Evidence of an association among age-related changes in physical, psychomotor and autonomic function

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Abstract

Background: autonomic modulation of the heart, as measured by heart rate variability, is directly associated with cardiorespiratory fitness and inversely associated with all-cause mortality. The extent to which cardiorespiratory fitness and heart rate variability are related in older adults is difficult to ascertain due to difficulties in assessing physical fitness among older age groups.

Objective: to examine heart rate variability and measures of physical function, thereby allowing for the inclusion of a greater cross-section of older adults than can be tested using traditional fitness tests.

Methods: 39 older adults (mean age: 73.2 ± 8.1 years; range = 60–93 years) underwent evaluation of short-term (5 min) heart rate variability and performance of the American Alliance for Health Physical Education Recreation and Dance Functional Fitness Assessment for Older Adults. Pearson correlation, stepwise multiple regression, and factor analysis were used to describe associations among age, heart rate variability, and functional fitness test-items.

Results: significant associations were observed for age and the standard deviation of all normal RR intervals \( (r = -0.39, P < 0.01) \), and the American Alliance for Health Physical Education Recreation and Dance cardiovascular endurance \( (r = 0.45, P < 0.01) \), strength \( (r = -0.53, P < 0.001) \), agility \( (r = 0.80, P < 0.001) \), and coordination \( (r = 0.57, P < 0.001) \) items. Standard deviation of all normal RR intervals was negatively associated with the American Alliance for Health Physical Education Recreation and Dance agility \( (r = -0.37, P < 0.01) \) and coordination \( (r = -0.49, P < 0.01) \) items. Stepwise multiple regression included only the American Alliance for Health Physical Education Recreation and Dance coordination performance in predicting standard deviation of all normal RR intervals [standard deviation = 63.98 ± 2.5 (coordination), \( F = 33.9, P < 0.01 \)]. Factor analysis revealed that age, agility, and coordination comprised one factor with a high degree of commonality.

Conclusion: the association between heart rate variability and coordination suggests concurrent aging of autonomic and psychomotor function.

Keywords: heart rate variability, physical function, physical fitness

Introduction

Autonomic nervous system modulation of the heart appears to deteriorate with age, as evidenced by reports of age-related reductions in heart rate variability (HRV) [1–6]. The physiological correlates of HRV have recently been reviewed by Berntson et al. [7]. In short, when expressed as the standard deviation of successive inter-beat intervals, HRV provides an index of vagal modulation of the heart. In addition, high-frequency modulations of the heart rate are also associated with vagal modulation of the heart, and low-frequency modulations provide index of mixed sympathetic and vagal control (see Berntson et al. [7] for a review). While evidence indicates that chronological age is associated with reductions in overall HRV, there appear to be no changes in the relative size of the low- and high-frequency power bands [2, 6, 8], suggesting age-related reductions in both sympathetic and parasympathetic modulation of the heart.
The extent to which age-related changes in autonomic modulation of the heart are due solely to age, and not other influences such as sedentary lifestyle and the concomitant effects on physical fitness, is not clear. Only a small number of studies have examined fitness and HRV in older adults, with the majority having identified a positive association between total HRV and aerobic capacity among healthy older adults [1, 3, 5, 9]. In addition, only Byrne et al. [1] included the spectral analysis of HRV in an older adult population, having reported no association of low- or high-frequency power with cardiorespiratory fitness.

One obstacle that has hindered efforts to elucidate the influence of fitness on physiological function in older adults is the technical difficulty in obtaining reliable measures of physical capacity in older adults. Traditional laboratory measures of fitness, such as maximal oxygen consumption, operationally define fitness as maximal work capacity. However, even among highly functional older adults, graded exercise tests have commonly failed to result in subjects achieving a ‘true’ maximal effort. This issue is addressed at greater length by Rikli and Jones [10].

Consequently, tests of physical function have been gaining popularity as alternatives to traditional laboratory measures of physical fitness. These tests, while validated against established laboratory methods, assign greater meaning to one’s ability to successfully accomplish activities of daily living and instrumental activities of daily living, as opposed to maximum work capacity. Presumably, one of the benefits of employing functional fitness tasks is that this approach facilitates the inclusion of a greater array of older adults, including many who otherwise could not successfully perform traditional ‘maximal’ work tests.

The general purpose of this investigation was to examine the relationships among age, fitness, and autonomic modulation of the heart in older adults, with the unique contribution of the study being the utilisation of functional fitness tasks. For the purpose of this investigation, functional fitness was defined as performance on the American Alliance for Health Physical Education Recreation and Dance (AAHPERD) Physical Functional Ability Test for Adults 60 years of Age and Older [11]. This test battery provides test items that have been validated as indicators of body composition, flexibility, agility and dynamic balance, coordination, muscular strength and endurance, and cardiovascular endurance.

Based on the results of previous studies, it was hypothesised that age would be inversely related to total HRV (but not spectral parameters) and performance on functional fitness tests. Moreover, inasmuch as the AAHPERD cardiovascular endurance item has been validated against tests of aerobic capacity, it was hypothesised that performance on this particular item would be positively associated with total HRV (but not spectral parameters).

**Methods**

**Participants**

Fifty-five adults 60–93 years of age (mean age $= 73.2 \pm 8.1$ years) responded to an invitation to participate in this study and subsequently provided written informed consent to participate. The invitation specifically targeted seniors who were not currently taking medication for cardiovascular diseases. Nonetheless, all respondents were screened for previous health history so as to exclude any individuals taking vasoactive medications or those with the presence of any disease or condition that would place the individual at high risk for adverse responses to exercise [12]. Of the 55 respondents, 41 met all of the requirements for participation in the study (28 female, 13 male) participants. Of the 14 respondents who were excluded, 12 were taking anti-inflammatory medications on a daily basis, and two were receiving medical management for the treatment of hypertension. The age range of the remaining 41 participants remained at 60–93 years.

Twenty-six of the participants reported a history of stable cardiovascular diseases (including mild hypertension and ischaemic heart disease), but none had a history of chronic heart failure, stroke, or myocardial infarction. Twenty-three participants reported a history of osteoarthritis, and eight reported a history of degenerative disc problems. Nineteen of the 41 participants reported the presence of two or more of these conditions. Many of the participants reported taking aspirin once daily, but discontinued use on the days of data collection.

**Instruments**

**Health screening**

The Health Status Questionnaire [13] was used for initial screening of the respondents. Medical histories were obtained where clarification was needed.

**Electrocardiographic tracings**

The Biopac 100 mpw and Acqknowledge software (Santa Barbara, CA) were used to collect and analyse the ECG data.

**Functional fitness testing**

The AAHPERD physical function test for adults over 60 years of age [14] was used to measure physical fitness. This battery of field-tests includes measures of flexibility, muscular strength and endurance, agility/balance, coordination, aerobic endurance, and ponderal index. This collection of test items has been validated for use in older adults [11] and each of these items has demonstrated
HRV and physical function

The flexibility test is the standard sit and reach test wherein the participants are seated with their heels 12 inches apart and on a line perpendicular to a measuring tape. The participants are asked to reach with both hands as far along the measuring tape as they comfortably can while keeping both knees straight. The score is the tape measure mark for the best of three trials.

The muscular strength and endurance task requires female participants to lift a 4 lb object and male participants to lift an 8 lb object, using a biceps curl motion, as many times as possible in 30 seconds.

For the agility task, participants started from a seated position and were asked to rise from a chair, walk around a cone located 6 feet to the left of and 5 feet behind the chair, return to the seat and sit down, stand again, walk around a cone 6 feet to the right of and 5 feet behind the chair, return to the seat and sit down, and then repeat the entire procedure. The participants were given two trials, and the raw score represents the faster of the two trials.

The coordination test involved the movement of three 12 ounce ‘soda-pop’ cans using the dominant hand. The cans were placed on a table, top-side-up and on a line indicated by a 30 inch length of masking tape. The cans were 10 inches from one another. The participants were seated at the table with the line of cans well within their grasp. The participants were then asked to perform two trials wherein they were asked to place each can top-side-down in a space adjacent to its original position but 5 inches closer to the next can on the line. Then the participants returned the cans to their original top-side-up position. Each trial consisted of performing these movements twice, and the raw score reflects the faster of two trials.

The aerobic endurance test was an 880-yard walk for time.

The ponderal index, a height-weight ratio, was computed as an index of body composition.

The AAHPERD provides a set of standardised instructions that were read to the participants in preparation for the performance of the test items [11]. Moreover, the agility, coordination, and strength and endurance tasks involve one or more practice trials, which were provided. For a more comprehensive discussion of the AAHPERD test items please see Osness et al. [11].

Procedures

All of the procedures described herein were approved by the institutional review board of the host site. Each respondent was instructed to arrive at the laboratory for the purpose of obtaining written informed consent and for the administration of the Health Status Questionnaire. Upon passing the health screening, medical records and physician consent were requested from the respondent’s primary-care physician. Once these items were obtained, and documentation indicated that the respondent met the criteria to be included in the study, the respondent was invited to participate in two additional testing sessions. During the first testing session, each participant performed the AAHPERD Physical Function Test. The participant was then asked to arrive at the laboratory 48–72 hours later for the collection of ECG data. Both sessions were held in the morning between 8.00 and 11.00 am. Furthermore, for the ECG data collection, each participant was asked to arrive at the laboratory 12 hours post-prandial (including caffeine), and 12 hours post-medication of any kind.

Assessment of HRV

The participant was instructed to lie supine for a 15-minute period of quiet rest. Immediately following this period, 5 minutes of continuous ECG data were collected at a sampling frequency of 500 Hz. The ECG data were then analysed for HRV in accordance with the guidelines set for by the European Society of Pacing and Electrophysiology [15] and in accordance with the recommendations of Berntson [7]. The raw ECG data were visually inspected for non-sinus beats, which, when found, were extracted from the data set and replaced with interpolated values so as to maintain the integrity of the time series. Non-sinus activity occurring at a frequency greater than 6 ectopic beats per minute would have resulted in excluding the participant from the study. The raw data were converted to tachograms of successive RR intervals, which were resampled at 4.0 Hz. MATLAB 6.3 (Mathworks, Natick, MA) was used to compute mean heart period (RR), standard deviation of all normal RR intervals (SDNN), and frequency domain parameters. High-frequency power (0.15–0.40 Hz), and low-frequency power (0.04–0.15 Hz) were derived and reported in normalised units (HFnu and LFnu, respectively). HFnu is thought to be a reliable index of relative contribution of vagal modulation of the heart, while LFnu is thought to reflect mixed sympathetic and parasympathetic modulation of the heart [7, 15]. The normalised units reflect the relative contribution of the low- and high-frequency power bands to the total power minus ultra and very-low frequency power (e.g. LFnu=LF/[total –(ULF + VLF)]). The LF/HF ratio is also reported as it purported to be an index of sympathovagal balance [7, 15]. As frequency domain HRV data are not interval data, they frequently violate assumptions of normality, in which case natural log transformations of the data were to be made.

Data analysis

Relationships among all variables (age, mean RR, SDNN, HFnu, LFnu, LF/HF, and the AAHPERD test items) were examined using Pearson interclass correlation. Wherever multiple items related to HRV indices, stepwise multiple regression and factor analysis were employed to examine the relative weights and unique predictive value
of the items associated with HRV indices. Alpha was set a-priori at \( P<0.05 \), and where functional fitness measures were concerned, alpha was adjusted using the Bonferroni equation for multiple comparisons, to \( P<0.01 \).

**Results**

Complete data were obtained for 39 participants \( (n=39) \). Two participants did not complete the 880-yard walk, and therefore are not included in the results. The descriptive statistics for these participants can be found in Table 1.

Significant correlation coefficients were observed for age and SDNN \( (r=-0.39, P<0.01) \), and the AAHPERD cardiovascular endurance \( (r=0.45, P<0.01) \), strength \( (r=-0.53, P<0.001) \), agility \( (r=0.80, P<0.001) \), and coordination \( (r=0.57, P<0.001) \) items. The association between age and mean RR interval was \( r=-0.31, P=0.07 \). These associations are depicted in Figure 1a-f. The endurance, agility, and coordination items are time to completion tasks. Therefore, the positive correlation coefficients indicate that physical functional performance deteriorated in an age-related fashion, as did total HRV. Moreover, SDNN was negatively associated with the AAHPERD agility \( (r=-0.37, P<0.01) \) and coordination \( (r=-0.49, P<0.001) \) items, as illustrated in Figure 2a-b. Again, these AAHPERD items are time to completion tasks, thus the negative correlation coefficients indicate that better performances were associated with greater HRV. Spectral parameters of HRV \( (\text{lnLFnu}, \text{lnHFnu}, \text{and ln LF/HF ratio}) \) were not associated with age or performance on any of the AAHPERD tasks.

Stepwise multiple-regression revealed that the strongest predictor of SDNN was the AAHPERD coordination performance. Neither age, nor agility scores added significant predictive value to the regression: \( \text{SDNN} = 63.98-2.5 \) (coordination), \( F=33.9, P<0.01 \). The remaining partial correlation coefficients were age: \( r=-0.21, F=1.5 \); and agility: \( r=-0.9, F=0.3 \). Factor analysis revealed that age, agility, and coordination comprised one factor with a high degree of commonality. The unrotated factor coefficients were 0.87, 0.91, and 0.85, respectively.

**Discussion**

The purpose of the present investigation was to examine relationships between age, functional fitness, and HRV in a group of older adults. The values observed for the functional fitness scores and the HRV data are as expected. The distributions of AAHPERD scores match up reasonably well with the age-based normative data provided by Osness et al. [11], with most of the individual scores falling in the 'normal' range. The few exceptions to this involved two participants who did not complete the 880-yard walk, and five cases where the agility scores fell only marginally into the 'low' range of values. Furthermore, the presupposed age-related changes in functional fitness are evident and in agreement with the normative data from Osness et al., as well. The HRV data are consistent with other reports of relatively healthy older adults. For example, Demeersman [3] examined HRV in highly functional adults up to age 83, and observed time domain values (SDNN) for heart rate variability perfectly in line with those observed in the present investigation.

The results of the present investigation support the hypothesis that HRV would be inversely related to age. The decrease in SDNN with no change in the relative contribution of spectral parameters is suggestive of no change in sympathovagal balance. Such findings are consistent with the results of Craft and Schwartz [2], Tullpo et al. [5], and Wood et al. [6]. The cause of the age-related reduction in modulation of the heart is not well

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**Table 1. Descriptive statistics**

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Standard deviation</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age</strong></td>
<td>73.2</td>
<td>8.1</td>
<td>60</td>
<td>93</td>
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<tr>
<td><strong>Height (cm)</strong></td>
<td>167.6</td>
<td>11.2</td>
<td>154.9</td>
<td>188.0</td>
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<tr>
<td><strong>Weight (kg)</strong></td>
<td>77.7</td>
<td>15.5</td>
<td>58.6</td>
<td>114.5</td>
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<td><strong>Functional fitness scores</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ponderal index</td>
<td>12.0</td>
<td>0.6</td>
<td>10.4</td>
<td>13.1</td>
</tr>
<tr>
<td>Flexibility (inches)</td>
<td>23.9</td>
<td>4.2</td>
<td>13.0</td>
<td>34.0</td>
</tr>
<tr>
<td>Agility/balance (s)</td>
<td>29.5</td>
<td>8.1</td>
<td>17.2</td>
<td>57.0</td>
</tr>
<tr>
<td>Coordination (s)</td>
<td>12.2</td>
<td>2.8</td>
<td>9.9</td>
<td>26.0</td>
</tr>
<tr>
<td>Muscle strength and end (repetitions)</td>
<td>21.2</td>
<td>6.5</td>
<td>13.0</td>
<td>38.0</td>
</tr>
<tr>
<td>Cardiovascular endurance (s)</td>
<td>526.3</td>
<td>77.0</td>
<td>384.7</td>
<td>737.0</td>
</tr>
<tr>
<td><strong>Heart rate variability</strong></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>RR interval (ms)</td>
<td>873.9</td>
<td>122.4</td>
<td>719.0</td>
<td>1196.2</td>
</tr>
<tr>
<td>SDNN (ms)</td>
<td>33.1</td>
<td>14.9</td>
<td>11.4</td>
<td>70.8</td>
</tr>
<tr>
<td>LF power (nu)</td>
<td>32*</td>
<td>19</td>
<td>18</td>
<td>74</td>
</tr>
<tr>
<td>HF power (nu)</td>
<td>68*</td>
<td>19</td>
<td>26</td>
<td>82</td>
</tr>
<tr>
<td>LF/HF ratio</td>
<td>0.5*</td>
<td>0.9</td>
<td>0.2</td>
<td>2.9</td>
</tr>
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</table>

*Median score.
understood. To date, age-related changes in sympathetic control of the heart have been attributed primarily to a down regulation of beta-adrenergic receptors and an alteration in post-receptor activity, namely a lower G-protein activity (see Lakatta [14] for a review). The mechanisms leading to a reduced vagal control of the heart with advanced age are less clear. It does not appear that cholinergic receptor reactivity is inhibited with age (see Lakatta). Other possibilities include alterations in efferent (vagal) nerve traffic, afferent (sensory) input, and/or integration of information at the cardiorespiratory centre of the brain. It should also be mentioned that these potential sources of variation have not been ruled out as sources of age-related changes in sympathetic control of the heart.

It was hypothesised that the cardiovascular endurance item of the AAHPERD test would relate to HRV. The data from this investigation do not support this hypothesis as evidenced by a mild but non-significant relationship between performance on the cardiovascular endurance test and SDNN ($r = -0.27$), and no appreciable association whatsoever between cardiovascular test scores and spectral parameters of HRV. These results, while in contrast to our hypothesis, are not altogether surprising. Given the relative good health of this study sample, it is quite possible that the discriminatory power of the time to complete an 880-yard walk was somewhat weak, thereby explaining its mild, but non-significant association with SDNN.

What was surprising about the present study, however, was the appearance of a strong relationship between SDNN and performance on the coordination item of the AAHPERD test battery. The association was of such strength that stepwise multiple regression on SDNN revealed that coordination was the strongest predictor and that no other test variables added predictive strength to the regression, including age. The coordination task is a psychomotor task, and it is difficult to reconcile the
relationship between psychomotor function and autonomic modulation of the heart in the context of the present understanding of aging of the heart, as the concurrent aging of these systems has not been investigated. However, it is thought that central motor planning influences autonomic activity [16, 17]. Therefore central deterioration, which appears to contribute to age-related behavioural slowing [18, 19] may be congruent with age-related decrements in autonomic modulation of the heart. There are at least two studies that are congruent with such a hypothesis. Sandroni et al. [20] and Toichi et al. [21] have reported neurological and psychotic disorders that affect cognitive function (e.g. non-familial cerebellar disorders, schizophrenia) are accompanied by autonomic dysfunction, typically marked by poor parasympathetic control.

The association between psychomotor function task and HRV identified in the present investigation may be of importance in deciphering the cause of age-related changes in autonomic modulation of the heart. It is difficult to speculate as to whether these changes appear as a result of changes in the autonomic nervous system per se, the heart itself, or other yet to be identified mechanisms (e.g. blood volume). There is some evidence that receptor function changes with time, and that this has some biological plausibility as an explanation for the deterioration in HRV with age. However, this does not preclude the possibility of age-related changes within either the cardioregulatory centre of the brain or in the behaviour of the afferent and/or efferent traffic leading to or emanating from the cardioregulatory centre or higher brain centres. The observation of an association between psychomotor and autonomic performance in older adults may be evidence that age-related changes in autonomic modulation of the heart are likely to involve, at least to some degree, mechanisms other than those related to myocardial receptor behaviour.

While these data also provoke a discussion regarding the nature of a possible link between autonomic and psychomotor aging, such inferences must be tempered in light of possible limitations as to the meaning of the age-related slowing of the psychomotor task. While information-processing delays are likely to be involved in age-related psychomotor slowing, neuromuscular slowing is also known to contribute to this phenomenon [22]. Moreover, we cannot exclude the possibility that the observed slowing of the psychomotor task may have been, even in part, due to age-related differences in the comprehension of the task.

In conclusion, the present investigation failed to reveal an association between functional tests thought to rely on cardiorespiratory performance and autonomic modulation of the heart in older adults. However, the appearance of a relationship between the coordination task of the AAHPERD test and overall HRV is a unique finding of this investigation that may further our understanding of age-related changes in autonomic function. Future investigations should attempt to further clarify the possibility of concomitant aging of psychomotor and autonomic motor control processes.

Key points

- Autonomic modulation of the heart is inversely associated with age.
- Autonomic modulation of the heart is directly associated with physical function.
- Surprisingly, psychomotor function is closely associated with autonomic control of the heart.

References


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