

A High Level of Physical Fitness Is Associated With More Efficient Response Preparation in Older Adults

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This study assessed the relationship between cardiovascular fitness and temporal preparation in elderly persons. 110 older adults (aged 60–69 or 70–79 years) were sorted into low- and high-fit groups based on aerobic fitness level estimated with a walking test. Response preparation processes were assessed with reaction time tasks in which short (1, 3, 5 s) and long (5, 7, 9 s) preparatory intervals varied randomly. The results suggest a better ability in high-fit individuals to maintain preparation over time (up to 9 s). Results of the present study suggest that in older adults, a high level of aerobic fitness is associated with more efficient response preparation processes.

Key Words: Cognitive aging—Physical fitness—Response preparation processes.

AGE-RELATED declines in cognitive functions have often been reported. Yet, age-related cognitive changes are heterogeneous and executive functions are most sensitive to the advance in age, likely due to substantial changes in frontal brain regions (Raz, 2000). However, recent findings suggest that age-related cognitive declines can be moderated by environmental factors (Kramer, Bherer, Colcombe, Dong, & Greenough, 2004). Regular physical activity is among lifestyle factors often associated with preserved cognitive functions with age.

Regular physical activity maintained throughout life has been associated with reduced incidence of cancer, diabetes, and heart disease (Booth, Gordon, Carlson, & Hamilton, 2000) and may help protect against age-related cognitive decline. Studies have also shown that in older adults, maintaining a high level of aerobic fitness is associated with preserved cognitive performances in tasks that measure attention and executive functions (Colcombe & Kramer, 2003).

Reaction time (RT) tasks have often been used to assess the relationship between physical fitness and cognitive performances. Spirduso (1975) compared performances of younger and older adults who were either regular racket and handball players or nonactive individuals. They found that nonactive older adults produced slower responses than younger (active and nonactive) and older active individuals in both simple and choice RT tasks. Clarkson-Smith and Hartley (1989) also compared performances of physically active and sedentary elderly participants (aged 55–91 years) and observed faster responses in active participants in both simple and choice RT tasks. Moreover, increasing response choices induced larger increases in RT in sedentary compared with active individuals. Abourezk and Toole (1995) also observed an advantage for active over nonactive women aged 60 years and older, but only in a choice RT task.

The studies reported earlier suggest that regular physical activity is associated with better performance on RT tasks. This set of results lends support to the notion that fitness training might improve controlled aspects of cognition (Hall, Smith, & Keele, 2001). Intervention studies, in which older adults engaged in a physical fitness training program, also tend to confirm that attentional control functions can be improved with fitness training in older adults. In the study by Kramer and colleagues (1999), two groups of sedentary elderly participants aged between 60 and 75 years were assigned either to an aerobic program (walking) or to a nonaerobic control group (stretching). The authors observed that the performances of participants in the aerobic group improved on several cognitive tasks (“answer compatibility task,” “task switching,” “stop signal”), but more so, in task conditions that required executive or controlled functions. The greater benefits of fitness training on executive functions are also consistent with the results of a meta-analysis on 18 intervention studies with participants aged 60 years and older (Colcombe & Kramer, 2003).

It is interesting to note, however, that in some studies, the benefits of physical fitness on performances have been reported in simple as well as in choice RT tasks, without clear evidence for larger benefits in more complex tasks. One potential explanation for this result is that simple RT tasks often involve controlled aspects of attention before stimulus occurrence if anticipation or response preparation can take place (Niemi & Näätänen, 1981). Preparatory processes, which are supported by executive functions, are a voluntary or attention-demanding set of strategic behaviors that sustain the development of an optimal processing state prior to the execution of movement (Stuss, Shallice, Alexander, & Picton, 1995). In RT tasks, a warning signal indicates to the participant to prepare for an upcoming stimulus occurring after a preparatory interval (PI). If the PI varies between

trials, the probability of stimulus occurrence increases with time after the warning signal. For example, consider the use of three PIs of 1, 2, and 3 s, each occurring randomly but equally often in a block of trials. In a given trial, the probability that the response signal will occur after 1 s is .33 and increases to .50 at 2 s. If no signal occurs after 2 s, the probability that it will occur at 3 s is 1. This produces a preparatory function according to which RT gets faster as PI duration increases. This temporal preparation phenomenon is more likely to take place if the appropriate response is known in advance, as in a simple RT task (Niemi & Näätänen). Thus, simple RT tasks often show larger response preparation effects than choice RT tasks (Henderson & Dittrich, 1998).

Recent studies have shown that response preparation is a controlled attentional process, which relies on the integrity of the frontal cortex (Stuss et al., 1995; Vallesi, Mussoni, et al., 2007; Vallesi, Shallice, & Walsh, 2007), and that it is impaired with advancing age (Bherer & Belleville, 2004; Salthouse, 1985). Salthouse has proposed that older adults can show two forms of inefficient preparation: an incapacity to develop an optimal prepared state rapidly and an inability to maintain preparation over time. Other studies have shown that older adults can also show a reduced preparation for unlikely events (Lahtela, Niemi, & Kuusela, 1985). As a result, larger age-related deficits can be observed for stimulus associated with a low probability of occurrence than when the stimulus is more likely to occur (Bherer & Belleville).

Hillman, Weiss, Hagberg, and Hatfield (2002) reported that age-related deficits in response preparation could be attenuated by maintaining a high level of aerobic fitness. In a cross-sectional design, the authors compared older and younger adults of different fitness levels using a visual discrimination task and recorded an electrophysiological marker of response preparation (the contingent negative variation [CNV]). The authors observed that the amplitude of the CNV was reduced in both younger adults and older fit individuals. They argued that older adults with better physical fitness condition engaged less cognitive resources to prepare a speeded response, which suggests a more efficient response preparation. However, these results are limited to nonspecific temporal preparation as the participants performed a choice RT task. Moreover, the authors did not distinguish among aspects that might be enhanced with greater fitness condition, that is, the ability to prepare for uncertain events, to maintain preparation over time, or to prepare quickly for a speeded action.

In order to further investigate the potential relationship between aerobic fitness and response preparation, the present study used simple and choice RT tasks in which temporal parameters were varied to assess specific preparatory effects that have been shown to be sensitive to age-related differences (Bherer & Belleville, 2004; Salthouse, 1985). Moreover, the experimental task provides a measure of both initiation and motor times. This allows one to dissociate the

benefits of physical fitness on attentional control processes involved in response preparation from the mere enhancement in motor speed.

METHODS

Participants

One hundred ten community dwellers aged between 60 and 79 years participated in this study. They were recruited through advertising announcements and at a physical training center for seniors. Participants were sorted into low- and high-fit groups based on VO_2max estimated for the entire sample (median split 19.83). Fifty-five older adults were classified as low-fit (mean age 69.89 years) and 55 as high-fit individuals (mean age 68.36 years). In each group, participants were further divided by age (60–69 and 70–79 years). The low-fit group was composed of 25 participants aged between 60 and 69 years (mean age 65.32 years) and 30 participants aged between 70 and 79 years (mean age 74.47 years). In the high-fit group, 35 participants formed the 60–69 group (mean age 64.06 years) and 20 formed the 70–79 group (mean age 72.65 years).

All participants completed a telephone interview that assessed physical health and life habits and a perceptual screening questionnaire for visual or auditory impairments. No participants reported history of neurological disease or major surgery in the year preceding the study. The Mini-Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975; cutoff score $<26/30$) and the Geriatric Depression Scale (GDS; Yesavage et al., 1983; cutoff score $>10/30$) were used to exclude participants suffering from dementia or depression. Participants' general cognitive abilities were also assessed with the Similarities subtest of the Wechsler Adult Intelligence Scale-III. All participants signed a consent form before engagement in the study. Participants were also screened for cardiovascular disease or vascular peripheral attacks and moderate to severe hypertension based on self-report. Participants also completed the modified questionnaire of aptitude to physical activity (Q-AAP) to detect persons at risk of engaging in intense physical activity.

Participants' characteristics are presented in Table 1. Age, level of education, results on the Similarities subtest, and scores on the MMSE and the GDS were compared using analyses of variance (ANOVAs) for each variable separately, with fitness and age groups as between-subject factors. Results showed that participants in the low-fit and the high-fit groups of each age groups were comparable with respect to score at the MMSE, $F(1, 106) < 1$; general mental abilities, $F(1, 106) = 1.63$, ns; and the GDS, $F(1, 106) < 1$. However, there was a significant difference in the education level between the age groups, $F(1, 106) = 9.83$, $p < .01$, $\eta^2 = .09$, older participants having completed less years of education (11.70) than younger participants (13.90). An ANOVA performed on results of the Rockport 1-mile test showed a significant difference between fitness groups

Table 1. Mean Scores and Standard Deviations (in parenthesis) for Participants' Characteristics as a Function of Age Groups

	Low-fit group (n = 55)		High-fit group (n = 55)	
	60–69 (n = 25)	70–79 (n = 35)	60–69 (n = 30)	70–79 (n = 20)
General				
Age	65.32 (2.78)	74.47 (2.97)	64.06 (2.86)	72.65 (2.76)
Education level	14.28 (4.47)	10.93 (3.22)	13.51 (3.18)	12.45 (3.68)
General mental ability				
MMSE	28.84 (1.55)	28.77 (1.07)	29.00 (1.09)	28.90 (1.12)
Verbal intelligence				
Similarities	23.20 (5.49)	19.97 (6.22)	23.40 (5.10)	22.90 (4.94)
Mood				
GDS	5.16 (6.34)	3.83 (2.97)	3.60 (4.85)	2.55 (2.65)
Fitness condition				
VO ₂ max	16.15 (3.13)	11.30 (7.57)	27.17 (4.99)	25.68 (4.31)
Walking time	19.03 (1.48)	20.09 (2.28)	16.63 (1.42)	17.01 (1.65)
MAQ	4.84 (5.12)	4.43 (4.16)	4.81 (3.57)	6.25 (4.45)

Notes: GDS = Geriatric Depression Scale; MAQ = Modifiable Activity Questionnaire; MMSE = Mini-Mental State Examination.

on walking time, $F(1, 106) = 64.78$, $p < .001$, $\eta^2 = .38$, as low-fit participants took more time to walk the mile (19.56 min) than high-fit participants (16.82 min). Walking time also differed with age, $F(1, 106) = 4.46$, $p < .05$, $\eta^2 = .04$, as the 60–69 group walked the mile faster (17.83 min) than the 70–79 group (18.55 min). There was no interaction between fitness level and age, $F(1, 106) = 1.00$, ns. There was no significant difference between fitness or age groups or interaction between these factors at the Modifiable Activity Questionnaire (MAQ; note that two persons did not complete the MAQ).

Procedure

All participants completed two testing sessions within the same week. In the first session, they completed the MMSE, the GDS, the Similarities subtest, the Q-AAP, and the MAQ (see subsequently). In the second session, they completed the computerized RT tasks and the cardiorespiratory fitness assessment.

Cardiorespiratory fitness assessment.—The Rockport 1-mile test (Kline et al., 1987) was used to assess cardiorespiratory fitness. This submaximum cardiovascular stress test provides an accurate estimate of the maximum level of oxygen consumption (VO₂max). In fact, Kline and colleagues have reported a correlation coefficient of .88 between VO₂max estimated based on performances during the Rockport 1-mile test and a direct measure of VO₂max during an increment test on a treadmill. Participants were required to walk 1 mile without stopping, as fast as possible. They were equipped with a Polar S120 Heart rate Monitor (Polar Electro, Lake Success, NY). Time required to complete the distance was manually recorded on a stopwatch. Heart rate frequency was recorded 1 min after the end of the walking test. VO₂max was estimated based on Equation 2 provided by Kline and colleagues [Kline et al. provided two equations to estimate VO₂max based on the performances

obtained at the Rockport 1-mile test. Equation 1 provides VO₂max estimate expressed in liter per minute and Equation 2, a VO₂max estimate expressed in milliliter per kilogram per minute. Equation 2 provides a more precise estimation and was used in the present study. Equation 2: VO₂max = 132.853 – (.0769 × weight) – (.3877 × age) + (6.3150 × sex) – (3.2649 × time) – (.1565 × heart rate), $r = .88$, standard error estimate = 5.0 ml/kg/min] that takes into account participants' weight, age, sex, cardiac frequency postexercise, and time taken to cover the 1-mile distance. Participants also completed the MAQ (Vuillemin et al., 2000) to evaluate the level of physical activity for the past 12 months.

RT tasks.—Response preparation was assessed with an RT paradigm that has shown age-related differences in response preparation (Bherer & Belleville, 2004). Participants completed a simple and a choice RT task in which they started each trial by pressing a central button on a response box with the index finger. They had to maintain the home key pressed down until the response signal occurred. An auditory signal occurring at the beginning of the trial served as preparatory signal. The response signal was a black circle appearing in the center of the screen (simple RT) or either on the right or the left side of a white circle located in the center of the screen (choice RT). In the simple RT task, the participant had to press the response key located on the right side of the home key with the index finger. In the choice RT task, the response button corresponded to the position of the black circle (left or right). In both, the choice and the simple RT tasks, temporal preparation was assessed using PIs embedded in a short (PI of 1, 3, 5 s) and a long (PI of 5, 7, 9 s) temporal window. In each window, the three PIs varied randomly and unexpectedly between trials. The presentation order of the long- and short-duration conditions was counterbalanced across participants. Participants were asked to respond as quickly and accurately as possible to each trial.

Dependent variables were initiation time (IT), which corresponds to the latency elapsed between the response signal and the release of the home key, and execution time (ET), measured by the time to move from the home key to the response key. Error rates were also recorded.

RESULTS

Response times were included in the analyses for correct answers only (Two types of errors could be produced in the preparation tasks. In both tasks, anticipation errors [AE] consisted in leaving the home key before the response stimulus actually occurred. Incorrect responses [IR] could be produced in the choice RT task only. Overall, participants produced very few AE and IR. Respectively for the simple and the choice RT tasks, percentage of AE produced was .03 and .04 in the low-fit 60–69 group, .05 and .04 in the high-fit 60–69 group, .09 and .05 in the low-fit 70–79 group, and .09 and .07 in the high-fit 70–79 group. Percentage of IR produced was .00 in the low-fit 60–69 group, .00 in the high-fit 60–69 group, .00 in the low-fit 70–79 group, and .01 in the high-fit 70–79 group.). Trials were not included in the analysis if IT was shorter than 100 ms or if the global response time (IT + ET) was longer than 3,000 ms. Given that education level differed between age groups, IT and ET were analyzed using an analysis of covariance (ANCOVA) with fitness group (low-fit and high-fit) and age group (60–69 and 70–79) as between-subject factors, and task (simple and choice), duration condition (short and long), and PI (first, second, third) as within-subject factors and education level as a covariate. For repeated factors, an effect is reported significant according to the adjusted alpha level (Huynh–Feldt) if Mauchly’s test of sphericity reached significance.

The ANCOVA (with education level as a covariate, $F(1, 105) = 9.14, p < .01, \eta^2 = .08$), performed on IT, revealed main effects of age group, $F(1, 105) = 4.11, p < .05, \eta^2 = .04$; task, $F(1, 105) = 9.74, p < .01, \eta^2 = .09$; and PI, $F(2, 210) = 37.60, p < .001, \eta^2 = .26$. Participants of the 60–69 group were faster (372 ms) than those of the 70–79 group (398 ms). IT was shorter in the simple task (353 ms) than in the choice task (417 ms) and also decreased with the length of the PI (first PI, 436 ms; second PI, 364 ms; third PI, 355 ms).

The analysis also showed a significant interaction between age group and task, $F(1, 105) = 4.14, p < .05, \eta^2 = .04$, which was due to a significant age-related difference in the choice RT task, $F(1, 105) = 5.11, p < .05, \eta^2 = .05$ (399 ms and 435 ms, respectively, for the 60–69 and the 70–79 groups), but not in the simple RT task, $F(1, 105) = 1.96, ns$ (345 ms and 361 ms, respectively, for the 60–69 and the 70–79 groups).

There were also two-way interactions of Task \times PI, $F(2, 210) = 5.97, p < .01, \eta^2 = .05$, and Duration Condition \times PI, $F(2, 210) = 35.93, p < .001, \eta^2 = .26$. These interactions are

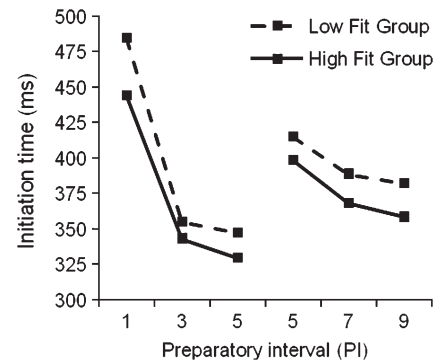


Figure 1. Adjusted means for initiation time (ms) in the low-fit (---) and the high-fit groups (—) as a function of preparatory interval for each duration condition.

typically observed with a variable PI design in which the PI effect tends to be larger in simple compared with choice RT tasks and steeper in short compared with long (>5 s) temporal windows (Niemi & Näätänen, 1981).

Of major interest for the present study, the analysis also revealed a significant Fitness Group \times Duration Condition \times PI interaction, $F(2, 210) = 6.76, p < .01, \eta^2 = .06$. Adjusted means are depicted in Figure 1. This interaction suggests that the difference in IT between high- and low-fit individuals as a function of PI depends upon the time window. Follow-up analyses indicated a significant group difference at the first PI of the short time window, $F(1, 107) = 6.16, p < .05, \eta^2 = .05$, but not at the first PI of the long time window, $F(1, 107) = 2.46, ns$. Moreover, high-fit individuals responded faster than low-fit individuals at the second PI, $F(1, 107) = 3.81, p < .05, \eta^2 = .03$, and the third PI of the long time window, $F(1, 107) = 5.16, p < .05, \eta^2 = .05$, and a similar trend was observed in the short time window, but only at the third PI, $F(1, 107) = 3.72, p = .056, \eta^2 = .03$ (second PI, $F(1, 107) = 1.66, ns$).

The ANCOVA (with education level as a covariate) performed on ET revealed a main effect of fitness group, $F(1, 105) = 18.26, p < .001, \eta^2 = .15$. There was also a significant two-way interaction of Fitness Group \times PI, $F(2, 210) = 3.78, p < .05, \eta^2 = .04$, which was due to a significant PI effect in the low-fit group only, $F(2, 108) = 9.01, p < .001, \eta^2 = .14$ (high-fit group, $F(2, 108) < 1$). The Fitness Group \times Duration Condition interaction almost reached significance, $F(1, 105) = 3.88, p = .052, \eta^2 = .04$, and was qualified by a three-way interaction of Fitness Group \times Age Group \times Duration Condition, $F(1, 105) = 4.81, p < .05, \eta^2 = .04$. This interaction is depicted in Figure 2. Further analyses performed separately for the short and the long temporal windows showed that in the short condition, high-fit individuals of the 70–79 group produced faster (212 ms) ET than low-fit individuals (315 ms), $F(1, 47) = 14.00, p < .001, \eta^2 = .23$, but this difference between fitness groups was not significant for participants in the 60–69 group, $F(1, 57) = 2.19, ns$. For the long duration condition, high-fit individuals also

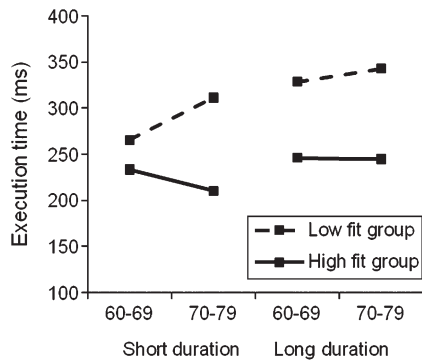


Figure 2. Adjusted means for execution time (ms) for the low-fit (---) and the high-fit groups (—) as a function of age groups.

produced faster responses than low-fit participants and this was significant in both the 60–69 group, $F(1, 57) = 8.19$, $p < .01$, $\eta^2 = .13$, and the 70–79 group, $F(1, 47) = 10.78$, $p < .01$, $\eta^2 = .19$.

DISCUSSION

This study investigated the relationship between aerobic fitness level and response preparation in older adults using simple and choice RT tasks in which temporal parameters were varied to generate specific preparatory effects that have been shown to be sensitive to age-related differences in previous studies (Bherer & Belleville, 2004). The analyses of IT indicated that participants showing higher levels of fitness condition responded faster at the shortest interval of the short temporal window. Moreover, high-fit individuals were able to maintain a higher level of preparation for a long period of time, up to 9 s. The findings of the present study suggest that in older adults aged between 60 and 79 years, maintaining a high level of aerobic fitness condition is associated with better response preparation in RT tasks. These results suggest that attentional control mechanisms supporting temporal preparation are sensitive to the level of physical fitness in older adults. This is not a trivial finding given that age-related deficits in response preparation as assessed in the present study have been observed in previous studies (Bherer & Belleville).

An interaction between age and fitness condition also emerged in ET (movement time from the home key to the response key). In fact, among participants of the older groups (aged 70–79 years), low-fit individuals showed slower ET than high-fit participants. This suggests that fitness condition may have a protective effect against age-related slowing in the execution of speeded motor responses.

The results of this study serve to enhance our understanding of the relationship between physical fitness and response preparation in older adults. Previous studies (Bherer & Belleville, 2004; Lahtela et al., 1985; Salthouse, 1985) have suggested that response preparation can be altered by normal aging in three different ways: (a) an incapacity to de-

velop an optimal prepared state rapidly, (b) an inability to maintain preparation for a long time period, and (c) a failure to prepare for events that have a low subjective probability. In the present study, the use of three variable PIs embedded in two temporal windows of different durations allowed for the assessment of differences between high- and low-fit individuals on these three sources of preparation deficits. The fact that high-fit participants responded faster than low-fit individuals at the short PI of the shortest temporal window, but not for the short PI of the longest temporal window, does not allow an interpretation in terms of response preparation, but rather suggests that high-fit individuals can respond more rapidly at a short time interval.

However, the results of this study also suggest that high-fit individuals showed better response preparation than low-fit individuals in some conditions. Indeed, high-fit individuals responded faster than low-fit participants at the second (7 s) and the third (9 s) PIs of the long temporal window, which suggests a greater ability to sustain an optimal preparation state over long delays. This suggests that physical fitness could help maintaining response preparation over time. These results are in line with previous studies showing that aerobic fitness is associated with more efficient motor preparation in older adults (Hillman et al., 2002). The present study extends this finding to response preparation abilities that rely on temporal parameters of the task, a phenomenon often referred to as temporal preparation. The implication of this finding would be that maintaining a high level of fitness condition might help older adults to better synchronize an action in time.

One limit of the present study was the use of an indirect measure of cardiorespiratory fitness. Although the Rockport 1-mile test does not provide a direct measure of $VO_2\max$, it is a convenient test to use with sedentary older persons. Moreover, previous studies have suggested that $VO_2\max$ estimation with the Rockport 1-mile test is highly correlated with direct measure of $VO_2\max$ (Kline et al., 1987). Be that as it may, the results reported in this study suggest that physical fitness, and more specifically aerobic fitness, may help maintaining more efficient preparation processes in aging.

It has been shown that the benefit of physical fitness on cognition in older adults is larger in tasks that tap executive functions or attentional control (Colcombe & Kramer, 2003; Kramer et al., 1999). The present study provides further support for this by showing that physical activity may help maintain efficient response preparation processes in healthy older adults. Many tasks that we perform every day, such as driving, entail substantial executive control demands. Response preparation also seems to be important in everyday life situations, given that we often have to anticipate and prepare fast and accurate responses (e.g., stopping at the intersection when a pedestrian crosses the street). Whether the positive effects of physical fitness on response preparation extend to activities of daily living must await further

studies. Moreover, additional physical fitness intervention studies would allow confirmation of the causal link between enhanced fitness condition through physical exercise and improvement in response preparation processes in older adults.

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