Cerebral Blood Flow during Interval and Continuous Exercise in Young and Old Men

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ABSTRACT

KLEIN, T., T. G. BAILEY, V. ABELN, S. SCHNEIDER, and C. D. ASKEW. Cerebral Blood Flow during Interval and Continuous Exercise in Young and Old Men. Med. Sci. Sports Exerc., Vol. 51, No. 7, pp. 1523–1531, 2019. Purpose: Aging is associated with impaired cerebral blood flow (CBF) and increased risk of cerebrovascular disease. Acute increases in CBF during exercise may initiate improvements in cerebrovascular health, but the CBF response is diminished during continuous exercise in older adults. The effect of interval exercise for promoting increases in CBF in young and old adults is unknown. Methods: We compared middle cerebral artery blood velocity (MCAv), end-tidal CO₂ (PETCO₂) and blood pressure (mean arterial pressure [MAP]) during intensity- and work-matched bouts of continuous (10-min 60% Wmax) and interval (10 × 1-min 60% Wmax, separated by 1-min rest) exercise in 21 young (25 ± 3 yr) and 10 old (69 ± 3 yr) men. Results: Middle cerebral artery velocity was higher during continuous compared with interval exercise in the young (P < 0.001), but not in the old. This trend was also seen for changes in PETCO₂. Although absolute MAP was higher in the old, the relative rise (%Δ) in MAP was similar between age groups and was greater during continuous exercise than interval. When we assessed the total accumulated change in MCAv (area under curve: exercise + recovery), it was higher with interval compared with continuous exercise in both groups (P = 0.018). Conclusion: These findings suggest that interval exercise may be an effective alternative for promoting acute increases in CBF velocity, particularly in those older adults who may have difficulty sustaining continuous exercise. Key Words: AGING, CEREBRAL PERFUSION, MIDDLE CEREBRAL ARTERY, MCAv, TCD

Aging and age-related neurodegenerative diseases, such as dementia, are associated with a reduction in cerebrovascular function and blood flow (1,2). Habitual exercise delays the age-related reduction in cerebral blood flow (CBF) by as much as a decade in older adults, with resting CBF shown to be 17% higher in active compared with inactive older adults (1).

The primary stimulus for the beneficial effect of exercise on peripheral arterial function is thought to be attributable to the repetitive, acute increases in blood flow and shear stress on the arterial wall (3). Similar increases in CBF, measured as middle cerebral artery velocity (MCAv), are also observed during exercise and likely contribute to positive cerebrovascular adaptations (4). Identifying the type and format of exercise that induce the greatest acute increases in MCAv would help optimize exercise programs for the enhancement of cerebrovascular function (5). This is particularly important in older adults given that the acute increase in MCAv during continuous aerobic exercise is attenuated compared with younger adults (6,7).

Interval exercise is characterized by short bouts of exercise separated by periods of rest or low-intensity recovery. This format of exercise training has become popular for promoting improvements in cardiovascular health, especially in older adults or those with chronic conditions who may have difficulty sustaining continuous exercise (8). Although there is interest in the use of high-intensity interval exercise, MCAv peaks during moderate intensity exercise (~70% VO₂peak) before decreasing toward baseline levels during more vigorous exercise intensities. Therefore, the use of high-intensity exercise to induce greater gains in CBF and shear stress would be counterintuitive (5). Nonetheless, the use of interval exercise at a moderate intensity may offer some advantages over traditional continuous exercise. Although MCAv increases at the onset of steady-state continuous exercise, a progressive increase in ventilation and a downward drift in PETCO₂ lead to reductions in MCAv after the initiation of exercise (9). It is
plausible that frequent rest periods during interval exercise would limit this reduction in \( \text{PETCO}_2 \), leading to a greater (10) or sustained (11) MCAv response at the same intensity of exercise. Moreover, by sustaining elevations in MCAv during short recovery periods, we hypothesized that interval exercise would lead to a greater overall accumulated cerebral flow velocity response compared with continuous exercise.

To date there have been no comparisons of the acute MCAv responses to continuous and interval exercise in younger and older healthy adults. This is important to establish the potential benefits of interval exercise on cerebrovascular health, especially in older adults who exhibit attenuated CBF during exercise (6,7). Therefore, the aim of this study was to compare the MCAv response between intensity- and work-matched bouts of continuous and interval cycling exercise in young and older men.

**METHODS**

**Subjects**

Characteristics of 11 young (age: 25 ± 3 yr) and 10 older (age: 69 ± 3 yr) male participants are summarized in Table 1. Each participant was screened before study entry using ACSM’s general health screening guidelines (12). Participants with hypertension (>140/90 mm Hg), diabetes mellitus, hypercholesterolemia, or diagnosed cardiovascular or cerebrovascular disease were excluded from participation. None of the participants were using prescribed or over-the-counter medications or were current smokers. All experimental procedures conformed to the Declaration of Helsinki and were approved by the research ethics committee of the University of the Sunshine Coast (protocol number S16954). A detailed verbal and written explanation of the study was provided, and before participation written informed consent was obtained from each participant.

**Study Overview**

Participants attended the laboratory on two occasions, separated by 3 to 7 d. Participants attended each visit after an overnight fast, and having refrained from alcohol and physical activity for 24 h, and caffeine for 12 h prior. At the two experimental visits, all measurements were performed on a cycle ergometer (Corival, Lode, Groningen, Netherlands) in an upright-seated position. During the first visit, participants performed a submaximal incremental cycling exercise test. During the second visit, participants performed a bout of continuous cycling exercise at a fixed moderate intensity, and a work-matched bout of interval cycling exercise, in random order. Continuous and interval exercise bouts were separated by 30 min to allow recovery and limit any potential carryover effects (13). Middle cerebral artery blood velocity, mean arterial pressure (MAP), \( \text{PETCO}_2 \) and HR were measured continuously throughout the two visits. Participants were instructed to maintain an upright posture and minimize head and eye movement during exercise to limit signal artifact. Laboratory conditions were standardized for each study visit, and external stimuli minimized. To control for diurnal variation in blood pressure and CBF velocity, each visit for each participant was performed at the same time of day.

**Exercise Protocols**

**Submaximal incremental exercise test (visit 1).** A discontinuous, incremental protocol was used, with each exercise stage of 3 min separated by 1 min of passive recovery. The exercise workload commenced at 0 W and was increased with each stage by 25 W until a HR of 85% of the age-predicted maximum (220 – age) was reached. Pedal cadence was maintained at 60 rpm throughout the test. Based on the linear relationship between HR and workload (W), the slope method was used to determine the predicted maximum workload (\( W_{\text{max}} \)), and the ACSM metabolic equation for cycling was applied to estimate the \( \dot{V}_O_2 \) at \( W_{\text{max}} \) (estimated \( \dot{V}_O_2\text{peak} \)) (14).

**Continuous and interval cycling exercise bouts (Visit 2).** Before each exercise bout, participants sat quietly on the ergometer for a 5-min baseline recording. To ensure a work-matched design, both protocols included a total of 10 min of exercise. The continuous exercise consisted of 10 min of continuous cycling followed by 10 min of seated rest. This duration of exercise is consistent with the minimum periods of exercise recommended for developing and maintaining fitness in healthy adults (15). The interval exercise consisted of 10 × 1-min bouts of cycling, each separated by 1 min of seated rest. The exercise intensity of each bout was set at 60% predicted \( W_{\text{max}} \). Pedal cadence was maintained at 60 rpm throughout the continuous and interval exercise bouts.

**Experimental Measures**

HR was monitored continuously using a three-electrode ECG (Lead-II configuration) (ADInstruments Bio-Amp, Bella Vista, NSW, Australia). Blood pressure was measured continuously at the left middle finger using finger photoplethysmography (Finometer MIDI; Finapres Medical Systems, Amsterdam, The Netherlands), and the left forearm was supported at heart level using a cushion, with the wrist and fingers relaxed. Participants were instructed to keep the arm and hand

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**TABLE 1. Participant characteristics and resting cardiovascular indices.**

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Young (n = 11)</th>
<th>Old (n = 10)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, yr</td>
<td>25 ± 3</td>
<td>69 ± 3</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>79.3 ± 6.3</td>
<td>77.6 ± 9.5</td>
<td>0.65</td>
</tr>
<tr>
<td>Height, m</td>
<td>1.83 ± 0.1</td>
<td>1.75 ± 0.1</td>
<td>0.04</td>
</tr>
<tr>
<td>BMI, kg m⁻²</td>
<td>24 ± 3</td>
<td>25 ± 4</td>
<td>0.25</td>
</tr>
<tr>
<td>SBP, mm Hg</td>
<td>123 ± 10</td>
<td>126 ± 10</td>
<td>0.29</td>
</tr>
<tr>
<td>DBP, mm Hg</td>
<td>67 ± 7</td>
<td>71 ± 6</td>
<td>0.004</td>
</tr>
<tr>
<td>Est. ( \dot{V}_O_2\text{peak} ), mL min⁻¹ kg⁻¹</td>
<td>48.7 ± 7</td>
<td>30.8 ± 8.9</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Baseline cardiac indices</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MCAv (cm s⁻¹)</td>
<td>67.3 ± 9.2</td>
<td>49.9 ± 9.6</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>MAP (mm Hg)</td>
<td>80 ± 12</td>
<td>95 ± 8</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>( P_{\text{ET}}\text{CO}_2 ) (mm Hg)</td>
<td>34.8 ± 3.1</td>
<td>30.9 ± 3.2</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>HR (bpm)</td>
<td>73 ± 12</td>
<td>67 ± 10</td>
<td>0.08</td>
</tr>
</tbody>
</table>

Data are displayed as mean ± SD.

BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; Est. \( \dot{V}_O_2\text{peak} \), estimated peak oxygen uptake; \( P_{\text{ET}}\text{CO}_2 \), partial pressure of end-tidal carbon dioxide.
still throughout the cycling and recovery periods to avoid interference with the finger blood pressure signal. Finger blood pressure was exported to generate beat-by-beat continuous MAP (MAP = 1/3 systolic blood pressure + 2/3 diastolic blood pressure) (16) (ADInstrument, PowerLab 8/35, Bella Vista, NSW, Australia). In addition, systolic and diastolic brachial arterial blood pressure was recorded at rest and before each exercise bout (Carescape V100, Woodley, Bolton, United Kingdom). RPE was assessed every 2 min during continuous and interval exercise using the Borg RPE scale (17).

MCAv was assessed using transcranial Doppler ultrasonography (TCD, Multigon; Neurovision, Elmsford, NY), where a 2-MHz probe was placed over the temporal window. The left and right MCAv signals were identified and tested according to standardized criteria guided by signal depth, velocity and wave characteristics (18,19). The side with the best signal quality, including the highest mean MCAv at rest, was used for testing. The ultrasound probe was fixed at a constant angle and secured with a headband (Multigon, Neurovision, Elmsford, NY), and the signal depth, sample volume and power remained constant throughout the test session after an optimal MCAv signal was established.

Participants breathed through a leak-free respiratory mask (Hans-Rudolph, Kansas City, MO), and expired air was continuously sampled (ADInstrument, PowerLab 8/35) for the determination of PETCO2, MCAv, MAP, PETCO2 and HR signals were sampled at 1000 Hz and stored (LabChart Pro v7.3.7 and PowerLab; ADInstruments). Time-aligned signals were resampled to second by second (1 Hz) for visual inspection and analysis. Baseline data were averaged over the last minute of the resting phase before exercise, and minute-by-minute averages were generated for comparison between exercise conditions. To account for differences in some baseline variables between age groups, responses during exercise were also calculated as the percent change from baseline (%Δ), whereas changes in HR were also assessed relative to the age-predicted maximum (%Δmax). The accumulated MCAv response, including the exercise and recovery periods, was determined for each protocol by determining the area under the curve (AUC) of the absolute delta of MCAv responses from baseline.

Data Analysis

Baseline values did not differ before the continuous and interval exercise tests, and we therefore averaged these data and compared between young and old groups using an independent t-test. The minute-by-minute comparison between continuous and interval cycling exercise was carried out using a three-way mixed ANOVA with the factors age (young vs old), exercise format (continuous vs interval) and time (min 1 to 20). The accumulated MCAv responses (AUC) to continuous and interval exercise were assessed using a two factor (age-exercise format) repeated measures ANOVA. For all ANOVA procedures, post hoc analyses were performed using a Bonferroni correction where there were significant main effects or interactions. Pearson correlation coefficients were calculated to determine the strength of the relationships between the relative mean changes in MAP, PETCO2, HR and MCAv during both continuous and interval exercise in young and old. All data are expressed as means ± SD, and statistical significance was set at P < 0.05. Statistical analyses were performed using Statistica 7.1 (StatSoft, Tulsa, OK).

RESULTS

Participant characteristics and resting cardiovascular indices are shown in Table 1. Resting diastolic blood pressure was higher, and MCAv was lower in the old, compared with the young group. During the incremental exercise test, the young group achieved a peak workload of 243 ± 29 W, which was higher than that achieved by the old group 145 ± 43 W (P < 0.001).

Responses to continuous and interval exercise. Continuous and interval exercise bouts were conducted at the same relative intensity, set at 60% Wmax. This resulted in a higher absolute workload for the young (182 ± 25 W) compared with the older men (106 ± 35 W, P < 0.001). Mean RPE was higher during continuous than interval exercise in both the young (continuous: 13.3 ± 1.3; interval: 11.6 ± 1.3, P < 0.001) and older men (continuous: 14.0 ± 1.2; interval: 11.8 ± 1.13, P < 0.001) and did not differ between the age groups. The minute-by-minute responses of MCAv, MAP, PETCO2 and HR during the 20-min protocols (10-min continuous exercise, 10-min recovery vs 20-min interval) are shown in Figure 1. We observed a three-way interaction for MCAv (P < 0.001, Fig. 1), where MCAv was higher during continuous exercise compared with interval exercise in the young, but not in the older men. Middle cerebral artery blood velocity increased during continuous exercise in both groups and was significantly elevated (P < 0.001) compared with baseline from the first minute of exercise until the first minute of recovery, before returning to baseline values from the second minute of recovery. During interval exercise, MCAv increased during the first minute of exercise and remained elevated (P < 0.001) compared with baseline until the 12th minute of exercise in the old group, and until the 20th minute in the young group. PETCO2, was also higher during continuous exercise in the young, but not different between exercise formats in the old. For each of these variables, there were significant age effects, where absolute values for MCAv, PETCO2 and HR were higher in the young, and MAP was higher in the old. The exercise responses as %Δ are shown in Figure 2. The increase in %ΔMCAv during continuous exercise was greater in the young compared with the old (P < 0.01, Fig. 2).

Total accumulated CBF velocity, measured as AUC of the ΔMCAv responses during the exercise and recovery periods, are shown for each exercise format in Figure 3. In line with our findings above, the AUC of ΔMCAv during exercise was greater during continuous compared with interval exercise in the young (P = 0.001), but not in the old (P = 0.90). The AUC of ΔMCAv during the recovery...
periods was greater during the interval format compared with continuous in both the young and old groups (P = 0.004). This resulted in a total accumulated MCAv response (exercise AUC + recovery AUC) that was higher with interval compared with continuous exercise in both the young and older men (P = 0.018).

Correlations. Mean %ΔMCAv during continuous exercise was strongly correlated with the %ΔMAP (r = 0.74, P < 0.01) and %ΔPETCO₂ (r = 0.75, P < 0.01) in the young group, but not in the old group (%ΔMAP, r = 0.51, P = 0.13; %ΔPETCO₂, r = 0.35, P = 0.32). The mean %ΔMCAv during continuous exercise was not correlated with %ΔHR (%max)
in either age group (young: $r = 0.16, P = 0.62$; old: $r = 0.21, P = 0.55$). During the ten 1-min interval bouts, mean $\%\Delta\text{MCAv}$ was strongly correlated with $\%\Delta\text{MAP}$ ($r = 0.85, P < 0.01$) in the young group, but not in the old group ($\%\Delta\text{MAP}$, $r = 0.45, P = 0.19$). Mean $\%\Delta\text{MCAv}$ was not significantly correlated with $\%\Delta\text{PETCO2}$ ($r = 0.47, P = 0.14$) in the

FIGURE 2—Relative responses to continuous and interval exercise. Middle cerebral artery flow velocity ($\%\text{MCAv; cm s}^{-1}$), $\%\text{MAP (mm Hg)}$, end-tidal carbon dioxide ($\%\text{PETCO2; mm Hg}$). Data are the relative change from baseline averaged for each minute during the continuous (squares) and interval protocols (triangles) in young (Y, black filled) and old (O, open). Dotted line denotes end of the continuous exercise period. Bold numerals on the time-axis indicate the periods of exercise during the interval condition. HR is presented as the averaged responses for each minute relative to the estimated HR maximum. $P$ values represent ANOVA results. Data are displayed as mean ± SD. Symbols are used to show significant exercise-format effects where: * indicates a significant difference between continuous and interval exercise in the young ($P < 0.01$); † indicates a significant difference between continuous and interval exercise in the old ($P < 0.01$).
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ous, and old interval exercise (exercise and recovery AUC compared with young interval exercise, old continuous, and old interval exercise (P < 0.01); # Indicates a significant difference in recovery AUC between continuous and interval, in young and old (P < 0.01).

FIGURE 3—Accumulated AUC of the MCAv responses to continuous and interval exercise, AUC of the change in ΔMCAv during continuous (CONT) and interval (INT) exercise in young (Y) and old (O) adults. Bars represent mean ± SD of the total AUC (exercise + recovery AUC). Filled area represents AUC of the exercise response, shaded (diagonal lines) area represents AUC of the recovery response. $ Indicates a significant difference in exercise AUC compared with young interval exercise, old continuous, and old interval exercise (P < 0.01).

young group, and moderately correlated in the old group (ΔΔPETCO2, r = 0.66, P = 0.03).

DISCUSSION

This study aimed to compare the effects of intensity- and work-matched interval and continuous exercise on the MCAv response in older and younger adults. We found that interval exercise induced similar increases in MCAv compared with continuous exercise in older, but not in young men. In young men, the increase in MCAv was greater during continuous compared with interval exercise. When we assessed the total volume of the response (MCAv AUC) over the duration of exercise and recovery, there was a greater overall change in MCAv during interval compared with continuous exercise in both young and older men.

Consistent with most (6,7), but not all previous reports (20), we observed a lower MCAv at rest and during exercise in older compared with young men. Although interval exercise did not lead to larger increases in MCAv, we have shown that interval exercise is at least as effective as continuous exercise for increasing MCAv in older men. It has previously been suggested that interval exercise, particularly of a high-intensity, may pose a danger in older adults due to the risk that spikes in blood pressure may be transmitted to the brain (5). To the contrary, the prescribed interval exercise used in this study might offer a useful strategy to induce increases in CBF velocity (and shear stress) without excessive rises in blood pressure. The lower perceived exertion during interval exercise in the present study suggests that this may be a more acceptable format of exercise. This is consistent with reports of greater enjoyment by high-intensity interval exercise training compared with continuous exercise training in sedentary adults (21). Interval exercise may be a useful exercise prescription approach for improving cerebrovascular function, particularly in older adults for whom the acute MCAv response is similar to that during continuous exercise.

In the young men, the rise in MCAv during the 1-min exercise intervals was significantly lower than that observed during steady-state continuous exercise. At the exercise intensity used in this study (~60% Wmax), MCAv did not reach its peak until the third or fourth minute of continuous exercise, which is consistent with that reported previously (9,22). It is likely that longer interval bouts of 4 min in duration would lead to a greater MCAv response in the young adults. This prescriptive approach of 4-min exercise intervals separated by 3 min of active rest has been used in healthy and clinical groups, resulting in significant improvements in systolic blood pressure (23), cardiac autonomic and left ventricular systolic function (24,25), and may be superior for peripheral vascular adaptation (26,27). Further research is needed to establish the long-term effects of interval exercise, and the optimal work:rest prescription, on cerebrovascular function in both older and younger adults.

The increase in MCAv during exercise has been shown to be largely driven by increases in PETCO2 and arterial blood pressure (28). In the present study, the higher overall PETCO2 response during continuous exercise (Fig. 2) might explain the higher increase in MCAv compared with interval exercise in the young. This is further supported by the strong correlation between the mean change in %ΔMCAv and %ΔPETCO2 responses during continuous exercise in the young. It has previously been shown that only 50% of the age-associated reduction in MCAv during exercise can be attributed to the %ΔPETCO2 response (7), and we observed no significant relationship between the change in %ΔMCAv and %ΔPETCO2 during continuous exercise in the old. The relative rise in MAP was higher during continuous compared with during interval exercise, and this corresponded with a greater rise in MCAv during continuous exercise in the young, but not in the older men. A similar dampened MCAv response, despite large increase in MAP, has been observed in older adults previously, and might reflect an altered pressure responsiveness compared with young adults (6,7). This is particularly evident when considering the higher absolute MAP reached during continuous compared with interval exercise in the old group in this study, as well as the strong associations between the changes in %ΔMAP and %ΔMCAv during exercise in the young, but not the older men. Further investigation is required to more fully understand the relative influence of changes in MAP and PETCO2 on the dampened MCAv response during exercise in older adults.
Vascular adaptations with exercise training are largely attributed to the repetitive increases in blood flow and shear stress observed during acute exercise (29). Local increases in blood flow and shear stress stimulate an Akt-dependent expression of endothelial nitric oxide synthase, and the subsequent generation of nitric oxide and an acute dilation response (30). With prolonged or repeated exposure to the elevations in flow and shear, structural remodeling of the vessel occurs, including an increase in vessel lumen diameter which effectively normalizes the vessel wall shear in a homeostatic fashion (29). Studies focused on the systemic (e.g., limb) vasculature have manipulated the formats and intensity of exercise to identify those that lead to the highest magnitude of these hemodynamic responses, and those that are likely to induce the greatest stimulus for adaptation (31,32). Our study design provided the opportunity to compare not only the magnitude of the MCAv response but also the total accumulated volume of the blood flow velocity response between exercise formats. We hypothesized that by sustaining elevations in MCAv during the short recovery periods, interval exercise may lead to a greater overall accumulated MCAv response (AUC) compared with continuous exercise. Indeed, we found a higher accumulated MCAv AUC during interval compared with continuous exercise in the old and the young. Whether this total accumulated response (exercise+recovery) is important for future cerebrovascular adaptation is not currently known; however, it would at least suggest that the acute “dose” of the blood flow and shear stress with interval exercise is greater than that achieved with continuous exercise. In a recent investigation where forearm blood flow and shear rate were manipulated using short intervals of cuff occlusion and release over a 6-wk period, it was shown that the vascular adaptations, including an increase in basal blood flow, were greater than that previously reported with continuous exercise or limb heating interventions (33). The authors attributed this to the strong and persistent stimulus achieved with the interval intervention, which lends some support to potential benefits of interval exercise for promoting adaptations in cerebrovascular function and structure. Given that vascular adaptation is largely influenced by the direction of shear stress as well as the magnitude (34), determining the contribution of both antegrade and retrograde CBF to the overall volume response, for example, by assessing shear stress at the internal carotid artery (35), may provide further insight into the CBF responses and the potential benefits of interval exercise for adaptation.

Limitations. There are some limitations of this study to consider. Exercise intensity for the interval and continuous conditions was established based on a predicted maximum workload, which was estimated with the use of an assumed age-limited maximum HR (i.e., 220 – age). Although this approach is commonly used when providing general guidance for exercise prescription, it should be noted that age-based predictions of maximum HR are not precise (36) and may underestimate maximum HR in older adults (37). As the differences in MCAv responses between age groups were very large, it is unlikely that any small error in workload estimates between the groups would have influenced the outcomes. Furthermore, as the absolute workload was fixed across the interval and continuous exercise conditions, the use of an estimated maximum workload has no impact on our findings in relation to exercise format. Higher levels of physical activity and fitness have been associated with higher basal MCAv in some (1,2) but not all (7) previous studies of younger and older adults. Although we did not collect data on the activity status of participants, the higher estimated cardiorespiratory fitness in the young may have influenced the differences seen between age groups. Currently, TCD is the only practical measure of intracranial CBF velocity during upright exercise. The assumption of this approach is that the cross-sectional diameter of the MCA remains constant so that increases in blood flow velocity are proportional to increases in CBF. Although dilation of the MCA is known to occur during marked elevations (>15 mm Hg) in $P_{ET\text{-}CO_2}$ (38), in the current study, the maximum changes in $P_{ET\text{-}CO_2}$ were relatively small during the continuous (8.3 ± 4.0 mm Hg) and interval exercise (7.3 ± 3.5 mm Hg). Thus, changes in MCAv are unlikely to be influenced by changes in artery diameter during submaximal exercise, as observed previously (39). We only investigated the effect of exercise on MCAv in young and older men, and therefore, our findings may not be generalizable to females. Given the known influence of menstrual cycle and hormone replacement on resting MCAv (40), we specifically included males to isolate the influence of exercise format as it interacts with age. During exercise, the magnitude of the MCAv response is similar between males and females, although the kinetics of the change in MCAv are significantly slower in older females compared with older males (22). This slower MCAv response at the onset of exercise may be associated with the blunted endothelial response to exercise in postmenopausal women (41), although this remains to be determined. Moreover, because of the slowed kinetics, it is likely that MCAv would not reach its full magnitude during a 1-min bout of interval exercise in older females, which would possibly exacerbate the differences between exercise formats that we observed in older men. Although it was not feasible to investigate the influence of sex in the current investigation, it is imperative that future research also includes females to address questions related to the interaction between sex and aging, especially given the greater risk of cerebrovascular disease in females with old age (42).

CONCLUSIONS

In conclusion, the acute increase in MCAv during intensity- and work-matched interval and continuous cycling exercise was not different in old men, whereas MCAv was higher during continuous exercise in young men. This suggests that interval exercise may be an effective alternative for promoting acute increases in CBF velocity, without excessive rises in blood pressure, particularly in those older adults who may not be able to sustain continuous exercise. In both older and younger participants, the accumulated change in MCAv (AUC of MCAv during exercise and recovery) was greater.

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with interval exercise compared with continuous exercise. Whether this reflects a greater “dose” of shear stress with interval exercise remains to be determined, and there is now a need to investigate the cerebrovascular adaptations to interval exercise training.

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Author’s contribution: T. K. was involved in conception and design of study, acquisition of data; analysis and interpretation of data, drafting and revising the article, final approval of the article for publication. T. G. B. and V. A. were involved in interpretation of data, critical revision of article, final approval of the article for publication. C. D. A. was involved in conception and design of study, analysis and interpretation of data, drafting and revising the article, final approval of the article for publication.


