Psychology and Aging
1989, Vol. 4, No. 2, 183-189

0882-7974/89/$00.75

Relationships Between Physical Exercise and Cognitive Abilities in Older Adults

Louise Clarkson-Smith and Alan A. Hartley
Scripps College, Claremont, California

We investigated relationships between physical exercise and the cognitive abilities of older adults. We hypothesized that the performance of vigorous exercisers would be superior to that of sedentary individuals on measures of reasoning, working memory, and reaction time. We gave a series of cognitive tasks to 62 older men and women who exercised vigorously and 62 sedentary men and women. Multivariate and univariate analyses of variance, with age and education as covariates, indicated that the performance of the exercisers was significantly better on measures of reasoning, working memory, and reaction time. Between-group differences persisted when vocabulary, on which the performance of exercisers was superior, was used as a third covariate. Subsequent analyses showed that neither self-rated health, medical conditions, nor medications contributed to the differences between exercise groups. Results suggest that the possible contribution of physical exercise to individual differences in cognition among older adults should be further investigated.

Researchers investigating age differences in abilities ranging from simple reaction time (RT) to complex problem solving typically report that the variance among older adults is much greater than it is among young adults (Birren, Woods, & Williams, 1980; Rabbitt, 1981; Schaie, 1979). This finding, which suggests that some older adults are retaining relatively high levels of ability, has stimulated an interest in sources of individual differences in abilities among older adults. One area of current interest is the possible beneficial effect of physical exercise on cognitive abilities.

Exercise and Health

The health benefits of physical exercise for elderly persons are well documented. A number of investigators (Cunningham, Rechnitzer, Howard, & Donner, 1987; de Vries, 1970; Dustman et al., 1984) have reported improvement in various indices of the cardiovascular–respiratory function of older adults after participation in an exercise program. Other studies (Kannel, Belanger, D'Agostino, & Israel, 1986; Paffenbarger, Wing, & Hyde, 1978) have suggested an inverse relation between physical exercise and heart attack risk. It has even been suggested that much of the loss of physical vigor associated with aging is a function of the sedentary life style typical of many older individuals (Bortz, 1982; deVries, 1983).

Exercise and Cognition

Although the precise mechanisms are unclear, it has been speculated (Birren et al., 1980, La Rue & Jarvik, 1982; Spirduso, 1980) that cardiovascular benefits derived from exercise may help to forestall degenerative changes in the brain associated with normal aging. The two most widely accepted cognitive hypotheses of aging assume that physiological changes in the central nervous system are the basis for age-related ability deficits. According to the speed hypothesis (Birren et al., 1980; Salthouse, 1985), diffuse slowing throughout the nervous system concomitant with the aging process is responsible for all age-related cognitive deficits. A second hypothesis attributes age differences in abilities to limitations in the capacity for attention (Craik & Byrd, 1982; Hasher & Zacks, 1979, Wright, 1981). Craik and Byrd explained capacity limitations in terms of *mental energy,* and proposed that there are physiological correlates to the age-related decline in mental energy as well as to the decline in physical energy. Because both slowing and capacity limitations are thought to be manifestations of a decline in the efficiency of central nervous system processing, it is reasonable to investigate the possibility that physical exercise, through its effect on the physiological functioning of an older individual, might enhance cognitive performance.

Exercise and Speed of Response

Recent research supports a positive relationship between exercise and speed of response in both older and younger people (see Spirduso, 1980, for a review). If, as proposed by adherents of the speed hypothesis, RT is an important indicator of the

The research was supported in part by National Institute on Aging Postdoctoral Fellowship Grant AG05370 to the first author. A portion of this research was presented at the annual convention of the American Psychological Association, New York, August 1987.

The authors wish to thank Dale Berger and three anonymous reviewers for helpful comments, and Amy Gamble for technical assistance. They are grateful for the interest and cooperation shown by the participants in the study and for the assistance of the following organizations and publications in locating participants: Claremont Adult School, The Claremont Club, Claremont University Club, Corona del Mar Track Club, Hillcrest Homes, Jocelyn Center, *Masters Journal,* Peer Counselors, Recording for the Blind, San Dimas Woman's Club, Saint Ambrose Church, and the Service Corps of Retired Executives.

Correspondence concerning this article should be addressed to Louise Clarkson-Smith, Scripps College, Claremont, California 91711.

functional integrity of the central nervous system, it might be expected that the greater speed of response seen in those who exercise should be accompanied by a general facilitation of all cognitive abilities. However, existing studies relating exercise to the performance of complex cognitive tasks have produced inconclusive results.

Exercise and Reasoning

Comparing relatively small samples of male exercisers (n = 26) and nonexercisers (n = 22) between the ages of 34 and 75 years, Powell and Pohndorf (1971) found that the exercisers outperformed the nonexercisers in tests of nonverbal reasoning, but the difference was not significant. In a later study, Elsayad, Ismael, and Young (1980) reported that high-fitness men performed better than did low-fitness men on measures of nonverbal reasoning. The assessments of reasoning were given before and after a 4-month exercise program, and both groups of men scored significantly higher on most postests than on pretests. However, as there was no control group, the possibility that the improvement was the result of practice rather than physical exercise cannot be ruled out. This possibility is supported in a recent study by Dustman et al. (1984), which found a significant improvement in fluid intelligence scores for a nonexercise control group but not for individuals who had participated in a 4-month exercise program.

The present study, comparing cognitive abilities of vigorous exercisers with sedentary individuals, attempted to correct some of the weaknesses of previous studies by choosing and using (a) participants who regularly participated in extensive strenuous exercise, (b) a larger sample that included both men and women, (c) more precise measures of the amount and intensity of physical exertion, and (d) statistical control for the extraneous variables, age, education, and health.

The following hypotheses were proposed: (a) Members of the high-exercise group would be superior to members of the low-exercise group in measures of physical fitness, (b) performance of individuals in the high-exercise group would be superior to that of individuals in the low-exercise group in all three domains of cognition, RT, working memory, and reasoning ability, and (c) vocabulary, which is assumed to have an experiential rather than biological basis, would be unrelated to the amount of physical exercise.

Method

Participants

Participants were selected from a larger sample of 300 men and women between the ages of 55 and 91, who had been recruited for a comprehensive study of activity–ability relationships. Participants were each paid $15.

An intensive interview was conducted with each of the 300 participants concerning the amount and type of physical exercise in which he or she had participated during the past year. Participants were asked to report all activities that required physical exertion, including not only athletic pursuits but also nonrecreational activities such as heavy housework, gardening, walking, and climbing stairs. Two measures of physical exertion were obtained: (a) an estimate of the average number of kilocalories expended per week on the aforementioned activities (Heyward, 1984) and (b) the average number of hours per week of participation in strenuous physical exercise, defined as more than 0.1 kcal/min/kg of body weight. The 62 most active participants were placed in the high-exercise group, and the 62 least active participants were placed in the low-exercise group. (As the oldest individual in the high-exercise group was 88 years old, individuals above that age were excluded from the low-exercise group.) High-exercise participants had expended at least 3,100 kcal per week in the reported activities and a minimum of 1¼ hr of strenuous physical exercise. Participants in the low-exercise group expended less than 1,900 kcal per week in the reported activities and no more than 10 min of strenuous exercise.

Table 1
Frequencies of High- and Low-Exercise Participants by Gender and Source of Recruitment

Variable	High exercise	Low exercise
Gender		
Men	35	10
Women	27	52
Source of recruitment		
Athletic groups	15	00
Bridge clubs	08	06
Adult education classes	06	07
Church groups	10	09
Senior centers	05	10
Volunteer organizations	11	08
Retirement communities	06	16
Other community organizations	01	06

As indicated in Table 1, participants were recruited from a variety of sources. All were living independently in the community or in retirement communities. The native language of all of the participants was English. In the low-exercise group, one woman was Black and one woman was of Asian descent. All of the other participants were White. Participants were screened for neuromuscular and central nervous system disorders, including the history of a stroke or ischemic attacks, and for visual disorders sufficiently severe to interfere with performance.

Systolic and diastolic blood pressure and heart rate were recorded using a Sharp digital blood pressure monitor, Model MB-500. Forced expiratory volume was measured with a Propper compact spirometer. One participant in the high-exercise group refused this test. Participants were asked to rate their health on a 7-point scale ranging from *excellent health* (7) to *poor health* (1). Participants were also asked to complete two questionnaires assessing subjective well-being, the Life Satisfaction Index A (Neugarten, Havighurst, & Tobin, 1961) and the Feelings scale from the Questionnaire for the Study of Modern Living (Bradburn & Caplovitz, 1965). The 20 items in the Life Satisfaction Index A were scored according to a system suggested by Wood, Wylie, and Sheafor (1969). Responses indicating a high level of satisfaction received a score of 2, those indicating a low level of satisfaction were scored 0, and uncertain or uncommitted responses were scored 1. The Feelings scale was scored in the standard manner with positive scores for positive feelings and negative scores for negative feelings. Means of demographic, health, exercise, and subjective well-being variables for the two exercise groups are presented in Table 2.

Procedure

Participants were tested in two sessions of approximately 1½ hr each. In addition to the previously described exercise interview, the first session consisted of a vocabulary test, measures of working memory, and measures of reaction time. The second session consisted of three written tests of reasoning and the two subjective-well-being questionnaires. Par-

Table 2
Means of Demographic, Health, Exercise, and Subjective Well-Being Variables for High- and Low-Exercise Groups

Variable	High exercise		Low exercise	
	M	*SD*	*M*	*SD*
Age	67.13	5.80	72.34	7.40
Years of education	16.62	2.14	15.37	2.10
Self-rated health	6.03	0.99	5.11	1.26
Kilocalories/week	4,614.16	1,275.88	947.03	551.40
Hours of strenuous exercise/week	5.66	2.92	0.01	0.03
Life Satisfaction Index	34.17	3.98	31.27	4.93
Feelings scale	6.30	3.63	4.62	4.64

ticipants were tested individually in the first session, and either individually or in small groups in the second session.

Vocabulary. The vocabulary test from the Shipley-Hartford Conceptual Quotient scale (Shipley & Burlingame, 1941) was presented on an Apple Macintosh computer.

Working memory. Three working memory tasks were given, letter sets, digit span, and reading span. Letter sets and reading span were presented on the Macintosh.

Letter sets was adapted from a task introduced by Crawford and Stankov (1983). The participant was required to hold in memory two sets of letters (e.g., LFG and GLS), compare them, and decide which letter was unique to each set. The letter sets were presented sequentially on the computer screen with an interstimulus interval of 1.5 s. Participants were instructed to read the letters aloud as they appeared on the screen and, after the second set disappeared, to name the letter that appeared only in the first set and the letter that appeared only in the second set. Initially, sets of two letters were presented for 6 trials, followed by 10 trials of three-letter sets and 10 trials of four-letter sets. Letters appeared on the screen just long enough for them to be read aloud, 1.5 s for two letters, 2.0 s for three letters, and 2.5 s for four letters. Three practice trials were presented at the beginning of the exercise, before starting the three-letter sets and before starting the four-letter sets. The exercise was terminated after five consecutive errors. The score was the number of correct responses, weighted by the number of letters in each set that were answered correctly.

Digit span (Wechsler, 1981) was administered in the standard manner, but the scoring was modified in order to be comparable with the scoring of the letter sets task. The score was the number of correct responses, weighted by the number of digits in each set. Both digit span forward and digit span backward were given, but only digit span backward was used in the analysis.

Reading span, modeled after a task introduced by Daneman and Carpenter (1980), required the participant first to read aloud a set of sentences presented on the computer screen and then to recall the last word of each of the sentences. The task started with two sentences in each set and increased, by increments of one, to a maximum of six sentences. Three sets of sentences were given at each level. The task was discontinued after the participant failed to make at least one correct response at any one level. Three practice trials were given at the beginning of the task. Scoring was similar to the other working memory tasks; the number of correct responses was weighted by the number of sentences in each set.

Reaction time. Simple, two-choice, and four-choice RT tasks were presented on an Apple Macintosh computer. In each case the stimulus was preceded by a tone followed by a variable interval, ranging from 0.1 to 3 s. For simple RT, the stimulus was a zero presented in the center of the screen. For choice RT tasks, the stimulus was a single digit, 1, 2, 3, or 4. The digits always appeared in the same location on the screen. The labels, 1, 2, 3, and 4, were applied to the keys, D, F, J, and K, respectively. Participants were instructed to rest their middle fingers on the keys labeled 1 and 4 and their index fingers on the keys labeled 2 and 3, and to press the key corresponding to the figure that appeared on the screen. For two-choice RT measures, only the keys labeled 1 and 4 were used. Geometric means and standard deviations, based on 30 errorless trials, were obtained separately for each of the three RT conditions. Three measures of RT were used in the analysis: (a) RT*M* averaged across the three conditions, (b) *SDM* averaged across the three conditions, and (c) slope, the linear increase in RT as a function of the number of bits of information. As suggested by Hicks (cited in Jensen, 1982), bits were calculated as $\log_2(n + 1)$, where n is the number of choices. Thus, the three RT conditions corresponded to 1.000, 1.585, and 2.322 bits of information.

Reasoning. The three reasoning tasks were (a) 30 common-word analogies, scaled for difficulty (Clarkson-Smith, 1984/1985), (b) 20 graded items selected from *Advanced Progressive Matrices, Sets I and II* (Raven, 1972, 1974), and (c) 15 letter series completion items (Horn, 1975). All three were paper and pencil tasks and were untimed.

Results

Exercise and Cognition

Because of the large number of dependent variables, multivariate analysis of variance (MANOVA) was believed to be the appropriate method to investigate differences between the two exercise groups while minimizing the probability of a Type 1 error. Preliminary analyses were performed on fitness and ability variables with exercise group as the independent variable, and age, years of education, and self-rated health as covariates. As no performance or fitness variables regressed significantly onto health, subsequent analyses were carried out with only age and education as covariates. A second set of preliminary analyses was carried out with gender and exercise group as dependent variables. Gender differences were nonsignificant for reasoning, working memory, and fitness variables. For RT variables, the significance of gender was borderline, $F(3, 118) = 2.56$, $p = .058$, but the interaction of exercise group with gender was not significant. Subsequent analyses were collapsed across gender.

Because of skewed distributions and the presence of outliers, square root or logarithmic transformations were performed on all ability variables except letter sets. Analyses were performed on both original and transformed values, but because only trivial differences resulted between the two analyses, data presented are based on analyses of untransformed data. For MANOVAs, F values are based on Wilks' lambda.

Fitness variables. To test the first hypothesis, that the high-exercise group would be superior in measures of fitness, a multivariate analysis of covariance (MANOVA) was performed on the four measures of fitness, diastolic blood pressure, systolic blood pressure, heart rate, and vital capacity. The value for vital capacity was the percentage of normal forced expiratory volume, adjusted for age, height, and gender (Kory & Smith, 1960). The effect of exercise group was significant, $F(4, 116) = 6.23$, $p < .001$. The regression of the fitness variables on the combined covariates was also significant, $F(8, 232) = 2.40$, $p < .05$. The results of the univariate analyses (ANOVAs), which are presented in Table 3, show that only vital capacity and heart rate contributed to the between-group difference, with the high-ex-

Table 3
Adjusted Means and F Values for Ability and Fitness Variables as a Function of Physical Exercise

Variable	High exercise *M*	High exercise *SD*	Low exercise *M*	Low exercise *SD*	*F*
Fitness measure[a]					
Vital capacity	0.90	0.18	0.75	0.18	18.69***
Heart rate	66.23	9.68	70.85	9.62	5.54*
Systolic blood pressure	131.51	18.47	134.23	18.00	0.53
Diastolic blood pressure	77.72	11.02	77.61	11.02	0.01
Reasoning[b]					
Analogies	23.97	3.00	21.29	4.51	12.72***
Matrices	15.55	2.56	11.82	4.54	26.57***
Series	12.08	2.26	10.04	3.55	11.97***
Working memory[b]					
Letter sets	46.42	14.98	34.16	16.61	14.72***
Reading span	13.69	7.80	10.97	5.62	4.19*
Digit span	26.13	14.75	26.39	13.90	0.01
Reaction time[b]					
Total RT *M*	514.84	44.15	574.34	77.75	22.61***
Total *SDM*	158.78	32.88	187.07	60.72	8.29**
Slope	2.07	0.48	2.48	0.88	8.12**

Note. Means and *F* values were based on raw scores adjusted for covariates. RT *M* = reaction time averaged across the three conditions.
[a] $df = 1, 119$. [b] $df = 1, 120$.
* $p < .05$. ** $p < .01$. *** $p < .001$.

ercise group having a higher vital capacity and a lower heart rate. The nonsignificant relationship of blood pressure with both age and exercise group may have been due to the fact that the blood pressure of 5 high-exercise participants and 14 low-exercise participants was regulated by medication.

Ability variables. Separate MANOVAS performed on the individual test scores comprising each of the three classes of abilities, resulted in significant between-group differences, $F(3, 118) = 9.02$, $p < .001$, $\eta^2 = .19$, for reasoning; $F(3, 118) = 5.90$, $p < .01$, $\eta^2 = .13$, for working memory; and $F(3, 118) = 7.87$, $p < .001$, $\eta^2 = .17$, for RT. The regression of the combined reasoning tests and of the combined working memory tests on the combined covariates was significant, $F(6, 236) = 2.76$, $p < .05$, and $F(6, 236) = 2.48$, $p < .05$, respectively. The relationship between the combined covariates and the combined RT measures was not significant.

As significant between-group differences resulted from MANOVAS for all three classes of ability variables, ANOVAS were performed to determine which individual tests accounted for the differences. Table 3 shows that the high-exercise group performed significantly better in all three tests of reasoning, in two of the tests of working memory (letter sets and reading span), and in all three measures of RT.

Contrary to predictions, a modest but significant difference between the two exercise groups was found for vocabulary, $F(1, 120) = 4.50$, $p < .05$, $\eta^2 = .04$. Vocabulary also regressed significantly on the combined covariates, $F(2, 120) = 5.78$, $p < .01$.

To summarize, results support the second hypothesis and are consistent with previous research. With adjustments made for age and education, significant between-group differences were seen for all of the ability variables in the MANOVAS, and only one task, digit span, failed to reach significance in the ANOVAS. However, the between-group difference in vocabulary was troubling, suggesting that ability differences unrelated to exercise may have existed between the two groups. To explore this possibility, a second set of analyses were performed with vocabulary as a third covariate. The results of the MANOVAS were similar to the results of the original analyses with no change in significance levels for any variables. In the ANOVAS, the significance level of only one variable, reading span, was reduced below the level of significance.

Health, Cognition, and Exercise

The finding that self-rated health did not account for a significant portion of the variance of any of the ability measures was surprising in view of the body of literature relating cognitive abilities among the elderly to health variables (see La Rue & Jarvik, 1982, for review). Although La Rue, Bank, Jarvik, and Hetland (1979) reported that self-ratings of physical health correlate highly with ratings of physicians, it was felt that possible biasing effects of health needed to be further explored. Although there is evidence that exercise promotes health, it is also true that poor health may curtail physical exercise. Therefore, in an attempt to tease apart the effect of exercise from the effect of health, a series of further analyses were carried out.

Three new subgroups were formed from the original sample of 300 participants. The low-health group was composed of the 52 participants who reported one of the following medical conditions thought likely to affect cognition: cardiovascular disease, other heart ailments, high blood pressure not corrected by medication, respiratory disorders, and diabetes. A second group, the medicated group, consisted of the 50 participants

Table 4
Adjusted Means and F Values for Ability and Fitness Variables of Exceptionally Healthy Participants as a Function of Physical Exercise

Variable	High exercise		Low exercise		
	M	*SD*	*M*	*SD*	*F*
Fitness measure					
Vital capacity	0.94	0.18	0.77	0.18	20.17***
Heart rate	66.23	10.64	69.62	7.04	2.82
Systolic blood pressure	133.57	20.88	132.92	17.95	0.88
Diastolic blood pressure	78.07	10.75	77.64	10.11	0.85
Reasoning					
Analogies	24.30	3.11	22.08	4.22	8.10**
Matrices	16.04	2.42	12.79	4.35	17.42***
Series	12.37	2.19	11.24	2.81	4.29*
Working memory					
Letter sets	47.22	15.58	37.05	14.91	9.29**
Reading span	14.41	7.96	13.76	7.47	0.15
Digit span	29.04	15.56	27.92	15.83	0.10
Reaction time					
Total RT *M*	517.26	49.85	551.97	70.44	6.78*
Total *SDM*	154.99	33.88	177.29	56.32	4.85*
Slope	2.02	0.52	2.38	0.79	5.39*

Note. Means were adjusted for covariates, age and education. $df = 1, 90$. RT*M* = reaction time averaged across the three conditions.
* $p < .05$. ** $p < .01$. *** $p < .001$.

who were regularly using at least one medication listed in the *Physician's Desk Reference* (Barnhart, 1986) as possibly causing psychomotor slowing, short-term memory impairmant, or mental confusion. The following classes of medications, used by one or more participants, fell into this category: tranquilizers, beta blockers, other antihypertensives, lithium, decongestants, barbiturates, and antihistamines. Eight participants were in both the low-health and medicated groups. A third group was the high-health group, consisting of participants who reported having no medical conditions nor using any of the previously mentioned medications and who rated their health as either very good or excellent. High- and low-health participants were equally represented in the two exercise groups. There were 13 low-health participants in each group, with 10 high-health participants in the low-exercise group and 9 in the high-exercise group. Seven participants in the medicated group were from the high-exercise group, and 13 were from the low-exercise group.

The performance of participants in the low-health group was contrasted with the performance of 50 participants, selected at random from among the 97 participants in the high-health group. Multivariate analyses of variance, similar to those performed for the exercise groups were carried out. The results were contrary to expectations and inconsistent with most previous research in finding no significant between-group differences for any of the ability or fitness variables. Multivariate analyses comparing the performance of the medicated group with the high-health group produced similar results.

To further demonstrate that the differences between exercisers and nonexercisers were independent of health considerations, a final analysis compared exceptionally healthy groups of high and low exercisers. Individuals in the high- and low-exercise groups were free from any of the medical conditions that had characterized the low-health group and from any of the medications taken by the medicated group. In addition, they all had rated their health as good, very good, or excellent. Exercise requirements had to be relaxed somewhat in order to place sufficient numbers of participants in each group. Participants in the low-exercise group expended no more than 2,000 kilocalories per week in the previously described activities and spent no more than 60 min in strenuous exercise. Participants in the high-exercise group expended a minimum of 3,100 kilocalories per week and a minimum of 140 min of strenuous exercise per week. There were 47 participants in each group. A comparison of characteristics of the two exercise groups showed a pattern similar to that of the original exercise groups, with participants in the high-exercise group somewhat younger, more educated, and higher in self-rated health. However, in contrast to the original groups, the scores on the two subjective well-being scales were very close.

Multivariate analyses of the three reasoning tasks, the three working memory tasks, and the four fitness measures resulted in significant differences between the two exercise groups, $F(3, 88) = 6.37$, $p < .01$; $F(3, 88) = 3.89$, $p < .05$; and $F(4, 87) = 6.00$, $p < .001$, respectively. Results of the ANOVAS, presented in Table 4, indicate that all three measures of reasoning reached significance. However, only one working memory task, letter sets, and only one fitness measure, vital capacity, was significantly different between the two groups. The MANOVA of the three RT measures just failed to reach significance, $F(3, 88) = 2.39$, $p = .074$. However, as indicated in Table 3, ANOVAS resulted in significant between-group differences for each of the three RT variables. Thus, the results of this second analysis of exceptionally healthy individuals follow a pattern very similar to the results of the first analysis of exercise groups.

Discussion

The present study has presented correlational data that show a positive relationship between exercise and performance in three areas of cognition, reasoning, working memory, and reaction time. These results are consistent with results of the few studies relating exercise to cognition and with the notion that exercise may exert a beneficial effect on cognition. Between-group differences persisted after we statistically controlled for age, education, and vocabulary scores. Although health was expected to be an important variable, neither self-rated health nor medical conditions influenced performance of the tasks in the present study. Furthermore, an analysis comparing smaller groups of exceptionally healthy high and low exercisers replicated the results of the original analysis. However, the strongest and the most consistent effect throughout the various analyses was for tasks measuring reasoning ability.

Previous investigators have frequently found a relationship between cognition and health, particularly between cognition and cardiovascular disease. We can only speculate why our results do not concur. Our subject sample probably differed from those of studies in which health was investigated. Because we were interested in activities, our participants were recruited primarily from volunteer organizations, interest groups, and other community organizations in which they were taking an active part. Thus, in general, these adults were an unusually active and healthy group, as indicated by the high self-ratings of health by individuals in both exercise groups. On the other hand, investigators interested in differences in cognition as a function of health are more likely to seek participants with greater extremes of health.

A second explanation, which is consistent with our hypothesis, is that today, perhaps more than in previous years, individuals with cardiovascular disease or high blood pressure are made keenly aware of the importance of those life-style factors that are important to maintain or improve cardiovascular health, such as diet and exercise. Thus, those individuals in our study who had been diagnosed with cardiovascular disease or high blood pressure may have been more conscientious than others in leading the kind of life that promotes cardiovascular health.

Although it is possible that exercisers might differ from non-exercisers in other variables, such as diet and achievement motivation, probably the most important variable lacking in our analysis was previous level of ability. It could be argued that those who are more mentally able are more likely to exercise because of increased awareness of the health benefits of exercise. As information on previous ability level was not available to us, years of education and vocabulary scores had to suffice as a rough estimate of this variable.

Although it has not been possible to control for all variables that might affect cognition, a conscientious effort has been made to control for the most important ones. Although the data is correlational, we believe that the relationship of exercise with the cognitive variables is strong enough to suggest that the possibility of a causal relationship between exercise and cognition should be further explored. Ideally, this would be done in a longitudinal study. The issue of the potential effect of physical exercise on mental abilities is of great practical significance. One of the most dreaded consequences of old age is the loss or reduction of mental abilities. The individual can do little or nothing about many of the factors influencing his or her ability level, heredity, past experience, and many aspects of health. However, the kind of activities in which one engages is under control of the individual.

References

Barnhart, E. R. (1986). *Physician's desk reference* (40th ed.). Oradell, NJ: Medical Economics Company.

Birren, J. E., Woods, A. M., & Williams, M. V. (1980). Behavioral slowing with age: Causes, organization, and consequences. In L. W. Poon (Ed.), *Aging in the 1980s: Psychological issues* (pp. 293–308). Washington, DC: American Psychological Association.

Bortz, W. M. (1982). Disuse and aging. *Journal of the American Medical Association, 248,* 1203–1208.

Bradburn, N. M., & Caplovitz, D. (1965). *Reports on happiness.* Chicago: Aldine.

Clarkson-Smith, L. (1985). The components of verbal analogies and their relations to fluid and crystallized intelligence (Doctoral dissertation, University of California, Riverside, 1984). *Dissertation Abstracts International, 45,* 2329B.

Craik, F. I. M., & Byrd, M. (1982). Aging and cognitive deficits: The role of attentional resources. In F. I. M. Craik & S. Trehub (Eds.), *Aging and cognitive processes* (pp. 191–211). New York: Plenum.

Crawford, J., & Stankov, L. (1983). Fluid and crystallized intelligence and primacy/recency components of short-term memory. *Intelligence, 7,* 227–252.

Cunningham, D. A., Rechnitzer, P. A., Howard, J. H., & Donner, A. P. (1987). Exercise training of men at retirement: A clinical trial. *Journal of Gerontology, 42,* 17–23.

Daneman, M., & Carpenter, P. A. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior, 19,* 450–466.

deVries, H. A. (1970). Physiological effects of an exercise training regimen upon men age 52–88. *Journal of Gerontology, 1970, 25,* 325–336.

deVries, H. A. (1983). Physiology of exercise and aging. In D. S. Woodruff & J. E. Birren (Eds.), *Aging: Scientific perspectives and social issues* (pp. 285–304). Monterey, CA: Brooks/Cole.

Dustman, R. E., Ruhling, R. O., Russell, E. M., Shearer, D. E., Bonekat, H. W., Shigeoka, J. W., Wood, J. W., & Bradford, D. C. (1984). Aerobic exercise training and improved neuropsychological function of older individuals. *Neurobiology of Aging, 5,* 35–42.

Elsayad, M., Ismail, A. H., & Young, R. J. (1980). Intellectual differences of adult men related to age and physical fitness before and after an exercise program. *Journal of Gerontology, 35,* 383–387.

Hasher, L., & Zacks, R. T. (1979). Automatic and effortful processes in memory. *Journal of Experimental Psychology, 21,* 43–54.

Heyward, V. H. (1984). *Designs for fitness: A guide to physical fitness appraisal and exercise prescription* (pp. 192–197). Minneapolis, MN: Burgess.

Horn, J. L. (1975). *Gf–Gc sampler.* Unpublished manuscript, University of Denver.

Jensen, A. R. (1982). Reaction time and psychometric *g*. In H. J. Eysenck (Ed.), *A model for intelligence* (pp. 93–132). New York: Springer-Verlag.

Kannel, W. B., Belanger, A., D'Agostino, R. D., & Israel, I. (1986). Physical activity and physical demand on the job and risk of cardiovascular disease and death: The Framingham Study. *American Heart Journal, 112,* 820–825.

Kory, R. C., & Smith, L. G. (1960). *Clinical cardiopulmonary physiology* (2nd ed.). New York: Grune & Stratton.

LaRue, A., Bank, L., Jarvik, L., & Hetland, M. (1979). Health in old age: How do physicians' ratings and self-ratings compare? *Journal of Gerontology, 34*, 687–691.

LaRue, A., & Jarvik, L. (1982). Old age and biobehavioral changes. In B. B. Wolman (Ed.), *Handbook of developmental psychology* (pp. 791–806). Englewood Cliffs, NJ: Prentice-Hall.

Neugarten, B. I., Havighurst, R. J., & Tobin, S. S. (1961). The measurement of life satisfaction. *Journal of Gerontology, 16*, 134–143.

Paffenbarger, R. S., Wing, A. L., & Hyde, R. (1978). Physical activity as an index of heart attack risk in college alumni. *American Journal of Epidemiology, 108*, 161–175.

Powell, R. R., & Pohndorf, R. H. (1971). Comparison of adult exercisers and non-exercisers on fluid intelligence and selected physiological variables. *Research Quarterly, 42*, 70–77.

Rabbitt, P. M. A. (1981). Cognitive psychology needs models for changes in performance with old age. In J. Long & A. Baddeley (Eds.), *Attention and performance IX* (pp. 555–573). Hillsdale, NJ: Erlbaum.

Raven, J. C. (1972). *Advanced progressive matrices: Set I.* London: Silver End Press.

Raven, J. C. (1974). *Advanced progressive matrices: Set II.* London: Silver End Press.

Salthouse, T. A. (1985). Speed of behavior and its implications for cognition. In J. E. Birren, & K. W. Schaie (Eds.), *Handbook of the psychology of aging* (Vol. 2, pp. 400–416). New York: Van Nostrand Reinhold.

Schaie, K. W. (1979). The primary mental abilities in adulthood: An exploration in the development of psychometric intelligence. In P. B. Baltes, & O. G. Brim, Jr. (Eds.), *Life-span development and behavior* (Vol. 2, pp. 67–115). New York: Academic Press.

Shipley, W. C., & Burlingame, C. C. (1941). A convenient self-administered scale for measuring intellectual impairment in psychotics. *American Journal of Psychiatry, 97*, 1313–1325.

Spirduso, W. W. (1980). Physical fitness, aging, and psychomotor speed: A review. *Journal of Gerontology, 35*, 850–865.

Wechsler, D. (1981). *WAIS-R: Wechsler Adult Intelligence Scale-Revised.* New York: Psychological Corporation.

Wood, V., Wylie, M., & Sheafor, B. (1969). An analysis of a short self-report measure of life satisfaction: Correlation with rater judgements. *Journal of Gerontology, 24*, 465–469.

Wright, R. E. (1981). Aging, divided attention, and processing capacity. *Journal of Gerontology, 36*, 605–614.

Received January 11, 1988
Revision received June 20, 1988
Accepted June 21, 1988 ■