circumstances, must be based on awareness of the independent contributions of Gf and Gc, as well as Gv, Gs, F and C. As for the verbal-quantitative distinction which McNemar favors, our position is that this fits at the level of primary factors, where V, CMR, etc. are distinguished from N and R. Both the verbal and quantitative scores of tests which utilize this breakdown indicate scholastic attainment – and thus acculturation – to a large extent, so both contain primarily Gc variance. Important as this variance is for prediction of academic achievements, exclusive dependence on it is probably shortsighted. Particularly over long periods of time, but not alone in such situations, Gf is apt to account for important parts of the variance on practical criteria.

Finally, we should make it very clear that the reasons for decline in Gf and for increase in Gc are not made clearly evident by our results. It is possible – perhaps even likely – that the decline is due to inevitable and unavoidable processes in the physiology of aging. Elsewhere (HORN, 1965a) we have summarized results from a number of studies showing that differences in central nervous system structure of older and younger persons parallel in some respects the differences in this structure of persons known to have suffered brain damage and persons who apparently have not suffered such damage. It was argued on this basis that there is need to look closely for factors which produce small amounts of brain damage in 'normal' aging. An accumulation of such small injuries within all persons could account for the results for Gf in this study. But the observed differences are in averages computed over many individuals at each age level, and such averages need not represent any particular individual. It is possible that only a very few people experience decline in Gf with age, but that the amount of decline for these few is substantial so the average Gf score for older persons can be significantly lower than for younger persons. If a few people suffered large brain damage, for example, this could result. But the decline seen in the averages would not point to any process inherent in aging, *per se*. The apparent increase with age of Gc can be explained in like manner. Our point is: the results obtained here need to be taken seriously, for they have important practical and theoretical implications, but too much should not be read into them.

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