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Exercise, Cognition, and the Aging Process among Active, Competitive, and Sedentary Middle-Aged and Older Adults

Katherine Adams

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Katherine Adams

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Introduction

By the year 2050, the United States will see considerable growth in its older population. In 2012, the elderly population ($\geq$65 years) was estimated to be 41.3 million and this is projected to be 83.7 million, almost double by the year 2050 (Ortman, Velkoff, & Hogan, 2014). With the elderly population expanding, managing their health and independence is an ongoing concern. Among older adults, there is a significant risk for mobility problems as well as cognitive impairment, thus leading the elderly to a loss of independence (Rikli & Jones, 1999).

The aging process not only affects physical performance, but cognitive performance as well. Advancing age is associated with a decrease in cognitive capacity, which significantly affects an individual's quality of life (Barnes, 2015). Cross-sectional studies over the past two decades have examined the correlation between cognitive status and functional independence (Scherr et al., 1988). For example, instrumental activities of daily living (IADLs), such as preparing meals and performing housework, are highly dependent on cognitive ability (Scherr et al., 1988). Since aging is accompanied by the decreased ability to perform such daily activities with their associated cognitive limitations, the medical community is challenged to help this population maintain their independence and a high quality of life.

This study aimed to examine the correlation between cognitive performance and exercise in older adults. Specifically, it was aimed at answering the question, "Do higher activity levels benefit cognitive performance as assessed by reaction time and dual-task performance between masters athletes, sedentary, and recreationally active older adults?" Within the lab, cognitive measures such as reaction time and dual-task performance (the simultaneous performance of two tasks) were used and tested between recreationally active individuals, masters athletes, and sedentary late middle-aged and older adults. Using these three distinct groups enabled this study to compare the retention of cognitive abilities across differing levels of physical activity.

In order to quantify cognitive functioning, reaction time and dual-task performance were measured. Measures of reaction time include observing controlled processes such as decision making simple and choice reaction timed tasks, as well as speed, both of which require low-level neurological functioning. In addition, tasks involving executive control such as dual-task (the simultaneous performance of two tasks) were measured. This can be a challenge among the elderly and impose a detrimental effect on balance control (Holtzer, Stern, & Rakitin, 2005). It is hypothesized that more physically active older adults will have a faster reaction time than their less active counterparts.

Throughout aging, cognitive processes undergo a normal and gradual decline. However, several studies have shown that there is a positive correlation of exercise training on cognitive measures such as balance, reaction time and gait performance all of which can act to slow the aging process (Scheffer, Schurrmans, Dijik, van der Hooft, & Rooij, 2007). This insight provides valuable information for researchers and medical professionals striving to improve this population's overall health and functional independence. Overall, these studies support that positive adaptations on cognitive processes can occur as a result of exercise. In order to prevent older adults from losing independence and to slow cognitive decline associated with aging, it is important to understand how cognitive performance could be improved by exercise.

Literature Review

Geriatric health is an ongoing concern as its population is one of the fastest growing demographics in the United States (Centers for Disease Control, 2013). One of the most common health issues in the elderly population is age-related cognitive impairment. Dementia, the loss of memory severe enough to interfere with daily life, is prevalent for 10% of the population over 65 years of age and the prevalence increases to 30% in individuals over 90 years of age (Njegovan, Man-Son-Hing, Mitchell, & Molnar, 2001). Therefore, it is essential to understand how the deterioration of cognitive performance occurs and what can be done to slow cognitive impairment throughout the aging process.

Cognition and Aging

There is a specific pattern of loss of physical function associated with cognitive decline. Activities of daily living (ADLs) that require a higher level of cognitive thinking, such as preparing meals and using the telephone are generally lost first when compared to those that require lower levels of cognitive function like walking on a flat surface or standing from a seated position (Holtzer et al., 2005). If individuals are not able to perform these skills, then they are likely to experience a decreased quality of life since ADLs represent skills that people need in order to live as independent adults.

In order to detect cognitive decline, several aspects can be measured. Some of these include memory, speed (which requires low level neurological functioning including simple reaction time), visuospatial ability (the ability to define visual and spatial relationships among subjects), controlled processes (tasks requiring some cognitive control, such as choice or decision-making reaction timed tasks), automatic processes (the unintentional, involuntary tasks) and executive control (scheduling and planning) (Smiley-Oyen, Lowry, Francois, Kohut, &

Ekkekakis, 2008). Research suggests that those tasks involved in executive control such as dual-task (simultaneous execution of multiple tasks), working memory, and task-switching are the most affected by aging whereas simple reaction time is less affected and is less likely to benefit from exercise (Colcombe & Kramer, 2003).

Exercise and Cognitive Performance

Historically, the relationship between the mind and the body has been studied as two distinct entities (Etnier, Salazar, Petruzzelo, Han, & Nowell, 1997). In recent years, however, contemporary researchers have examined the mind and body as inseparable entities, each one influencing the other. The research is limited on humans due to the fact that it can be costly and invasive, but most propose that exercising can have a beneficial effect on cognitive performance. For example, Spirduso and Clifford (1978) compared runners and sedentary individuals on simple, choice, and movement timed tasks reporting that the athletes' performance on these tasks was significantly better than the older sedentary adults'. This suggests that exercise has a positive influence on reaction time and thus better cognitive ability.

Additionally, some research has examined the mind-body relationship by using modern methods such as Xenon clearance techniques, which measures scalp blood flow. From this method, high intensity exercise has been shown to increase cerebral blood flow as a result of exercise (Etnier et al., 1997). It is suggested that the increase in cerebral blood flow benefits overall cognitive functioning because it increases the supply of nutrients like glucose to the brain (Etnier et al., 1997). These findings demonstrate the idea that exercise is positively correlated with cognitive performance. Some research also found that aerobic exercise, specifically, has a positive impact on cognitive function on a molecular level. Black, Issac, Anderson, Alcantara, and Greenough (1990) found that there was an increase in capillary density in the cerebellum of rats when exercising on a running wheel. It may be reasonable to conclude that the changes observed in response to exercise in mice may underlie improvements in cognitive processes in adult humans.

Another mechanism that helps explain the link between the body and the mind is how exercise can influence neurotransmitters in the brain. Neurotransmitters are chemical messengers that process and transmit information throughout the brain and body. In past research with mice, increased levels of norepinephrine (a type of neurotransmitter) correlated with better memory and as such, the synapses themselves play important roles in the memory process (Zornetzer, 1985). Some investigators have found that after a single bout of exercise, there are increases in levels of norepinephrine and its precursors (Ebert, Post, & Goodwin, 1972). Even studies examining the influence of chronic exercise on neurotransmitters, found that it leads to more long-term increases in norepinephrine levels in humans (Poehlman, Gardner, & Goran, 1992). This information is important because it helps explain another way cognitive performance can be improved by exercise on a more biological level.

Another aspect that engaging in exercise influences is permanent structural changes in the brain. The effects of aging on the brain and cognition result in a reduction in brain volume, primarily in the frontal cortex. However, increasing brain density (thickness) and volume has a positive influence on performance abilities of the brain (Peters, 2006). Jonasson et al. (2017) investigated whether aerobic exercise improved cognition by altering cortical thickness or volume in brain structures important to cognition. Scanned with magnetic resonance imaging, three frontal regions involved in selecting information in working memory and monitoring processes were observed and predicted to undergo changes from aerobic exercise. They found sedentary older adults assigned to aerobic exercise demonstrated a significant improvement in cognitive performance when compared to adults assigned to stretching and toning control training. Furthermore, aerobic fitness exhibited a positive relationship with cortical thickness at baseline as well as changes over time. This information takes into consideration a potential pathway for exercise-induced improvements in cognition. Since biological aging is not completely tied to chronological aging, slowing down biological aging may reduce the possibility of developing dementia and other age-related cognitive diseases (Etnier et al., 1997).

Aside from exercise playing a role in changing cognitive function at the molecular and structural level, it also has differing influence on specific cognitive processes. Kramer et al. (2003) observed 124 older adults divided into a walking group (aerobic) and stretching group (non-aerobic) over a six-month period. They observed that the aerobic group showed increased performance in high-executive control tasks whereas the groups did not differ in the low-executive control tasks. When tested in the laboratory, after the six-month period, aerobic exercise had the strongest effect on executive-control tasks, followed by controlled processes, visuospatial tasks, and finally speed tasks. Additionally, Smiley-Owen et al. (2008) hypothesized that aerobic exercise even in small bouts are necessary for short-term cognitive improvement to occur.

The Aging Decline and Dual – Task Performance

Most activities that people perform on a daily basis require completing multiple tasks simultaneously such as talking on the phone while watching television for example. Usually, most people are able to perform both motor and higher cognitive tasks at the same time with ease, but that is not always the case with the elderly. The simultaneous performance of two tasks (dual-task) can be extremely challenging and impose a detrimental effect on balance control among the elderly due to the reduction in cognitive resources.

Dual-task testing has been used to evaluate the executive functions of cognition but in relation to neuropsychological measures, it has not been studied extensively (Holtzer et al., 2005). In the lab, completing two tasks simultaneously evaluates dual-task performance. There is a positive relationship between standardized neuropsychological tests and dual-task performance (Holtzer et al., 2005). For example, walking while counting backwards by threes is a dual-task measure that can be used in the laboratory setting. Dual-task performance has been researched extensively as it relates to aging process whereas some researchers have failed to detect the age-related decline in dual-task performance (Holtzer et al., 2005). Performing well in dual-task measures is important especially for senior citizens, since it will improve their ability to perform tasks independently and thus improve their quality of life.

In summary, it is extremely important for older adults to maintain a regular exercise routine not only for cognitive measures but also for overall cardiovascular and physical health. The American College of Sports Medicine (ACSM) recommends that every U.S. adult should participate in at least 30 minutes or more of moderate physical activity on most, and preferably all days of the week (Nelson, Rejeski, Blair, Duncan, & Judge, 2007). The ACSM has even issued a separate recommendation for the elderly ($\geq$ 65 for both men and women) who have functional limitations to participate in a minimum of 30 minutes of moderate activity five days per week or a minimum of 20 minutes vigorous aerobic activity on three days per week (Nelson et al., 2007).

In the present investigation, cognitive function through dual-task and reaction time tests was measured among elderly recreationally active, sedentary, and master athletes. Recreationally active athletes are defined as individuals who participate in physical activities to have fun and be healthy. Sedentary individuals are those who participate in either no or irregular physical activity. Moreover, master athletes are classified as individuals who train and compete in organized forms of competitive sport (Reaburn & Dascombe, 2008). The Rapid Assessment of Physical Activity and the 6-minute walk test was used to give a more clear indication of their aerobic fitness and thus, current activity level.

The relevance of dual-task and reaction time have been widely reported but with mixed results due to differences in the activity levels of the participants (Holtzer et al., 2005). The current study is significant and of value to this field of study because three different groups of varying activity levels will help identify how much physical activity, and if any, affects cognitive performance.

The overall purpose of this study was to examine the correlation between cognition and exercise by comparing reaction time and dual-task performance among recreationally active, masters athletes, and sedentary older adults. We hypothesized that the masters athletes will have the fastest reaction time and best dual-task performance followed by the recreationally active older adults and sedentary adults.

Methodology

Participant Selection

A total of 59 older adults (27 males, 32 females) of ages between 50 to 88 years old were recruited to participate in this study. Participants were recruited from various clinics, community centers, exercise and sports groups, and fitness centers throughout the Northwest Arkansas area. The participants were categorized based on their activity level and placed into either the sedentary, recreationally active, or masters athlete group. Depending on their Rapid Assessment of Physical Activity (RAPA) score, the participants were classified as sedentary if their score was low and recreationally active if their score was high. Participants were classified as a masters athlete if they participated in a sanctioned event in the previous six months from the beginning of the study. There were 19 sedentary, 27 recreationally active, and 13 masters athletes in total that participated in the study. Exclusion criteria included: uncontrolled cardiovascular, metabolic, or pulmonary disease, inability to walk without assistance, inability to stand without assistance, and balance impairments. All procedures and measures affiliated with this project were approved by the University of Arkansas Institutional Review Board and informed consent received by all participants prior to testing.

Procedures

Rapid Assessment of Physical Activity (RAPA). Participants were asked to complete the Rapid Assessment of Physical Activity questionnaire prior to testing. It is an assessment of aerobic physical activity intensity (i.e. light, moderate, or vigorous) that consists of seven yes/no questions. Question 1 states, “I rarely or never do any physical activities” and Question 7 states, “I do 20 minutes or more of vigorous physical activities, 3 or more days a week.” The participant was classified as sedentary if they scored a 1-5. The participant was classified as recreationally active if they scored a 6 or 7. The question with the highest score with an affirmative response is the one that was selected to classify the participant into their respective activity level group.

Gait Speed with associated dual-task component. Dual-task assessment involves measuring baseline performance on a single motor task (e.g. time to complete walking for a specified distance) in addition to measuring performance on a single cognitive task (e.g. counting backwards by threes). Both tests are performed at the same time in order to understand the implications of performing real-life situations that require doing multiple tasks at once.

When instructed to “go”, participants walked 10-meters at two different speeds, either habitual pace (normal everyday walking speed) or fast pace (the fastest speed at which they can safely walk), with and without a dual-task component. With the dual-task component included, participants were given a random number selected from the Microsoft Excel random number generator. The generator was set up to randomly select numbers in increments of 25 within the range of 125 to 250. Then, the participants were instructed to walk the 10-meters either at habitual pace speed or fast pace speed while counting backwards aloud by threes from that number. There was a 5-meter lead in and a 5-meter lead out before and after the 10-meters to account for acceleration and deceleration. Automatic timing gates were set up to most accurately record time of completion (Glenn, Vincenzo, Canella, Binns, & Gray, 2015).

Simple Reaction Time. Simple reaction time tests for a known stimulus to elicit a known response. It was measured with the MoART (Multi-Operational Apparatus for Reaction Time) reaction timer. For the simple reaction time test, subjects were instructed to place their index fingers on the specified location marked with tape in front of the board. Then, they were asked to respond by touching the MoART board with either their right or left index finger as quickly as they could once they saw a light appear. Three sets of 10 trials of this test were given to all participants and the average of the 30 trials was recorded (Hultsch, MacDonald, & Dixon, 2002).

Choice Reaction Time. Choice reaction time is similar to the simple reaction time, except that there are two possible stimuli and two possible responses, indicating a higher level of cognitive functioning as there is more than one stimulus to elicit a known response. It was measured with the MoART (Lafayette Instruments) reaction timer. Participants were asked to touch the MoART board as quickly as they could with one of their index fingers once they saw a light appear either at the upper right or upper left corner of the board. Three sets of 10 trials of this test were given to all participants and the average of the 30 trials was recorded (Hultsch, MacDonald, & Dixon, 2002).

6-Minute Walk Test. The 6-minute walk test is a submaximal measure of aerobic capacity and overall is a useful measure of functional capacity. This test was used to clarify the differences in aerobic fitness levels between the activity groups. The test indicates the distance that an individual can walk on a hard surface in a period of 6 minutes. When instructed to "go", participants were asked to walk as far as possible, going back and forth between each endpoint of the hallway marked by cones 75 feet apart for the entire 6 minutes. The total distance covered in the 6-minute time interval was recorded with a measuring wheel (American Thoracic Society, 2002).

Statistical Analysis. The statistical analysis program used to analyze the data was SPSS version 22. We conducted two one-way ANOVAs to determine the differences in the dependent variables (cognitive variables) and the independent variables (activity groups: sedentary, recreationally active, masters athlete). In regard to the dual-task variable, the dual-task decrement speed was used for both the habitual and fast paced trials in order to account for differences in gait speed between participants. A third one-way ANOVA was performed using the 6-minute walk test results in order to show a clearer picture of aerobic fitness differences between activity groups. The level of significance was set at $\alpha = .05$. The Bonferroni test correction was performed in order to account for several dependent tests. Thus, the level of significance was adjusted to $\alpha = .02$.

Results

The purpose of this study was to examine the differences between cognition and exercise in the aging population by comparing reaction time and dual-task performance among masters athletes, recreationally active, and sedentary older adults. Specifically, higher activity levels were thought to benefit cognitive performance as assessed by reaction time and dual-task performance.

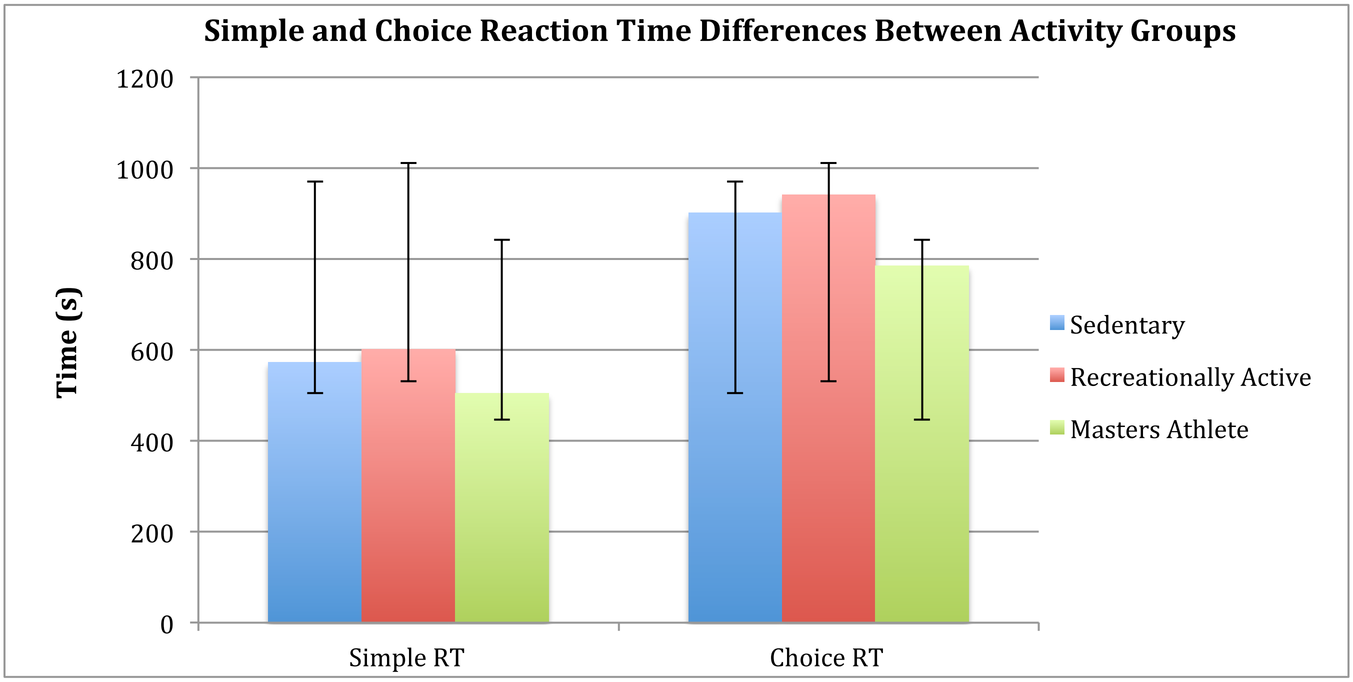

Figure 1. This graph displays the differences in simple and choice reaction time tests between the activity groups..

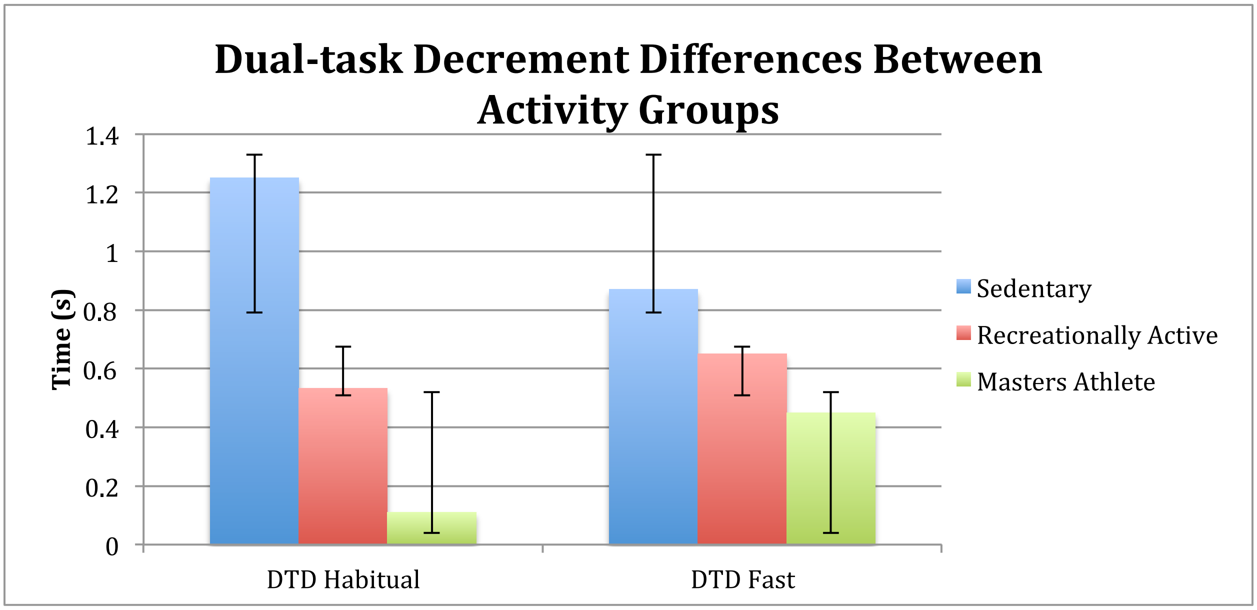

Figure 2. This graph shows the differences in habitual dual-task decrement speed and fast dual-task decrement speed between activity groups. Based on total averages, the masters athletes had the best dual-task performance compared to the sedentary and recreationally active individuals.

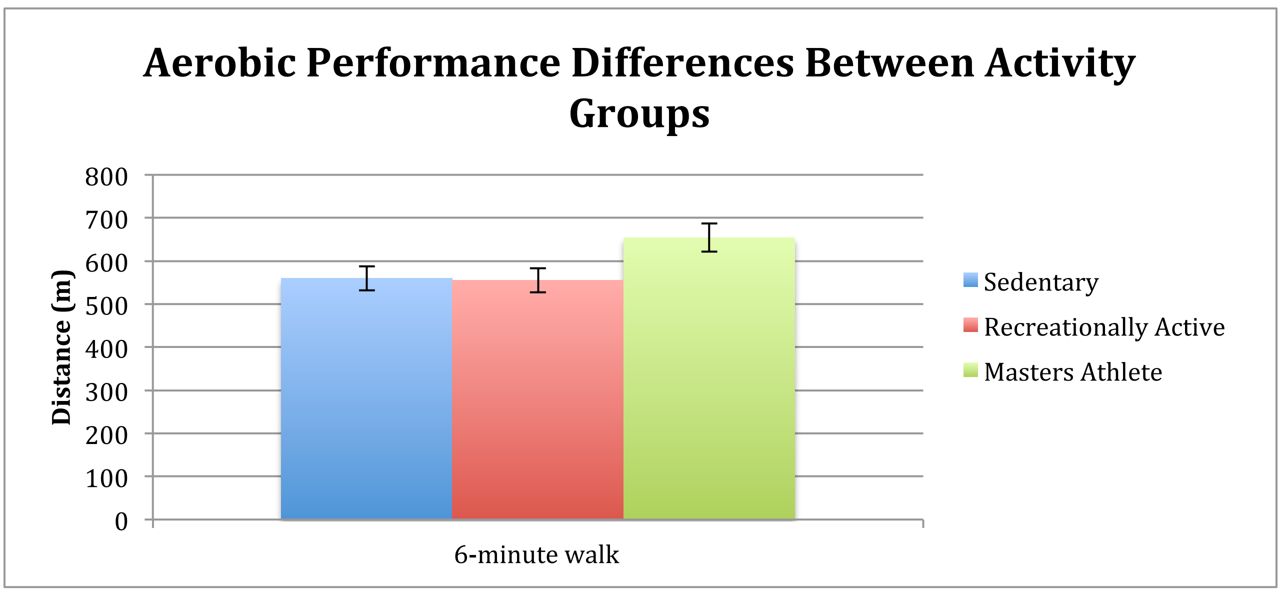

Figure 3. This graph shows the differences in aerobic performance between activity groups as assessed by the 6-minute walk test. Based on total averages in each group, the masters athletes walked the farthest within the 6-minute time interval and thus had greater aerobic performance. The sedentary and recreationally active individuals did not differ as much in regard to aerobic capacity.

Hypothesis One Results

The first aim of this study examined differences between simple and choice reaction time between masters athletes, recreationally active, and sedentary older adults via completion of the reaction time test with the MoART reaction time panel. It was hypothesized that that the masters athletes would have the fastest reaction time followed by the recreationally active older adults and then sedentary adults. One-way ANOVA indicated no statistical differences between activity groups for simple reaction time (p= .09) and for choice reaction time (p= .14). However, the scores showed a trend toward clinical relevance between the sedentary and masters athlete groups (p= .41) and between the recreationally active and masters athlete group (p= .08). It is relevant for clinical use because it hints at a positive relationship between exercise and cognition.

Hypothesis Two Results

The second aim of this study examined the dual-task performance difference between masters athletes, recreationally active, and sedentary older adults; specifically, statistical analysis examined the dual-task decrement speed to account for inter-individual differences in gait speed. It was hypothesized that the masters athletes would have the best dual-task performance followed by the recreationally active older adults and then sedentary adults. One-way ANOVA analysis indicated no statistically significant difference in habitual dual-task decrement speed (p= .10) or fast dual-task decrement speed (p= .10) between activity groups. Although there are no significant differences among habitual and fast dual-task decrement speeds, the difference among activity levels indicated trends. When comparing sedentary individuals to recreationally active, there is less of a difference in habitual dual-task decrement speed (p= .36) than when comparing sedentary individuals to masters athletes (p = .12). Similarly, when comparing sedentary individuals to recreationally active, there is also less of a difference in fast dual-task decrement speed (*p*= .28) than when comparing sedentary individuals to masters athletes (*p*= .13). This means that the sedentary individuals and masters athletes had the greatest differences, and thus the less active a person was the worse they performed on cognitive testing. Although there is no significant relationship, the results from this study indicate a trend toward clinical relevance and greater variation of dual-task decrement speed between activity groups.

Summary

Results of all analyses indicate no significant differences with reaction time and dual-task performance scores between activity groups. Thus, the hypotheses were not supported by the findings of the study.

Discussion

The objective of this study was to compare reaction time and dual-task performance between masters athletes, recreationally active, and sedentary individuals. Results of this study partially support both hypothesis one and two. Even though there was not a statistical significance in the dual-task performance and reaction time tests between activity groups, there was a trend showing there could be a statistical significance between groups with the masters athletes having better dual –task performance and faster reaction time if the population size was greater.

Hypothesis One

The first hypothesis that the masters athletes would have the fastest simple and choice reaction time was not statistically supported by the results of the study. Spirduso and Clifford (1978) found that exercise significantly influenced cognitive measures such as reaction time. Their results indicate that exercise has a positive influence on cognitive performance. In the present study, since there was a trend showing clinical relevance between the sedentary and masters athletes groups, it is likely that the smaller sample size may be the reason that a stronger congruence was not found between activity groups. The question remains as to what extent exercise influences cognition.

Hypothesis Two

The second hypothesis that the masters athletes would have the best dual-task performance was not statistically supported by the results of the study. One-way ANOVA indicated no significant correlation between masters athletes, recreationally active, and sedentary individuals. However, the results presented a greater decrement between the masters athletes and sedentary individuals compared to sedentary and recreationally active individuals for both the habitual and fast paced dual-task decrements, indicating that hypothesis two may have been more strongly supported if there was a larger sample size. In comparison to other research, there should have been a statistically significant trend in the differences between activity groups.

Limitations

Despite the results not having statistical significance, the numbers at least show the trend that would support the hypothesis that masters athletes have the fastest reaction time and best dual-task performance. In order to adequately determine these relationships in the data, more participants were needed. Ideally, having at least 30 individuals in each category (90 participants total) may have sufficed to achieve more significant trends. With even more individuals, however, an even greater statistical significance probably would have emerged. Having such a small sample size hindered our results overall. Ideal recruitment would have been to get at least 30 individuals in each activity group to participate in the study. The small sample size was due to difficulty in finding subjects who were willing to participate in the study since there was no compensation offered for participation as well as finding availability for subjects since most appointments were scheduled on weeknights.

Another limitation to the study was not giving a more clear definition for the difference between the recreationally active individual and masters athlete. Since we defined the masters athlete as being an individual who participated in a sanctioned event in the past 6 months, we did not take into consideration the fact that this individual may not actually be more physically active than someone who is classified as recreationally active in the study. The results taken from the third one-way ANOVA indicated that the difference in aerobic fitness from performing the 6-minute walk test was not statistically significant between the groups, $p = .85$. This indicates that the fitness levels of our independent variables (masters athlete, sedentary, and recreationally active) were more similar than originally hypothesized. This limited our data because the more similar our groups are based on activity level, the less the results will be able to show differences. In order to see if certain levels of exercise affect cognition, the activity groups must be well defined and differ in ability enough to show that trend. A greater difference in cognitive measures between the differing activity levels would lead to the conclusion that exercise plays an important role in improving cognition. Similar to the cognitive measures, however, there was a trend showing the masters athletes overall walked a greater distance than the recreationally active and sedentary individuals, indicating that differences in activity levels were still present even though our criteria for classifying individuals in each group was not as effective as it could have been. Our results could have shown a greater difference between activity groups if the definition of the masters athlete was corrected. It could be corrected by using different criteria than what was used. For this study, a masters athlete was defined as an individual who competed in a sanctioned event in the previous six months as well as participated in at least 150 minutes of physical activity per week.

For a future study, I recommend that a fitness test such as the 6-minute walk test be considered more heavily than a questionnaire such as the RAPA in order to ensure the individual is placed in the correct activity group. Additionally, using a VO_2 max test would be an even more accurate way of sorting individuals into their appropriate activity group. Another way of indicating the difference between a recreationally active individual and masters athlete would be to ask about their mindset on competitiveness. If their goal is to compete, they should be considered a masters athlete since someone with a competitive mindset would treat the tests differently than someone who does not have that same competitive drive. Lastly, gender differences were not accounted for in this study. In the sample population, we did not recruit an equal number of women and men in the study as we had 32 women and 27 men total that participated. Future studies should consider examining sex differences among cognitive measures such as dual-task performance and reaction time.

Conclusions

The results of this study indicate that there are no significant differences among the activity groups (masters athletes, recreationally active, sedentary) when comparing cognitive measures (reaction time and dual-task performance). Thus, the relationship between cognition and exercise remains unclear. Although there was no statistical significance, the results indicate that there would be more significant trends with a larger population size. Thus, it is reasonable to suggest that the study showed a slight positive correlation between exercise and cognition due to the more prominent differences in cognitive measures between the masters athletes and sedentary individuals. We asked the question, “Do higher activity levels benefit cognitive performance as assessed by reaction time and dual-task performance among older adults?" This study cannot confirm the answer to this question, but it can at least show subtle trends in answering that question with a "yes". These results underscore the need for more studies with an even greater population size that can better resolve the link between exercise and its effects on the cognitive measures of reaction time and dual-task performance. Future studies should also consider comparing males and females in cognitive measures to account for any discrepancies as well as using an aerobic test to determine a subject's activity group. Overall, our results suggest that the more trained an individual is, the higher the cognitive capacity they maintain. Thus, older adults must learn to stay physically active throughout the aging process and develop good exercise habits in order to slow cognitive decline.

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