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Physical Fitness, Aging, and Psychomotor Speed: A Review

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The robustness of a relationship among physical fitness, psychomotor speed, and aging is discussed by reviewing the descriptive and correlational evidence provided by studies from several different research areas. These areas are those that relate psychomotor speed to (a) athletic status, (b) physical fitness status, (c) physical conditioning training programs, (d) hyperbaric oxygenation treatment, and (e) presence of cardiovascular disease. Several potential physiological mechanisms that might support such a relationship are discussed under the general categories of brain function and cerebral circulation, and the trophic influence of physical activity on the central nervous system.
Key Words: Physical fitness, Aging, Psychomotor speed, Rats

THE decline of neuromuscular efficiency with age has been well documented in both animals and humans almost since the beginnings of experimentation with psychomotor speed. Reaction time and other relatively simple tasks requiring information processing in humans, and conditioned responses such as avoidance latencies in animals, are vulnerable to aging. Not only is psychomotor performance in individuals slower, it is also less consistent. Because individuals age very differently, considerably more between-subject variability exists in samples of older individuals.

Although aging results in deterioration at several levels of neural organization, the decrement in central processing rather than peripheral function has been targeted as the primary contributor to a decline in behavioral responses. Peripheral functions, such as reflex and motor time, apparently do not decline with the same celerity as central processing does (see Clarkson, 1978, for review). Conversely, cognitive tasks with a large psychomotor component that must occur within a time limit are almost universally shown to be slower in aged individuals. Inasmuch as deterioration of the physical work capacity of aging individuals has been successfully delayed in persons who chronically exercise (Faria & Frankel, 1977; Kavanagh, 1977; Pollock, et al., 1974b; Saltin & Grimby, 1968), an obvious extrapolation is that exercise and its concomitant benefits might also postpone age-related psychomotor deterioration. *Mens sana in corpore sano* may, in fact, be more plausible than was thought — at least in the later decades of life. Several authorities in the area have suggested that psychomotor speed may be related to physical fitness in the aged, especially in cases of questionable cardiovascular integrity (Botwinick & Thompson, 1978; Welford, 1977). The general rationale, discussed in more detail later, is that exercise contributes beneficially to aerobic capacity and to cerebral circulation integrity in addition to having a trophic influence on the neurons that supply the muscle fibers.

The relationship between physical fitness, aging, and psychomotor performance seems tantilizingly intuitive, yet it has proven to be exceedingly abstruse. Karoven (1969) reported that the functional capacity of the neuromuscular system is higher in trained than in untrained men, while Gutman and Hanzlikova (1975) suggested that training "should" affect the nervous system. They stated that all trained people are physiologically "younger" than untrained ones in terms of the nervous system, but there is a very large difference in saying that trained older individuals "should" be physiologically younger and showing that they are, in fact, younger. In this review, the findings from several different areas of research are synthesized from the perspective of the role that exercise might play in postponing psychomotor decline. Almost all the evidence reviewed is indirect or speculative, yet taken

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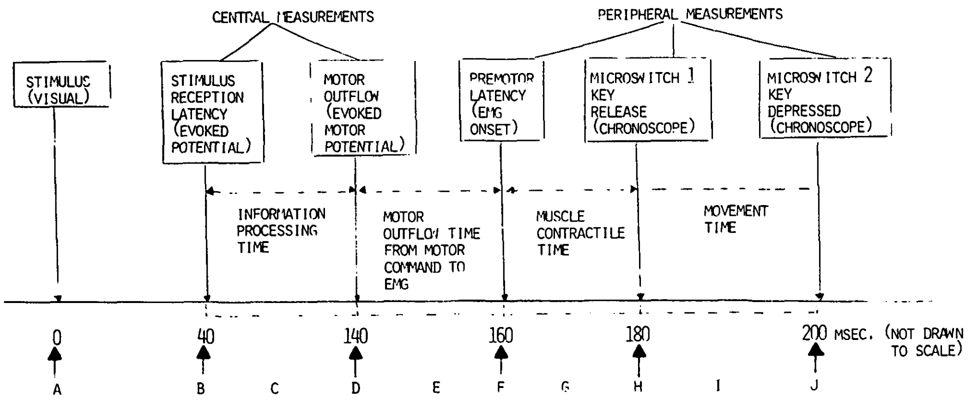
as a whole provides enough support to encourage serious contemplation regarding the topic. Psychomotor speed in athletes, physically fit groups, and cardiovascular diseased individuals will be reviewed. The effects of supplemental oxygenation and physical conditioning on psychomotor speed will also be discussed. The review is concluded by the suggestion of several mechanisms that may account for a relationship between physical fitness and psychomotor speed.

Definitions: Physical fitness, psychomotor speed. — In this paper, the term *physical fitness* refers to that facet of physical fitness that is the physical work capacity of an individual (assumed or measured), defined as the maximum level of physical work of which an individual is capable. Physical work capacity, a measure of aerobic capacity, is reported in terms of oxygen consumption per kilogram per body weight per minute, and increases with physical training. Individuals who participate in frequent physical activity are consistently shown to have higher physical work capacity values (oxygen consumption/kg/min.) than their sedentary counterparts and are said to be more physicaly fit. *Psychomotor speed* is a rubric describing the speed with which an individual can perform a task which involves reacting motorically to an environmental stimulus.

Tasks frequently used to assess psychomotor speed are tasks such as simple and choice reaction time, tapping, moving the limb from one point to another, or crossing out symbols with a pencil or pen. When fractionated by recording techniques, reaction time tasks have been shown to have both central and peripheral components, the central component being identified as an early target of aging. In Fig. 1 a diagram is provided indicating the components that have been proposed by investigators. Also indicated in the diagram is the method of instrumentation generally employed to measure them, and their identification as central or peripheral events. As can be seen, some components have been derived by subtraction. For instance, information processing time in a visual simple reaction time task has been proposed to be the difference between the latency with which a stimulus evokes a response in the occipital cortex (evoked potential) from the time at which an evoked potential is recorded from



A = VISUAL STIMULUS INITIATED; CHRONOSCOPES INITIATED
B = EVOKED POTENTIAL IN OCCIPITAL CORTEX
C = D-B; DEPENDANT ON TASK COMPLEXITY
D = EVOKED POTENTIAL IN MOTOR CORTEX
E = F-D; NERVE CONDUCTION TIME, INCLUDING AN UNKNOWN BUT RELATIVELY SMALL NUMBER OF SYNAPTIC TRANSMISSION TIMES SUPRASPINALLY AND AT THE SPINAL MOTOR POOL
F = ONSET OF ELECTROMYOGRAPHICAL INTERFERENCE PATTERN
G = H-F; DEPENDENT ON MECHANICAL AND ELECTRONIC CHARACTERISTICS OF MICROSWITCH CIRCUITRY
H = REACTION TIME; RELEASE OF MICROSWITCH AND TERMINATION OF FIRST CHRONOSCOPE
I = J-H; DEPENDENT ON DISTANCE BETWEEN MICROSWITCHES
J = DEPRESSION OF MICROSWITCH AND TERMINATION OF SECOND CHRONOSCOPE

Fig. 1. Fractionation of a reaction time task into central and peripheral components. This is a conceptual schema of the process; differences in methodology and interpretations of components exist among investigators.

the motor cortex (motor potential). Similarly, motor outflow time is derived by subtracting the motor potential latency from the premotor latency. The general consensus of many experimenters is that the component showing the greatest age deterioration is the central component designated as information processing time. This component has also been fractionated behaviorally into simulus identification, response organization, and response execution, each of which needs to be investigated in terms of the effects of aging. The majority of studies reviewed have utilized visual reaction time tasks as indicants of perceptual motor speed. However, occasionally other psychomotor tasks that require rapid information processing, such as tapping or crossing-out symbols, have also been reported. These tasks also reveal something of the status of the central nervous system. Rapid tapping requires fast motor organization, integration, and execution and has been suggested as the motor equivalent to the indicant of visual sensory integrity, critical flicker fusion frequency. Rapid crossing-out of symbols requires stimulus identification, response organization, and response execution. It is somewhat unfortunate that the study of psychomotor speed in the aged preceded the relatively recent advances that have been made in identifying components of psychomotor speed, so that the identity of which components were being analyzed in some of the older literature is not always clear.

Measurements of peripheral components that have not been shown to be as sensitive to age changes, such as stimulus reception and muscle contractile time (see Fig. 1), as well as reflex latencies, have been excluded from this review. The peripheral component of movement time, generally conceded to be little affected by aging, is included, however, since some very recent studies have provided contradictory evidence.

THE RELATIONSHIP OF PHYSICAL FITNESS TO PSYCHOMOTOR SPEED: DESCRIPTIVE AND CORRELATIONAL EVIDENCE

The signficantly faster neuromuscular responses of highly trained individuals when compared to untrained individuals has suggested a relationship between exercise and psychomotor speed. Certainly evidence that highly fit individuals respond very quickly to stimuli and that aerobic training regimes decrease response latency, provides a basis for anticipating that persons who exercise might maintain neuromuscular response speed throughout the aging process.

Psychomotor speed in athletes. — Both simple and choice reaction times have been found to be significantly faster in young athletes than in young non-athletes, and one of the early explanations proposed was that the athletes were in better physical condition than the nonathletes. Botwinick & Thompson (1968), for instance, suggested that the slowing seen in simple reaction time with aging may really be an artifact of physical fitness

Table 1. Athletes vs Nonathletes.

Fast	SRT	Slow	SRT	Source	
Fencers	(.217)	Nonfencers	(.230)	Pierson	(1956)
Racketball	(.207)	Graduate Students	(.235)	Knapp	(1961)
Athletes	(.148)	Nonathletes	(.176)	Botwinick & Thompson	(1968)
Athletes	(.165)	Nonathletes	(.205)	Wyrick	(1972)
Athletes	(.250) (.241)	Nonathletes	(.260) (.264)	Yandell	(1978)
Skilled	(.249)	Unskilled	(.294)	Beise & Peaseley	(1937)
Athletes	(.290)	Nonathletes	(.343)	Olsen	(1956)
Athletes	(.248)	Nonathletes	(.273)	Youngen	(1958)
Athletes	(.140)	Nonathletes	(.156)	Burpee & Stroll	(1936)
Athletes	(.263)	Nonathletes	(.282)	Burley	(1944)

*SRT = simple reaction time, reported in hundredths of a second. More recently SRT has been customarily measured in milliseconds; all but two of these are very old studies.

level, since they found young athletes in their sample to be much faster than young nonathletes, while the young nonathletes were as slow as their older subjects. Their assumption was that athletes are more physically fit than nonathletes, and therefore reaction time might be related to their aerobic capacity. In fact, at least eleven studies of athlete-nonathlete comparisons in young persons can be assembled (Table 1) and all report faster times during a one day testing session. The fact that athletes may be significantly faster than nonathletes does not make a very strong case for a relationship between psychomotor speed and physical fitness, however, because the genetic profile of athletes probably includes many speed factors that are more salient than the conditioning factor. Samples comprised entirely of athletes almost certainly contain individuals who have become athletes because fast reaction time, among other variables, has contributed to their level of physical performance. Studies of simple reaction times in samples of old athletes compared to old nonathletes have not been found.

Psychomotor speed of aged individuals in different physical fitness categories. — A better approach to understanding the relationship of physical fitness to psychomotor speed has been to analyze highly conditioned groups comprised of subjects who were not athletes. Older men who were physically active as racketsports enthusiasts reacted to a visual stimulus as quickly as college men, whereas sedentary aged men revealed the classic aging effect in simple and choice reaction time (Spirduso, 1975). Four groups of 15 subjects were formed on the basis of age (young/old) and activity level (active/nonactive). The younger groups included men who ranged in age from 20 to 30 years, while the older groups ranged from 50 to 70 years of age. The sports groups included men who played squash, racketball, or handball a minimum of three times a week. In the case of the older sports-

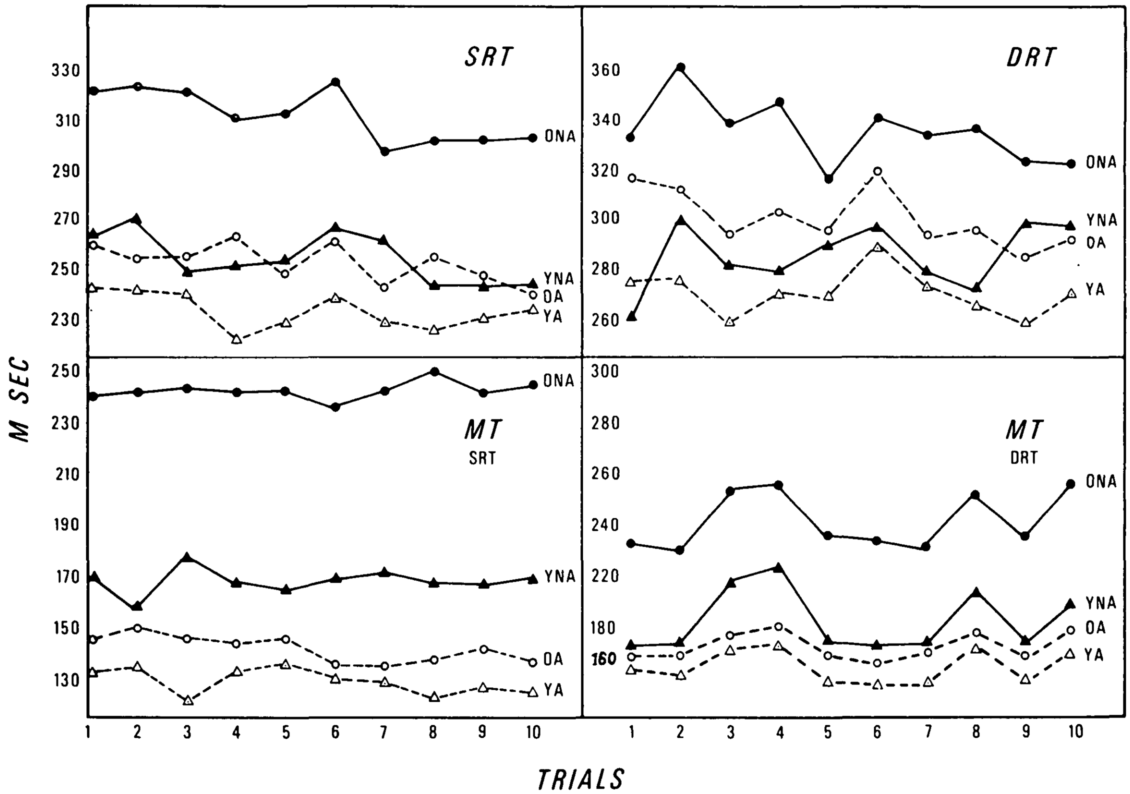


Fig. 2. Simple reaction time (SRT), discrimination reaction time (DRT), and movement time under SRT conditions (MT_{srt}) and DRT conditions (MT_{drt}) as a function of activity level and age (Spirduso, 1975). ONA = Old Nonactive subjects (50 to 70 years); YNA = Young Nonactive subjects (20 to 30 years); OA = Old Active subjects (50 to 70 years); YA = Young Active subjects (20 to 30 years).

men, their life style over the past 30 years included racket-sports competition at least three times a week. The young sportsmen had been playing racketsports 2 to 3 years. The nonsports groups included men who did not and who never had participated in sports of any type on a regular basis. Thus, four groups of 15 each were formed: older active sportsmen, older nonactive males, young active sportsmen, and young nonactive males.

In simple reaction time and movement time, the order of speed of response was young active, old active, young nonactive, and old nonactive. In choice reaction time, the order was the same except that the young nonactive group was faster than the old active group. A strong statistical interaction between age and activity level existed and further analysis revealed that it was attributable to the old nonactive group which was far slower than either of the other three groups on simple reaction and movement time (Fig. 2). Spirduso and Clifford (1978) replicated the relationship between physical activity and age grouping, and in addition showed that within-subject and between-subject variance, both of which have been consistently reported to be greater in older individuals, were in fact not statistically different from the variability seen in young men. It can be seen in Fig. 3 that both simple and choice reaction time of the old inactive group is substantially different from all other groups, on both latencies and variability. Clarkson and Kroll (1978), using the same classification system of age and physical activity and the same psychomotor tasks, corroborated these results, and later extended the findings by showing that both the within and between-subject variability of older physically active men are much more like that of younger men than that of their aged counterparts. The overall results of these studies agreed with a much earlier report by Pierson and Montoye (1958) who found that movement time was

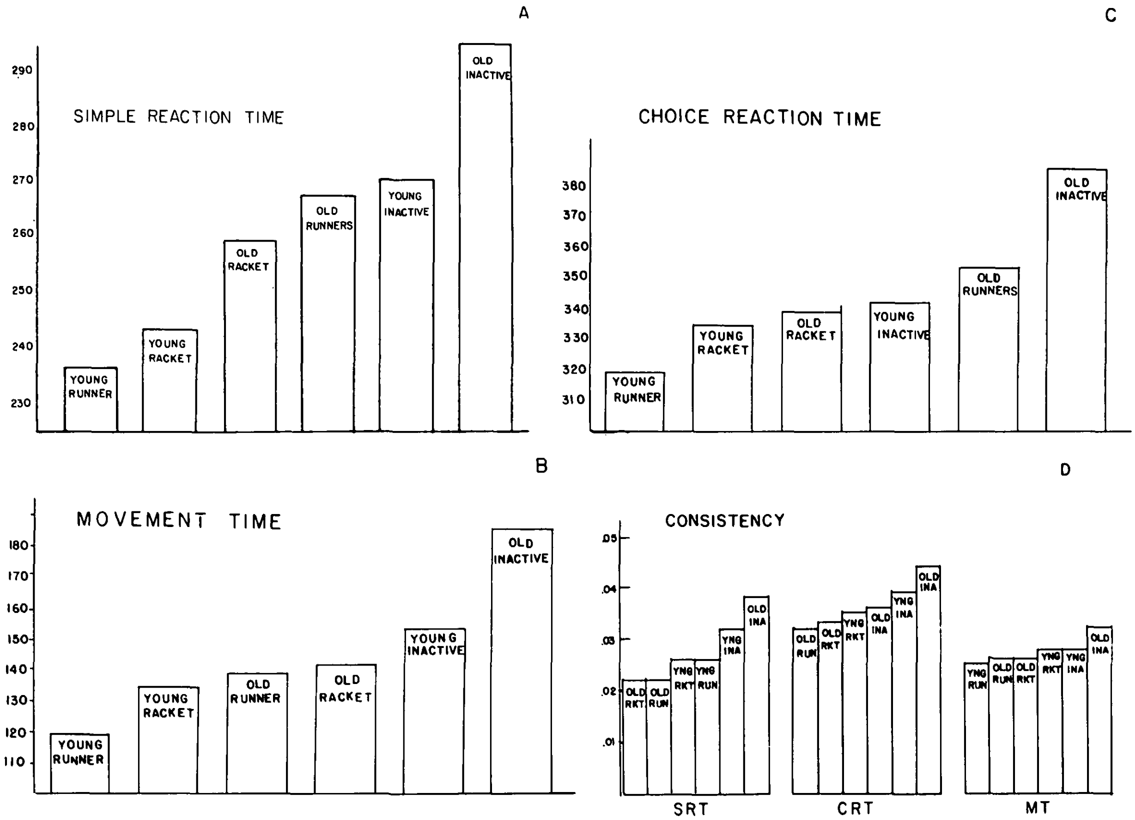


Fig. 3. Upper left: simple reaction time; upper right: choice reaction time; lower left: movement time, in groups differentiated on the basis of physical activity participation and age. Lower right: consistency = within-subject standard deviations for each variable. Ordinal values are in milliseconds (Spirduso & Clifford, 1978).

slower in old men. They also suggested that movement time was actually faster in older active men than in young nonactive men.

Not much information is available regarding the psychomotor performance of aging women, probably because the population of women exercisers over the age of 60 is very small. Consequently, it is exceedingly difficult to obtain a sample of aged female exercisers. Scarborough (1973) categorized women into four groups on the basis of fitness level and age. High fitness was determined by their physical exercise profile in conjunction with their performance on a bicycle ergometer submaximal test. Unfortunately, her older women only averaged 45 years of age while the younger women averaged 20 years of age. As can be seen in Fig. 4, the physically fit older women revealed a trend to be faster than the unphysically fit older women, especially on the second day.

Another observation that can be made to understand the relationship between physical fitness and psychomotor speed is to examine individuals who are not diseased but who have low physical fitness levels. Although statistical tests could not appropriately be applied, the simple reaction times of men and women of various ages who voluntarily entered The Univ. of Texas Adult Fitness Program were compared with the simple reaction times reported for the sample of average adults reported by Hodgkins (1963). In Fig. 5, it can be seen that the Adult Fitness (AF) reaction times of 138 individuals were substantially slower for both sexes than the reported norms. These individuals were also well below average on physical fitness criteria of percent body fat, oxygen consumption, maximum heart rate, and vital capacity. Although there are many contaminants in this type of comparison, it is still instructive to observe, with due amount of caution, that the AF group is lower than average *at all ages* in both physical fitness variables and in a simple psychomotor task — that of simple reaction time.

The relationship between physical fitness, age, and psychomotor speed is not completely confirmed by these studies, however, for three reasons. First, although the majority of studies of this type have found old exercisers to be faster in psychomotor speed, two studies did not. Botwinick, et al. (1979) reported a physical

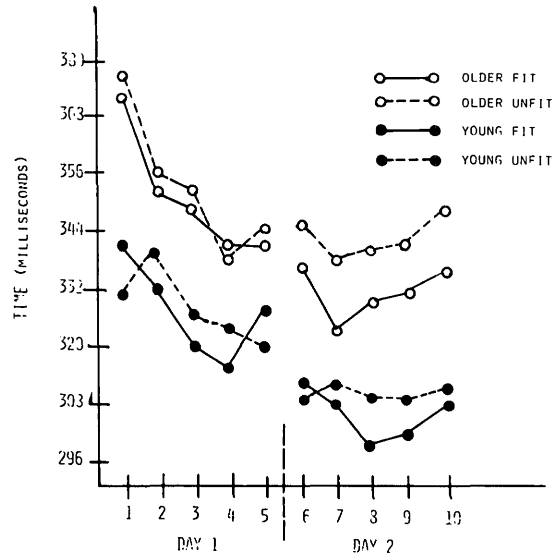


Fig. 4. Choice reaction times of women categorized on the basis of physical fitness and age (Scarborough, 1973). Old category = 40 to 50 years; Young category = 18 to 22 years. Criteria for fitness category included: (a) strenuous physical activity one hour per day at least three times per week, (b) body weight within 10% of desirable weight, (c) minimum predicted maximal oxygen uptake value of 35 ml/kg/min. Five blocks of 10 trials on each day.

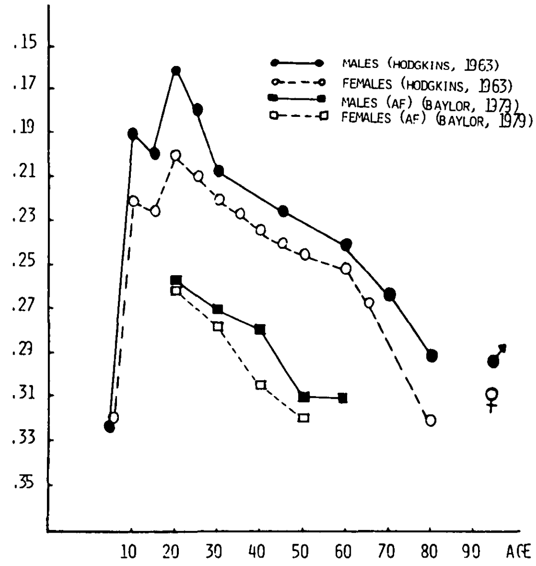


Fig. 5. Simple reaction times, in hundredths of a second, of men and women at various ages in the normal population compared to those obtained from subjects enrolled in an Adult Fitness Program Circles represent SRTs of males and females in normal population, as reported by Hodgkins (1963), and squares represent males and females in the Adult Fitness Program. Age is in years.

fitness-psychomotor speed relationship existed only for their young groups and not for their old groups, while Burpee & Stroll (1936) reported a physical activity difference only in reaction time of large muscle reaction time, not in small muscle RT. Second, all of these studies suffer from the assumption that individuals who claim to exercise for specified durations of time per week are in fact physically fit. Aerobic capacity has never been directly measured in conjunction with phychomotor performance. Participating in sports one hour per day may push one individual close to his maximum physical capacity while minimally stressing another. Whereas some individuals are competitively motivated to play at intense levels of physical work, others may be playing only for the enjoyment and therefore stressing themselves very little. Additionally, an investigator never knows how accurate self report on exercise may be. Some subjects may report, when asked the number of hours of participation per week, their good intentions rather than their behavior. The Botwinick & Storandt (1974) study exemplifies this problem because the criteria established to identify high exercise groups depended on activity classification and self report, and in addition were not very demanding. Only one hour a day twice a week of exercise was required to place a subject in the active group, and the type of exercise was unspecified. Without direct aerobic capacity assessment the level of fitness in exercise groups must be accepted as conjecture.

Third, groups categorized on the basis of age and exercise level may also be described differentially on the basis of other unknown variables such as smoking habits, intelligence, medication, motivation, genetic profiles, and a host of other potential variables. Any of these variables are candidates for a functional relationship with psychomotor speed, irrespective of physical fitness levels. Viewed within the perspective of the weakness of exercise group studies, the relationship that seems to exist between physical fitness, age, and psychomotor speed might be seriously doubted. Yet, other relationships have been reported that also suggest that physical fitness contributes to fast reactions in the aged. One of these is the suggested effect of physical training on measures of neuromuscular response.

Psychomotor speed and physical conditioning programs. — A relationship between exercise and psychomotor response has also been suggested by a few investigators who attempted to show that neuromuscular speed can be altered by aerobic conditioning and/or sport training, but the issue is far from clear. Simple reaction time has been reported to improve after six weeks of aerobic training (Gibson et al., 1961), but Beise & Peasley (1937) found no simple reaction time differences among three groups of women who completed 7 weeks of sport training in sports differing in degree of physical intensity. Matsui (1971) suggested that physical training might have a beneficial effect on reaction time, but Lawther (1951) stated that, at least in athletes, simple reaction time appears to be immodifiable by physical training. Both of these opinions were based on theoretical considerations rather than experimental data. Tweit et al., (1963) reported that a group selected for their low scores on a physical fitness test improved on visual reaction time after 6 weeks of physical conditioning.

It is obvious that the effect that physical conditioning might have on psychomotor speed in general, and upon aging in individuals' performances specifically, is far from being resolved. To avoid confounding learning with physical conditioning, effects of this nature should be analyzed on reaction time performance that is quite stabilized (i.e., after a minimum of 5 days of practice). Unfortunately, none of the available information has been based on stabilized measures. Effects of training on the psychomotor speed of older individuals has not been directly studied at all.

Psychomotor speed under supplemental oxygenation. — Another finding that provides indirect evidence for a relationship between exercise and psychomotor performance is that of the ameliorative effects of supplemental oxygenation on psychomotor performance, as well as other cognitive functions. Experiments in which supplemental oxygen was provided to aged subjects were a predictable extension of McFarland's (1963) anoxia model, in which he proposed that the perceptual and mental impairments seen in aged individuals were remarkably similar to those impairments seen in indivduals performing under conditions of oxygen deprivation. He suggested that a similar mechanism might be operative in both aged and oxygen-deprived individuals; that is, an impaired central nervous system metabolism due to inaccessibility of oxygen. His model was based on experimental evidence and clinical observations showing relationships between the deterioration of perceptual and motor variables (sensory acuity, muscular responses, reaction time) and oxygen deprivation (from performance at altitude, occlusion of cerebral blood flow, or forced inhalation of an hypoxic air mixture). McFarland suggested that in both hypoxia and aging, the availability and/or utilization of oxygen in the central nervous system may be decreased due to a reduced rate of oxygen transport to the cells or an inadequacy of cellular enzymatic activity. Botwinick (1973) has suggested this anoxia model as a possible mechanism accounting for decrements seen in aged individuals' processing of sensory information. Hemiplegics, who generally participate in little if any physical activity have been shown to suffer from chronic low-grade hypoxemia (Haas & Rusk, 1965). Because the investigators hypothesized that hypoxemia might be contributing to the mental-dysfunctioning characteristic of patients with hemiplegia, they systematically treated them with 100% normobaric oxygen by an oronasal mask. The results were clear-cut: oxygen significantly improved perceptual and psychomotor functioning in the hemiplegic patients. Beneficial changes in performance on psychological test batteries sometimes occurred only during the supplemental oxygen treatment, but have been reported to last as long as 3 weeks (Jacobs, 1971).

Hyperbaric oxygenation presumably affects autoregulatory mechanisms which in turn improve cerebral blood flow (Ben-Yishai & Diller, 1973). This was the proposed mechanism by which mental functioning in hemiplegics and the aged was improved. Exercise may also stimulate autoregulatory mechanisms which will maintain normal levels of blood flow to the brain. Adequate cerebral blood flow is extremely critical to normal mental functioning and psychomotor performance, as will be seen in the discussion which follows of cardiovascular disease and its relation to both cerebral blood flow and psychomotor function.

Psychomotor speed in the cardiovascular diseased (CVD). Age and/or disease related deterioration of the cardiovascular system, such as occurs in artereosclerosis and heart disease, reduces cerebral blood flow. A summary of several investigators' work revealed that cerebral blood flow in the population declines almost 50% by age fifty (Kety, 1956). Cerebral oxygen consumption also is decreased and cerebral resistance increased in older persons. In addition, cardiovascular disorders, degenerative anthropathies, and atherosclerotic changes of the great vessels of the neck — all of which have detrimental effects upon cerebral circulation — are found more and more frequently in older age groups. The hypothesis proposed is that cerebral circulatory insufficiency, hypoxia, or hypertension lead to secondary tissue damage, a reduction in metabolic rate, neuronal degeneration and finally to a decrease in cognitive and psychomotor function. In one category of senile dementia, multi-infarct dementia, higher cortical function becomes impaired due to reduced blood flow, decreased energy production, and the consequent depletion of neurotransmitters (Meyer, et al., 1976). This hypothesis is not unanimously accepted, at least in its application to memory and learning loss, as Goldfarb (1975) believes that it has been greatly overemphasized as a cause of these losses. However, investigators who have failed to find relationships between CVD parameters and intellectual functioning in the aged have generally been studying the constructs of memory and reasoning rather than time-limited cognitive functioning. Certainly brain activity is influenced in some way by cerebral circulation, as evidenced by the many studies showing EEG changes paralleling deficient cerebral circulation and oxygen consumption (Fitzpatrick et al., 1976; Herrschaft & Kunze, 1977; Ingvar et al., 1976; Obrist, 1965). Given the dependence of brain integrity on cardiovascular integrity, it is not surprizing to find a host of scientists reporting that persons with CVD or hypertension also have slower motor responses to environmental stimuli.

The report of Hicks and Birren (1970) is representative of many studies in which it is shown that persons with cardiac insufficiency have slower reaction time. In these studies slowed reaction time seemed to be independent of age, suggesting that declines of reaction time with age in cross-sectional studies primarily reflect increasing proportions of CVD subjects in the older segments of the samples. Even persons predisposed to CVD, but not showing clinical CVD symptoms, were slower in both simple and choice reaction time tests (Abrahams & Birren, 1973). Finally, the speed of reaction to stimuli may also be a function of an age by CVD interaction, as both visual and auditory simple reaction times were slower in older brain diseased individuals than in young brain diseased persons (Benton, 1977).

Other psychomotor task decrements also seem to be associated with CVD and/or hypertension. Tapping speed, where one digit is tapped in one place as rapidly as possible, was slower in hypertensive and CVD patients, and decreased more rapidly throughout the tapping trials than the performance of normals (Simonson & Enzer, 1941). Tapping speed, a reflection of the maximum frequency of impulses a motor center can receive or emit, is used as a measure of the functional state of the motor center. Performance on a flicker fusion frequency test is also thought to represent the same functional integrity of perceptual centers as tapping performance reveals for motor centers. At some frequency when visual stimuli of very short duration (150 to 200 msec) are repeated at rapid regular intervals, each individual's critical fusion frequency (CFF) is reached. This is the frequency at which trains of discrete stimuli are perceived as a steady visual stimulus. At this point the individual cannot complete the processing of each stimulus before another one appears. The higher the CFF, the greater the integrity of the central nervous system. Critical fusion frequency is lower in aged individuals (Brozek & Keys, 1945; Huntington & Simonson, 1965; Jalavisto, 1968; Misiak, 1947; Simonson et al., 1967), and Simonson (1965) has synthesized several studies that reveal a striking parallel between the decrease in CFF with age and the corresponding decrease in cerebral blood flow. When age group CFFs, obtained from several studies, were subtracted from the values obtained from young subjects, the regression of CFF decreases over age was similar to the regression of cerebral blood flow over age. He remarks that although this relationship cannot be claimed as causal, "... most likely the drop of cerebral blood flow in age is involved in the drop of CFF" (Simonson, 1965).

In general, any task with a substantial psychomotor component, time limits, and complex nonverbal material is likely to produce poorer times for persons with hypertension (Birren et al., 1963; Birren & Speith, 1962; King, 1965; Light, 1975; Speith, 1964, 1965; Wilke & Eisdorfer, 1971; Wilke et al., 1976). Although not considered psychomotor tasks, it seems appropriate to note also that such cognitive functions as memory and intelligence have been reported to be more deteriorated in aging CVD and hypertense individuals than in normals (Hamsher & Benton, 1978; Hertzog et al., 1978; Simonson & Anderson, 1976). Individuals with excessive diastolic blood pressure declined more in 10 years on their Weschler Adult Intelligence Scale score than those with lower or normal blood pressures (Wang, 1973; Wilke & Eisdorfer, 1971). Powell and Porndorf (1971) also reported a striking parallel between the decline in fluid intelligence[2] and the increase in systolic blood pressure with age (Fig. 6). Similarly, performance on three psychomotor tasks contributed substantially to the prediction of death of the subjects over the 5 year period following the administration of the test battery (Botwinick et al., 1978). The CVD brain function relationship, when viewed in parallel with the observation that dramatic differences exist in individuals' patterns of psychomotor decline, has led more than one student of the topic to suggest that neuromuscular responses may be more highly related to health than to age.

Psychomotor speed confounded with physical fitness in aged samples. — Differential proportions of CVD in each decade of life in the population may be contributing a substantial sampling bias which results in an apparent dramatic decline in psychomotor speed with each increasing decade. Speith (1964) has pointed out that samples of subjects in their second decade are drawn from a population containing less than 5% CVD, while samples of subjects in their sixth decade are drawn from a population where more than 50% of the individuals have from mild to severe CVD.

[2]Fluid intelligence pertains to the ability to perceive relationships, as well as to conduct operations such as reasoning, concept formation, and problem solving; this is in contrast to crystallized intelligence, which also involves reasoning and manipulation of figural and symbolic content, but relies heavily on acculturation and education. Fluid intelligence is thought to be more related to the neurophysiological status for the individual and to decline at a faster rate with aging (Horn & Cattell, 1966).

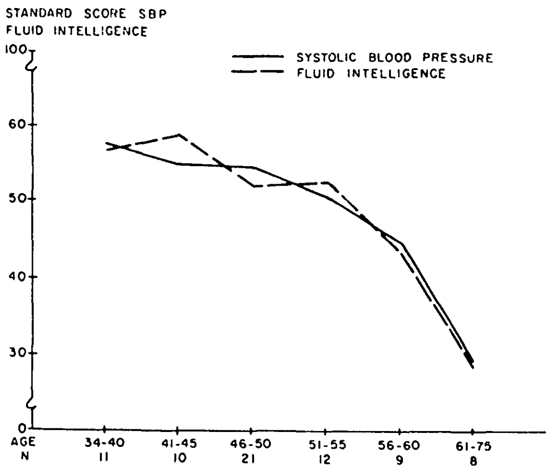


Fig. 6. Mean systolic blood pressure compared with mean fluid intelligence (Powell & Porndorf, 1971). Ordinate values = standard scores, abscissa values = age in years. Solid line = systolic blood pressure in standard scores; dashed line represents standardized fluid intelligence scores. (Permission for publication must be obtained.)

Hence, presence of CVD may contribute substantially to large individual differences that are known to exist in physiological aging, and consequently appear in behavioral performance. Many investigators who study psychomotor speed in the elderly selected samples from institutions, homes, or hospitals, where older subjects were available in large numbers. It is probable that the presence of CVD in these situations is higher than in samples of older subjects who are active in the community or perhaps still functional in their occupation.

Although it is not common, it is possible to find older individuals who are extremely active and in exceptional states of physical fitness. Middle aged men who exercise chronically, maintain an adequate diet, and do not smoke have much higher aerobic capacity than the normal adult (Robinson et al., 1973, 1976). Many studies have in fact shown that it is possible for middle aged and older men to maintain very high levels of aerobic capacity (Cureton, 1964; Dill, 1965; Grimby & Saltin, 1966; Pollock et al., 1970, 1974a, b). The physical performance of these individuals would certainly be misrepresented by a group mean that included a majority of average persons sampled. Would their psychomotor performance also be misrepresented? Individual difference in decline cannot be detected from cross sectional studies, which measure only differences in psychomotor speed present in each decade but not the changes in psychomotor speed. It is entirely possible that vigorously active individuals decline in both cardiovascular integrity and psychomotor speed very little over almost their entire life span, while others begin deteriorating in the third decade and continue to decrease gradually throughout their lifetime.

Physiological Mechanisms Supporting the Relationship Between Physical Fitness and Psychomotr Speed in the Aged

Mechanisms by which chronic exercise might postpone the decline in psychomotor speed have not been documented, but two areas which are promising are (1) the effects of exercise on the oxidative capacity of the brain, and (2) the trophic effect that exercise may have on central nervous system function.

Brain function and cerebral circulation. — Implied in discussions of a relationship of cardiovascular integrity to brain function, is that both the cardiovascular inefficiency and disease that frequently occur in aging result in deficient cerebral circulation which in turn causes a decrease in brain oxidative capacity. Such a decrease in oxidative capacity results in less energy available to the brain for proper functioning and maintenance of tissue. The relationship between cerebral blood flow and oxidative capacity of brain tissue has not been directly measured, although a decrement in the oxidative capacity of cerebral cortex in aged animals has been documented (Patel, 1977). A linear relationship between blood flow and oxygen uptake has been reported in other tissue (Ingvier, 1978), however, and it is highly probable that this relationship exists in brain tissue as well. Decreases in brain function might be expected to parallel the decrease in blood flow and oxidative capacity as evidenced by a decrease in the dominant frequency of EEG with a decline in cerebral oxygen uptake (Fitzpatrick, 1976). Substantial support has been generated that the EEG has some relationship to oxidative metabolism of brain tissue, as well as to the cerebral blood flow, which is normally controlled by the metabolism (Ingvar, 1967; Ingvar & Lassen, 1975; Ingvar et al., 1976; Paulson & Sharbrough, 1974). Ingvar et al. (1976) reported that the cortical blood flow is coupled to the level of synaptic activity of the cortical neurons. Ingvar (1958) also reported several studies in which investigators found an increased cortical blood flow following sensory stimulation, brain stem activation, or arousal reactions in general. To this date no causal relationship, nor even a direct correlational relationship has been shown among the three factors of cerebral blood flow, EEG parameters, and behavioral indices of psychomotor performance. However, the reports of relationships between several pairs of the three factors suggests that study of the interaction of cerebral blood flow, brain function, and behavior in the aged should be pursued. The relationship of cerebral blood flow to EEG has been documented above. A second relationship between pairs, EEG frequency and psychomotor tasks, has also been shown. Surwillo (1963, 1964) showed that simple reaction time is related to EEG frequency during the period from the stimulus to the reaction time (From A to H in Fig. 1). The EEG frequency during this period was used as an indicant of information processing, and both EEG frequency and reaction time declined with aging. Surwillo suggested that frequency of the EEG may be the factor behind the age-associated decline in the information processing capacity of the central nervous system. The third pair of these three factors involves a relationship between regional cerebral blood flow and movement initiation. This relationship is discussed below.

Inasmuch as cerebral blood flow increases in active brain regions, it is possible that metabolic decreases in motor centers of the inactive individual demands less blood flow into that region and eventually initiates a cyclic effect that becomes pathological when it interacts with aging. It is not that active individuals may be different from inactive individuals in overall cerebral blood flow, or even in patterns of regional blood flow when similar tasks are performed. What may occur is that individuals who continually activate motor centers maintain cerebral circulation to these centers, and perhaps postpone the age related deterioration of neurons in these centers. The relationship between neuronal maintenance and vascularization was suggested by Govoni et al. (1978), and is discussed later.

The fact that total cerebral blood flow remains constant regardless of the level of physical work being done (Fixler et al., 1976) does not eliminate consistent exercise as a potential modifier of cerebral circulation. Regional blood flow shifts according to the metabolic demands of the different regions. Physical work has been shown by the radioactive ^{133}Xe method to increase regional cerebral blood flow in areas of the brain as specific as prefrontal, somatosensory, and primary areas of the motor cortex (Lassen et al., 1978). Shifts in cerebral circulation that are specific not only to physical activity such as hand clenching, typewriting, and finger touching (Halsey et al., 1979) but to the ideation and planning of the movement (Ingvar & Philipson, 1977; Orgogozo & Larsen, 1979) have been reported. Specific brain areas responsible for planning, initiating, and executing movement therefore receive an increase in blood flow while total blood flow to the brain remains constant. A regular exercise regime may arrest or slow the aging decline in blood flow to the brain areas responsible for motor control, just as exercise maintains levels of oxygen consumption in the whole body (Shepard, 1978). Thus, exercise may prevent or postpone a commonly existing cycle: disuse decreases metabolic demands in motor and somatosensory brain tissue, which decreases the need for circulatory flow, which may result in neuronal destruction, leading to disuse of the brain tissue, and so on. Exercise of course also reduces acquired hypertension (Scheuer & Tipton, 1977), an effect which would decrease the possibility of cerebral hemorrhage resulting in damage to specific brain areas.

Brain function has also been linked to cerebral blood flow within the framework of information processing theory (Swets, 1964), in which the brain is considered to be composed of "noisy" communication channels. In this theory, decisions about sensory input — such as reacting to a visual stimulus — are based upon information that is distorted by random neural firing (noise) within the central nervous system itself. It is primarily the time required to distinguish the signal from neural noise that appears to increase with age, rather than the time required for response decisions and uncertainty, (Szafran, 1965). Since greater amounts of neural firing (noise) occur with aging (Crossman & Szafran, 1956) it has been speculated that the reduced role of cerebral blood flow that also occurs in aging may contribute to the random neuronal firing of the brain (Gregory, 1957; Szafran, 1965). Consequently, chronic physical exercise and its subsequent effects of cerebral blood flow maintenance in areas of brain specific to that type of decision, may serve to reduce or maintain a lower amount of random firing of neurons, above which a signal (sensory input) might be more easily detected.

In concluding this section, it should be emphasized that the evidence supporting the relationship between brain function and cerebral blood flow is at this point circumstantial. It is still not even fully resolved as to whether CBF decreases in normal, nondiseased, aging individuals. Studies are needed that make direct and simultaneous comparisons of EEG parameters, behavioral psychomotor performance, and regional cerebral blood flow, both within-between physically fit and unfit individuals in different age categories. The relationship between brain function and cerebral blood flow has been summarized in this section to suggest that this area remains a possibility for future research, not to imply a simplistic relationship in an extremely complex and controversial area of study.

Trophic influence of physical activity on the central nervous system. — The effect that exercise has on central nervous system function is not very well known and is in fact almost an unresearched area. Muscles have a trophic influence on the nerves that innervate them and upon other immediate central connections (Eccles, 1973), but the influences of muscular activity on higher nervous centers, such as the reticular activating system and the basal ganglia is not clear at all. Long ago an "overuse" principle of nerve cells was postulated in which cell aging is influenced to a large degree by the amount of activity in which the cell is involved (Vogt & Vogt, 1976). As Mateef (1961) suggested, "A correct combination of mental activity and physical exercise or sports is at present the best method of preserving for as long as possible the activity of the brain cells on a high level with respect to their extremely important regulating and trophic function of the organism." Later studies have supported this idea by showing that the decline in transmitter synthesis, speed of muscular contraction, weight and size of muscle that commonly occur in aging does not occur in the diaphragm muscle and in respiratory muscles that receive neural stimulation consistently throughout the lifetime (Gutman & Hanzlikova, 1972; Tucek & Gutman, 1973; Vyskocil & Gutman, 1972). A behavioral application of this theory was made by Nebes (1978) who reported that voice reaction time was not slower in his aged subjects. He hypothesized that the continual stimulation of speech areas in the brain throughout life deters deterioration.

The specific effect that physical training has on transmitter substances or intracellular energy sources is unknown, but this promises to be a fruitful area of research. Psychomotor performance is dependent upon efficient synaptic transmission in the mobilization of elaborate neuronal networks in many areas of the brain. Some evidence, though scanty, is beginning to be produced that supports the concept that exercise can, either immediately or chronically, alter variables that influence synaptic transmission. Exercising skeletal muscle has been shown to release ATP in quantities sufficient enough to alter cerebral blood flow and increase brain metabolism during exercise (Forrester, 1978). Both norepinephrine and serotonin (5-HT) brain concentrations were changed after an 8 week exposure to exercise, with norepinepherine levels being higher in the cerebrum and serotonin concentrations being higher in the midbrain area (Brown et al., 1979). A particularly intriguing hypothesis is that chronic exercise may maintain the regional blood flow to the striatum, thus maintaining dopaminergic neurons in the substantia nigra and retaining their output of dopamine to the caudate nucleus. It has been suggested that one of the reasons the substantia nigra and caudate nucleus selectively deteriorate earlier with aging (Samorajski, 1977) is that these areas are highly vascularized (Govoni et al., 1978). The striatum loses as much as 40% dopamine receptor site binding in old rats (Govoni et al., 1978) and 20% in old mice (Finch, 1973). Similarly, caudate tyrosine hydroxylase, the rate limiting enzyme of dopamine, decreases by age 60 to 17% of its original amount (McGeer et al., 1971). Inasmuch as Wolf (1979) has made a strong case for the striatum as a mediator in the initiation of fast ballistic movement, the hypothesis that exercise can indirectly influence the dopaminergic system and thus effect behavioral changes is very attractive.

There has been much progress in recent years in relating behavior to the amount and function of transmitter substances and their precursors (Samorajski, 1977). For example, acetylocholine concentration in the ascending reticular system cortex and thalamic nuclei have been related to some aspects of arousal (Iversen & Iversen, 1975) which certainly influences psychomotor performance. It is probable that future research will reveal that adaptation effects of chronic exercise training include optimum levels and turnover rate of catecholamines, efficient functioning of monaminergic neurons, and an optimum balance between transmitter systems that regulate brain function. Moreover, these effects probably take on increasing importance with each decade of aging. As the evidence accumulates, exercise is becoming a strong candidate as a contributor to a general regulatory mechanism for high quality psychomotor function.

CONCLUSIONS

The indirect evidence relating physical fitness to psychomotor speed in aged individuals has been reviewed, and several potential mechanisms by which this relationship might operate were suggested. The correlational evidence suggests a relationship between physical fitness and psychomotor speed. When highly physically fit groups are compared to sedentary, low fit groups, whether athletes or non-athletes, their reaction times and movement times are faster. When low fit groups have undergone physical training regimes, their RTs have become faster. Finally, when psychomotor responses are measured in individuals with hypertension and other forms of cardiovascular disease, their performance is slower. These findings must at the present time be considered within the perspective of the experimental design problems, many uncontrollable, that necessarily preclude conclusiveness in interpretation.

A major problem with previous studies regarding psychomotor speed and physiological fitness level is that records of physical activity patterns or cardiovascular fitness tests have been used as indirect estimates of brain metabolism. Aerobic capacity has not been a well controlled and rigorously measured factor in studies of exercise and psychomotor speed. It has either been assumed, measured by indirect tests, or worse, measured by questionnaires such as the cardiovascular scale of the Cornell Medical Index — a symptom check list. Other health status factors such as smoking habits, alcohol consumption, and chronic medication have not been controlled. Aerobic capacity has not been directly assessed, before and after an exercise program, in conjunction with psychomotor tasks. In many previous studies perceptual activity reaction, latency, and movement speed are ambiguously defined and perhaps even combined. Other factors such as state anxiety, motivation, and instructional set also have varied from study to study, so that the specific focus of neuromuscular slowing is unclear.

Similarly, previous attempts to measure psychomotor response capacities have not been completely reliable, primarily because a relatively small number of trials was administered on only one day. The results from studies reporting changes in reaction time with training have to be viewed with caution, inasmuch as it is well established that reaction time and movement time decrease with practice over test days (Clarkson & Kroll, 1978; Kroll, 1969; Yandell, 1978). Thus, most reaction time and training studies to date have not controlled adequately for learning effects. Investigators have realistically determined age differences in initial learning and adaptation to a psychomotor task, rather than the capacity to initiate movement quickly to an external stimulus.

Despite all these problems, and the indirectness of the behavioral evidence, the relationship between exercise and psychomotor speed in aged individuals seems robust enough to continue studying, particularly when specific physiological functions are good logical candidates as mechanisms to account for the relationship. Whether the aging human organism can substantially postpone, by chronic exercise, the decline in oxidative capacity of the brain is not verified at this time, but there is indirect evidence and theoretical supposition that it is possible. Certainly this relationship should be pursued, as exercise is a costless, unobtrusive, and self-imposed intervention in the aging process. Understanding the role that exercise may play in postponing psychomotor decline has substantial significance in terms of lengthening the productive activities of the aged. If time-limited psychomotor processing can be maintained by physical training at a higher level throughout aging, several societal benefits would accrue. A greater efficiency in older industrial manpower, accompanied by a more alert, active, and independent aging phase in older citizens might be realized. Physically trained aged individuals may maintain a better capacity to cope with daily environmental hazards such as is demanded in emergency decisions in automobile driving and pedestrian reactions. Those with maintained psychomotor integrity may successfully resolve environmental threats, and function safely for a longer working period in the presence of occupational risks. Perhaps more important than the societal benefits are the personal psychological benefits that accompany efficiency and independence. Dignity in aging depends on confidence and a strong self image, both of which are substantially enhanced through psychomotor efficiency and control.

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