Aged Men Experience Disturbances in Recovery Following Submaximal Exercise

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Background. Physiological responses to exercise of moderate intensity and duration among aged compared to young adults have yet to be clearly defined. Further, the effects of aging on the rate and effectiveness of postexercise recovery are unknown.

Methods. Here, selected physiological responses during and following exercise of the same relative intensity were examined in untrained young and aged men.

Results. Generally, the two groups displayed similar responses during 30 minutes of exercise. During recovery, however, numerous age-related differences were manifested. Relative heart rate (% peak) was higher during recovery among the aged group. Postexercise lactate remained increased longer among aged men, and blood glucose regulation was impaired during recovery. This difference in circulating glucose was associated with insulin responses whereby young, but not aged men experienced a postexercise spike. Unlike that in young men, rectal temperature among aged men continued to increase through the entire recovery period.

Conclusions. These data suggest that aged men encounter problems in recovering from submaximal exercise.

Virtually every major health organization in the United States, including the Centers for Disease Control and Prevention, the National Institutes of Health, the US Surgeon General’s Office, and the American College of Sports Medicine, recommends that aged persons (≥65 years old)—who represent the fastest growing segment of American society—regularly participate in exercise (1–4). Among the health benefits derived by aged persons as a result of cardiovascular conditioning are reductions in the incidence and severity of risk factors associated with heart disease [e.g., hypertension, hypercholesterolemia (5–9)], improved insulin sensitivity (7,8,10), decreased risk of some cancers (11,12), improved body composition (13–15), and maintenance of bone mineral density (16,17).

To achieve these benefits, older individuals are advised to adhere to the same exercise prescription guidelines as those developed for younger individuals (18). That is, present exercise recommendations for intensity, duration, and frequency of exercise do not differ for young adult and aged populations. Yet, there has been surprisingly little investigation directly quantifying and comparing physiological responses to submaximal exercise bouts, as presently prescribed to improve health, among young and aged persons. Moreover, there are even fewer data available that document the rate of postexercise recovery in young and aged individuals. This paucity is troubling because the deleterious effects of aging may be manifested not only during the exercise session itself, but also during the postexercise recovery phase that is included in a properly designed workout, but during which physiological monitoring rarely occurs. Thus, the objective of the present investigation was to monitor physiological responses to, and recovery from, an aerobic exercise session of moderate intensity and duration among young and aged adults. It was hypothesized that during exercise of the same intensity, aged men would demonstrate a greater degree of physiological stress than would young men, and that this age-related difference would persist throughout a postexercise recovery phase.

Methods

Participants

Nine healthy young men and nine aged men possessing no contraindicated medical conditions served as participants; none were on prescribed medications. Neither aged nor young participants were engaged in a formal exercise training program, and as determined by a questionnaire (19), they were similarly active on a recreational and habitual basis. Participants’ descriptive data are displayed in Table 1.

After receiving a verbal description of the investigation, its potential risks, and the experimental procedures to be used, the participants provided written informed consent. All experimental procedures were approved by the Protection of Human Subjects Committee at The College of William & Mary.

Experimental Design

During the first laboratory session, descriptive data for the participants were collected. Measurements included height, weight, and body composition as determined by the Jackson and Pollock formula (20).

Participants then performed a graded exercise test to volitional exhaustion on an electrically braked cycle
ergometer (Excalibur Unit; Lode, Groningen, The Netherlands), Consistent with American College of Sports Medicine guidelines (21), a physician was present during maximal effort cycling of aged participants, and 12-lead electrocardiogram recordings (Philips Page Writer 100 Cardiograph; Philips Medical Systems, Andover, MA) were collected. Age-specific maximal effort test protocols were initially set at 80 W, but increased by 20 W with each successive stage. The protocol completed by aged men began with a 3-minute warm-up at 50 W, followed by 2-minute work intervals and increased by 30 W at each successive stage. The exercise intensity was established within 5 minutes and was maintained throughout the 30-minute exercise session by altering the workload (watts) as needed. At the end of the exercise bout, the participant remained seated on the cycle ergometer for a 15-minute passive recovery period. The same parameters recorded preexercise were also collected during the 15th and 30th minute of exercise, as well as 5 and 15 minutes into recovery. Also recorded at the 15th and 30th minute of exercise was the participant’s rating of perceived exertion (RPE).

**Quantitation**

HR was monitored with a portable telemetry unit (Polar Electro, Woodbury, NY) that was strapped around the participant’s chest. Blood pressure was measured with a sphygmmomanometer (Welch Tycos; Tycos Instruments, Arden, NC) and a stethoscope (Littman Select; 3M Health Care, St. Paul, MN). Mean arterial pressure (MAP) was calculated as the diastolic pressure plus 33% of the difference between the systolic and diastolic pressures. This value represents the average pressure driving blood into the tissue over the entire cardiac cycle (23). Pulse pressure (difference between systolic and diastolic pressures) was also assessed, as this cardiovascular variable is a reliable measure of large artery stiffness (24). Rectal temperature was monitored with a thermistor (model 400; VWR Scientific, Bridgeport, NJ). RPE was assessed with Borg’s original 6–20 point scale (25).

Blood samples were collected into heparin-treated tubes (Vacutainer; BD Biosciences, Franklin Lakes, NJ). Aliquots of whole blood were immediately used for hemoglobin and hematocrit analyses. Hematocrit was assayed in triplicate in microcapillary tubes after centrifugation at 4000 g for 5 minutes. Hemoglobin values were measured in duplicate with an automated meter (Stat-Site M; Stanbio Laboratory, Boerne, TX). Exercise-induced plasma volume shifts were determined from hematocrit and hemoglobin values according to Dill and Costill (26). The remaining whole blood was centrifuged at 3000 g for 10 minutes at 4°C, and plasma was stored at −75°C.

Plasma lactate and glucose concentrations were quantified with a blood chemistry analyzer (Vitros DT 60 II; Johnson & Johnson Clinical Diagnostics, Rochester, NY). Cortisol and insulin concentrations were measured with enzyme immuno assays (EIA) and enzyme-linked immunosorbent assays (ELISA), respectively (Diagnostic Systems Laboratories, Webster, TX), in conjunction with a microplate reader (Multiskan RC; Labsystems, Helsinki, Finland). For each hormone, all samples were quantified on a single microplate to avoid inter-assay variation. Selected samples were run in duplicate; intra-assay variation for each hormone was <10%. Assay sensitivities for cortisol and insulin were 0.1 μg/dL and 0.26 μU/ml, respectively.

**Statistical Analysis**

All data are reported as means ± SE (standard error). Independent t-tests were used to compare descriptive characteristics of the young and aged groups. A two-way, repeated-measures analysis of variance (ANOVA) (2 groups × 5 time points) was used to analyze each parameter of interest. In the event of a significant F ratio, post hoc procedures were used to identify significant differences over time within each group and to detect significant

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**Table 1. Physical Characteristics of Participants**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Young</th>
<th>Aged</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>20.9 ± 0.3</td>
<td>72.9 ± 1.7*</td>
</tr>
<tr>
<td>Height, cm</td>
<td>180.5 ± 2.7</td>
<td>176.9 ± 2.8</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>79.0 ± 4.4</td>
<td>78.7 ± 3.4</td>
</tr>
<tr>
<td>Body composition, % fat</td>
<td>17.4 ± 2.4</td>
<td>27.4 ± 1.8*</td>
</tr>
<tr>
<td>Preexercise heart rate, beats/min</td>
<td>73.9 ± 4.7</td>
<td>70.8 ± 2.9</td>
</tr>
<tr>
<td>Preexercise mean arterial pressure, mmHg</td>
<td>92.1 ± 2.3</td>
<td>95.6 ± 1.2</td>
</tr>
<tr>
<td>Peak heart rate, beats/min</td>
<td>192.8 ± 2.6</td>
<td>161.1 ± 5.7*</td>
</tr>
<tr>
<td>Peak VO₂, ml/kg/min</td>
<td>42.0 ± 2.4</td>
<td>24.2 ± 1.8*</td>
</tr>
</tbody>
</table>

*Significant (p ≤ .05) between-group difference.

Notes: Values are means ± standard error; N = 9/group.
between-group differences at each time point of data collection. Significance was established at \( p \leq .05 \).

**RESULTS**

**Metabolic Variables**

Peak VO\(_2\) data indicate that, despite the similar levels of habitual and recreational activity between the two groups, young men had a significantly greater degree of cardiovascular fitness (42.0 vs 24.2 ml/kg/min). However, during the submaximal exercise sessions participants from both groups maintained the desired work intensity at 15 minutes (64\% and 62\% of peak VO\(_2\) in young and aged men, respectively) and 30 minutes (64\% and 63\% of peak VO\(_2\) in young and aged men, respectively) of exercise. Results from the two-way, repeated-measures ANOVA indicated significant Group (\( p = .0001 \)), Time (\( p = .0001 \)) and Interactive effects (\( p = .0001 \)). Therefore, post hoc tests were completed to determine the location of the significant effects. Both groups demonstrated the same alterations in VO\(_2\) over time. Oxygen uptake was significantly higher at 15 and 30 minutes of cycling than it was preexercise, as well as 5 and 15 minutes postexercise. As expected (given the higher peak VO\(_2\) levels in the young men), the absolute rate of oxygen uptake (ml/kg/min) during the two exercise intervals was greater in young participants than in older ones (26.3 vs 14.7, and 26.2 vs 14.7 at 15th and 30th minute of exercise, respectively). This age-related difference in VO\(_2\) persisted into the recovery phase, although no between-group difference was detected before the onset of exercise.

ANOVA results regarding minute ventilation (\( V_{E} \)) were similar to those of VO\(_2\). Again, statistical significance was identified for Group (\( p < .05 \)), Time (\( p = .0001 \)), as well as Interactive effects (\( p = .0001 \)), allowing post hoc analysis. Across time, exercise-induced increases in \( V_{E} \) mirrored those of VO\(_2\). Both young and aged participants displayed significantly elevated \( V_{E} \) at 15 minutes and 30 minutes of exercise relative to pre- and postexercise values. And as with VO\(_2\), significant between-group differences in \( V_{E} \) (young > aged participants) were identified during cycling (55.1 vs 38.6, and 54.0 vs 41.4 L/min at 15 and 30 minutes of exercise, respectively). However, unlike oxygen uptake, age-related differences in postexercise \( V_{E} \) were not evident.

Evaluation of respiratory exchange ratio (RER) revealed more obvious metabolic disparities between young and aged men. Our ANOVA showed significant Group (\( p = .03 \)) and Time (\( p = .0001 \)) effects. Young participants manifested RER values at 15 minutes of exercise that were significantly higher than at any other time point, including 30 minutes of exercise. In contrast, RER in aged men was significantly higher at 15 minutes and 30 minutes of cycling, as well as 5 minutes postexercise, than it was prior to exercise or 15 minutes into recovery. While RER values at 30 minutes of exercise approached a significant between-group difference (\( p = .07 \)), older men indeed displayed significantly higher RER than young men at both postexercise time intervals. Metabolic data are presented in Table 2.

**Cardiovascular Variables**

The ANOVA results for HR showed significant Time (\( p = .0001 \)) and Interactive effects (\( p = .0001 \)), enabling post hoc procedures. When examined over time within each group, HR responses were identical among young and aged men. Yet, when we directly compared HR measurements, young men exhibited greater values than the aged men did at 15 and 30 minutes of exercise; no differences were noted at pre- or postexercise intervals.

HR was also measured relative to its peak value recorded during the test to establish peak VO\(_2\). Quantified in this way, the two-way repeated-measures ANOVA again revealed significant Time (\( p = .0001 \)) and Interactive effects (\( p = .0002 \)). Post hoc analysis established that young men experienced a significant decrease in relative HR during the interlude from the 5th to the 15th minute of recovery; no such decrement was noted among the aged men. When direct comparisons of relative HR were made at each time point, no significant age-related differences were observed before or during exercise. However, at both 5 minutes and 15 minutes postexercise, the aged group demonstrated a significantly higher relative HR than did the young group (63\% vs 54\%, and 57\% vs 48\% at 5 and 15 minutes postexercise, respectively). Findings regarding HR are presented in Figure 1 (absolute values) and Figure 2 (relative values).

When data on blood pressure (MAP) were examined with ANOVA procedures, significant Group (\( p = .02 \)) and Time (\( p = .0001 \)) effects were identified. Significant between-group differences in MAP were apparent at both 15 and 30 minutes of cycling. At those intervals, MAP in both groups was significantly amplified relative to pre- and postexercise intervals.
recordings, but aged men exhibited significantly higher MAP than did young men. No age-related differences were observed at pre- or postexercise data collection points. Blood pressure results can be found in Figure 3.

ANOVA results on pulse pressure revealed significant Group ($p < .05$) and Time ($p = .0001$) effects. Post hoc analysis showed that the age-related differences observed at rest (aged = 46 mmHg, young = 38 mmHg) were obscured during exercise, i.e., no between-group differences. However, by the 15th minute of recovery, age-related differences in pulse pressure were again apparent. Data on pulse pressure are exhibited in Figure 4.

**Rectal Temperature**

Our ANOVA results on temperature identified a significant Time effect ($p = .0001$). It was found that the rectal temperature of young men was significantly elevated by the 30th minute of cycling and remained so throughout the 15-minute recovery period. As with young participants, older participants also exhibited increased rectal temperature at 30 minutes of exercise, as well as at 5 and 15 minutes postexercise. Yet, unlike young men, the aged men showed continually increasing temperature throughout the 15-minute recovery period. Indeed, among the aged men, rectal temperature was significantly higher at 5 and 15 minutes postexercise than it was at the 15th minute of exercise. But when making direct between-group comparisons, no age-related differences were identified. These data are presented in Figure 5.

**Plasma Lactate**

ANOVA performed on our plasma lactate measurements yielded significant Time ($p = .0001$) and Interactive
effects. Across time, young and aged men demonstrated differences in lactate responses during and after exercise. In the young group, lactate was significantly increased by 15 minutes of exercise and remained so through 5 minutes, but not 15 minutes of recovery. Unlike those of the young men, lactate levels of aged men remained elevated even at 15 minutes postexercise. Only during the 15th minute of cycling, the point at which lactate peaked for young (6.0 mmol/L), but not aged men (4.1 mmol/L), was a significant between-group difference observed. Lactate results are displayed in Figure 6.

Plasma Glucose
Our ANOVA results revealed a significant \( (p = .007) \) interactive effect for plasma glucose concentrations. Over time, young and aged men exhibited distinct glucose responses to the same exercise stimulus. The young group showed no significant glucose alterations during or following 30 minutes of submaximal exercise. But among aged participants, glucose was significantly higher at both 5 and 15 minutes postexercise than it was before exercise. Moreover, only during the recovery period was there any evidence \( (p = .05) \) of an age-related difference in plasma glucose (106 vs 92 \( \mu \)U/ml in aged and young men, respectively). Figure 7 shows plasma glucose data.

Plasma Cortisol
Because this hormone was measured to provide an indication of stress associated with exercise, cortisol values were adjusted for exercise-induced plasma volume shifts to more accurately reveal adrenal secretory rates. Our ANOVA failed to identify any significant effects. That is, neither young nor aged participants experienced significant cortisol alterations over time, and at no time point were
between-group differences observed (data not shown). It is of interest that these same negative results were evident even when circulating cortisol was not adjusted for plasma volume shifts.

**Plasma Insulin**

In contrast to cortisol, the primary interest in measuring blood-borne insulin was to assess its potential impact on glucose regulation by target tissues. Accordingly, insulin values were not corrected for plasma volume shifts. ANOVA results indicated that young and aged men exhibited different insulin responses over the course of the data collection protocol. Specifically, young men experienced significant decrements at 30 minutes of exercise, whereas no such exercise-induced reductions were noted among aged men. Insulin data are presented in Figure 8.

**Perceived Exertion**

Both young and aged participants rated their level of exertion between “fairly light” and “somewhat hard” during cycling exercise. In neither age group was RPE modified over the course of the exercise bout, and at neither 15 nor 30 minutes of exercise were age-related differences manifested (data not shown).

**DISCUSSION**

Current exercise prescription guidelines do not differentiate according to age. Regardless of age, it is suggested that to optimally improve cardiovascular fitness one should exercise at an intensity equivalent to 50%–85% of one’s maximal rate of oxygen uptake for a duration of 20–60 minutes per session (27). Several studies have reported that,
while working for brief periods of near-maximal intensity, aged and young adults demonstrate similar physiological responses (28–31). Less well defined, however, are potential age-related differences in physiological responses during a typical exercise session consisting of moderate intensity and duration that would be featured in a fitness program constructed according to present recommendations. Thus, the present investigation aimed to quantify various measures of physiological stress experienced by young and aged men during, as well as following, an exercise session that would be included in a long-term exercise program designed to maximize cardiovascular fitness and health.

The results presented here suggest that, in general, untrained young and aged men characterized by similar levels of daily physical activity and exercise demonstrate similar physiological responses while exercising at the same relative (60%–65% of peak VO2) intensity. Among metabolic variables, RER—an indicator of exercise intensity—demonstrated age-related differences. In young, but not aged, men RER peaked at 15 minutes of exercise and significantly declined by the 30th minute of cycling. Most notable though, was that following exercise, RER values recovered more quickly among young men than among aged men. This was the first indication of age-specific recovery patterns following exercise of moderate intensity and duration.

The most obvious difference between young and aged men that occurred during exercise (as opposed to recovery) was displayed by the cardiovascular system. At both 15 and 30 minutes of exercise, young men exhibited higher HRs than did aged men. This has been documented by others (29,32), and it has been postulated that the lower HRs noted among aged individuals for a given relative exercise intensity is related to the inexorable decrease in maximal HR that occurs with aging (28,29,33). MAP demonstrated age-specific responses during exercise that were opposite to those of HR. It was determined that blood pressure was
higher among aged men than among young men at both 15 minutes and 30 minutes of cycling. The higher exercise-induced MAP elevations among the aged men may reflect a greater stroke volume to compensate for the diminished HR response (32). Indeed, during exercise systolic blood pressure, like MAP, was greater among aged participants than among young ones, suggesting augmented stroke volumes among aged individuals. Alternatively, the higher blood pressures observed among aged men during exercise may be a consequence of greater total peripheral resistance to blood flow, although typically this is more evident among older women than among older men (29).

In the important cardiovascular measure of relative HR, it was again during recovery, not exercise, that age-related differences were manifested. That is, recovery was more effective in young men, as they experienced a significant decrease in relative HR from the 5th to the 15th minute of recovery. Aged men showed no change during this interval. As further evidence of the greater challenge of postexercise recovery encountered by aged persons, relative HR was higher among the aged men than among the young men at both the 5th and 15th minute of recovery.

Similar to other physiological variables, age-related differences in temperature were most apparent following, not during, exercise. Whereas young men showed successive, if not statistically significant, decrements in temperature throughout the postexercise period, aged men experienced continual increases in temperature during the recovery phase.

The impaired thermoregulation of aged participants following exercise may be related to body composition. Aged men were found to have significantly more body fat than were young men (27% vs 17%), and the insulating effect of subcutaneous fat impairs the body’s ability to dissipate heat (34,35). Thus, increased body fat probably accounted for the thermoregulatory difficulties demonstrated by aged men following exercise (36).

Circulating levels of lactate and glucose also revealed age-specific differences, and again those differences were most obvious following, not during, exercise. The young group’s lactate concentrations continually decreased from the 15th minute of exercise such that, by the end of the recovery period, this marker of muscular stress was no longer elevated from preexercise levels. In contrast, lactate remained significantly increased throughout the 15-minute recovery period in aged men. And as with lactate, age-related differences in plasma glucose responses were most notable during recovery, not during exercise. Unlike those of younger men, glucose concentrations of older participants were significantly higher during recovery than they were prior to the onset of exercise.

These distinct responses of circulating glucose may be linked to age-related differences in plasma insulin concentrations. In young men, insulin was significantly increased from the end of the exercise bout by even 5 minutes postexercise, and remained so throughout the 15-minute recovery period. Conversely, aged participants showed no significant response in plasma insulin following exercise. This inability to rapidly adjust insulin as needed to ensure glucose homeostasis at the conclusion of exercise may account for the glucose elevations identified among older men during recovery.

The other hormone of interest, cortisol, was assessed as an endocrine measure of exercise-induced stress. Neither young nor aged men displayed significant variation of cortisol from base line values throughout the exercise and postexercise time points. In young men, it appears that threshold levels of exercise intensity and/or duration must be reached before significant alterations in cortisol concentration occur (37–39). The moderate intensity and duration of the exercise stimulus presented here was probably insufficient to trigger a response of the hypothalamic–adrenocortical axis. Importantly, the data presented here suggest that such a threshold is well maintained even into old age.

It should be noted that there are several limitations to the present investigation. For example, the number of participants per group (nine) was relatively small primarily because of the difficulty recruiting aged participants who fit the desired profile, i.e., physically active, but not trained, and free of contraindicated medications or medical conditions. Also, the current study included only male participants. To expand on this work, our laboratory is presently conducting a similar investigation of young and aged women. Also, in the study reported here, blood pressure was assessed with standard auscultatory methods, rather than more precise and sophisticated procedures such as direct oscillometry.

All told, the data presented here indicate that it is not during exercise that most age-related differences are evident, but rather during postexercise recovery. Every physiological system examined revealed that the homeostatic mechanisms used during recovery in attempting to counter exercise-induced adjustments were less effective among aged men than among young ones. It is difficult to determine the underlying mechanism(s) that may account for our findings. It is tempting to speculate that differences in cardiovascular fitness (young men = 42 ml/kg/min, aged men = 24 ml/kg/min) may have contributed to age-related disparities in rates of recovery. However, while exclusively examining young participants that demonstrate significant differences in cardiovascular fitness in our laboratory, it was noted that regardless of peak VO₂, these young individuals recovered equally well following the same exercise stimulus used here (our unpublished observations). This finding suggests that aging itself is responsible for the difficulties observed among older participants in effectively recovering from exercise-induced responses. Moreover, it is apparent from the data reported here that the aging-related cause(s) is overarching, because numerous physiological systems experienced delays or disturbances in postexercise recovery dynamics.

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