Exercise, Aging and Cognition: Healthy Body, Healthy Mind?

Arthur F. Kramer[1], Sowon Hahn[1], Edward McAuley[1], Neal J. Cohen[1], Marie T. Banich[1], Cate Harrison[1], Julie Chason[1], Richard A. Boileau, Lynn Bardell[1], Angela Colcombe[1] and Eli Vakil[2]

Beckman Institute[1]
University of Illinois at Urbana-Champaign, U.S.A

Department of Psychology[2]
Bar-Ilan University, Israel

Running Head: Aging, fitness and cognitive function

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The main goal of our chapter is to examine the relationship between improvements in aerobic fitness and the cognitive function of sedentary older adults. We have attempted to accomplish this goal in two ways; through a critcal review of the literature and by presenting the results of a recent study conducted in our laboratory. The main hypothesis for our study, motivated by a critical analysis of the literature on fitness, aging, and cognition, was that improvements in aerobic fitness would result in selective improvements in cognitive function. More specifically, we predicted that improvements would be observed in executive control processes (i.e. planning, scheduling, coordination, inhibition), that is those processes subserved largely by the frontal and prefrontal regions of the brain.

Before beginning our review of the literature on the relationship among aging, fitness and cognition it might be helpful to explicitly describe the logic which underlies research in this domain. First, it is generally the case that cerebrovascular and cardiorespiratory insufficiency increases between young adulthood and old age (Marchal et al., 1992; Meyer et al., 1994). Second, declines in cognitive function can be caused by decreases in cardiorespiratory and cerebrovascular efficiency (Emery et al., 1998; Dustman et al., 1994). Third, cardiovascular conditioning has been demonstrated to enhance cerebrovascular sufficiency by increasing aerobic capacity or cardiac output through increased stroke volume and oxygen extraction in older humans (Boutcher et al, 1998), to promote the development of new capillary networks in the brains of old rats (Jones et al., 1998), to enhance cortical high affinity choline uptake and increase dopamine receptor density in the brains of old rats (Fordyce & Farrar, 1991), and finally to increase brain derived neurotrophin factor (BDNF) gene expression in rats (Neeper et al., 1995). Finally, on the basis of this chain of logic and supporting data it has been speculated that cardiorespiratory conditioning will enhance cerbrovascular efficiency which in turn will serve to reduce age-related decline in cognitive function (Blumenthal & Madden, 1988; Cotman & Neeper, 1996; Dustman et al., 1994; Hawkins et al., 1992).

Aging, Fitness and Cognition

Early cross-sectional studies of the potential benefits of aerobic fitness on cognitive processing in older adults focused on simple and choice reaction time tasks and provided evidence that fitness may be associated with slower age-related declines. In a classic study, Spirduso (1975) found that older racquet sportsmen were significantly faster on simple, choice and movement response times than older non-exercisers. In a follow-up study, Spirduso and Clifford (1978) found similar results for runners compared to non-runners (see also Offenbach et al., 1990; Stones & Kozma, 1988). Additionally, exercisers have been found to outperform non-exercisers on tasks such as reasoning, working memory, Stroop, Trails-B, Symbol digits, vigilance monitoring, and fluid intelligence tests (Abourezk & Toole, 1995; Bunce et al., 1996; Cook et al., 1995; Dustman, 1994). However, differences in performance on seemingly similar tasks between lifetime exercisers and non-exercisers have not always been found. Reports of failures to find beneficial effects of exercise on the performance of simple and choice reaction time tasks, short-term memory and digit span tasks and for measures of somatosensory thresholds have been reported (Abourezk & Toole, 1995; Dustman et al., 1990; Clarkson-Smith & Hartley, 1990; Van Boxtel et al., 1997).

Although the research reviewed above has, in general, found beneficial effects of exercise on the cognitive processes of older adults, the cross-sectional nature of these studies complicates their interpretation. Thus, the positive effects may reflect a genetic predisposition of the exercisers towards fast and accurate responding rather than a benefit of aerobic fitness achieved through exercise. A number of researchers have at least partially circumvented the problem of self-selection by employing longitudinal exercise interventions. Dustman et al (1984) found improvements in the performance of a number of tasks including, critical flicker fusion, digit symbol and Stroop following a four month exercise program. These improvements were specific to an aerobic exercise group exhibiting a considerable improvement in cardiovascular function (i.e. 27% improvement in VO_2max). Subjects who had participated in a strength and flexibility program and those in a nonexercise control group did not show improvements in performance across test administrations. However, consistent with previous longitudinal studies, there were also a variety of tasks in which aerobic exercise failed to have a beneficial effect. These tasks included choice RT and Culture Fair IQ. Rikli and Edwards (1991) found that a three year aerobic fitness program served to eliminate declines in choice reaction time performance that were observed for a non-exercise control group. Interestingly, fitness-related performance sparing was not observed for a simple reaction time task. Finally, Hawkins et al. (1992) found significant improvements in the dual-task performance of a group of elderly adults who participated in a 10 week aerobic fitness program while failing to observe any improvement in the dual-task conditions for a non-exercise control group. Both the exercise and non-exercise control group showed comparable performance improvements on the single tasks, presumably due to practice. Taken together, the results of these longitudinal studies (see also Chodzko-Zajko & Moore, 1994; Moul et al., 1995) are supportive of selective improvements in a number of cognitive processes with short-term programs of aerobic exercise.

Other longitudinal studies have failed to find aerobic exercise benefits in human information processing. Blumenthal and Madden (1988) reported that both aerobic and anaerobic exercise groups improved their performance on a memory search task across test administrations that spanned 12 weeks. Failure to find a performance improvement attributable to the aerobic exercise program may be the result of a number of factors. First, the subjects were relatively young, ranging in age from 30 to 58. Previous studies have found more robust effects of exercise on cognitive processes for older adults. Second, the participants were relatively fit prior to the exercise program with an average VO_2max of 34 $ml \times kg^{-1} \times min^{-1}$. Third, improvement in cardiovascular function was markedly less than the improvement reported by Dustman et al. Finally, rehearsal time in the memory task was uncontrolled. Subjects were permitted to view the memory set as long as they wished. Thus, it is conceivable that aerobic exercise may have had a beneficial effect on encoding processes.

Madden et al. (1989) reexamined the effects of aerobic exercise on memory search performance. Older (60 to 83) and less fit subjects performed memory search both separately and in conjunction with a secondary auditory task. The secondary task was included in an effort to determine whether more attentionally demanding tasks would benefit from short term programs of exercise. There was no difference in the pre/post memory performance exhibited by members of an aerobic exercise group or control groups. The cardiovascular improvement exhibited by the aerobic group was again smaller than that reported by Dustman et al (see also Blumenthal et al., 1991; Hill et al, 1993; Panton et al, 1990).

To summarize, the literature suggests that although a lifetime of aerobic exercise may help preserve a selective subset of cognitive capabilities in older adults, the benefits of exercise intervention programs are much more equivocal. A plausible interpretation of the literature concerns the nature of the cognitive processes that have been examined as well as the exercise interventions. A comparison of the fitness levels reported for the post-exercise groups in the longitudinal studies and those reported for the lifetime exercisers clearly suggests that high levels of fitness are achieved after years rather than months of training. Therefore, it might be unreasonable to expect that brief programs of exercise will have beneficial effects on a wide variety of cognitive processes. Instead, it is conceivable that short-term exercise benefits might be restricted to those processes that have the most room for improvement, that is those processes (i.e. executive control processes) which are most susceptible to aging. In the next section we describe the literature which has examined age-related differences in executive control processes and the brain structures which support them.

Aging and Executive Control

Within the last decade there has been a renewed interest among cognitive psychologists and cognitive aging researchers in executive control functions. Such functions are concerned with the selection, inhibition, scheduling and coordination of the computational processes that are responsible for perception, memory, and action. The interest in the executive control of cognitive processes has been reflected in the development of models of cognition that reserve an important role for executive control functions (Baddeley, 1992; Shallice, 1994) as well as in the detailed empirical examination of a subset of executive control processes of young and old adults (Allport et al., 1994; Kramer et al, 1999, 2000; Rogers & Monsell, 1995; Verhaeghen et al., 1997).

In his recent critical review of the literature on the neuroanatomy, neurophysiology and neuropsychology of aging West (1996) concluded that relatively strong evidence exists for the frontal lobe hypothesis of cognitive aging. The frontal lobe hypothesis suggests that older adults are disproportionately disadvantaged on tasks that rely heavily on cognitive processes (i.e. executive control processes) that are supported by the frontal and prefrontal lobes of the brain. Indeed, there is a good deal of evidence to suggest that morphological and functional changes in brain activity do not occur uniformly during the process of normal aging. Researchers have reported substantially larger reductions in gray matter volume in association areas of cortex, and in particular in the prefrontal and frontal regions, than in sensory cortical regions (Raz et al., in press). Studies of functional brain activity employing Positron Emission Tomography (PET) have reported similar trends, with prefrontal regions showing substantially larger decreases in metabolic activity than sensory areas of cortex (Azari et al., 1992; Salmon et al., 1992).

These data on the structure and function of the aging brain are consistent with numerous reports of large and robust age-related deficits in the performance of tasks that are largely supported by the frontal and prefrontal regions of the cortex, as compared to relatively small age-related deficits on non-frontal lobe tasks (Daigneault et al, 1992; Shimamura & Jurica, 1994). Indeed, many of the tasks subserved, in large part, by the frontal lobes involve processes associated with executive control functions such as the selection, control, and coordination of computational processes that are responsible for perception and action. For example, large age-related deficits have generally been reported when adults are required to perform two or more tasks at the same time or to rapidly shift emphasis among tasks (Kramer et al., 1999; Rogers et al., 1994). Functional magnetic resonance imaging (fMRI) and PET studies have shown enhanced activation of regions of the prefrontal and frontal cortices when two tasks are performed together but not when they are performed separately (D'Esposito et al., 1995). Verhaeghen et al (1997) have also reported that reliably larger age-related performance decrements are observed in tasks which require coordinative operations (i.e. mental arithmetic operations in which a product must be held in working memory as other computations are performed) than for tasks which require sequential operations (i.e. mental arithmetic operations that do not require storing and retrieving products from working memory while carrying out arithmetical operations).

Older adults also show disproportionate age-related performance deficits in tasks which require the inhibition of prepotent responses such as the antisaccade paradigm (Kramer et al, 2000) and the Stroop task (Brink & McDowd, 1999; Hartley, 1993). The antisaccade paradigm requires that subjects quickly shift their eyes in the direction opposite of a stimulus, that is they are to inhibit a reflexive eye movement to the stimulus and move their eyes in the opposite direction. Performance on this task is extremely difficult for patients with lesions in the dorsolateral prefrontal cortex and frontal eye fields and has been shown to activate these brain regions in PET studies (Corbetta et al., 1998). The Stroop task requires subjects to name the color of the ink in which a word is presented. Response times and errors are elevated when the word names an incongruent color, particularly for older adults.

In summary, our abbreviated review of the cognition and aging literature suggests relatively strong support for the hypothesis that older adults are more disadvantaged by tasks that rely heavily on executive control processes (and the frontal and prefrontal cortices) than tasks which rely on component task processes (i.e. perceptual and action-related processes). Although it is clear that older adults are often slower to perform many tasks than are young adults (Salthouse, 1996), tasks that rely heavily on the executive control processes of planning, scheduling, coordinating, and inhibition of prepotent responses appear to suffer a disproportionate cost both in terms of performance as well as in the brain structures and functions which support them.

Aging, Fitness and Cognition: Revisited

The literature which we have just reviewed on cognition and aging suggests that older adults are disproportionately disadvantaged when they must perform tasks which rely heavily on executive control processes and the brain regions which support them. In this section we re-examine the literature on aging, fitness and cognitive function in light of the cognition and aging literature. The main question that we address here is whether there is any evidence for our hypothesis that improvements in aerobic fitness will have a larger positive impact on tasks which entail executive control than on tasks which involve little if any executive control processing.

Another hypothesis concerning the relationship between aerobic fitness and cognition appears, at first glance, to be similar to our proposal. Chodzko-Zajko and Moore (1994) suggested that tasks which require controlled, effortful processing should be more sensitive to fitness differences among older adults than tasks that can be executed via automatic processing. Indeed, there is some support for this hypothesis. Larger fitness effects have been found on choice than on simple RT tasks (Rikli & Edwards, 1991) and on increasingly difficult Stroop interference conditions but not on non-interference versions of color and word naming (Schuler et al., 1993). However, a number of other studies have failed to find larger fitness effects for tasks that have been assumed to require more effortful (and less automatic) processing (Lupinacci et al., 1993; Toole et al., 1993). Thus, at best the support is mixed for Chodzko-Zajko's proposal that tasks which require controlled, effortful processing should be more sensitive to fitness differences among older adults than tasks that can be executed via automatic processing.

One might argue that this lack of consistency in the relationship between fitness and degree of effortful processing belies our hypothesis that improvements in aerobic fitness will have a larger positive impact on tasks which entail executive control than on tasks which involve little if any executive control processing. However, we would argue that tasks which require effortful processing do not necessarily entail executive control processes. Indeed, many of the experiments which failed to find evidence in favor of Chodzko-Zajko's effortful processing hypothesis contrasted fitness effects on simple and choice reaction time tasks. Whereas choice RT tasks may be more effortful than simple RT, neither of these tasks entails any substantial executive control functions.

Of course, the crucial question is whether there is any evidence in support of our proposed executive control/aerobic fitness hypothesis? We believe that there is some, albeit limited evidence for this proposal. For example, Hawkins et al (1992) found that subjects who had been trained in water aerobics showed a significantly larger improvement in dual-task performance than a non-exercise control group. Interestingly, both groups showed similar performance improvements in the separate auditory and visual discrimination tasks. Given the obvious coordination and scheduling requirements of successful dual-task performance, as well as previous studies which have found enhanced activation of regions of the prefrontal and frontal cortices when two tasks are performed together but not when they are performed separately (D'Esposito et al., 1995), these results are clearly consistent with our executive control hypothesis. Similar results were found in a cross-sectional study in which fitness effects were compared for a simple RT and a three-choice RT task which required that subjects continually re-map the stimulus-response relations on the basis of pre-cue information (Abourezk & Toole, 1995). Such a choice RT task clearly requires the executive control processes of planning and coordination and also the inhibition of previously employed response mappings. Consistent with our executive control hypothesis subjects performed equivalently on the simple RT task while high fit older adults significantly outperformed their low fit peers on the three-choice task (see also Emery et al., 1998; Moul et al., 1995; Van Boxtel et al., 1997).

Thus, there is a small but growing body of studies which are consistent with our hypothesis that improvements in aerobic fitness will have a larger positive impact on tasks which entail executive control than on tasks which involve little if any executive control processing. However, there is an important caveat. That is, that none of the reviewed studies were explicitly designed to contrast fitness effects on the executive and non-executive processing of older adults.

Current Study

In an effort to test our *executive control/fitness hypothesis*, we trained sedentary but healthy older adults for a period of 6 months with either an aerobic (walking) or anaerobic (toning and stretching control) exercise protocol. Each of the subjects was tested in a variety of attention, memory and perceptual speed tasks including; task switching, response compatibility, stopping, Rey Auditory Verbal Learning (Rey AVL), spatial attention, visual search, n-back spatial and verbal, face recognition, forward and backward digit span, digit-digit and digit-symbol match, self-ordered pointing, and pursuit rotor. We chose these particular behavioral tasks because components of a subset of these tasks have been shown, either through human lesion, neuroimaging, or animal studies, to entail executive control processes and be supported, in large part, by the frontal or pre-frontal regions of the brain.

Components of the first nine tasks listed in Table 3; stopping, task switching, response compatibility, Rey AVL, n-back verbal, n-back spatial and backward digit span, self-ordered pointing and face recognition have been shown to entail executive processes mediated in the frontal and prefrontal regions of cortex. These components include (1) in the stopping paradigm, the Stop Signal RT (SSRT) which provides a measure of the ability to abort a preprogrammed action, (2) in the task switching paradigm, the difference in RT between those trials on which subjects switch to a new task and those trials on which subjects continue to perform the same task which provides a measure of task set reconfiguration and inhibition (3) in the response compatibility paradigm, the difference between RT on the compatible and incompatible trials which provides a measure of the ability to ignore task-irrelevant stimuli, (4) in the Rey AVLT paradigm, the number of words recalled in list A after the presentation of list B and the ability to recall a list of 15 words in their initially presented order (5) in the n-back and backward digit span paradigms, the ability to update and maintain multiple items in working memory, particularly at longer lags, (6) in the self-ordered pointing task the ability to keep track of and update the items selected on previous trials and (7) in the face recognition paradigm, the ability to successfully encode and retrieve novel faces.

Performance on the other six paradigms; forward digit span, pursuit rotor, spatial attention, visual search, and digit/digit and digit-symbol, and the other components of the Stopping (simple

RT and choice RT components), Task Switching (non-switch trial RT), Response Compatibility (compatible trial RT), Rey AVL (number of words recalled from list A on the first several trials), and n-back verbal and spatial working memory (1-back measures; Braver et al., 1997) appear to depend less on executive control processes and the frontal regions of the cortex and therefore would not be expected to substantially benefit from improvements in aerobic fitness.

In summary, we predict selective cognitive benefits with improved aerobic fitness and more specifically benefits in those tasks which entail executive control processes which are supported, in part, by frontal and prefrontal regions of the brain.

Method

Subjects.

Sedentary older adults (60 to 75 years of age) were recruited to participate in a 6-month randomized exercise intervention. One hundred and seventy four individuals passed the initial screening protocol for participation in the study. The screening criteria are illustrated in Table 1. Participants were randomly assigned to one of two treatments, an aerobic activity program (walking) and a nonaerobic stretching and toning program. The toning program participants served as a control group against which to evaluate changes in neurocognitive functions with improved aerobic fitness. Fifty subjects were subsequently dropped from the study as a result of a decision to withdraw from the exercise training or as a result of incomplete data on the neurocognitive or cardiorespiratory tests. These subjects were equally divided between the walking and the toning groups and did not differ from the subjects who completed the studies in any of the demographic characteristics.

One hundred and twenty four subjects completed the study. Sixty six of the subjects (20 male) were in the toning group, fifty eight of the subjects (13 male) were in the walking group. The mean age of the subjects in the toning and walking groups were 66.0 (sd = 5.3) and 67.3 (sd = 5.2), respectively. The two groups also had similar Kaufman K-Bit IQ composite scores (115.2 and 113.9 for the toning and walking groups, respectively). Average attendance in the exercise training classes did not differ between the participants in the toning and walking groups.

Neurocognitive Tests.

The present section provides a brief description of each of the tasks employed in the cognitive battery. Each of these tasks were administered both before and after the six month exercise intervention.

Visual search task. This task examines subjects' ability to rapidly search through a visual array. Two different search tasks were performed by the subjects. In the *feature search task* subjects detected a target that differed from distractors by a single feature. That is, subjects searched for an X target among O distractors. Display sizes of 5, 10 and 15 items were used. The target was present on 50% of the trials. Subjects depressed one key on the computer keyboard for a target present response and another key for a target absent response. In the *conjunction search task* subjects detected a small X target among large X and small O distractors. The same display sizes, response keys, and target probabilities that were used in the feature search task were also used in the conjunction search task

Subjects performed one practice block of 20 trials followed by one 120 trial feature search block and two 120 trial conjunction search blocks in the visual search task. The main dependent variables included mean RT, error rate, and RT search slopes.

Response compatibility task. This task examines subjects' ability to ignore task-irrelevant stimuli. Subjects were presented with three letters in the center of the display. Subjects were instructed to attend and respond to the letter in the middle of the three letter array. If the letter in the center of the array was an X they were to press one key on the computer keyboard. If the letter in the center of the array was an S they were to press another key on the keyboard.

There were two different conditions, each occurring on 50% of the trials. In the response compatible trials the center letter was flanked by two of the same letters (an X in the middle surrounded by X's) while in the incompatible trials the center letter was flanked by the other letter (an X in the middle surrounded by S's). The flankers appeared .25 degrees of visual angle from the target. Subjects performed one practice block of 20 trials followed by one experimental block of 120 trials. The main dependent variables included mean RT and error rate.

Task switching paradigm. This task examines subjects' ability to rapidly disengage from one task and switch to another. Subjects performed two different tasks which alternated every third trial. That is, subjects performed an odd/even numerical judgment task (i.e. is a single digit number odd or even ?) for two trials followed by the performance of a vowel/consonant judgment task for two trials. The task stimuli, a letter and a single digit number, were presented in a two by two matrix which was centered in the middle of the computer screen. When the letter and digit were located in the upper quadrant of the matrix subjects performed the odd/even judgment task, when the letter and digit were in the lower two quadrants of the matrix subjects performed the consonant/vowel judgment task. The letter and digit were presented in the matrix in a continuous clockwise direction. Thus, the occurrence of a task switch was predictable.

Each stimulus pair was presented until the subject responded and then the next stimulus pair was presented 400 ms following the subjects response. Subjects responded with one of two keys on the computer keyboard for each of the tasks.

Subjects first performed two 30 trial single task blocks followed by one 30 trial task switching block as practice. The practice blocks were then followed by four 60 trial task switching blocks The main dependent variables included mean RT and error rate.

Stopping paradigm. This task examines subjects' ability to rapidly abort a preplanned manual response. There were several different task components in the stopping paradigm; a simple RT (SRT) task, a choice RT (CRT) task, and the stopping task. Subjects first performed the SRT task. The subjects manually responded to the presentation of a 75dB, 100 Hz tone (200 ms duration). Subjects practiced the SRT task for 20 trials and then performed another 50 experimental trials. Subjects then performed the CRT task in which they were required to discriminate between two letters, an F and a E. Subjects pressed one key on the computer keyboard when the F appeared and another key when the E appeared. Subjects performed the CRT task for 20 practice trials and 60 experimental trials.

Subjects next performed the stopping task. In this task subjects were instructed to perform the CRT task unless a tone was presented which indicated that the response to the CRT task was to be aborted. The tone was presented on 30% of the trials and these trials are called stop-signal trials. The tones were presented at one of three delays relative to the presentation of the letter. The stop-signal delays were calculated, separately for each subject, by subtracting the SRT (i.e. the average SRT to the tone only block of trials), from the RTs from the 20^{th}, 50^{th} and 80^{th} percentile RTs from the CRT block.

Subjects performed 30 practice trials of the stopping task and then three blocks of 120 trials each. The mean RTs and error rates served as dependent variables for the SRT and CRT tasks. Two dependent variables were calculated in the stopping task. One variable was the probability of responding given the occurrence of a stop signal, P(respond/signal), and the second variable was the stop signal reaction time (SSRT). The P(respond/signal) provides a measures of the subjects ability to inhibit an overt response while the SSRT provides an indication of the speed of the stopping process. The SSRT was estimated from the data using the race model proposed by Logan & Cowan (1984).

Spatial attention task. This task examines subjects' ability to rapidly re-orient attention in the visual field. The subjects task was to detect and respond to the appearance of a bright asterisk positioned either 4 degrees of visual angle to the left or right of fixation within a box. One of two boxes was cued for 50 ms, followed 100 ms later by the appearance of the asterisk target. The cue correctly predicted the location of the asterisk target on 70% of the trials. Subjects performed one block of 35 practice trials followed by two blocks of 55 experimental trials. The main dependent variables included mean RT and accuracy.

Rey auditory verbal learning test (AVLT) This task examines a number of components of verbal working memory including recognition and recall of a list of ordered stimuli. The subjects' task was to recall as many words as possible from two different word lists. In trials 1 through 5 subjects are read a list (the A list) of 15 common nouns and subjects are asked to recall as many words as possible, in the correct order, as soon as the experimenter has finished reading the word list. In trial 6 a new list of words (list B) is read and subjects are asked to recall as many of the 15 words as possible. On trial 7 no list is read and subjects are asked to recall as many words as possible from the A list. Trial 8 takes place after a 30 minute delay at which time subjects are again asked to recall as many words as possible from list A. Trial 9 is a recognition test. The experimenter reads a list of 50 words and the subject is instructed to say "Yes" to any word from list A. Finally, trial 10 is a temporal order task. The subjects are given a sheet of paper with the 15 words from list A presented in a scrambled order. The subject is then asked to arrange the words in the order in which the list was originally read to them.

The dependent measures are the accuracy of recall (or recognition) for each of the first nine experimental trials and the correlation between the subjects recall order and the correct order of the words on trial 10.

Pursuit rotor task This task examines subjects' ability to learn a complex spatial-temporal pattern. The subjects task was to match the position of a computer controlled target, presented on the computer screen, with a cursor which is controlled via a digitizing tablet. On each trial the target first moves randomly around the screen for 10 secs followed by a movement pattern which repeats across trials for 10 secs, and finally another 5 secs of random movement. Each subject performed eight blocks of four trials each. The first six blocks included the same repeating pattern (the training blocks) while a new repeating pattern replaced the initial repeating pattern in blocks seven and eight (the transfer blocks). The dependent variable was root mean square (RMS) tracking error.

Self-ordered pointing task This task examines subjects' ability to monitor and maintain in working memory a series of responses to stimuli which are not verbally codeable. Subjects performed blocks of nine trials. On each trial nine abstract objects were presented in the cells of a three x three matrix on the computer screen. The subjects' task was to point to a new object, by using the numeric keypad, on each of nine sequentially presented trials. The objects were presented in a new position in the matrix on each trial. Each subject performed one practice and four experimental blocks of nine trials each. The dependent variable was the average number of unique items that the subject selected.

Spatial working memory (N-back spatial) This paradigm examines subjects' spatial working memory. On each trial subjects see a three by three matrix with a black box in one of the cells. In the 1-back trial blocks subjects were required to make one response if the box in the present trial is in the same location as the box in the previous trial. In the 2-back trial blocks subjects were required to decide whether the location of the box, in the three by three matrix, was the same as that two trials ago. Subjects performed one 50 trial practice block of trials and then two 50 trial experimental trial blocks, one for the 1-back and one for the 2-back version of the task. There were a total of 18 trials on which a match occurred in the 1 and 2-back versions of the task. The dependent variable was the number of trials in which subjects correctly detected a match.

Verbal working memory (N-back verbal) This paradigm examines subjects verbal working memory. This task was the verbal analog of the spatial working memory task. Instead of matching spatial positions subjects were instructed to determine whether letters matched across either 1 or 2 trials. The number of practice and experimental trials and the dependent variables were the same as in the spatial working memory task.

Face recognition task This task examines subjects' non-verbal working memory, specifically for human faces. A series of 50 black and white photographs of male faces were presented for 3 secs each on the computer screen. Subjects were instructed to provide a verbal report as to whether each of the faces was pleasant or unpleasant. Immediately after the study block the subjects were given a recognition test, in which 25 pairs of faces were presented (with one new and one old face in each pair) on the computer screen. Subjects were asked to judge which of the two faces was presented in the previous block. After a period of one hour a delayed recognition task was performed. This task was identical to the immediate recognition task, except that the other 25 initially studied faces were paired with new faces. Subjects judged which of the faces in each pair was the "old" face. The dependent measure was the percent of correctly recognized stimuli in the immediate and delayed recall tests.

Digit-Digit and Digit-Symbol tests These tests examine subjects ability to rapidly perform perceptual comparisons. In the digit-digit task subjects are presented with two rows of nine single digits such that a digit in the top row is aligned with a digit in the second row. Subjects are then presented with a pair of vertically aligned digits and are asked to determine, by consulting the rows of digits at the top of the screen, whether the single pair matches one of the pairs of digits at the top of the screen. The digit-symbol task is similar to the digit-digit task. However, in the digit-symbol task numbers are aligned with symbols from the computer keyboard. Subjects performed one 10 trial practice block and one 50 trial experimental block of each of these tasks. The dependent variables were mean RT and accuracy.

Forward and backward digit span These tests examine subjects ability to maintain a number of elements in working memory and to retrieve these elements on command. In the forward digit span test subjects were presented with sets of digits from the WAIS-R IQ test and asked to repeat them back, in the order in which they had initially been presented, to the experimenter. The backward digit span test was administered in the same manner as the forward digit span test with the exception that the subjects were to recall the digits in the opposite order in which they were initially presented.

The main dependent variable, for the forward and backward digit span tests, was the number of points earned by the subjects with one point received for each string recalled until the point in which subjects failed to recall both digit sets at a particular numerosity.

Exercise Interventions

Aerobic Exercise Group. The aerobic exercise intervention was designed to influence physical fitness as typified by cardiorespiratory endurance. Basic principles and guidelines for exercise programming were followed, including adequate warm-up and cool-down periods, progressive and gradual increments in exercise duration and energy expenditure, and instruction regarding avoidance of exercise-related injury. With respect to the exercise prescription, the intensity level began at light levels (50-55% VO_2max) and gradually increased to more moderate levels (65-70% VO_2max) by the midpoint of the program. Duration of exercise was also gradually increased beginning at 10-15 minutes per session and increasing by a minute per session until participants were exercising for 40 minutes per session. The exercise classes were conducted by trained exercise specialists and employed brisk walking as the aerobic component. The exercise program was conducted three times a week for six months.

Activity sessions were initially conducted on the University of Illinois campus and involved participants walking outdoors on one of two premeasured routes. These routes were less than five minutes from the daily starting point and involved walking along, through, and around either a large university quadrangle or a partially wooded park-like area. As the weather conditions became more severe and precluded outdoor activity for these individuals, activity sessions were moved to a local indoor shopping mall.

Stretching and Toning Control Group. This group of individuals met 3 times per week for an hour for six months in a large gymnasium and were led by an experienced exercise leader, and therefore received the same amount of attention as our aerobic training group. The focus of this program was on the provision of an organized program of stretching, limbering, and toning for the whole body. Each stretch was constant, controlled and smooth and progressions were gradual and steady. All stretches were within each subject's range of motion and were held to the point of slight discomfort. This program emphasized stretches for all large muscle groups of both the upper and lower body. Each stretch was held for approximately 20-30 seconds and repeated 5-10 times. Each stretching/toning session lasted for approximately 40 minutes. Each session was preceded and followed by 10 minutes of warm-up and cool-down exercises.

Assessment of Aerobic Capacity. Aerobic endurance capacity was determined for all subjects prior to and following the intervention. Because many older individuals are unable to attain an objective verifiable VO_2max, in which a plateau in VO_2 is demonstrated between two or more work levels (treadmill graded) during progressive graded incremental walking, we assessed VO_2peak at the point of test termination due to volitional exhaustion. This measure of aerobic endurance capacity was assessed on a motor-driven treadmill by employing a modified Balke protocol (ACSM, 1991). The protocol involves walking at a speed of 3 mph with increasing grade increments of 2% every 2 min. Measurements of oxygen uptake, heart rate and blood pressure were continuously monitored.

Oxygen uptake (VO_2) was measured from expired air samples taken at 30 second intervals until a peak VO_2, the highest VO_2, was attained at the point of test termination due to symptom limitation and/or volitional exhaustion. Heart rate was taken during each work stage through continuous direct 12-lead electrocardiographic monitoring. Blood pressure was measured by auscultation and a sphygmomanometer. A physician and nurse monitored and supervised all aspects of the graded exercise testing.

We also had subjects complete the Rockport One Mile Fitness Walking Test (Kline et al., 1987). This measure estimates cardiorespiratory fitness and maximal oxygen uptake and requires subjects to walk one mile as quickly as possible. This measure correlates highly with direct measures of aerobic capacity andhas been cross-validated.

Results

The results section will be organized in the following manner. First, we will begin by reporting analyses on the cardiorespiratory measures both to establish comparability of measures across the walking and toning groups before the exercise intervention and also to examine changes in these measures as a function of the exercise interventions. Next, we will report analyses on the neurocognitive measures. Given the limited space only the most relevant dependent measures will be reported here.

Cardiorespiratory Measures.

The cardiorespiratory measures obtained in our study are presented in Table 2. As can be seen from the table improvements were observed on the three measures, with the exception of the $V0_2$ max measure for the toning group, as a function of exercise. Each of the three measures were submitted to mixed mode ANOVAs with exercise group (walking and toning) as the between subjects factor and session (before and after the 6 month exercise intervention) as the within subjects factor. Significant main effects for session were obtained for time on the treadmill ($F(1,122)=14.6$, $p<.01$) and the Rockport 1 mile walk ($F(1,122)=87.3$, $p<.01$) measures. Subjects were able to remain on the treadmill longer and complete the 1 mile walk more quickly after the 6 month exercise program. More importantly however, we obtained significant two-way interactions between session and exercise group for the $V0_2$ max ($F(1,122)=10.3$, $p<.01$), time on treadmill ($F(1,122)=9.1$, $p<.01$) and the Rockport 1 mile walk ($F(1,122)=7.3$, $p<.01$) measures. In each of these cases, cardiorespiratory performance improved to a greater extent for the walking than for the toning group as a function of the exercise program.

The percent improvement for the walking group on the $V0_2$ max, time on treadmill and Rockport 1 mile walk measures was 5.1, 12.9 and 9.6%, respectively. The comparable percent improvement scores for the toning group subjects were -2.8, 1.7 and 4.4%, respectively.

<u>Neurocognitive Tasks and Measures.</u>

The dependent measures in each of the neurocognitive tasks are presented in Table 3. The measures for each of the tasks in the neurocognitive battery were submitted to mixed mode ANOVAs with exercise group as the between subjects factor and session as a within subjects factor. Given the number of paradigms and measures we will focus specifically on the significant group x session interactions, that is, those interactions which indicate whether the magnitude of performance improvement was larger for the walking or for the toning group subjects as a function of the exercise intervention.

As indicated previously, we predicted that tasks which require executive control processes and specifically those processes supported, in part, by frontal and pre-frontal regions of the brain would be most sensitive to improvements in aerobic capacity. This is, in large part, what we found in the ANOVAs performed on the attentional tasks but to a lesser extent with the memory tasks.

<u>Stop Signal Paradigm.</u> As indicated in Table 3 several different sub-tasks were included in the Stopping paradigm, a simple RT (SRT) task, a choice RT task (CRT), and the stopping task. We predicted that differential performance improvements for the two groups would be found for the stopping task, given the need to inhibit inappropriate preprogrammed actions in this task. Indeed, this is what we found. A 17% decrease in stop signal RT (SSRT) was observed for the walking group following the 6 month exercise program. On the other hand, the toning group subjects showed a 4% increase in SSRT after 6 months ($F(1,122)=24.7$, $p<.01$). Also consistent

with predictions there were no group differences on the SRT and CRT tasks, tasks which do not require executive control processes, over the course of the exercise intervention.

Task Switching Paradigm. As illustrated in Table 3, large switch costs (i.e. switch RT – non-switch RT) were obtained for both groups of subjects, consistent with previous literature. However, while the switch costs declined from 906 to 474 ms for the walking group over the course of the 6 month exercise intervention, switch costs actually increased for the toning group from 681 to 806 ms. This difference was reflected in the significant three-way interaction among the group, session and trial type (i.e. switch versus non-switch trials, $F(1,122)=12.1$, $p<.01$). Thus, consistent with our selective improvement hypothesis increases in aerobic fitness had a beneficial effect on those aspects of the task which entail executive control processes, including inhibition and task set reconfiguration, which are subserved, in part, by prefrontal regions of the brain. Also consistent with our hypothesis, performance on non-switch trials, which do not require executive control processes, showed equivalent improvements for both groups.

Response Compatibility Task. A significant three-way interaction between group, session and compatibility was obtained for the response compatibility task ($F(1,122)=4.1$, $p<.05$). Subjects in the walking group reduced their compatibility effect (i.e. response incompatible RT – response compatible RT) from 79 ms in the session prior to exercise training to 25 ms in the session after the six month exercise intervention. However, the response compatibility effect was relatively constant for the subjects in the toning group (i.e. 72 ms and 73 ms in the first and second session, respectively). The magnitude of the response compatibility appears to reflect subjects ability to successfully ignore task-irrelevant information with smaller response compatibility effects being associated with a more successful focus on the task-relevant information. The ability to successfully ignore or inhibit conflicting information in response compatibility and other similar tasks has been found to be associated with activation of a variety of prefrontal regions such as the DLPFC and the anterior cingulate (Taylor et al., 1996). Thus, the selective improvement in the response compatibility effect for the aerobic (walking) group is consistent with our hypothesis concerning executive control processes, aging, and aerobic fitness.

REY auditory verbal learning test. As indicated in Table 3 a number of different measures are obtained from the Rey with these measures reflecting different components of memory processes. Given our executive control/fitness hypothesis we predicted that improvements in aerobic fitness would be associated with improvements in performance for a subset of these measures which reflect executive control processes including inhibition (i.e. Trial 7 - number of words recalled from list A following the presentation of list B) and maintenance of temporal order information (Trial 10 - temporal order ranking). Indeed, significant group x session interactions favoring the aerobically trained subjects were found for both the trial 7 ($F(1,122)=9.9$, $p<.01$) and trial 10 measures ($F(1,122)=8.5$, $p<.01$). Interestingly, a significant two-way interaction between session and group was also obtained for the trial 9 measure which presumably reflects the encoding and retrieval processes underlying recognition ($F(1,122)=5.4$, $p<.05$). Although recognition memory is usually not associated with executive control, the added burden of ensuring that the recognized words were from list A may have been sufficient to invoke inhibitory processes (i.e. to inhibit or suppress the word representations from list B), thereby benefiting from improved aerobic fitness.

<u>N-back verbal and spatial tasks</u>. Ample neuroimaging evidence exists to indicate that constantly maintaining and updating working memory as well as determining whether previously encoded items match current items, especially with higher lags engages a variety of executive control processes which are subserved by regions in the frontal and prefrontal areas of cortex (Braver et al., 1997). Therefore, we expected to observe significant group x session interactions for accuracy measures in these tasks, and in particular for the lag-2 measures. Although larger improvements in performance were observed for lag 2 measures for the walking than for the toning group for both the verbal and spatial tasks neither of these effects were significant (p's>.10).

<u>Self-ordered pointing task</u> Given that this task entails the ability to monitor and maintain in working memory a series of responses to stimuli which are not verbally codeable as well as previous demonstrations of the integral role of mid and posterior dorsolateral cortex in successful performance of the task (Petrides et al., 1993) we expected to observe a larger improvement in performance for the aerobically trained subjects. However, as can be seen in Table 3 neither of the subject groups showed any improvement in performance over the course of the intervention.

<u>Face recognition task.</u> As can be seen in Table 3, subjects in the walking group showed improvements in both the immediate and delayed recognition measures on the task. This is in contrast to declines in recognition performance for the toning group's subjects over the period of the exercise intervention. However none of the relevant interactions were significant (p's>.10). Thus, although the trends in performance were in the predicted direction on the face recognition test they did not achieve conventional levels of statistical significance.

<u>Backward and forward digit span tasks</u>. We predicted a group x session interaction favoring the aerobically trained adults for the backward but not for the forward digit span tasks since while the forward digit span task provides a measure of short term memory it does not require the temporal order transformations, like the backward memory digit span task, that form one of

the hallmarks of executive control processes (Baddeley, 1992). Neither the main effect of session nor the interaction of session and group attained significance.

Pursuit rotor task. Given the minimal level of executive control required for the pursuit rotor task, whether with repeating or new patterns, we predicted that any performance differences that were observed over the course of the exercise intervention would be the same for the walking and the toning groups. Indeed, a main effect was obtained ($F(1,122)=5.3$, $p<.01$) for session. However, as predicted the session x group interaction was not significant ($F<1.0$).

Spatial attention task. Given that this task appears to rely mainly on parietal cortex and midbrain structures rather than the frontal lobes (Posner & Petersen, 1990) and entails little or no executive control we predicted equivalent performance changes for the walking and toning group subjects over the course of the 6 month exercise intervention. The results were consistent with predictions. The amount of improvement in the speed of responding did not differ between the toning and walking groups ($F<1.0$).

Visual search task. Previous studies have suggested that striate, extrastriate, parietal and temporal cortices play an important role in visual search for both feature and conjunction targets (Posner & Gilbert, 1999). Therefore, our expectation was that although improvements in search might be observed, as a function of practice over the course of the 6 month exercise intervention, such improvements would be found for both the toning and walking groups. As indicated in Table 3, a main effect was observed for session ($F(1,122)=12.5$, $p<.01$). RTs were faster in the session following the exercise intervention. However, group did not interact with session in the two or three-way interactions (p's >.50). Thus, consistent with our predictions improvements in performance occurred for both aerobically and non-aerobically trained adults.

Digit-digit and digit-symbol tasks. These tasks entail simple comparison and response processes that are unlikely to involve more than minimal executive control (Salthouse 1996). Therefore, we predicted that changes in performance on these two perceptual comparison tasks would occur for both the toning and walking groups. Improvements in response speed were observed in both tasks following the 6 month exercise interventions (digit-digit, $F(1,122)=6.7$, $p<.05$, digit-symbol, ($F(1,122)=4.6$, $p<.05$). However, neither of these effects interacted with group (p's >.35).

Regression Analyses.

In general, the results were consistent with predictions. That is, those tasks (and specific components of tasks) that involve executive control processes and are supported, in part, by frontal and pre-frontal regions of the brain showed improvements in performance for the walking but not for the toning group subjects. This was the case for components of the task switching, stopping, response compatibility and Rey AVLT tasks. On the other hand, tasks which involve little or no executive control were not expected to benefit from aerobic training. Consistent with this prediction equivalent performance benefits, likely the result of practice effects, were found for the walking and toning groups for the pursuit rotor, spatial attention, visual search, and digit/digit and digit/symbol tasks.

However, predictions were not confirmed for all of the tasks. Selective improvements were also expected for a variety of working memory tasks including the n-back tasks, self-ordered pointing, digit span, and face recognition given the role of executive control processes, and regions of prefrontal and frontal cortex, in these paradigms. Although there were performance improvement trends in the predicted direction for a variety of these tasks (or task components), they did not attain conventional levels of statistical significance.

There are certainly a multitude of reasons why our predictions might not have been confirmed in these particular tasks. However, one possibility that we could examine with the present data set concerns the relationship between the magnitude of improvement in aerobic fitness and potential improvements in the performance on these tasks. Inspection of the distributions of percent change in VO_2 max, as a function of the 6 month exercise programs, indicated a fairly substantial overlap in these distributions for the walking and toning groups. The percentage of VO_2 change ranged from –30 to +45 % across groups.

Thus, given the substantial overlap in the distributions of the percentage of change in VO_2 max for the walking and toning group subjects we decided to examine the relationship between the change in aerobic fitness, as indexed by the VO_2 max measure, and performance changes in our battery of tasks over the course of the 6 month exercise interventions. That is, we ignored group distinctions (i.e. toning or walking group assignment and training) and analyzed the aerobic and performance change measures as continuous variables. To this end, we performed a series of hierarchical regression analyses in which we entered the VO_2 max score obtained prior to the exercise intervention (i.e. to control for absolute level of aerobic efficiency) on the first step and then let the VO_2 max post-intervention score enter as an additional predictor if it accounted for significant residual variance in the performance change score. The VO_2 max post-intervention predictor accounted for significant residual variance in (a) the SSRT measure in the Stopping task (15.0%), (b) the switch cost measure in the Task Switching paradigm (12.2%), (c) the response interference measure in the Response Compatibility task (14.4%), (d) trial 7 (9.1%), trial 9 (8.4%), and trial 10 (10.3%) measures in the REY AVLT task, (e) the 2-back measures in the Verbal (7.7%) and Spatial (6.4%) n-back tasks, (f) the backward digit span measure (5.0%) and (g) the immediate (6.9%) and delayed recall (5.8%) measures in the Face Recognition task.

Thus, the regression analyses indicated a significant relationship between improvement in $V0_2$ max, over the course of the 6 month exercise interventions, and improved performance on both the tasks in which we obtained significant group x session interactions in the ANOVA's as well as the memory tasks (i.e. n-back, face recognition, backward digit span) which we predicted would be sensitive to improved aerobic fitness. The only exception was the self-ordered pointing task for which we did not obtain a significant relationship between VO_2 max change and performance change over the course of the 6 month exercise intervention.

Discussion

The present study examined the relationship between improved aerobic fitness, engendered by a 6 month fitness training program, and improvements in cognitive function on a variety of attentional and memory paradigms. More specifically, we tested the hypothesis that improvements in performance would be observed to the extent that the task components relied on executive control processes such as monitoring, scheduling, planning, inhibition, and working memory, that is, those processes which are subserved by the frontal and prefrontal regions of the brain (Shallice, 1994). To that end, we included tasks in our computerized cognitive assessment battery which required executive control processing as well as tasks and task components that do not require such processes.

Our initial analyses which involved ANOVAs on performance measures as a function of subject group and session provided strong support for our hypothesis with the attention tasks. Improvements in performance were found for the walking but not for the toning group members on the predicted components of the response compatibility, stopping and task switching paradigms but not on components of these tasks which do not entail executive control. Additionally, as predicted we did not find selective benefits for the performance of the aerobically trained subjects on the spatial attention, visual search and digit/digit and digit/symbol tasks. These task do not entail executive control processes and are subserved, in large part, by non-frontal regions of cortex.

However, our initial analyses of the memory paradigms were less encouraging. Although, as predicted we did find selective performance benefits on a subset of the measures of the Rey AVLT which involve executive control processes, we failed to observe such benefits for the n-back, face recognition, backward digit span, and self-ordered pointing tasks, although there were trends in the predicted direction for a subset of these paradigms. However, our hierarchical regressions did, for the most part, provide data more supportive of our selective improvement hypothesis. When we ignored group distinctions (i.e. distinctions between the walking and toning training groups) and instead focused on changes in aerobic fitness across groups we found that the aerobic fitness changes accounted for significant residual variance, after first taking account of baseline VO_2 max differences, in the performance on a number of memory tasks predicted to be sensitive to fitness effects. Indeed, we observed the same types of dissociations between task components with substantial executive control demands as compared to task components with little demand for executive control processes in a number of these analyses that we had observed in the session x group interactions for the attention tasks. For example, for the spatial and verbal n-back tasks we found significant VO_2 max performance relationships in the 2-back but not in the 1-back conditions. Such a finding is consistent with our predictions given previous reports of graded patterns of frontal lobe activation with larger n-back lags (Braver et al, 1997). Similar dissociations were found between the forward and backward digit span tasks.

One interesting issue concerns the relative robustness of the fitness/performance relationship for the attention and memory tasks. That is, why could the fitness/performance relationship be discerned in both the group comparisons and regression analyses for the attention but not for the memory tasks? Although a more definitive answer to this question must await additional research there are several possibilities to consider. First, previous meta-analyses of mnemonic training effectiveness with older adults have indicated larger training benefits with younger seniors (Verhaeghen, Marcoen & Goossens, 1992). Therefore, it is conceivable that any aerobic fitness benefits might also be larger for younger than older participants. In order to examine this issue we performed a median split on age and recomputed the ANOVAs. The results were quite clear. No significant interactions of age were found with group and session for any of the attention or memory tasks. Therefore, at least in the present case, it appears that aerobic fitness benefits (or the lack thereof) do not depend on the age of our participants.

Another possible reason for the differential strength in the relationship between fitness and performance for the attention and memory tasks might be the subset of executive control processes, and their underlying neuroanatomical substrates, which are involved in the tasks. For example, while all of the memory tasks required both encoding and retrieval operations the attentional tasks were more focused on mapping simple stimuli to responses while ignoring task-irrelevant stimuli and actions. Although the executive control processes which support performance in both the attention and memory tasks have all been shown to be influenced by aging, they are also somewhat distinct thereby making it conceivable that they might be differentially sensitive to changes in aerobic fitness. One way to further address the issue of differential sensitivity of different executive control processes to aerobic fitness would be to include tasks with multiple components (e.g. working memory tasks in task switching and stopping paradigms) in assessment batteries.

A somewhat related issue concerns the dependent measures and subject strategies employed in the attention and memory tasks. The attention tasks stressed rapid and accurate performance while the memory tasks stressed accurate performance. Indeed, the strongest fitness effects were obtained with the reaction time and not the accuracy measures. Thus, it is possible that aerobic fitness benefits might be more readily observed under speed stress conditions. Such a possibility could be examined in future studies by varying speed/accuracy emphasis on a subset of the assessment tasks. In any event, there are clearly a number of hypotheses concerning the strength of fitness/performance relationships which merit additional study.

In our initial discussion of the aging, fitness and cognition literature we briefly described another hypothesis concerning the relationship between these factors. Chodzko-Zajko and Moore (1994) suggested that tasks which require controlled, effortful processing should be more sensitive to fitness differences among older adults than tasks that can be executed via automatic processing. Can this hypothesis also account for the pattern of obtained in the present study? Given the usual association of more effortful processing with slower performance the answer is no. For example, consider the stopping paradigm (see Table 3). The executive control/fitness hypothesis predicted that aerobic fitness benefits would be found only in the measure of stopping performance (i.e. SSRT) and not in measures of performance in the simple (SRT) and choice reaction (CRT) time components, even though these components took longer to perform than aborting a pre-programmed response. On the other hand, the effortful processing hypothesis predicts stronger fitness/performance benefits for the more difficult tasks (i.e. tasks which are performed more slowly). Clearly, the data is consistent with the executive control and not with the effortful processing hypothesis. Of course, another problem for the effortful processing hypothesis is mapping levels of effortfulness to different task components (i.e. how is a scale of effortfulness defined?).

Throughout the paper we have attempted to draw parallels between age-related changes in cognition, neuroanatomy and neurophysiology. Indeed, there is strong support both from human lesion and neuroimaging studies for the link between executive control and frontal lobe processes (Corbetta et al., 1991; D'Esposito et al., 1995; Petrides et al., 1993). Disproportionate age-related changes have also been reported in prefrontal and frontal lobe function and structure and in the executive processes these regions support (Raz et al., in press; West, 1996). However, thus far, there have been no attempts to examine the relationship between aerobic fitness, cognition, and brain function and structure. This is not surprising given the fairly recent developments in functional neuroimaging and the complexity of conducting fitness interventions with older adults. However, given our increasing knowledge of the relationship between fitness and brain function and structure gained in animal research (Jones et al., 1998; Neeper et al., 1995) along with the development of nonintrusive neuroimaging techniques such as fMRI (D'Esposito et al., 1999) the time is now ripe to examine fitness effects on both brain and mind.

Another important issue that remains to be addressed is the degree to which the cognitive changes that result from improved aerobic fitness impact activities of daily living for older adults. Clearly, many of the tasks that we perform on a day-to-day basis such as driving, planning and cooking a meal, and working in a busy office entail substantial executive control demands. Thus, it is certainly conceivable that the cognitive improvements measured on relatively simple laboratory tasks such as those employed in our study will translate into improvements in performance on everyday tasks. However, a more systematic examination of this issue is required to confirm such a speculation.

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Table 1. Inclusion-exclusion criteria for subject acceptance into the study.

Inclusion	Exclusion
1) 60 to 75 years of age	Below 60 years of age
2) Sedentary (no physical activity in the last 6 months	Self-reported activity on a regular basis (2 times per week) in the last 6 months
3) Capable of performing exercise	Any physical disability that prohibits mobility (walking, stretching, etc)
4) Personal physician's examination & consent to participate in exercise intervention	Non-consent of physician
5) Successful completion of graded exercise test without evidence of cardiac abnormalities	Evidence of abnormal cardiac responses during graded exercise testing
6) Initial depression score on the GDS below clinical level	Depression score on the GDS indicative of clinical depression
7) No history of neurological disorders	History of neurological disorders
8) Corrected (near & far) acuity of 20/40 or better	Corrected (near & far) acuity of greater than 20/40
9) Fewer than three errors on the Pfeiffer (1975) Mental Status questionnaire.	More than three errors on the Pfeiffer questionnaire

Table 2. Pre- and posttreatment values for the cardiorespiratory tests administered to the Walking and Toning groups (standard errors are in parentheses).

Measure	Walking Group Pre	Walking Group Post	Toning Group Pre	Toning Group Post	
$V0^2$ max (ml/kg/min)	21.5	22.6	21.8	21.2	*
	(.60)	(.64)	(.60)	(.54)	
Time on treadmill (mins)	11.6	13.1	11.3	11.5	*
	(.35)	(.42)	(.40)	(.45)	
Rockport 1 mile walk (mins)	17.7	16.0	18.0	17.2	*
	(.25)	(.26)	(.25)	(.27)	

Notes:
* indicates a significant interaction (p<.01) between exercise group and session.

Table 3. Pre- and posttreatment values for the neurocognitive tests administered to the Walking and Toning groups (standard errors are in parentheses). Reaction times (RT) are in ms. Accuracies are in percent correct.

	Walking Group		Toning Group		
Task Name	Pre	Post	Pre	Post	
Stopping Task					
Simple RT (to the tone)	351	361	356	361	
	(15.1)	(13.2)	(12.0)	(12.6)	
Accuracy (for simple RT task)	93.7	94.2	94.3	95.6	
	(1.9)	(1.3)	(1.3)	(1.1)	
Choice RT (to the letters)	664	640	656	635	
	(16.6)	(17.4)	(19.1)	(18.5)	
Accuracy (for choice RT)	90.9	93.1	93.6	92.3	
	(3.4)	(2.4)	(1.9)	(2.8)	
Stop Signal RT (SSRT)	256	213	249	260	*
	(8.6)	(5.4)	(6.4)	(7.5)	
P(Respond/Stop Signal)	.40	.39	.38	.36	
at the intermediate delay	(.02)	(.03)	(.03)	(.03)	
Task Switching Paradigm					
RT (non-switch trials)	1590	1484	1560	1457	
	(71.6)	(84.8)	(64.1)	(81.7)	
RT (switch trials)	2496	1959	2241	2263	*
	(112.9)	(107.1)	(96.7)	(117.2)	
Accuracy (non-switch trials)	96.7	97.3	98.5	96.6	
	(.85)	(.73)	(.72)	(.77)	
Accuracy (switch trials)	95.3	95.8	96.4	95.6	
	(.87)	(.83)	(.79)	(.91)	
Response Compatibility Task					
RT (compatible trials)	797	701	796	698	
	(34.7)	(23.9)	(37.1)	(21.9)	
RT (incompatible trials)	876	726	868	771	*
	(40.5)	(25.4)	(35.7)	(26.7)	
Accuracy (compatible trials)	96.7	99.0	98.5	98.6	
	(.25)	(.17)	(.24)	(.38)	
Accuracy (incompatible trials)	96.8	97.7	97.8	97.7	
	(1.1)	(.87)	(.68)	(.52)	
Rey Auditory Verbal Learning Test					
Trial 1 -- number of words recalled	6.1	7.3	5.9	6.9	
from list A	(.21)	(.21)	(.19)	(.22)	
Trial 5 – number of words recalled	11.8	12.6	11.7	12.6	
from list A	(.28)	(.26)	(.26)	(.29)	

Trial 6 – number of words recalled from list B	5.5 (.25)	5.6 (.25)	5.4 (.25)	5.6 (.29)	
Trial 7 – number of words recalled from list A	9.3 (.42)	11.4 (.37)	9.6 (.36)	10.3 (.35)	*
Trial 8 – number of words recalled after 30 min delay	9.7 (.40)	11.4 (.38)	9.7 (.38)	10.9 (.39)	
Trial 9 – number of words recognized	13.4 (.21)	14.2 (.15)	13.8 (.18)	13.9 (.13)	*
Trial 10 – temporal order ranking - correlation measure.	.60 (.03)	.70 (.03)	.66 (.03)	.67 (.03)	*
N-back Verbal					
N-back 1	16.8 (.21)	17.3 (.12)	17.1 (.20)	17.4 (.14)	
N-back 2	12.8 (.47)	14.0 (.43)	13.5 (.53)	14.1 (.44)	
N-back Spatial					
N-back 1	15.9 (.36)	16.6 (.30)	16.9 (.18)	17.1 (.21)	
N-back 2	11.4 (.58)	13.8 (.62)	12.6 (.44)	14.5 (.35)	
Self-ordered Pointing					
Number of unique items	6.1 (.20)	5.9 (.15)	6.2 (.16)	6.1 (.17)	
Face Recognition					
Immediate Recognition (% correct)	77.0 (1.9)	80.2 (2.5)	80.4 (1.7)	78.7 (3.0)	
Delayed Recognition (% correct)	72.1 (1.8)	75.1 (2.4)	74.7 (1.4)	71.4 (2.9)	
Backward Digit Span	6.9 (.26)	7.2 (.24)	7.0 (.26)	7.1 (.26)	
Forward Digit Span	8.2 (.26)	8.0 (.26)	8.4 (.28)	8.4 (.26)	
Pursuit Rotor Task					
Trial 1 -- RMS for repeating pattern	37.9 (2.0)	32.9 (1.8)	35.6 (1.5)	32.7 (1.4)	
Trial 6 -- RMS for repeating pattern	29.4 (1.2)	28.1 (.53)	30.2 (1.3)	27.1 (.51)	
Trial 7 -- RMS for new pattern	29.8 (.55)	29.5 (.61)	30.8 (.56)	30.3 (1.1)	
Trial 8 -- RMS for new pattern	29.4 (.53)	28.1 (.39)	29.7 (.50)	29.1 (.69)	

Spatial Attention Task				
RT (valid trials)	463	447	468	460
	(8.4)	(7.7)	(8.9)	(9.0)
RT (invalid trials)	514	502	522	512
	(13.0)	(9.8)	(11.1)	(10.8)
Accuracy (valid trials)	96.9	98.6	98.7	98.4
	(.42)	(.32)	(.24)	(.29)
Accuracy (invalid trials)	92.1	95.6	95.9	95.7
	(.98)	(.97)	(.91)	(.85)
Visual Search				
Feature Search RT slope	5.2/22.8	2.8/19.2	4.6/19.1	2.9/19.9 @
	(.38/1.3)	(.36/1.4)	(.50/1.6)	(.31/1.1)
Conjunction Search RT slope	7.3/45.2	7.5/38.1	7.3/42.1	7.4/37.6
	(.56/2.4)	(.48/2.1)	(.55/2.6)	(.53/2.1)
Feature Search Mean Accuracy	93.3/99.2	96.1/99.4	94.3/98.6	95.5/98.4
	(.52/.47)	(.49/.38)	(.53/.46)	(.41/.33)
Conjunction Search Mean Accuracy	94.1/99.1	97.6/99.4	96.1/99.4	96.9/99.1
	(.55/.40)	(.46/.39)	(.50/.45)	(.47/.39)
Digit-Digit Match				
RT	839	777	851	804
	(16.4)	(18.2)	(20.1)	(18.6)
Accuracy	97.6	98.4	97.5	97.9
	(.33)	(.26)	(.38)	(.34)
Digit-Symbol Match				
RT	1907	1870	1905	1884
	(53.5)	(49.1)	(55.6)	(61.7)
Accuracy	96.3	96.5	96.1	95.7
	(.49)	(.51)	(.53)	(.78)

Notes:
* indicates a significant interaction ($p<.01$) between exercise group and session.
@ for visual search the first number is the slope in ms (or s.d.) for the target present trials and the second number is the slope (or s.d.) for the target absent trials.