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Critical Flicker Frequency and Intelligence*

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Tests of verbal intellegence (Concept Mastery Test) and nonverbal intelligence (Raven's Advanced Progressive Matrices) showed nonsignificant zero-order correlations and a nonsignificant multiple correlation with critical flicker frequency (CFF), in 100 university students. Age-partialled correlations were even lower, and corrections for attenuation and restriction of range yielded unimpressive results. It was concluded that CFF has a negligible relationship to psychometric intelligence and is probably a poor tool in the investigation of the nature of *g*.

The visual apparatus is an imperfect light-registering instrument for intermittent light. When flashes of light are presented intermittently, interrupted by dark periods, the subjective sensation of intermittent light reflects the objective intermittency only for light/dark cycles below a certain rate (measured in cycles per second, or herz [Hz]). The precise rate of objective intermittency at which the subjective sensation of clear-cut intermittency finally ceases (after changing through successive sensations described as coarse flicker and fine flicker) and becomes a sensation of perfectly steady light is termed the *fusion frequency*, or the *critical flicker frequency* (CFF).

The frequency at which a person can perceive flicker may be regarded as an index of the fidelity and efficiency of his visual sensory system. There is also evidence that central neural functions as well as strictly ocular mechanisms are involved in CFF phenomena (Osgood, 1953, pp. 145–146). Probably for this reason, a number of psychologists have wondered if the highly reliable individual differences in CFF might also be related to individual differences in constructs such as general intelligence, or *g*, biological intelligence (Halstead, 1947), or fluid intelligence (Cattell, 1963). For example, as early as the 1940s, Halstead (1947) included CFF among the dozen tests in his battery for assessing what he termed "biological intelligence." A principal components analysis of this battery, on a sample of 50 normal adults, shows CFF to have a loading of $+.47$ ($p < .01$) on the first principal component. The Henman–Nelson IQ shows

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TABLE 1
Summary of Correlations Between Critical Flicker Frequency and Psychometric Intelligence

Study	Subjects	N	Test		Correlation with CFF
Halstead (1947)	Normal adults	50	Henman-Nelson IQ		+.117 n.s.
Young (1949)	Mental patients, ages 20–61 years	30	Wechsler-Bellevue:	Verbal IQ	−.08 n.s.
				Full Scale IQ	−.07 n.s.
			Age-partialled	Full Scale IQ	−.03 n.s.
Tanner (1950) Study I[a]	Male university students	25	ACE Total Score		+.182 to +.264 n.s.
Study II[b]	Male university students	21	ACE Total Score		+.147 to +.513 ($p < .05$)
Colgan (1954a)	Men, ages 65–95 yrs.	40	Wechsler-Bellevue:	Verbal IQ	+.32 n.s.
				Full Scale IQ	+.46 ($p < .01$)
			Age-paartialled	Full Scale IQ	+.36 ($p < .05$)
Colgan (1954b)	Male college sophomores	40	ACE Total Score		nonsig. *r*s
King & Clausen (1956)	Mental patients, ages 22–57 yrs.	37	Wechsler-Bellevue:	Verbal IQ	−.18 n.s.
				Full Scale IQ	−.20 n.s.
			Age-partialled	Full Scale IQ	−.14 n.s.
Landis & Hamwi (1956)	Mental patients, ages 16–45 yrs.	33	Wechsler-Bellevue:	Verbal IQ	+.06 to +.08 n.s.
			Age-partialled	Verbal IQ	+.01 to +.02 n.s.
	Mental patients, ages 16–45 yrs.	91	Kent EGY: Total Score		+.23 ($p < .05$)
			Age-partialled Total Score		+.22 ($p < .05$)
Barratt, Clark, & Lipton (1962)	5th grade pupils	42	Wechsler Intelligence Scale for Children: Full Scale IQ		−.09 n.s.
5th grade pupils	42	Cattell Culture Fair Intelligence Scale		+.43 ($p < .01$)	
	College sophomores	70	Otis Quick Scoring Mental Ability Test		+.329 ($p < .01$)
	College sophomores	70	Cattell Culture Fair Intelligence		+.243 ($p < .05$)

[a]Each study used 8 different light/dark ratios.
[b]Study II used longer durations and lower intensity of the light.

a loading of +.69 on the same component. (The zero-order *r* between CFF and Henman-Nelson IQ, however, was only a nonsignificant +.117 [p. 40].) The essential results of the subsequent studies that I have been able to find in the literature on the relationship of CFF to psychometric intelligence are summarized in Table 1.

It should be noted that, since CFF is conventionally measured in number of light/dark cycles per second, a *positive* correlation indicates that flicker-fusion threshold occurs at a *faster* frequency of objective intermittency for subjects who earn higher scores on intelligence tests.

The results shown in Table 1 are scarcely impressive; they lend little encouragement to the hypothesis that CFF is related to psychometric intelligence. Twelve out of the 20 reported correlations are nonsignificant, and eight of the 20 correlations (one of them significant at the .01 level) are *negative,* that is, contrary to the favored hypothesis.

But the designs and subject populations of most of these studies are hardly more impressive than the results. Four of the studies, for example, used mental patients (many of them prelobectomy patients) as subjects, and in most studies the samples were small, the average sample size being only 43, which is less than ideal for a correlational study.

Barratt, Clark, and Lipton (1962) argued that previous studies had generally failed to reveal significant or impressive correlations because they did not use "culturally free" measures of fluid intelligence. In their own study of the relationship of CFF to intelligence, they showed a nonsignificant correlation of −.09 with the Full Scale IQ of the Wechsler Intelligence Scale for Children and a significant *negative* correlation with the Otis IQ, but a significant positive correlation (+ .243, $p < .01$) with the Cattell Culture Fair Intelligence Scale, a measure of fluid *g*. Barratt et al. viewed their finding as casting doubt on the conclusions of an earlier review of the rather meager evidence on the correlation between CFF and intelligence by Landis and Hamwi (1956), who stated:

> There is no obvious reason why intelligence should act as a determinant of CFF. There are enough well-established determinants of CFF to suggest that the [significant] correlations reported by Tanner [1950] and Colgan [1954a, 1954b] are examples of random fluctuation. (p. 461)

The purpose of the present study was to obtain further evidence on the relationship between CFF and measures of fluid and crystalized intelligence. University students were employed as subjects. Although this group has the disadvantage, for a correlational study, of a restricted range (which may be corrected statistically) on psychometric intelligence, they have the distinct advantage that central neurological impairments (a factor which has confounded some previous studies) are notably rare among young university students.

METHOD

Subjects

The subjects were 50 male and 50 female university students, who were recruited by an advertisement in the student newspaper and were paid for participating in the study. Their mean age was 21 years, 8 months (SD = 3 years, 5 months). Prior to their participation, prospective subjects were asked if they used eyeglasses or had any visual problems, and only those who answered in the negative were accepted.

Psychometric Tests

In two separate sessions, one day apart, subjects were given nonverbal and verbal intelligence tests. The nonverbal test was the Advanced Progressive Matrices (APM), a figural test of reasoning ability, which, when factor analyzed with other cognitive tests, is generally found to be highly loaded on what can be identified as Spearman's *g* factor. The verbal test was Terman's Concept Mastery Test (CMT), a high-level test of verbal reasoning originally devised by Terman to measure the intelligence of intellectually gifted children when they became adults. The advantage of both the APM and CMT is that these tests show no ceiling effect for superior university students. Both tests were given without time limit, and subjects were encouraged to attempt all items. Raw scores on each test were used in all statistical calculations.

Critical Flicker Frequency (CFF)

The author sought advice on the measurement of CFF from a professor of physiological optics,[1] who, dissatisfied with the commercially available instruments, specially constructed the CFF apparatus used in the present study. The subject wore an eye-patch over one eye while the other eye was being tested. After 5 minutes of dark adaptation, the subject put his or her open eye up to the eyepiece of the CFF apparatus, as if looking into a telescope. A ruby spot of light against an entirely black background was the flicker stimulus, created by a L.E.D. (light-emitting diode), with a light/dark ratio of 1:1. The red spot subtended a visual angle of 1.5°, so as to just fill the fovea, thereby minimizing the need for accommodation. A red light was used to emphasize cone vision, and particularly foveal vision. To minimize or eliminate peripheral vision by eyemovement scanning, the spot of red light had to be viewed through a 2 mm aperture in the eyepiece, i.e., an aperture which approximates the size of the human pupil. Rate of flicker, in hertz (Hz), or cycles per second, was controlled

[1]The author is greatly indebted to Professor Theodore E. Cohn of the School of Optometry, University of California, Berkeley, for the construction and use of the CFF apparatus and for his helpful advice concerning optimal procedures for reliably measuring individual differences in CFF.

by a rheostat operated by the subject's turning a dial. The readings of the flicker rate could be read off the apparatus only by the experimenter. Before each trial, the experimenter would reset the dial to a predetermined position (clear-cut flicker or complete fusion) and instruct the subject to turn the dial slowly until the point that the flicker appeared to fuse into a steady light, or until the steady light first appeared to flicker.

Subjects were tested for CFF in two sessions, one day apart. In each session, after dark adaptation and three practice trials, subjects were given five test trials ascending (i.e., going from flicker to fusion) and five test trials descending (i.e., going from fusion to flicker), first with the right eye and then with the left eye. Thus there were 40 trials in all: 2 sessions × 2 directions × 2 eyes × 5 trials in each condition. The subject's CFF score was simply the mean of 40 trials, expressed in Hz units (i.e., the average number of light/dark cycles per second recorded at the subjective flicker-fusion threshold.

RESULTS AND DISCUSSION

Means and Standard Deviations of Variables

The Advanced Progressive Matrices: $\bar{X} = 27.48$, $SD = 5.23$. The Concept Mastery Test: $\bar{X} = 80.67$, $SD = 31.72$. Although there are no norms for these tests based on the general adult population, it is known from other evidence that the present subjects are sampled from an intellectually quite select group and therefore represent a restricted range of ability as compared with the variability in the general population. Other studies of the same university population have shown it to have a mean Wechsler Adult Intelligence Scale IQ of about 120 (i.e., at about the 90th percentile of the general population), and a *SD* of about 8 IQ points, or slightly more than half of the *SD* of the general population ($\sigma = 15$ IQ points). These statistical characteristics of this population must be taken into account in evaluating the correlations between variables in the present study.

The CFF, or flicker-fusion threshold, is conventionally measured in Hz, or number of light/dark cycles per sec. In the present sample, the mean CFF was 29.96 Hz, $SD = 2.71$ Hz. The mean period (i.e., duration of a single light/dark cycle) of the flicker at the flicker-fusion threshold was 33.38 ms, $SD = 3.30$ ms.

Reliability of CFF

The following correlations were found between CFF measures obtained under the different conditions of the testing procedure. (The correlations boosted by the Spearman-Brown formula are shown in parentheses.)

Day 1 × Day 2:	$r = .748$ (.856)
Right Eye × Left Eye:	$r = .698$ (.822)
Ascending × Descending:	$r = .704$ (.826)

These S-B corrected correlations may be regarded as different forms of reliability of CFF. The internal consistency reliability, that is, the Spearman-Brown boosted average correlation between trials within a single condition (e.g., Day 1, right eye, ascending) is .951. An overall estimate of the reliability, r_{xx}, of the average CFF score based on all 40 trials can be obtained from a complete analysis of variance of all the CFF data, as follows: r_{xx} = (Between Subjects Mean Square − Within Subjects Mean Square)/(Between Subjects Mean Square), where the Within Subjects Mean Square consists of the total sums of squares of all of the interactions (of days, eyes, and directions) involving subjects, divided by the total degrees of freedom for all of these interaction terms. The resulting reliability, r_{xx}, for the present CFF data is .941. This is probably the best estimate of the reliability of subjects' total (or average) CFF score, which is the only CFF score that was used in all of the following analyses.

Correlations Between Variables

The simple, or zero-order, intercorrelations (Pearson *r*) among all of the variables in this study are shown in Table 2, along with the partial intercorrelations among APM, CMT, and CFF, with age and sex both partialled out. Sex was not considered in the subsequent analyses, for two reasons: (a) the within-sex correlations between CFF and the two psychometric tests do not differ significantly from zero (nor from each other); (b) there is no consistent evidence of population sex differences in the Raven Matrices (Court & Kennedy, 1976) or in the CMT, and therefore the correlations of sex with the APM and CMT in the present sample would seem to be most reasonably interpreted as a true, albeit slight, sex difference in ability in this sample and therefore should not be partialled out of the correlations between the psychometric tests and CFF. Also, in trying to detect a possibly weak effect, namely, a correlation between CFF and psychometric intelligence, it would seem unwise to stack the cards so as to favor the null hypothesis. Partial correlations, therefore, should be regarded more as a means of

TABLE 2
Simple (Zero-order) Correlations (Above Diagnoal) Among All Variables and Partial Correlations with Effects of Sex and Age Partialled Out (Below Diagonal)

	Age	Sex[a]	APM	CMT	CFF
Age		.215*	−.257**	.105	−.098
Sex[a]			.177	.347**	.225**
APM				.477**	.103
CMT			.485**		.126
CFF			.053	.055	

[a]Sex is coded as male = 1, female = 0.
*$p < .05$
**$p < .01$

assessing the robustness or the limits of the obtained zero-order correlations, rather than as an improved inference of the population correlation.

The Pearson r between the APM and CMT is .477. The partial r, holding chronological age (in months) constant, is .525. If we make the reasonable assumption that the standard deviation (*SD*) of this university sample is only one half of the *SD* in the general population on one of the tests, and correct the obtained correlation for restriction of range (see McNemar, 1949, p. 126), the range-corrected r between APM and CMT becomes .735, and with age partialled out it becomes .777. This is very close to the correlation typically found between verbal and nonverbal intelligence tests in the general population. If also corrected for attenuation, assuming test reliability of .90, the correlation would be about .86.

Because CFF shows a nonsignificant negative correlation of −.098 with age, and correlations of −.257 ($p < .01$) and +.105 (n.s.) with the APM and CMT, respectively, the correlations between CFF and the psychometric tests have been computed both as simple (i.e., zero order) Pearson r and as a partial r, with age held constant. Table 3 shows the various correlations, without and with corrections for restriction of range and attenuation due to unreliability. The correction for range restriction is based on the assumption that the *SD* of the psychometric test scores in the present sample (APM and CMT) is one half the *SD* of the unrestricted general population. This calculation is intended merely to give a rough approximation of what the correlation might be in the unrestricted population, provided it were assumed that the presently obtained correlations are not merely chance deviations from a true correlation of zero. However, it should be

TABLE 3
Correlations (Pearson r) Between CFF and Advanced Progressive Matrices (APM) and Concept Masutery Test (CMT)

	Type of Correlation	APM	CMT
a)	Simple r	.103	.126
b)	*a* corrected for restriction of range[a]	.203	.246
c)	*a* corrected for attenuation[b]	.106	.130
d)	*b* corrected for attenuation[b]	.209	.254
e)	*a* with age (in months) partialled out	.085	.097
f)	*e* corrected for restriction of range[a]	.168	.191
g)	*e* corrected for attenuation[b]	.088	.100
h)	*f* corrected for attenuation[b]	.173	.197

[a]Corrected for restriction of range only on the APM or CMT, under the assumption that the present sample's *SD* on these tests is only one half of the *SD* in the general population.

[b]Corrected only for attenuation due to unreliability of CFF, with estimated reliability of .941. As no attenuation correction is made for the psychometric tests, these must be regarded as lower-bound estimates of the disattenuated correlations.

noted that the simple *r*s between CFF and the psychometric tests are not significantly greater than zero at the 5 percent level of confidence, even by a one-tailed test. With a sample size of 100, correlations of at least .165 and .234 would be required for significance at the 5% and 1% levels, respectively, by a one-tailed test. (The corresponding partial correlations would have to be .166 and .235.) As the simple *r*s in this study fall short of statistical significance, the corrections for restriction of range and attenuation can merely play a speculative purpose. They show that even if the obtained simple *r*s were fully significant and free of sampling error, the population correlations that could be inferred from them would still be quite small, the largest of them (.246) accounting for only about 6% of the total variance. About the most that could be said for the observed correlations between CFF and the psychometric measures is that they are *positive*, as would be predicted if greater resolving power for intermittent stimuli were indeed related to higher intelligence. Also, even within this youthful, highly age-restricted sample, there is a *negative* correlation (−.10) between CFF and age, which is consistent with the general finding of negative correlations reported in the CFF literature (Landis & Hamwi, 1956; Misiak, 1951).

In order to determine the maximum correlation that the present data could yield, a multiple correlation (R) was computed between APM and CMT (as the independent variables) and CFF (as the dependent variable). The $R = .135$ ($p = .410$). With age partialled out, $R = .105$. (This value, if corrected for range restriction, would become .207, which falls short of the R of .24 required for significance at the 5% level.)

CONCLUSION

The statistical analyses, using zero-order correlations, age-partialled correlations, and multiple correlation, all corrected for restriction of range and for attenuation, were intended to allow the null hypothesis (i.e., zero correlation between CFF and psychometric intelligence) to be rejected. Yet none of these statistics leads to unequivocal rejection of the null hypothesis for these data, by either a two-tailed or a one-tailed test. The most that can be said for the contrary hypothesis is that the direction of the nonsignificant correlation between CFF and the psychometric tests is what would be predicted from the hypothesis that greater resolving power for intermittent stimuli is a component of biological intelligence. Both the sum total of evidence in the literature and that of the present study cannot be claimed to contradict the earlier conclusion of Landis and Hamwi (1956), that the few reported significant correlations are merely examples of "random fluctuation."

If general intelligence, or Spearman's *g*, is conceived of essentially as information processing capacity, involving the speed or efficiency of decisions that objectively reduce uncertainty, it is indeed difficult to imagine how CFF would meet the criterion of conveying information, or at least information of sufficient complexity to reflect reliably individual differences in information processing capacity. According to Osgood (1953, p. 146), the primary locus of the CFF phenomenon exists in the visual receptors, and reflects chiefly the resolving power of the retina itself. CFF, therefore, could scarcely reflect central processes that would be characterized as cognitive. Osgood notes that CFF in the cat and in the conger eel, as recorded directly from the optic nerve, shows fusion at approximately the same flash rates as is found in humans.

Until new evidence is brought forth which compellingly contradicts the present findings, it would seem safe to conclude that CFF has little or no relationship to intelligence and is unlikely to be a useful tool for furthering our understanding of the biological nature of *g*.

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