Aerobic fitness and neurocognitive performance in older adults from Kansas and Costa Rica

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Abstract

Background and Objectives: There is a dearth of comparative studies on the association between aging, cognitive function and cardiorespiratory fitness in older adults from developed and developing countries. The purpose of the study was to determine the association between aerobic power and neurocognitive performance in older adults from the Kansas (KS, USA) and Costa Rica (CR).

Research Design and Methods: In a cross-sectional study, older adults from CR (n = 78) and KS (n = 100) underwent a maximal cardiopulmonary function test to determine aerobic power and a comprehensive battery of cognitive function dimensions including a cognitive screen, and tests of simple speed of processing, spatial visualization, visuospatial processing, episodic memory and verbal abilities, executive functioning and cognitive control, and working memory tasks. Raw data from the dimensions were z-transformed to compute an overall index of global neurocognitive performance.

Results: Aerobic power was similar between male and female older adults from CR and KS. Regardless of gender, elderly from CR scored lower in cognitive measures than elderly from KS. For the entire sample, a small correlation was found between aerobic power and Visuospatial processing/fluid ability ($r = 0.197$, $p = 0.009$).

Discussion and Implications: Elderly males and females from KS and CR reported similar aerobic power. The association between aerobic power and cognitive domains was inconsistent between genders and groups studied. More comparative ethnic/racial studies are needed to determine potential lifestyle factors related to cognitive decline in the elderly living in different societies.

Keywords: Cognition, Ethnic, Hispanics, Aerobic power, Performance

Introduction

The aging individuals have a high incidence of physical and cognitive impairment (e.g., Alzheimer's disease, AD) (Cunningham, McGuinness, Herron, & Passmore, 2015; Miljkovic, Lim, Miljkovic, & Frontera, 2015). High income countries are pushing morbidity back toward the end of life while the opposite is true in low-and-middle-income countries, primarily due to inadequate reduction in risk factors for neurological disorders such as cardiovascular disease (Silberberg, Anand, Michels, & Kalaria, 2015).

Diseases such as AD are estimated to affect millions of older people in the United States (Cornutiu, 2015). AD is the most frequent cause of institutionalization for long-term care and is a leading cause of years lived with disability. This disease destroys the active, productive life of its victims, and distresses their families financially and emotionally (Dodel et al., 2015; Gustavsson et al., 2011). Epidemiological projections suggest that people with AD will increase with the aging of the population unless effective lifestyle interventions are found (Cornutiu, 2015). Indeed, worldwide prevalence and incidence of AD will rise as life expectancy increases across the globe. In developed countries, this issue already looms as aging generations have benefited from improved public health and the introduction of effective life extending medical technologies. In developing nations, the rates of AD prevalence will increase fastest due to increased incidence and duration of survival with disease. This increase in neurocognitive illnesses is expected to be up to 433% in Latin America and in the first prevalence Costa Rican report, data shows a 4.1% prevalence in dementia and 8% in mild cognitive impairment during 2014. These data reflect the need to increase resources directed towards research and prevention (National Council of the Elderly Person, 2014).

Physical activity (PA) has shown positive benefits for protection against cognitive decline in older adults with and without dementia (Burns et al., 2008; Colcombe et al., 2003; Colcombe

& Kramer, 2003; Heyn, Abreu, & Ottenbacher, 2004; Laurin, Verreault, Lindsay, MacPherson, & Rockwood, 2001), but yet it has been recognized the high rate of sedentary elderly in the United States. In a study of older adults with and without AD, the majority of participants only engaged in unstructured and low intensity PA, including walking and housework (Watts, Vidoni, Loskutova, Johnson, & Burns, 2013). However, walking and household chores were related to objective positive health outcomes including cardiorespiratory capacity, speed, and body composition, suggesting that lifestyle interventions aimed at increasing participation in unstructured activities may be useful for reducing time spent in sedentary activities and improving health outcomes, especially among the least active.

In Costa Rica elderly people report spending on average 2-3 hours per week in unstructured physical activities and it was positively correlated with education, income, positive affect, executive function and health. However, as the age of the sample increased, the number of hours dedicated to physical exercise decreased (Blanco-Molina & Salazar-Villanea, 2017). Other evidence also shows that elderly spend nearly 60% of waking time in sedentary activities (Dipietro, Caspersen, Ostfeld, & Nadel, 1993; Stewart et al., 2001; Tudor-Locke & Myers, 2001; Washburn, Smith, Jette, & Janney, 1993). Therefore, structured training aimed at change sedentary lifestyle is recommended in this population. Aerobic exercise activities are a well-documented pathway to healthy brain aging (Sparling, Howard, Dunstan, & Owen, 2015). Given that a dose-response exists for PA and health benefits, evidence has shown that reducing progressively sedentary time may prove more realistic and pave the way to more intense exercise and better cardiorespiratory fitness (Vidoni et al., 2015).

Although the large and rapidly growing number of older adults who have risk potential for developing cognitive decline is major concern, evidence comparing elderly populations from different countries on PA and cognitive health is scarce. Racial/ethnic differences have been described in cognitive function or PA in aging individuals within a country (e.g., USA) (Diaz-Venegas, Downer, Langa, & Wong, 2016; Vasquez, Botoseneanu, Bennett, & Shaw, 2015). Some key findings from these studies are that older Hispanics/Latinos had lower cognition than older participants from other racial/ethnic categories along a wide range of aging groups; however, the differences in cognitive measures endpoints disappear after controlling for the influence of age, gender and education. In addition, PA has been positively associated to cognitive function (Diaz-Venegas et al., 2016; Vasquez et al., 2015). However, these studies have methodological limitations such as the use of brief telephone interviews, a limited number of cognitive function measures, and the use of indirect assessment of PA as a by proxy for cardiorespiratory fitness. The preferred method for PA assessment would be to perform a graded treadmill exercise test to determine maximal aerobic power, the gold standard for cardiorespiratory fitness (Hayes, Hayes, Cadden, & Verfaellie, 2013). The latter being supported by evidence suggesting a positive association between PA, aerobic power, a healthy aging brain, and the prevention of dementia (Beydoun et al., 2014; Burns et al., 2008; Colcombe et al., 2003; Colcombe & Kramer, 2003; Foster, 2015; Hayes et al., 2013; Laurin et al., 2001; Paillard, Rolland, & de Souto Barreto, 2015).

Therefore, comparison of data from different countries might help understanding the potential features preventing or delaying the deleterious effect of aging on cognitive function, as well as to identify modifiable lifestyle risk factors associated to the onset or impairment of cognitive function. For instance, the lifespan of the Costa Rica (CR) inhabitants is longer than in the United States of America (USA) (Rosero-Bixby, Dow, & Laclé, 2005), and cultural and lifestyle factors might explain why Costa Rican elderly may experience slower declines in cognitive health and physical function compared to the elderly living in the United States (Salazar-Villanea, Liebmann, Garnier-Villarreal, Montenegro-Montenegro, & Johnson, 2015).

Comparing potential differences in the relationship between physical fitness and neurocognitive performance between older adults from CR and USA might allow for a better understanding of lifestyle factors related to their overall health. Therefore, the purpose of the study was to compare the aerobic power and neurocognitive performance in older adults from the Kansas (KS) and Costa Rica (CR), and to determine whether a correlation exist between aerobic power and neurocognitive measures.

Design and Methods

Participants

Volunteers were recruited as a convenience sample through community talks and existing databases of individuals willing to be in research studies. A community-dwelling sample of 100 participants from KS were recruited (males = 35, females = 65) and given a testing appointment at the Alzheimer's disease Center at (ADC) the University of Kansas. A sample of 78 CR participants (males = 26, females = 52) was recruited from the Epidemiology and Development of Alzheimer's Disease project, the Costa Rican Gerontological Association, and the Institutional Program for Adults and Older Adults from the University of Costa Rica (UCR).

Volunteers were screened and allowed to participate only those meeting the following inclusion criteria: a) to be at least 60 years old, b) to approve a medical review and interview, c) score in the unimpaired range on the cognitive status screen (MMSE > 24), and d) have visual and auditory abilities sufficient to complete all cognitive assessments. Volunteers with current clinically significant systemic illness or significant pain or musculoskeletal disorder that would prohibit participation in fitness testing were excluded. Participants meeting the inclusion criteria were given a testing appointment at the ADC and at the Human Movement Sciences Research Center at the UCR. The Scientific Ethics Committee at the UCR and the Institutional Review

Board at the University of Kansas approved their respective protocol, and written informed consent was obtained from each participant.

Measurement instruments

Participants underwent body weight (kg), height (cm), and body composition assessments. In both testing sites, dual-energy X-ray absorptiometry (DXA) Lunar Prodigy (GE Medical Systems, Madison, WI) was used to determine lean body mass (LBM). Both measurement teams followed safety precautions and quality control according to international standards and manufacturer's guidelines (International Society for Clinical Densitometry, 2015).

Aerobic power was measured according to current guidelines (American College of Sports Medicine, 2010, 2014) with a Jaeger CPX metabolic cart (CareFusion Corporation, San Diego, CA) for the CR sample and a TrueOne 2400 (Parvomedics, Sandy, UT) for the KS sample. Both pieces of equipment were calibrated before each test using gases with known concentrations (CO_2 = 5%, O_2 = 16%, Balance de N_2) according to the manufacturer's instructions.

The neurocognitive assessment consisted on a comprehensive test battery designed to assess different cognition domains through a personal interview, performed by a licensed psychologist. This battery included a cognitive screen, simple speed of processing, spatial visualization, visuospatial processing (fluid ability), episodic memory and verbal abilities, executive functioning and cognitive control, and working memory (simple attention) tasks. The cognitive screen, consisted on completing the *Mini-Mental State Examination* (MMSE) (Folstein, Folstein, & McHugh, 1975), a brief structured test of cognitive function validated in Costa Rica with an elderly sample (Castro-Rojas & Salazar-Villanea, 2014). The simple speed of processing was measured with the *Stroop test* (Stroop, 1935), which was used to assess executive function. The test consists on reading words, colors, and color words printed in unusual colored ink. The participant must read the color words on the first page, the colors on the second page, and the color of the ink (i.e., not the words) on the third page. The final score is the time spent in reading correctly the maximum number of words in each page. The spatial visualization was measured with the *Space Relations Test* (SRT) (Bennet, Seashore, & Wesman, 1972), a timed test of visuospatial executive functioning, requiring the imaginary folding a two-dimensional target figure to compare against a target set of close 2-dimensional variants confounded by planar and mirror-imaged rotations of the target figure. Sixteen pictures were presented to the participants, four pictures in four cards. Participants were asked to identify and name each one of the pictures of each card, directed by a semantic cue given before by the rater. After that, the card was removed and the participants had to recall all of the pictures presented. In case of no recall, the semantic cue was given. After learning all sixteen pictures, participants were asked to recall as many pictures as they could in three different trials, with a distraction activity of 30 s between each trial.

The visuospatial processing/fluid ability was measured with the *Block Design Test* (BDT) (Wechsler, 1997), which was used to partially assess intelligence, spatial visualization ability and fine motor skills. Participants were required to use hand movements to rearrange blocks that have a two-color pattern on different sides to match a pattern. The *Digit Symbol Substitution Test* (DSST) (Wechsler, 1997), was used to assess cognitive processing ability . The DSST has been used in elderly with mild cognitive impairment and has proven its validity (Hart, Kwentus, Wade, & Hamer, 1987). The *Trail-making Test* (TMT) *forms A* and *B* (Armitage, 1946), was used to assess information regarding visual search, scanning, speed of processing, mental flexibility, and set switching as an executive function. The form A requires participant to draw lines sequentially, as quickly as possible, connecting 25-circled numbers distributed on a sheet of paper. The form B is similar to form A; however, the participant is required to alternate between two sequences, numbers and letters as quickly as possible. The final score is the time obtained in each part of the test.

The episodic memory and verbal abilities was measured with the *Boston Naming Test* (BNT) (Goodglass & Kaplan, 1983), a measure of visual confrontational word retrieval using black and white line drawings of progressive difficulty. Participants are required to name verbally the item in each picture when it is presented. The BNT has been validated for Spanish-speaking populations (Fernández & Fulbright, 2015; Jahn et al., 2013), maintaining its original validity and reliability (Ferraro & Lowell, 2010). *Logical* and *delayed memory* (Wechsler, 1997) were measured by a prose recall of short narrative passages immediately after the auditory presentation the story (reading out loud), and then prose recall of short narrative passages after a 20 min delay of the auditory presentation the story (reading out loud).

The executive functioning and cognitive control were measured with the TMT (form B) and the Stroop Test (interference task), were used to assess executive function and cognitive control. In addition, verbal fluency (Goodglass & Kaplan, 1983), was measured by a verbal test which consists of saying as many words as possible from a category in one minute. This could be semantic or phonologic. In this study, there were two verbal fluency tests of two different semantic categories, animals and vegetables. The final score is the number of correct words said. Intrusions and perseverations were also considered in the final scoring.

Finally, the working memory (simple attention) was measured with the *Digit Span forwards and backwards* (DSF involves reciting back a list of numbers to read to the subject, DSB involves reciting back a list of numbers in reverse order) and the *Letter Number Sequencing* (LNS) tests was used to assess working memory (Wechsler, 1997).

Procedures

Anthropometric and aerobic power assessment. Data collection was performed in the morning after a voiding attempt. Anthropometric measures and body composition were determined by standard protocols (American College of Sports Medicine, 2010, 2014; Nana, Slater, Stewart, & Burke, 2015). Body height was measured to the nearest 0.1 cm using a stadiometer. Body mass was measured in kg on a digital platform balance. Body composition was assessed by DXA. Scans were performed and analyzed by the same-trained operator, according to the laboratory standard protocol (International Society for Clinical Densitometry, 2015).

Cardiorespiratory capacity was determined by a graded treadmill exercise test using a modified Cornell treadmill protocol. Participants began walking at a pace of 2.73 km/h at 0% incline. Expired gases were collected continuously (breath by breath) in a metabolic cart. The treadmill grade, speed or both were increased every 2-min until peak oxygen consumption (VO_2peak) was achieved when meeting three out of four criteria: a) a plateau in O_2 consumption, b) a respiratory exchange ratio (RER = VCO_2/VO_2) ≥ 1.1, c) a maximal heart rate within 90% age-predicted maximum, or d) volitional fatigue (Hawkins, Raven, Snell, Stray-Gundersen, & Levine, 2007).

Neurocognitive assessment. A licensed psychologist received participants in a quiet room where the neurocognitive battery tests were performed. All participants sat quietly and were given the option to drink a beverage and eat a light snack during the length of the testing session, which lasted approximately 2-h allowing for breaks when needed.

Statistical analysis

Statistical analysis was performed with the IBM-SPSS Statistics, version 22 (IBM Corporation, Armonk, New York). Descriptive statistics are presented as mean and standard deviation (M ± SD), unless otherwise noted. For KS and CR participants, neurocognitive performance scores were converted to z-scores as follows: z = (raw score – mean)/SD. Higher z-scores represented better performance. The cognitive dimensions (screening, simple speed of processing, spatial visualization, visuospatial processing/fluid ability, episodic memory and verbal abilities, executive functioning and cognitive control, and working memory) were analyzed in raw and z-scores separately. Participant's mean performance z-scores on each dimension were determined to create an index of global neurocognitive performance called cognitive function total score (CFTS). Inferential analysis was performed by 2 x 2 ANOVA (sample by gender) for age, body height, weight and LBM. A 2 x 2 ANCOVA (sample by gender) was computed for VO_2peak (adjusted by age and LBM), and a 2 x 2 ANCOVA (sample by gender) was computed for raw scores for cognitive variables (adjusted by age and education level). Finally, a 2 x 2 ANCOVA (sample by gender) was computed for z-scores for cognitive variables (adjusted by age and education level). Post-hoc analysis was completed using Tukey comparisons. Pearson correlations were computed between aerobic power (VO_2peak) and cognition dimensions and CFTS. The level of significance was set *a priori* at $p \leq 0.05$.

Results

In the study, participants were 100 older adults from KS and 78 from CR. Descriptive statistics for anthropometric, VO_2peak, and cognitive variables are presented in tables 1 and 2.

Anthropometric and aerobic power. In general, the KS sample (M = 72.84 ± 5.59 yr.) was older than the CR sample (M = 68.91 ± 4.79 yr.) ($p \leq 0.001$). The CR sample (M = 158.63 ± 8.77 cm) had a smaller body height than the KS sample (M = 167.39 ± 9.72) ($p \leq 0.001$). In general, females (M = 158.54 ± 7.21 cm) had smaller body height than males (M = 172.99 ± 8.39 cm) ($p \leq 0.001$). A significant interaction between samples and genders in body weight was found ($p = 0.046$). Post hoc analysis showed that within KS and CR samples, males (M = 84.27 ± 16.15 kg) were heavier than females (M = 69.05 ± 11.61 kg) ($p < 0.05$). In addition, between samples, KS participants (M = 78.60 ± 15.28 kg) had a higher body weight than CR participants (M = 68.84 ±

13.17 kg) ($p < 0.05$). A significant interaction was found between KS and CR male and female older adults in LBM ($p = 0.030$). KS females showed lower LBM than KS males ($p \leq 0.001$), and CR females showed lower LBM than males ($p \leq 0.001$). Males from CR showed lower LBM than males from KS ($p \leq 0.001$), and no differences were observed between CR and KS females ($p = 0.689$). Males showed higher mean VO_2peak values than females ($p \leq 0.001$) after adjusting for the influence of age and LBM. The ANCOVA summary table on raw scores adjusted for age and education level for cognitive variables is presented in table 3. The findings are described below.

Cognitive screen and simple speed of processing. In general, the cognitive screen (i.e., MMSE) showed similar mean scores, both, within and between samples and genders ($p = 0.245$). The KS sample (M = 96.3 ± 1.5) showed higher mean scores on the Stroop Word Reading than the CR sample (M = 90.1 ± 1.7) ($p = 0.009$) (Table 2 and 3).

Spatial visualization. The KS sample (M = 8.1 ± 0.2) showed lower mean scores on the SRT-trial 1 than the CR sample (M = 9.5 ± 0.3) ($p \leq 0.001$). The KS sample (M = 9.6 ± 0.2) showed lower mean scores on the SRT-trial 2 than the CR sample (M = 11.2 ± 0.3) ($p \leq 0.001$). Regardless of the sample, the mean score on the SRT-trial 2 was higher in females (M = 10.7 ± 0.2) than in males (M = 10.0 ± 0.3) ($p = 0.021$). The KS sample (M = 10.3 ± 0.2) showed lower mean scores on the SRT-trial 3 than the CR sample (M = 12.1 ± 0.3) ($p \leq 0.001$). In general, males (M = 10.7 ± 0.3) scored lower on the SRT-trial 3 than females (M = 11.7 ± 0.2) ($p = 0.003$). The CR sample (M = 6.2 ± 0.3) showed lower mean scores on the SRT cued recall trial 1 than the KS sample (M = 7.9 ± 0.2) ($p \leq 0.001$). The CR sample (M = 3.8 ± 0.2) showed lower mean scores on the SRT cued recall trial 3 than the KS sample (M = 5.6 ± 0.2) ($p \leq 0.001$). In general, females (M = 4.1 ± 0.2) scored lower on the SRT cued recall trial 3 than males (M = 5.3 ± 0.3) ($p = 0.001$) (Table 2 and 3).

Visuospatial processing/fluid ability. The CR sample (M = 25.8 ± 1.2) showed lower mean scores on the BDT than the KS sample (M = 35.2 ± 1.1) ($p \leq 0.001$). In general, females (M = 28.4 ± 0.9) scored lower on the on the BDT than males (M = 32.6 ± 1.3) ($p = 0.011$). The CR sample (M = 36.4 ± 1.1) showed lower mean scores on the DSST than the KS sample (M = 48.1 ± 0.9) ($p \leq 0.001$). The KS sample (M = 27.8 ± 1.3) showed lower mean scores on the TMT form A than the CR sample (M = 48.7 ± 1.5) ($p \leq 0.001$). In general, females (M = 40.6 ± 1.1) scored higher on the on the TMT form A than males (M = 35.9 ± 1.6) ($p = 0.022$). The CR sample (M = 59.7 ± 1.3) showed lower mean scores on the Stroop Color Naming Test than the KS sample (M = 73.1 ± 1.1) ($p \leq 0.001$) (Table 2 and 3).

Episodic memory and verbal abilities. Regardless of gender, the mean score in logical memory was higher in the KS sample (M = 14.6 ± 0.3) than in the CR sample (M = 9.5 ± 0.4) ($p \leq 0.001$). Regardless of the sample, the mean scores in logical memory was higher in females (M = 12.6 ± 0.3) than in males (M = 11.5 ± 0.4) ($p = 0.024$). The mean score in delayed logical memory was higher in the KS sample (M = 13.3 ± 0.4) than in the CR sample (M = 8.6 ± 0.4) ($p \leq 0.001$). Regardless of the sample, the mean scores in the BNT was higher in males (M = 28.1 ± 0.3) than in females (M = 27.1 ± 0.2) ($p = 0.006$). Regardless of the gender, the KS sample (M = 28.6 ± 0.3) scored higher on the BNT than the CR sample (M = 26.6 ± 0.3) ($p \leq 0.001$) (Table 2 and 3).

Executive functioning and cognitive control. The KS sample had lower mean scores on the TMT form B (M = 79.4 ± 5.4) than the CR sample (M = 120.9 ± 6.3) ($p \leq 0.001$). The CR sample had lower Stroop Interference Task mean scores (M = 29.4 ± 1.1) than the KS sample (M = 37.3 ± 1.0) ($p \leq 0.001$). The mean score in verbal fluency for animals was higher in the KS sample (M = 21.3 ± 0.5) than in the CR sample (M = 18.9 ± 0.6) ($p = 0.004$). The CR sample had more verbal fluency for animal perseverations (M = 1.10 ± 0.1) than the KS sample (M = 0.6 ±

0.1) ($p = 0.026$). The mean score in verbal fluency for vegetables was higher in females (M = 16.2 ± 0.4) than in males (M = 13.2 ± 0.5) ($p \leq 0.001$). Regardless of the gender, the KS sample (M = 15.5 ± 0.4) scored higher on the verbal fluency for vegetables than the CR sample (M = 14.1 ± 0.5) ($p = 0.043$) (Table 2 and 3).

Working memory (simple attention). The KS sample had higher mean scores on the DSF (M = 8.6 ± 0.2) than the CR sample (M = 5.6 ± 0.2) ($p \leq 0.001$). The KS sample had higher mean scores on the DSB (M = 6.6 ± 0.2) than the CR sample (M = 3.7 ± 0.2) ($p \leq 0.001$). The KS sample had higher mean scores on the LNS (M = 10.4 ± 0.3) than the CR sample (M = 6.2 ± 0.3) ($p \leq 0.001$) (Table 2 and 3).

The ANCOVA summary table on z-scores scores adjusted for age and education level for cognitive dimensions is presented in table 4. No significant interactions between samples and genders were found on dimensions of cognitive screen ($p = 0.254$), simple speed of processing ($p = 0.785$), visuospatial processing/fluid ability ($p = 0.741$), episodic memory and verbal abilities ($p = 0.570$), executive functioning and cognitive control ($p = 0.305$), and in the CFTS ($p = 0.115$). Significant interactions were found between samples and genders on spatial visualization ($p = 0.027$) and working memory (simple attention) ($p = 0.002$) dimensions (Figure 1A, 1B). No significant gender main effects were observed in any of the cognitive dimensions ($p > 0.05$). The CR sample (M = -2.7 ± 1.2) scored lower on the CFTS than the KS sample (M = 0.8 ± 1.5) ($p = 0.032$).

In general, no significant correlations were found on the entire sample of elderly adults between VO_2peak and cognitive dimensions and CFTS. A significant correlation was found on visuospatial processing/fluid ability for the entire sample and the KS female elderly. In addition, significant correlations were found for KS males on working memory, KS females on executive functioning and cognitive control and CFTS, and inverse correlations in CR females on cognitive screening and executive functioning and cognitive control (Table 5).

Discussion and Implications

The study was designed to compare the aerobic power and neurocognitive performance in older adults from KS and Costa Rica CR, and to determine whether a correlation existed between aerobic power and neurocognitive measures. The main findings of this study confirm gender differences in anthropometric and cardiovascular measures. Regardless of the country of origin, males were taller, heavier, and leaner and had higher aerobic power than females (Kaminsky, Arena, & Myers, 2015). For cognitive variables, after adjusting for the influence of age and education level (Vasquez et al., 2015), most variables were similar between males and females and, in general, the cognitive screening showed similar mean scores within and between samples and genders. However, differences were found between elderly from KS and CR. After transforming raw- to z-sores and computing an overall measure of cognitive function (i.e., CFTS), we found that the elderly CR scored lower than their KS counterparts. This result is consistent with a previous study were scores on the cognitive measures were comparable to age and education normative data for lower educated convenience samples used widely in US clinical research, where Costa Rican's only differed from US-based sample in their self-reported affective profiles since positive affect was very high, 10 points higher than US normed comparisons while negative affect was about equivalent (Salazar-Villanea et al., 2015). Finally, we only found a significant correlation between aerobic power (i.e., VO_2peak) and visuospatial processing/fluid ability for the entire sample of elderly. This specific cognitive domain should be considered as a core domain for future research.

It is recognized that PA is a modifiable health behavior that shows promise for protection against cognitive decline and gray matter loss (Burns et al., 2008; Coelho et al., 2013; Colcombe et al., 2003; Voss et al., 2013). Evidence suggests that increased aerobic fitness from a walking program (i.e., PA), enhanced brain white matter integrity and short-term memory (Voss et al., 2013). Evidence has shown that physically-active older adults have better cognitive performance (Colcombe et al., 2003; Tyndall et al., 2013), and decreased risk of cognitive impairment and AD (Chodzko-Zajko et al., 2009; Kimura, Yasunaga, & Wang, 2013; Laurin et al., 2001) than their sedentary counterparts. Individuals with AD are particularly susceptible to decline in the systems and functions that PA supports, including lean mass (Burns, Johnson, Watts, Swerdlow, & Brooks, 2010), bone density, cognitive function and cardiorespiratory fitness or power (Burns et al., 2008).

The association between VO_2peak, a proxy of aerobic fitness, and cognitive function is consistent across different age groups and genders (Hayes et al., 2013). For instance, fit college-aged women (i.e., VO_2peak = 44.6 $ml \cdot kg^{-1} \cdot min^{-1}$) showed better executive functioning scores (e.g., attention, learning/shifting, working memory, problem-solving) than low-fit women (Scott, De Souza, Koehler, Petkus, & Murray-Kolb, 2016). In the current study we computed an overall score of cognitive function based on a comprehensive battery of tests; however, we only found a significant correlation with VO_2peak in the KS female elderly (Table 5). Indeed, the statistical significance disappeared when merging all participants from KS and CR, which might have given higher statistical power to the correlational analysis. This finding was unexpected given the body of knowledge supporting the purported association between cardiorespiratory fitness and different cognition domains, including executive function, in older adults with and without cognitive impairment (Hayes, Forman, & Verfaellie, 2016; Hayes et al., 2013; Morris et al., 2017; Vidoni et al., 2015).

Baseline levels of VO_2peak have been related to the magnitude in cognitive decline over time (Wendell et al., 2014). In the present study, VO_2peak was related to executive function and cognitive control in the KS females and inversely related to the same domain in the CR females (Table 5). Therefore, we did not find a consistent association between aerobic power and cognitive domains. This inconsistent finding is commonly reported in the literature when summarizing randomized controlled trials (Freudenberger et al., 2016; Gajewski & Falkenstein, 2016; Young, Angevaren, Rusted, & Tabet, 2015). Although some evidence suggest that aerobic training enhances cognitive function, more studies are warranted to determine the causal effects of increased aerobic fitness on selected cognitive domains and to determine the precise physiological mechanisms explaining the purported benefits, even when aerobic training lacks to enhance cognition or at least does not impair it (Roever & Bennett, 2016).

The present study has some limitations. We performed a cross-sectional study, and other factors might have influenced our results (e.g., nutrition, blood pressure, and genetics). We reported associations between VO_2peak and cognition domains, which does not necessarily represent a causal relationship between aerobic power and cognition. Another important aspect that must be considered is that the positive correlations between cognitive domains and PA have mostly been reported in sedentary elderly samples (Voss, Carr, Clark, & Weng, 2014) which was not the condition in this study. Further study of the diet regulation as a main contributing factor to cognitive brain health and its interaction with aerobic exercise is also needed.

In conclusion, findings from this study were consistent with previous work showing gender differences in anthropometric and cardiovascular function variables. We also found differences in cognitive variables between elderly from KS and CR. However, we did not find a consistent association between aerobic power/fitness and cognitive domains. Further comparative ethnic/racial studies will allow us to better understand potential lifestyle factors related to cognitive decline in the elderly living in different societies.

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Table captions

Table 1. Descriptive statistics (M ± SD) for anthropometric and fitness variables for male and female older adults from Kansas (KS) and Costa Rica (CR) (n = 178).

Table 2. Descriptive statistics (M ± SD) for cognitive variables for male and female older adults from Kansas and Costa Rica (n = 178). Values are unadjusted raw-means ± SD.

Table 3. ANCOVA summary table on raw-scores adjusted for age and education level.

Table 4. ANCOVA summary table for cognitive function variables z-scores adjusted for age and education level.

Table 5. Pearson correlations between aerobic power (VO_2peak) and z-score cognitive dimensions.

Figure caption

Figure 1. Spatial visualization (Panel A) and working memory dimensions (Panel B) in males and females from Kansas and Costa Rica. Values are age- and education-adjusted z-scores ± SE.

Table 1. Descriptive statistics (M ± SD) for anthropometric and fitness variables for male and female older adults from Kansas (KS) and Costa Rica (CR) (n = 178).

	Males (n = 61)		**Females (n = 117)**	
Variable	**KS (n = 35)**	**CR (n = 26)**	**KS (n = 65)**	**CR (n = 52)**
Age (yr.)	73.6 ± 6.4	68.9 ± 4.5	72.5 ± 5.1	68.9 ± 5.0
Weight (kg)	90.5 ± 14.7	75.8 ± 14.3	72.1 ± 11.2	65.3 ± 11.1
Height (cm)	177.6 ± 5.9	166.8 ± 7.3	161.8 ± 6.3	154.5 ± 6.2
Lean body mass (kg)	57.2 ± 5.6	51.9 ± 6.8	39.1 ± 4.3	37.3 ± 4.1
VO_2peak ($ml \cdot kg^{-1} \cdot min^{-1}$)	23.8 ± 4.7	25.7 ± 3.7	20.5 ± 3.5	21.4 ± 4.0

Table 2. Descriptive statistics (M ± SD) for cognitive variables for male and female older adults from Kansas and Costa Rica (n = 178). Values are unadjusted raw-means ± SD.

	Males (n = 61)		**Females (n = 117)**	
Variable	**KS (n = 35)**	**CR (n = 26)**	**KS (n = 65)**	**CR (n = 52)**
Cognitive screening and simple speed of processing				
• MMSE Score (0-30)	29.1 ± 1.1	29.6 ± 0.8	29.3 ± 1.0	29.3 ± 1.3
• Stroop Word Reading (score)	96.0 ± 16.2	93.7 ± 12.2	95.7 ± 12.9	88.6 ± 12.9
Spatial visualization				
• Space Relations Test (Trial 1, Free recall) (score)	7.6 ± 2.2	9.8 ± 2.2	8.3 ± 2.1	9.7 ± 1.9
• Space Relations Test (Trial 2, Free recall) (score)	9.0 ± 1.9	11.6 ± 1.6	9.9 ± 1.9	11.8 ± 1.9
• Space Relations Test (Trial 3, Free recall) (score)	9.6 ± 2.2	11.9 ± 1.8	10.7 ± 2.4	12.8 ± 1.5
• Space Relations Test (Trial 1, Cued recall) (score)	8.3 ± 2.2	6.0 ± 2.0	7.7 ± 2.1	6.1 ± 1.7
• Space Relations Test (Trial 2, Cued recall) (score)	7.0 ± 1.9	4.4 ± 1.5	6.1 ± 1.9	5.5 ± 9.5
• Space Relations Test (Trial 3, Cued recall) (score)	3.5 ± 1.6	4.1 ± 1.7	5.1 ± 2.2	3.2 ± 1.5
Visuospatial processing/fluid ability				
• Block Design (0-68)	38.5 ± 11.8	27.8 ± 9.4	31.6 ± 10.5	25.0 ± 8.1
• Digit Symbol Substitution Test (0-93)	46.2 ± 10.0	40.0 ± 9.3	48.5 ± 9.4	35.4 ± 9.4
• Trail-making Test A total time (s)	27.5 ± 7.1	41.4 ± 8.8	30.8 ± 10.0	50.5 ± 19.0
• Trail-making Test A (errors)	0.2 ± 0.6	0.2 ± 0.5	0.2 ± 0.4	0.2 ± 0.6
• Stroop Color Naming (score)	72.7 ± 11.4	60.6 ± 9.3	72.9 ± 11.4	59.0 ± 8.0
Episodic memory and verbal abilities				
• Logical memory (score)	14.1 ± 3.2	9.7 ± 3.3	15.3 ± 3.1	9.6 ± 2.7
• Delayed logical memory (score)	13.0 ± 3.2	8.4 ± 3.5	13.7 ± 3.7	8.9 ± 3.2
• Delayed logical memory reminding (score)	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.1	0.0 ± 0.0
• Delayed logical memory time elapsed (min)	23.2 ± 3.6	22.9 ± 2.7	23.3 ± 3.6	23.5 ± 2.6
• Boston Naming Test (score)	29.0 ± 1.4	27.6 ± 1.7	28.0 ± 1.8	26.1 ± 3.7
Executive functioning and cognitive control				
• Trail-making Test B total time (s)	78.9 ± 46.0	108.7 ± 46.5	65.0 ± 38.1	120.5 ± 66.9
• Trail-making Test B (errors)	0.5 ± 0.8	0.9 ± 1.2	0.7 ± 1.1	0.9 ± 1.8
• Stroop Interference Task (score)	34.8 ± 8.0	30.0 ± 7.7	38.5 ± 10.5	29.8 ± 8.2
• Verbal fluency animals (score)	21.4 ± 5.6	19.0 ± 3.4	21.2 ± 5.7	18.9 ± 3.9
• Verbal fluency vegetables (score)	14.1 ± 4.9	12.6 ± 3.9	16.8 ± 4.0	15.5 ± 3.6
• Verbal fluency animals intrusions (score)	0.1 ± 0.4	0.0 ± 0.0	0.1 ± 0.3	0.0 ± 0.0
• Verbal fluency vegetables intrusions (score)	1.0 ± 2.0	1.2 ± 2.3	0.3 ± 0.7	1.2 ± 2.9
• Verbal fluency animals perseverations (score)	0.7 ± 1.0	1.1 ± 1.6	0.5 ± 0.7	1.1 ± 1.3
• Verbal fluency vegetables perseverations (score)	0.3 ± 0.5	0.4 ± 1.0	0.5 ± 0.8	0.8 ± 1.1
Working memory				
• Digit Span forwards (score)	8.9 ± 1.7	5.6 ± 1.1	8.2 ± 1.9	5.7 ± 1.1
• Digit Span backwards (score)	6.9 ± 2.2	3.6 ± 0.9	6.4 ± 2.2	3.6 ± 1.0
• Letter Number Sequencing (score)	10.8 ± 2.0	6.7 ± 2.1	9.7 ± 2.3	6.2 ± 3.3

Note: MMSE: Mini Mental State Examination

Table 3. ANCOVA summary table on raw-scores adjusted for age and education level.

	Source of variance		
Variable	**Sample (A)**	**Gender (B)**	**Interaction (AxB)**
Cognitive screen			
• MMSE (0-30)	0.544	0.890	0.245
Simple speed of processing			
• Stroop Word Reading (unlimited)	**0.009**	0.415	0.536
Spatial visualization			
• Space Relations Test (Trial 1, Free recall)	**0.000**	0.220	0.600
• Space Relations Test (Trial 2, Free recall)	**0.000**	**0.021**	0.620
• Space Relations Test (Trial 3, Free recall)	**0.000**	**0.003**	0.879
• Space Relations Test (Trial 1, Cued recall)	**0.000**	0.429	0.311
• Space Relations Test (Trial 2, Cued recall)	0.471	0.865	0.460
• Space Relations Test (Trial 3, Cued recall)	**0.000**	**0.001**	0.570
Visuospatial processing/Fluid ability			
• Block Design	**0.000**	**0.011**	0.093
• Digit Symbol Substitution Test	**0.000**	0.789	0.186
• Trail-making Test A	**0.000**	**0.022**	0.703
• Trail-making Test A errors	0.575	0.710	0.599
• Stroop Color Naming	**0.000**	0.778	0.749
Episodic memory and verbal abilities			
• Logical memory	**0.000**	**0.024**	0.605
• Delayed logical memory	**0.000**	0.054	0.712
• Delayed logical memory reminding	0.723	0.519	0.431
• Delayed logical memory time elapsed	0.503	0.832	0.836
• Boston Naming Test	**0.000**	**0.006**	0.959
Executive functioning and cognitive control			
• Trail-making Test B	**0.000**	0.714	0.545
• Trail-making Test B errors	0.143	0.777	0.620
• Stroop Interference Task (unlimited)	**0.000**	0.243	0.238
• Verbal fluency animals	**0.004**	0.918	0.718
• Verbal fluency vegetables	**0.043**	**0.000**	0.825
• Verbal fluency animals intrusions	0.065	0.359	0.419
• Verbal fluency vegetables intrusions	0.114	0.247	0.378
• Verbal fluency animals perseverations	**0.026**	0.732	0.279
• Verbal fluency vegetables perseverations	0.156	0.112	0.785
Working memory (simple attention)			
• Digit Span forwards	**0.000**	0.350	0.086
• Digit Span backwards	**0.000**	0.648	0.305
• Letter Number Sequencing	**0.000**	0.209	0.106

Note: MMSE: Mini Mental State Examination

Table 4. ANCOVA summary table for cognitive function variables z-scores adjusted for age and education level.

	Source of variance		
	Sample (A)	**Gender (B)**	**Interaction (AxB)**
Cognitive dimension	p ≤	p ≤	p ≤
Cognitive screen	0.915	0.852	0.254
Simple speed of processing	0.170	0.582	0.785
Spatial visualization	0.073	0.057	0.027
Visuospatial processing/fluid ability	0.099	0.192	0.741
Episodic memory and verbal abilities	0.426	0.995	0.570
Executive functioning and cognitive control	0.103	0.208	0.305
Working memory (simple attention)	0.022	0.466	0.002
Cognitive function total score	0.032	0.572	0.115

Table 5. Pearson correlations between aerobic power (VO_2peak) and z-score cognitive dimensions.

		Males (n = 61)		**Females (n = 117)**	
Variable	**All (n = 178)**	**KS (n = 35)**	**CR (n = 26)**	**KS (n = 65)**	**CR (n = 52)**
Cognitive screening	-0.063	0.159	-0.309	0.004	-0.286[b]
Simple speed processing	0.044	0.220	-0.126	0.179	-0.077
Spatial visualization	-0.098	0.189	-0.120	0.045	0.005
Visuospatial processing/fluid ability	0.197[a]	0.230	0.193	0.342[e]	-0.034
Episodic memory and verbal abilities	0.130	0.230	0.356	0.025	-0.011
Executive functioning and cognitive control	-0.048	-0.043	-0.031	0.356[f]	-0.345[c]
Working memory (simple attention)	0.077	0.396[d]	0.047	0.141	0.045
Cognitive function total score	0.087	0.236	0.070	0.327[g]	-0.163

Note: [a]$p = 0.009$; [b]$p = 0.040$; [c]$p = 0.012$; [d]$p = 0.019$; [e]$p = 0.006$; [f]$p = 0.004$; [g]$p = 0.008$.

Figure 1. Spatial visualization (Panel A) and working memory dimensions (Panel B) in males and females from Kansas and Costa Rica. Values are age- and education-adjusted z-scores ± SE.