Relationship between Physical Activity and Age on the Main Categories of Cognitive Processes

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Abstract

Many transversal studies show a positive relationship between physical activity and a large panel of cognitive functions. However, the majority of studies in this domain separately investigated categories of cognitive functions (e.g., attention, executive functions, visuospatial abilities). Studies simultaneously addressing the main categories of cognitive functions are rare. Moreover, assessment methods to measure physical activity are diverse (i.e., direct method with VO_2max or indirect method with questionnaires). The purpose of this study was to summarize the relationship between physical activity and performances on a large panel of psychometric tests assessing the main categories of cognitive processes (i.e., based on the broad level of the three stratum model of human cognitive abilities, developed by Carroll in 1993). Thirteen active and thirteen inactive men and women aged between 60 and 70 years old were recruited from the community to participate in this study. Measures obtained included self-reports about health status and educational level, an estimate of the VO_2max (Rockport 1-Mile Walk Test), indirect estimate of physical activity (the Modifiable Activity Questionnaire) and several categories of psychometrics tests. Categories used were fluid intelligence (Matrix Reasoning test), crystallized intelligence (Similarities), general memory and learning (Digit Span and Letter-Number Sequencing), visual perception (Cancellation test), retrieval ability (Rey Auditory Verbal Learning Test), processing speed (Digit Symbol Substitution Test, Number Comparison Test, Directional Heading Test), psychomotor speed (Reaction and Movement Time tests) and psychomotor abilities (Pegboard test). One-Way Analyses of Variance (ANOVAs) were conducted, with performance scores obtained on each cognitive tests as the dependent variable, and amount of physical activity (active vs. inactive) as the independent variable. Results revealed that active older adults perform better than inactive older adults in the large panel of psychometric tests measuring several cognitive abilities, with significant effects observed for fluid intelligence, broad visual perception, broad cognitive speediness, psychomotor abilities and psychomotor speed. Results also revealed medium effect size for crystallized intelligence and general memory and learning. This research provides further support that regular physical activity may offer a protective buffer against the cognitive declines associated with aging. However, as this study employed a cross-sectional design, only precautious conclusions can be drawn from the current findings. Future intervention studies should examine whether the beneficial effect of an active physical lifestyle on cognition is a causal one. Training interventions with participants randomly assigned to aerobic training and control groups would increase the heuristic value of this research.

Relationship between Physical Activity and Age on the Main Categories of Cognitive Processes

Aging can be characterized by decrements in a variety of cognitive processes (e.g., Hasher & Zacks, 1988; Park & Gutchess, 2002). However, the impact of aging is not the same for all individuals, and some factors, related to the lifestyle, could modulate its effects (e.g., Kramer, Bherer, Colcombe Dong & Greenough, 2004). One component that has been implicated in maintaining and enhancing multiple aspects of physical and psychological functioning across the lifespan is physical activity (e.g., Emery, Burker & Blumenthal, 1991; McAuley, Kramer & Colcombe, 2004; Spirduso, 2005). Indeed, many transversal studies show a positive relationship between physical activity and a large panel of cognitive functions (for review, see Lemaire & Bherer, 2005). However, studies addressing simultaneously the main categories of cognitive functions into a unique protocol are rare. The majority of studies in this domain who showed a beneficial impact of physical activity have separately investigated categories of cognitive functions such as inductive reasoning (e.g., Clarkson-Smith & Hartley, 1989), attentionnal resources (e.g., Bunce, 2001; Bunce, Barrowclough & Morris, 1996), reaction time (e.g., Spirduso, 1975, 1978; Emery, Huppert & Schein, 1995; Rikli & Busch, 1986), learning (Etnier & Landers, 1997; 1998; Etnier, Romero & Traustadottir, 2001) or psychomotor function (Spirduso, McRae, McRae, Prewitt & Osborne, 1988). This trend is confirmed in the recent Etnier et al (2006)'s meta-analysis of 37 studies examining the relationship between aerobic fitness and cognition. In this study, cognitive tests were coded into seven categories (fluid intelligence, crystallized intelligence, general memory and learning, visual perception, auditory perception, retrieval ability, speediness and processing speed). Studies reporting cross-sectional design with healthy older participants assessed either one (processing speed: Abourezk, 1990; Blaney et al., 1990; Brisswalter et al., 1997; Mero et al, 1989; general memory and learning: Chodzko-Zajko et al., 1992; visual perception: Hillman, Weiss, Hagberg & Hatfield, 2002) or two cognitive categories (general memory and learning and processing speed: Dustman et al., 1990; fluid and crystallized intelligence: Elsayed, Ismail, & Young, 1980). In this meta-analysis, only one study (Shay and Roth, 1992) simultaneously addressed more than two categories of cognitive functions (i.e., crystallized intelligence, general memory and learning, visual perception, retrieval ability and processing speed).

The goal of this study was to summarize the relationship between physical activity and performances on a large panel of neuropsychological tests assessing the main categories of cognitive processes within one experiment. Different studies have revealed beneficial effects of a higher level of physical activity on some cognitive functions that are generally affected by aging. However, all the main cognitive domains have not been generally examined in the same study. Therefore, establishing an inventory of physical activity benefits on cognitive functioning is not an easy task. Moreover, previous studies frequently differ among several methodological dimensions (such as the way to categorize participants) and consequently make comparison validity questionable.

Neuropsychological tests were chosen in order to take into account several theoretical classifications. The first main classification considered was the broad level of the three stratum model of human cognitive abilities, developed by Carroll in 1993. We decided to integrate tests of fluid intelligence, crystallized intelligence, general memory and learning, broad visual perception[1], broad retrieval ability, broad cognitive speediness, and processing speed. According to previous and more precise classifications about processing speed (e.g., Ackerman & Cianciolo, 2000; Catano, 1995), this last category was divided into two subcategories of functions: psychomotor speed and psychomotor abilities. Psychomotor speed corresponds to the ability of rapidly and fluently performing body motor movements independently of cognitive control. Psychomotor abilities correspond to the ability of performing body motor movements with precision and coordination with more temporal and spatial constraints (Ackerman & Cianciolo, 2000). This categorization also takes into account the three categories of determinants related to skill acquisition, developed by Ackerman (1988) (i.e., cognitive, perceptual speed and psychomotor abilities). Moreover, it integrates simultaneously performance level tests, requiring participants to realize the highest score with no time pressure, and speed of processing tests with a high time constraint.

Based on previous findings about the impact of physical activity on various neuropsychological functions (for review, see Lemaire & Bherer, 2005), we summarized each results into the broad levels of the three stratum model of human cognitive abilities (Carroll, 1993). Then, we examined the hypothesis that a high level of physical activity would be linked to better performances on all neuropsychological tests, except for those evaluating crystallized intelligence, which is generally spared by age-related deficits (Botwinick, 1984; Etnier & Berry, 2001; Park & Gutchess, 2002).

Methods

Participants

Twenty-six independent elderly adults (13 men, 13 women, aged between 60-70 years) were recruited from the community and they volunteered to take part in this cross-sectional study. All participants were of European, Caucasian origin. They gave their informed consent and were not compensated for their participation. Neuropsychological screening confirmed that participants were non-demented (as assessed with the Mini-Mental State Examination).

Measures

Health, educational level and amount of physical activity. Health status was measured with a short questionnaire (questions relating to cardiac and neurological health, medication intake, discomfort, recent or eventual hospitalizations). Exclusion criteria were (a) a history of cardiovascular disease, stroke, or neurological disease; (b) hospitalization in the preceding month; and (c) prescribed medication for hypertension. All potential subjects also rated their health on a 5-point likert-type health scale (1 = very bad, 2 = bad, 3 = fair, 4 = good, 5 = excellent), and those who rated their health as very bad or bad were excluded. Because educational level is recognized as a moderator of age-related deficits on cognitive functions (e.g., Bherer, Belleville, & Peretz, 2001), only participants with at least 12 years of education were selected, in order to control the effects of this variable. Active and inactive participants were recruited, based on the amount of regular physical activity reported. First, 30 participants were contacted by phone and provided a self-reported estimation of physical activity with an interview. Based on these answers, 26 of the initial participants corresponded to the criteria of being active or inactive, and were assigned to the corresponding group (13 active participants, with 7 men and 6 women, and 13 inactive participants, with 6 men and 7 women). The criteria used were inspired from the recommendations of several health guides (e.g., Canadian Health Network in Canada, Institut National de Prévention et d'Education pour la Santé in France). People reporting more than 4 hours of physical activity per week were considered as active, whereas people reporting less than 1 hour of physical activity per week were considered as inactive. Then, the accuracy of the classification in the active and inactive groups was confirmed by both a direct and an indirect method. The direct method was an aerobic test of cardiorespiratory fitness and the indirect method was a physical activity questionnaire. The aerobic test used to assess cardiorespiratory fitness was the Rockport 1-mile walk test (Kline et al., 1987) which is a sub-maximal field test to estimate VO_2max. Participants were required to walk one mile (1.6 kilometers) as quickly as possible over a level terrain. The test is easily administered and is well-suited for sedentary and/or older individuals. Significant differences for the VO_2max estimation were found between active and inactive participants ($F(1,24) = 27.01$, $p < .05$, $\eta^2 = .53$). Because researchers have suggested that VO_2max may reflect genetic factors more than actual activity levels (Bouchard & Lortie, 1984; Bouchard & Malina, 1983), an activity questionnaire was also given to participants. The interviewer-administered « Modifiable Activity Questionnaire » (MAQ, Kriska et al., 1990) that evaluates past week and past year participation in leisure time physical activity and sports in adults. Subjects are read a list of common activities and asked to provide information on the number of months, times per month or week, and the average duration of participation for each activity they participated in over the past year. The amount of physical activity reported was converted into a Metabolic Equivalent of oxygen consumption per unit of body size at rest (MET; from a standard MET unit value for each sport indicated by the questionnaire, Ainsworth et al., 1993; Fox & Mathews, 1984). Furthermore, MET units were used because each activity does not represent the same amount of energy expenditure. Significant differences for the amount of physical activity reported were obtained between active and inactive participants ($F(1,24) = 321.78$, $p <.05$, $\eta^2 = .93$). These results were found for both measurement units (hrs/week and METs-hrs/week). Active and inactive groups are described in Table 1 (insert table 1). No significant differences between active and inactive groups were observed concerning the participants' age ($F(1,24) = 0.03$, p = n.s.), the educational level ($F(1,24) = 0.06$, p = n.s.) and the self-rated health level ($F(1,24) = 3.00$, p = n.s.).

Psychometric tests. Each participant completed a neuropsychological tests battery, administered individually in a quiet testing room and following standard tests instructions. A complete description of these standard tests can be found in Lezak, Howieson & Loring (2004). Neuropsychological tests were coded into categories based upon Carroll’s structure of cognitive abilities (1993) as derived from factor analytic analyses. The categories used were (i) fluid intelligence, (ii) crystallized intelligence, (iii) broad general memory and learning,

(iv) broad visual perception, (v) broad retrieval ability, (vi) broad cognitive speediness, (vii) psychomotor speed and (viii) psychomotor abilities[2].

Fluid intelligence: the *Matrix Reasoning Test (WASY)* measures abstract nonverbal reasoning ability. It consists of a sequence or group of designs, where the individual is required to fill in the missing design from a number of choices.

Crystallized intelligence: the *Similarities Test (WAIS-R)* measures verbal abstract reasoning and conceptualization abilities. Examinees must state in what way two objects or concepts are alike.

General memory and learning: the *Digit Span Test (WAIS-R)* is commonly used to assess verbal working memory. It requires for the participants to repeat the numbers in sequential order. The *Letter-Number Sequencing Test (WAIS-III)* assesses attention and working memory. The tester verbally presents increasingly longer sequences of intermixed numbers and letters. After each sequence, the participant is asked to repeat the numbers in ascending order first and then the letters in alphabetical order.

Broad Visual perception: the *Cancellation Test*, a typical perceptual speed test (Ackerman, 1990) consists of a page of randomly generated uppercase English letters. All letters occurred with equal probability and participants were instructed to place a line through each occurrence of a target letter.

Broad Retrieval ability: the *Rey Auditory Verbal Learning Test* (Rey, 1941) provides measures of recall following a long delay period. The test consists of five presentations of a 15-word list (List A), followed by a free recall of a second word list (List B), and a sixth recall trial of List A. Delayed recall is examined with a seventh recall trial of the List A after a delay of approximately 30 minutes.

Broad Cognitive Speediness: In the *Digit Symbol Substitution Test (WAIS-R)* participants must write down symbols associated to numbers using a table in which both (numbers and symbols) are paired together. The *Number Comparison Test* (Ackerman & Cianciolo, 2000) consists of two columns of numbers pairs. Participants are instructed to place a check mark between the numbers that match exactly. The *Directional Headings Test* (Cobb & Mathews, 1972) involves the translation and integration of arrows, numbers and letter direction abbreviations. Participants are instructed to place a check mark between the 3 directional cues that match exactly.

Psychomotor Speed: *Simple Reaction Time* (SRT; the time it takes to make a response) and *Simple Movement Time* (SMT; the time to move a finger from a specific button to a target button) were evaluated. Instructions and stimuli were presented with a Pentium 4 PC, with standard keyboards and E-prime software which recorded accuracy and response time (version 1.1 beta 1.0, Schneider, Eschman & Zuccolotto, 2002). The stimulus was a red square. Responses were made using the corresponding key on the computer numeric keypad. Performance was measured as the mean *SRT* and *SMT* in milliseconds on a block of 12 trials.

Psychomotor Abilities: *the Pegboard Test* (Fleishman, 1954) measures the ability to make precisely coordinated movements of the hands and the fingers with manipulation of pegs. Participants have to introduce pegs on a board with holes as quickly as possible.

Procedure

Assessment of each participant was done across two sessions on separate days. During the physical activity assessment session, participants read and signed informed consent, completed the health and physical activity questionnaires, and realized the walk test. During the laboratory session, the battery of cognitive measures was administered.

Analyses

One-Way Analyses of Variance (ANOVAs) were conducted, with performance scores obtained on each cognitive test as the dependent variable, and amount of physical activity (active vs. inactive) as the independent variable. A significant alpha (p) level of .05 was used.

With regards to our short sample of participants and in order to avoid Type II error, effect sizes were also reported for each test (Cohen's *d*).

Results

Active participants did not obtain significant superior performance scores in crystallized intelligence compared to their inactive counterparts. No significant effect was observed for the *Similarities Test* (p = n.s). However, with an alpha (p) level of.05, the Type II error is high (42.9 %). The effect size revealed a medium impact of physical activity on the *Similarities Test* (Cohen's d = 0.42) (figure 1). Active older adults performed better than inactive older adults on the test measuring fluid intelligence (*Matrix Reasoning Test*: F (1, 24) = 5.46, $p < .05$, $\eta^2 = .18$, Cohen's d = 0.91) (figure 1). Concerning general memory and learning category, no significant effects of physical activity for the *Digit Span Test* and the *Letter-Number Sequencing Test* (p = n.s) were found. However, like the *Similarities Test*, the Type II error is high (70.6 % for the *Digit Span Test* and 54.3% for the *Letter-Number Sequencing Test*). The effect size revealed a medium impact of physical activity on the *Digit Span Test* (Cohen's d = 0.56) and a high impact on the *Letter-Number Sequencing Test* (Cohen's d = 0.73) (figure 2). Concerning the broad visual perception category, the results revealed a significant effect of physical activity level, active individuals obtaining better performances than inactive individuals on the *Cancellation Test* (F (1, 24) = 21.17, $p < .05$, $\eta^2 = .46$, Cohen's d = 1.80) (figure 1). Delayed recall of the *Rey Auditory Verbal Learning Test* measuring broad retrieval ability showed a significant difference between our two groups in favor of active individuals (F (1, 24) = 6.64, $p < .05$, $\eta^2 = .21$, Cohen's d = 1.01) (figure 1). A significant effect of physical activity on each tests of the broad cognitive speediness category was also found (*Digit Symbol Substitution Test*: F (1, 24) = 36.4, $p <.05$, $\eta^2 = .60$, Cohen's d = 2.22; *Number Comparison Test*: F (1, 24) = 20.98, $p < .05$, $\eta^2 = 0.46$, Cohen's d = 1.80; *Directional Heading Test*: F (1, 24) = 9.346, $p < .05$, $\eta^2 =.28$, Cohen's d = 1.20) (figure 3).

Performance scores on tests of psychomotor speed were significantly higher for active older adults than for inactive older adults (*Simple Reaction Time*: F (1, 24) = 4.20, p = .05, η^2 = .14, Cohen's d = 0.80; *Simple Movement Time*: F (1, 24) = 7.37, p < .05, η^2 = .23, Cohen's d = 1.07). Finally the analysis showed a significant effect on psychomotor abilities, the active individuals outperforming their inactive counterparts on the *Pegboard Test* (F (1, 24) = 10.07, p < .05, η^2 = .29, Cohen's d = 1.25) (figure 4).

Discussion

This study explored the relationship between physical activity and age in a large panel of neuropsychological tests. Results confirmed previous findings about the beneficial effect of physical activity on age-related cognitive deficits (Colcombe & Kramer, 2003; Kramer et al., 1999). Indeed, the active group performed better than their inactive counterparts on all categories recognized to be sensitive to age-related deficits. Thus, this study suggests a protective effect of physical activity on cognitive decline induced by aging. Therefore, maintaining an active lifestyle in old age seems to be associated with slowing down aging cognitive impacts (Stones & Kozma, 1988). This positive influence of lifestyle (on cognitive ageing) is coherent with the physiological interpretation of the effect of physical activity on cognitive functions (Etnier & Landers, 1997). With age, it is generally recognized that the amount of oxygen transported to the brain decreases (e.g., Jacobs, 1969). Regular exercise would maintain cerebrovascular integrity by increasing cerebral blood flow, thus increasing oxygen transport and reducing the risk of brain hypoxia (*e.g.*, Herholtz et al., 1987). Moreover, this study emphasizes that physical activity could also moderately increase performance on crystallized functions recognized insensitive to age-related deficits (size effect = 0.42). It seems that for physical activity to have a beneficial impact, cognitive functions do not necessarily already need to be declining. However, this positive relationship on crystallized functions is to a lesser extent than other categories of functions, because no significant differences were obtained. This trend has to be imperatively replicated with larger samples to be confirmed.

This study also emphasizes that impact of physical activity is more pronounced for tests requiring processing speed. Indeed, effect sizes reveal higher benefits for tests with high time pressure such as psychomotor speed, psychomotor abilities, processing speed and visual perception. Impact of physical activity was inferior for performance output tests of crystallized intelligence and memory. These results support previous studies showing that active individuals performed faster than sedentary individuals, especially on tests requiring information processing speed and psychomotor functions (Dustman et al., 1984; Hillman et al., 2002; Spirduso, McRae, McRae, Prewitt & Osborne, 1988; Stacey, Kozma & Stones, 1985; Stones & Kozma, 1988). This higher relationship could be due to regular and large solicitation of speed of movement and speed of response across physical activity practice (Hillman et al., 2002; Spirduso et al., 1988). Indeed, the link between physical activity and processing speed seems to be sufficiently strong to observe a more beneficial impact of physical activity on tests requiring responses to be given as fast as possible.

Results obtained in this study also provide advancements in the skill acquisition domain. Indeed, the distribution of psychometric tests also takes into account the three categories of determinants developed by Ackerman (1988). These categories are relevant determinants of individual differences during skill acquisition. Many tasks are expected to show changes in ability demands in a predictable fashion, as the learner develops the appropriate task skill. Skill acquisition is described as occurring in three qualitatively different phases: cognitive, perceptive and psychomotor. During the initial cognitive phase of skill acquisition, performance is most highly associated with cognitive abilities. During the intermediate associative phase of skill acquisition, performance is most highly associated with processing speed abilities. Finally, as learners developed autonomous skills, individual differences in performance are most highly related to psychomotor abilities. Thus, benefits noted in this study also concern the skill acquisition domain, physical activity allowing the course of age-related deficits to be slowed down on skill acquisition determinants. With higher cognitive processing speed and psychomotor abilities, it would be easier for older active participants to cross learning stages.

To conclude, this study suggests a positive relationship between physical activity and age-related deficits on cognitive functioning. However, even if the implications of the findings are significant, they would have to be replicated with larger samples. The small number of participants that were included in this study is a real limit. Furthermore, our cross-sectional design does not allow exploring whether there is a clear causal relationship. Consequently, this study opens the way to future intervention studies. Training interventions with participants randomly assigned to aerobic training and control groups would increase the heuristic value of this research. It could also be relevant to integrate active and inactive younger groups, in order to study whether physical activity affects cognitive functioning in a consistent fashion regardless of age group. Indeed, it is not clear if the beneficial impact of physical activity is general to all individual or specific to older persons (Perrot, Gagnon & Bertsch, in press). Moreover, it could be pertinent to assess the impact of other potential moderating factors. Although physical activity could indeed have been responsible for performance differences exhibited by the active and inactive participants, so could a multitude of other factors (e.g., socioeconomic status, leisure activities, diet, etc.) that may have covaried with cognitive functioning. Finally, this study suggests that even in old age, a high level of physical activity could help maintain better cognitive capacities.

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Notes

Note 1: Tests of broad auditory perception were not integrated in this study.

Note 2: Inversely to Etnier et al. (2006) meta-analysis, the auditory was not tested and the speediness category was divised in two sub-categories, according to Carroll et al (1993)'s classification: psychomotor speed and psychomotor abilities

Table 1

Means of demographic, health, educational, and physical activity variables for both groups of participants

	Old participants (N = 26)			
	Inactive (n = 13)		Active (n = 13)	
Variables	*M*	*SD*	*M*	*SD*
Age	64.5	3.4	64.3	3.2
Self-rated Health	3.9	0.6	4.3	0.5
Years of education	15.4	3.3	15.7	2.9
MMSE	28.7	1.3	29.4	0.8
Geriatric Depression Scale	6.3	2.7	4.8	3.1
MAQ (hr/week)	1.0	0.6	7.9	1.1
MAQ (METs-hr/week)	3.9	2.6	54.7	9.9
VO_2max estimation (O_2/kg/min)	26.3	5.6	39.7	7.4

Note: M = Mean, SD = Standard Deviation MMSE = Mini Mental State Evaluation MAQ = Modifiable Activity Questionnaire, MET = Metabolic Equivalent of oxygen consumption per unit of body size at rest.

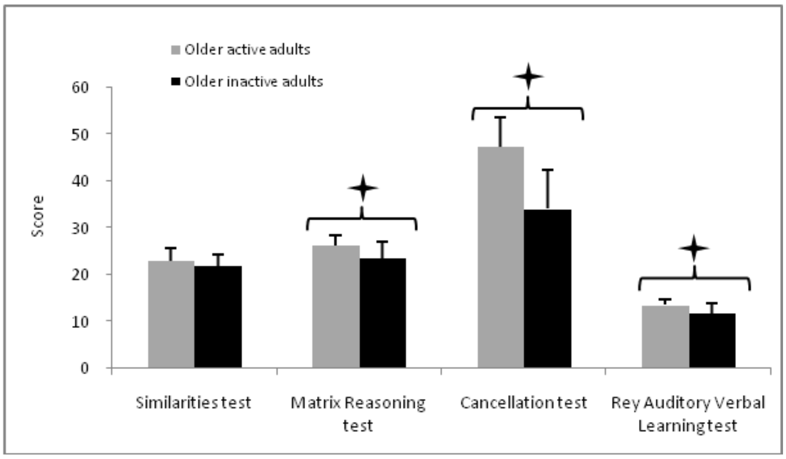
Figures Captions

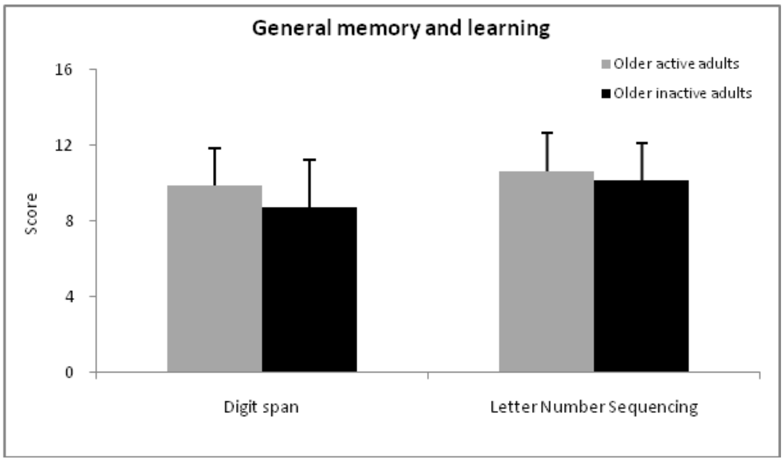
Figure 1. Results obtained by active and inactive groups on four categories : crystallized intelligence (*Similarities test*), fluid intelligence (*Matrix Reasoning test*), broad visual perception: (*Cancellation test*) and retrieval ability (*Rey auditory verbal learning test).* ✦: significant effect ($p < .05$)

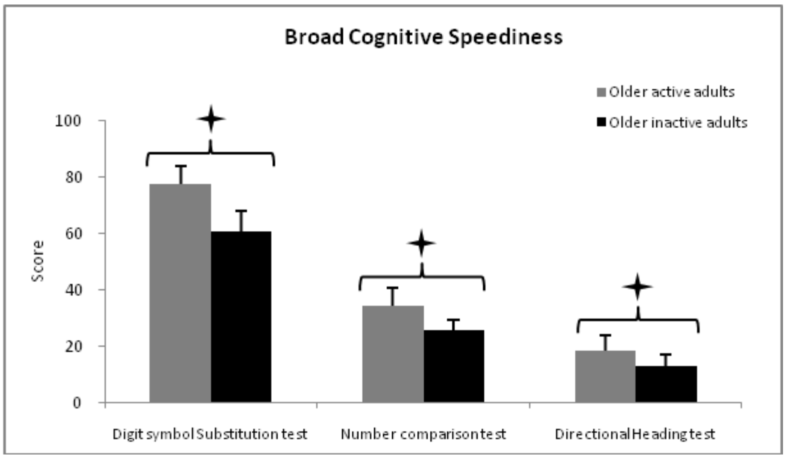
Figure 2. Results obtained by active and inactive groups on general memory and learning category (*Digit Span test* and *Letter Number Sequencing test*).

Figure 3. Results obtained by active and inactive groups on broad cognitive speediness category (*Digit Symbol substitution test*, *Number comparison test* and *Directional Heading test).* ✦ : Significant effect ($p < .05$)

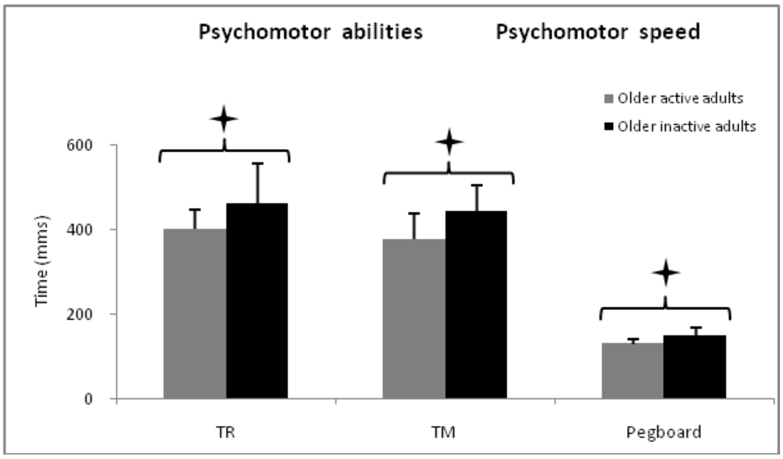
Figure 4. Results obtained by active and inactive groups on psychomotor abilities category (*Pegboard test)* and psychomotor speed category (*Simple Reaction Time* and *Simple Movement Time).*✦ : Significant effect ($p < .05$).


Older active adults
Older inactive adults
Score
60
50
40
30
20
10
0
Similarities test
Matrix Reasoning test
Cancellation test
Rey Auditory Verbal Learning test


General memory and learning
Older active adults
Older inactive adults
16
12
8
4
0
Score
Digit span
Letter Number Sequencing



Broad Cognitive Speediness
Older active adults
Older inactive adults
100
80
60
40
20
0
Score
Digit symbol Substitution test
Number comparison test
Directional Heading test


Psychomotor abilities
Psychomotor speed
Older active adults
Older inactive adults
Time (mms)
600
400
200
0
TR
TM
Pegboard