Effect of Task Complexity on the Relationship Between Physical Fitness and Reaction Time in Older Women

Tami Abourezk and Tonya Toole

Thirty-four women ages 60 to 75 years were divided into two groups based on self-reported physical activity levels. The presence of significant fitness differences between the two activity groups was confirmed by testing all subjects on a well-established submaximal mile walking test. Both groups performed a reaction time task under two levels of task complexity: simple reaction time (SRT) and complex choice reaction time (CCRT). Time to react in milliseconds was recorded for both levels of task complexity. Analysis of variance revealed that the active group reacted faster ($p < .05$) than the less active group on CCRT (active $M$, 1.100 sec; less active $M$, 1.818 sec). However, SRT times did not differ between groups (active $M$, .345 msec; less active $M$, .374 msec). This finding lends support to the hypothesis that cognitive task complexity influences the strength of the association between physical fitness and cognitive performance in older adults.

Key words: cognitive processing, fitness level, attention-demanding

There is evidence that age related decrements in cognitive performance increase in magnitude as task complexity increases. With increases in task complexity, progressively larger performance differences are found between younger and older adults for a variety of cognitive tasks (Cerella, Poon, & Williams, 1980; Salthouse, 1985; Spirduso & MacRae, 1990). While definitions of task complexity in cognitive research vary, most researchers agree that more complex tasks require an increased number of mental operations (Salthouse, 1985) and/or deeper and more elaborate processing (Craik, Byrd, & Swanson, 1987).

In recent years investigators have focused on the relationship between fitness and cognition in an attempt to explain the considerable variability in cognitive performance declines with advancing age. Using a variety of cognitive tasks, researchers have demonstrated that older fit individuals often outperform less fit or sedentary individuals of the same chronological age (see Spirduso, 1986, 1991, for reviews). Furthermore, when complex cognitive tasks requiring...
additional mental operations are used to assess cognitive performance in older adults, the effect of physical fitness is often augmented (Baylor & Spirduso, 1988; Rikli & Busch, 1986; Spirduso, 1975; Spirduso & Clifford, 1978).

According to Hasher and Zacks (1979), attention-demanding tasks require "effortful" as opposed to "automatic" processing. In other words, greater attention is needed during effortful processing. Chodzko-Zajko (1991) has suggested that complex tasks involving effortful processing are more sensitive to the effects of exercise among older adults than those involving automatic processing. He attributes this to the possibility that attentional resources in older fit individuals are not as compromised as those of older sedentary individuals.

Early cross-sectional studies (Spirduso, 1975; Spirduso & Clifford, 1978) using reaction time tasks suggest that complex tasks are most sensitive to physical fitness effects. In these studies, simple (SRT) and choice (CRT) reaction times were assessed in high and low fit subjects. In the SRT condition, subjects were typically asked to pair a single response with a single stimulus. Conversely, during CRT one of several possible stimuli was presented, resulting in multiple response choices and an associated increase in processing demand and task complexity. Spirduso (1975) and Spirduso and Clifford (1978) compared reaction times of young active and nonactive men ages 20 to 30 with old active and nonactive men ages 50 to 70. In both studies the older active groups, compared to the older nonactive groups, responded significantly faster on SRT and CRT; a greater fitness effect was demonstrated for CRT. Similar findings have been reported in subsequent reaction time studies (Baylor & Spirduso, 1988; Rikli & Busch, 1986).

Abourezk (1989) has also reported that the magnitude of the physical fitness/cognition relation varies as a function of processing demand. Participants in that study were divided into discrete physically active and inactive groups and were subsequently tested on a dichotic listening task. Specifically, they heard three pairs of digits simultaneously in both ears. Subjects (ages 50 to 70) reported the digits heard in one ear, followed by the digits heard in the other ear. During this attention-demanding task, second-ear digits were held in short-term memory while first-ear digits were being recalled. There was no significant group difference for first-ear recall (active M, 23.10%; nonactive M, 22.20%). However, the active group (M, 13.40%) reproduced more digits from the second ear than did the nonactive group (M, 6.0%). These data demonstrate that while no fitness/activity related differences were found for the less complex condition (first-ear recall), significant fitness/activity effects were found under the more complex condition (second-ear recall).

In a recent investigation, Schuler, Chodzko-Zajko, and Tomporowski (1993) used a modified version of the Stroop test to assess response speed under four levels of task complexity. Subjects in that study were 18 to 90 years of age. As expected, a significant age-by-cognitive-performance relationship was found. An increase in age was positively correlated with slower performance for all levels of task complexity; however, the magnitude of this age difference was greatest for the two most attention-demanding conditions, reading colored words and Stroop words. Of importance to the present study, Schuler et al. also reported that for the most complex tasks, Stroop words and reading colored words, reaction time decreased as fitness level increased. However, this was not the case for the relatively simple test conditions of word reading time and color naming time.

Interestingly, however, other cross-sectional and longitudinal studies have failed to corroborate a relationship between fitness and task complexity in older
adults. For example, Toole, Park, and Al-Ameer (1993) found that both simple and complex cognitive tasks exhibit similar fitness effects. They compared active and less active subjects on Sternberg’s reaction time task, which involves encoding and retrieval memory processes. Task complexity was manipulated by increasing the memory set size and requiring subjects to recall the items from memory sets. The active subjects, compared to the less active subjects, responded significantly faster during the simple as well as the complex versions of this task.

Lupinacci, Rikli, Jones, and Ross (1993) reported that fitness effects were not more pronounced in performance on complex tasks. They compared low fit and high fit young (age < 50 yrs) and older (age > 50 yrs) university professors on three tasks (SRT, CRT, and DSST) which varied in level of complexity. According to Lupinacci et al., the effect of fitness level across age groups decreased as task complexity increased. Specifically, the high fit groups did not significantly outperform the low fit groups on the most complex task (DSST).

Longitudinal studies have reported mixed findings regarding an increased sensitivity of complex tasks to fitness changes. While some studies have failed to document significant postexercise training improvements on any cognitive tasks, others have reported significant changes for some simple and some complex tasks. For example, Dustman, Ruhling, Russell, et al. (1984) put a group of sedentary subjects ages 55 to 70 on a 4-month exercise program. Although they found significant postaerobic training differences for SRT, digit-symbol substitution (DSST), Stroop color test, critical flicker fusion, and dots estimation, performance for CRT and digit span did not change significantly due to exercise.

Likewise, Stacey, Kozma, and Stones (1985) reported improved simple reaction time and digit-symbol substitution performance among subjects (M age 60 yrs) after a 6-month exercise program. In light of both studies, it should be noted that the reported significant exercise training improvement in simple reaction time (low complexity) does not support the fitness and task complexity relationship. Rather, one would expect to find significant improvement in only the complex task condition.

Additional longitudinal studies have reported no significant posttraining effects on either simple or complex cognitive tasks. Blumenthal and Madden (1988) found no fitness effects on their memory search task. They put subjects on a 4-month exercise program and measured changes in aerobic capacity and memory search time. Despite an increase in fitness level, subject performance did not improve on this complex task.

Similarly, after a 3-year exercise program, subjects in the Rikli and Edwards (1991) study did not show posttraining improvement in choice reaction time. Finally, Whitehurst (1991) found significant improvements in subjects’ aerobic capacity following 2 months of exercise, but no change in simple or choice reaction times.

Based on the research to date, it is unclear whether high levels of fitness disproportionately affect performance on tasks that demand greater attentional capacity in older adults. While some studies provide qualified support for this hypothesis (Abourezk, 1989; Baylor & Spirduso, 1988; Rikli & Busch, 1986; Schuler et al., 1993; Spirduso, 1975; Spirduso & Clifford, 1978; Stacey et al., 1985), few of them were designed to specifically examine the fitness-complexity interaction.

In order to better understand the relation between fitness and age related cognitive performance, Chodzko-Zajko (1991) has recommended “systematic manipulation” of task complexity. The present investigation sought to directly manipulate cognitive complexity by using a single reaction time task under two
distinct levels of complexity. The purpose of the study was to determine whether the effects of fitness among older adults would be more pronounced under the more complex condition in which demands on attentional capacity were increased. It was hypothesized that older active adults would respond significantly faster than older less active adults during the complex version of the task, but that there would be no group differences during the simple version.

Method

SUBJECTS

Thirty-four older women were divided into two groups: 17 active (M age 66 yrs) and 17 less active (M age 69 yrs). All subjects were volunteers recruited from local community centers, exercise classes, and church groups. The active group reported having participated in regular aerobic exercise that involved fast walking, aerobic exercise class, swimming, or dance (M 47.46 = min/day, 4.35 days/week, 5.3 yrs). The less active group had not participated in regular aerobic exercise but did report having participated in stretching and flexibility exercises (M = 38.92 min/day, 3.8 days/week, 3.33 yrs). In order to confirm the validity of the group assignments, subjects in both groups participated in a 1-mile submaximal walking test (Kline et al., 1987). They were instructed to walk the mile as quickly as possible. Total walking time and heart rate were determined upon completion of the mile (see Table 1). O'Hanley et al. (1987) have demonstrated a strong relationship between metabolic demand in the 1-mile walk test and oxygen consumption during more traditional treadmill exercise tests.

Subjects also completed a questionnaire concerning activity level, educational status, and health status. A screening criterion was used to control for potential confounding effects that may affect information processing ability. All subjects met the screening criterion as being nonsmokers and free from heart disease, diabetes, asthma/other respiratory, orthopedic, and other major health problems that could affect information processing ability. In addition, all subjects reported having at least a high school education. Other academic credentials included one doctoral degree (active group), two master’s degrees (both groups), one bachelor’s degree (less active group), and four associate’s degrees (two subjects per group).

APPARATUS

A reaction time task with two levels of complexity, simple reaction time (SRT) and complex choice reaction time (CCRT), was used to measure cognitive processing. Both SRT and CCRT required subjects to lift either their first, middle,

| Table 1 Means and Standard Deviations for Group Walk Times and Heart Rates |
|-----------------------------|-----------------------------|
| Active                      | Less active                 |
| Walking time                | 15.15 ± 1.28 min            | 19.26 ± 2.24 min            |
| Heart rate                  | 103 ± 8 bpm                 | 105 ± 18 bpm                |
or ring finger from a microswitch as quickly as possible at the onset of a stimulus light. For the two tasks, a microswitch board with three microswitches aligned in parallel and a multiple light stimulus (MLS) were placed directly in front of the subject (see Figure 1). A four-bank timer initiated both the warning light (top row of lights on the MLS) and the stimulus light (lights labeled 1, 2, and 3 on the MLS). The task was initiated with a warning light. A stimulus light was then illuminated after a variable time interval (1.5, 2.0, or 2.5 msec). When the stimulus light was lit, three millisecond timers began timing. Each clock stopped when the corresponding finger was lifted.

PROCEDURE

For the SRT condition (low complexity) the subjects released a microswitch using either their index (first), middle (second), or ring (third) finger. Each finger was paired with a specific stimulus light (index finger, Light 1; middle finger, Light 2; ring finger, Light 3). In order to control for possible speed differences across fingers, all three fingers were tested. Subjects were told which finger to lift before the trial began. The order of finger lifts was randomly determined. Each finger was lifted 20 times for a total of 60 trials.

During the CCRT condition (high complexity), subjects always lifted the finger that corresponded with a target number. In order to determine the target number, subjects were first given a directional cue ("right" or "left") prior to a warning light. The stimulus light then served as the starting point for a directional three-number sequence. Therefore subjects saw one of three numbered lights on the MLS (1, 2, or 3). Given the starting number and the direction, subjects then determined which finger to lift by counting two numbers to the right or left of the stimulus light to the target number (see Figure 2). They then lifted the finger corresponding with the target number. For example, "right" followed by the No. 1 light resulted in a 1, 2, 3 sequence, with 3 being the target number. In this case subjects lifted the ring finger.

![Figure 1. Multiple light stimulus and microswitch board.](image)
Subjects determined which finger to lift by counting two numbers to the right or left to the target number, then lifted the finger corresponding with the target number.

When necessary, a wraparound procedure was used so that a directional cue of “left” and a stimulus number of 2 resulted in a target number of 3. Subjects were instructed to determine the last number in the sequence and lift the appropriate finger as quickly as possible. Every combination of all three fingers and both directions resulted in each finger being lifted 20 times for a total of 60 trials. All possible sequences were randomly distributed throughout the testing session. Subjects rested 2 minutes between every 15 trials. After each rest period, subjects were reminded to continue responding as fast as possible.

Prior to both SRT and CRT tasks, each subject performed a minimum of 6 (2 trials per finger) practice trials, though they were encouraged to take as many trials as necessary. Subjects were required to complete, without making an error, all possible sequences before the trials began. The time in milliseconds needed to initiate the appropriate response as well as the number of errors (lifting the wrong finger) were recorded. Error trials (lifting the wrong finger) were repeated at the end of 15 trials, therefore all subjects had the same number of correct responses that were used for final analysis.

A factorial ANOVA for repeated measures was conducted, with the main factors being group (active vs. less active), complexity level (SRT vs. CCRT), and trial block (first vs. second). The purpose of the trial blocks factor was to examine changes in processing speed over trial blocks and to account for variability due to trial blocks. The dependent variable was time to react in milliseconds. Alpha was set at a .05 level of confidence. A simple effects post hoc test was used for significant interaction effects.

Results

In order to reduce trial variability, outlier trials were eliminated using a criterion of each individual's mean ±2 SD for each condition. Based on this criterion, a small percentage of trials were eliminated for both the active (SRT: 1st block $M = 3.5\%$, 2nd block $M = 4.1\%$; CCRT: 1st block $M = 3.7\%$, 2nd block $M = 5.1\%$) and less active groups (SRT: 1st block $M = 5.7\%$, 2nd block $M = 5.7\%$; CCRT: 1st block $M = 6.2\%$, 2nd block $M = 6.4\%$).

Means and standard deviations for both groups, tasks, and trial blocks are summarized in Table 2. The group-by-task interaction reached significance, $F(1,$
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32) = 5.47, p =.02. The post hoc simple effects test revealed that although both groups performed similarly on SRT, the active individuals responded significantly faster (p =.01) on CCRT. The task-by-trial-block interaction also reached significance (p =.01), F(1, 32) = 9.15. According to the post hoc test, both groups significantly improved on CCRT from Trial Block 1 to Trial Block 2. A significant trial block improvement was not observed for SRT. According to the group main effect, the less active subjects (M = 1.096 sec) reacted more slowly (p =.01) on both tasks combined than did the active subjects (M = .723 msec), F(1, 32) = 6.32.

When reaction times were combined over groups, all subjects responded more slowly (p =.01) during the most complex condition (CCRT M = 1.459 sec) compared to the simple condition (SRT M = .360 sec), F(1, 32) = 55.70. Based on a significant block main effect, all subjects reacted faster (p =.01) during Trial Block 2 compared to Trial Block 1, when reaction times were combined over tasks, F(1, 32) = 12.29. The group-by-task-by-trial block interaction failed to reach statistical significance (p =.14), F(1, 32) = 2.20 (see Table 3). Finally, both groups made approximately the same number of errors on the complex task (active M = 1.80, SD = 1.97; less active M = 1.1, SD = 1.58).

Discussion

The significant group-by-task interaction supports the concept of a positive relationship between a task’s complexity and its ability to discriminate between high and low fit older adults. This finding is in agreement with those of prior investigations in which fit subjects outperformed less fit subjects on complex tasks (Abourezk,

<table>
<thead>
<tr>
<th>Group</th>
<th>Simple RT Block 1</th>
<th>Simple RT Block 2</th>
<th>Complex choice RT Block 1</th>
<th>Complex choice RT Block 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active</td>
<td>0.360</td>
<td>0.331</td>
<td>1.185</td>
<td>1.016</td>
</tr>
<tr>
<td></td>
<td>(0.075)</td>
<td>(0.053)</td>
<td>(0.224)</td>
<td>(0.207)</td>
</tr>
<tr>
<td>Less active</td>
<td>0.380</td>
<td>0.368</td>
<td>2.029</td>
<td>1.608</td>
</tr>
<tr>
<td></td>
<td>(0.104)</td>
<td>(0.107)</td>
<td>(1.511)</td>
<td>(0.918)</td>
</tr>
</tbody>
</table>

Table 3  Means and Standard Deviations (parentheses) for Tasks and Blocks

<table>
<thead>
<tr>
<th>Tasks</th>
<th>Block 1</th>
<th>Block 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple RT</td>
<td>0.370 (0.090)</td>
<td>0.350 (0.085)</td>
</tr>
<tr>
<td>Complex choice RT</td>
<td>1.607 (1.147)</td>
<td>1.312 (0.721)</td>
</tr>
</tbody>
</table>
Both SRT and CCRT required the subject to lift a single finger in response to a single stimulus as quickly as possible. However, the CCRT required additional mental operations to determine which finger to lift, presumably placing a greater demand on attentional resources. Although both groups needed significantly more time to perform CCRT compared to SRT, a significant interaction revealed that at the highest level of task complexity the active individuals required less time to process information than did the less active individuals. While the time difference between low complexity (SRT) and high complexity (CCRT) was .755 msec for the active subjects, the difference for the less active group was 1.453 sec.

Based on this result, a larger fitness effect was seen during the complex task. The differences between the available attentional resources in fit and less fit older adults might account for the relationship between fitness level on task complexity. According to Chodzko-Zajko (1991), normal age related declines in attentional capacity may be less pronounced in fit older adults. Consequently these individuals often outperform their sedentary cohorts on attention demanding tasks. As expected, active subjects in the current study demonstrated superior performance on the attention demanding version of the task (CCRT). In addition to the issue of attentional capacity, the notion of CNS inhibition has been proposed as another mechanism by which physical fitness might influence cognitive performance (Dustman, Emmerson, Ruhling, et al., 1990; Dustman, Emmerson, & Shearer, 1990, 1994). Specifically, Dustman and colleagues have suggested that those who are behaviorally faster as a group also demonstrate greater CNS inhibition, which may serve to enhance focused attention for complex behavioral responding. Dustman, Emmerson, and Shearer (1990) report that,

EEG and ERP findings suggest a diminution of inhibitory strength in old age with a shift in excitatory-inhibitory balance such that excitation exerts an increasingly greater influence on behavior. A relative inability to inhibit irrelevant internal and external stimuli and to interrupt (inhibit) a current activity might contribute to the losses in attention, concentration and mental flexibility reported for old people. (p. 136)

Dustman et al.’s EEG cortical coupling data from both fit older and fit younger adults support the hypothesis that endurance exercise modulates excitation/inhibition relationships (Dustman, Emmerson, & Shearer, 1994). Specifically, they suggest that stronger inhibition results from long-term involvement in aerobic exercise, and that although there is a general reduction in CNS inhibition with older age, exercise may serve to ameliorate this loss of inhibition.

It is important to note that the results of the present cross-sectional investigation are not consistent with those of many prior longitudinal-training studies (Blumenthal & Madden, 1988; Dustman et al., 1984; Rikli & Edwards, 1991; Whitehurst, 1991). Dustman et al. (1994) suggest that subjects in cross-sectional studies, compared to those in longitudinal-training studies, might represent a different population of individuals. Similarly, Chodzko-Zajko and Moore (1994) note that fitness differences between groups in cross-sectional studies are typically much greater than fitness changes observed in training studies. They suggest that high fit subjects in cross-sectional studies have generally been active much longer than most individuals in exercise training studies, and that these factors may
contribute to the discrepancy between the results of cross-sectional and training studies. In our study, participants in the physically active group had been active much longer than the 4- to 8-month duration of most exercise intervention studies.

Conclusion

Subjects in the active group reacted significantly faster on the CCRT task, while the groups did not differ on SRT. These results suggest that fitness level interacts positively with cognitive functioning in older adults, especially for attention demanding tasks. It was suggested that fit older adults do not experience the same changes in attentional capacity, and this might explain the link between fitness and complex cognitive processing (Chodzko-Zajko, 1991). Age related changes in cognitive processing might be related to reduced CNS inhibition in the general older adult population. Older fit individuals, however, may not experience this reduction to the same extent (Dustman, Emmerson, Ruhling, et al., 1990; Dustman, Emmerson, & Shearer, 1990). Future studies should continue to investigate this notion as well as attempt to identify other variables that might influence the fitness, age, and cognitive performance relationship.

References


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