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1 **CARDIORESPIRATORY FITNESS, BLOOD PRESSURE, AND CEREBRAL**
2 **OXYGENATION DURING A DUAL-TASK IN HEALTHY YOUNG MALES**

3

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13

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15 of the manuscript.

16

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1 **Abstract**

2 This study aimed to evaluate the effects of cardiorespiratory fitness (CRF) and mean arterial pressure
3 (MAP) on the prefrontal cortex (PFC) oxygenation and dual-task performance in healthy young
4 males. Changes in the concentration of oxygenated (ΔHbO_2) and deoxygenated hemoglobin (ΔHHb)
5 in the right and left PFC were examined during a cognitive auditory 2-back task. Cognitive
6 performance (2-back task's accuracy) and walking motor performances were measured in single-
7 tasks (single motor and single cognitive) and dual-task (2-back task + walking). Thirty-six young
8 males were ranked according to their $\dot{V}\text{O}_2\text{peak}$. The second tertile was excluded to generate two
9 groups of different CRF (high fit group: $n=12$ and $\dot{V}\text{O}_2\text{peak} = 56.0 \pm 6.7 \text{ ml.kg}^{-1}.\text{min}^{-1}$; low-fit
10 group: $n=12$ and $\dot{V}\text{O}_2\text{peak} = 36.7 \pm 4.1 \text{ ml.kg}^{-1}.\text{min}^{-1}$). The CRF groups were further split into two
11 subgroups according to 24-hour MAP (higher-MAP, lower-MAP). Two-way ANOVA (CRF x n-
12 back conditions) revealed a significant interaction between the CRF and cognitive task condition on
13 2-back accuracy ($p = .007$) and a main effect of CRF on ΔHHb in the right and left PFC ($p < .05$).
14 These results suggest that in healthy young males: 1) for CRF, only low-fit individuals demonstrate
15 dual-task costs in accuracy (Dual < Single), and 2) that in comparison to the low-fit group, the high
16 fit-group demonstrated greater changes in PFC oxygenation in ΔHHb , but not ΔHbO_2 .

17

18 **Highlights:**

- 19 • Aerobic fitness (CRF), mean arterial pressure, prefrontal oxygenation, and dual-task were
20 examined
- 21 • In comparison to those with lower CRF, those with higher CRF demonstrated more accurate
22 working memory performance in dual-task condition
- 23 • Higher CRF was associated with greater PFC oxygenation on ΔHHb , but not ΔHbO_2 .

24 **Keywords:** cardiorespiratory fitness; cerebral oxygenation; near-infrared spectroscopy; dual-task;
25 young males

1 INTRODUCTION

2 There is an increasing amount of knowledge supporting a close relationship between
3 cardiorespiratory fitness (CRF), brain health, and cognitive performance in older adults [1]–[5]. This
4 link is particularly well-established for fluid intelligence. This high-level cognitive function, which
5 declines with aging [6], refers to the ability to solve novel problems [7] and is commonly used as a
6 predictor of general intelligence [8]. Working memory (WM), which is the executive function that
7 correlates the most with fluid intelligence, represents the ability to hold short-term information in
8 mind while using that information to accomplish a task [9]. One of the typical tests used to assess
9 WM is the n-back task, which consists in presenting a series of stimuli and ask the participant to
10 respond to the stimuli they saw or heard “n” items-back. Several studies have shown that n-back task
11 performance, which is under the control of the prefrontal cortex (PFC), was a predictor of inter-
12 individual differences in fluid intelligence and was associated with CRF in older adults [10], [11].
13 Studies in younger adults have reported a lack of association between CRF and n-back task
14 performance [12], [13] even though higher-fit younger adults have exhibited better WM performance
15 than lower-fit young adults using a different WM tasks such as the Automatic Operation Span
16 (Aospan) task [14] and Sternberg’s Working Memory Search (SMS) task [15]. This inconsistency in
17 the younger adult findings relating to CRF and WM initiates a debate on the potential links between
18 CRF, PFC, and WM, especially in younger adults.

19 Younger adults typically have better WM performance than older adults [16]. Therefore,
20 considering their larger cognitive reserve and physical performance capacity, the level of task
21 complexity required for the CRF to become a limiting factor is much greater in younger adults
22 compared to older adults [16], [17]. In this regard, the dual-task walking paradigm may provide the
23 increased task complexity needed for younger adults [18]. The dual-task walking paradigm is a
24 procedure that requires an individual to perform a motor and a cognitive task simultaneously (or
25 dual-task), in order to compare performance with single-task conditions (i.e., walking alone or

1 responding to cognitive task alone). Considering the high cognitive demands of this task, a reduced
2 cognitive reserve may result in an alteration of motor performance, cognitive performance or both
3 [19]–[21]. In addition, low CRF has been associated with less automaticity in movement and greater
4 cognitive control during complex motor tasks [22]. It has recently been suggested that increased gait
5 instability and higher stride variability that has been observed in individuals with low CRF could be
6 partly compensated by cognitive strategies, thus replacing automated sensorimotor processing with
7 effortful higher-order functions [19]. When cognitive resources are allocated for locomotion,
8 capacity theories [23] propose that these cognitive resources are less available for other activities
9 while walking. Therefore, regardless of age, individuals with low CRF may have more difficulty than
10 those with a high CRF to walk and concurrently engage in a cognitive activity [24], [25].

11 Several underlying mechanisms, involving both the structure and the function of the brain,
12 have been proposed to explain this beneficial effect of exercise on executive functions [3], [4], [26],
13 [27]. In fact, CRF has been positively associated with white matter integrity, cortical thickness, and
14 gray matter volume of the PFC in older adults [28], [29]. From a functional point of view, oxygen
15 availability appears to play a major role in cerebral functioning [30]. Cerebral oxygen availability is
16 determined in part by the interaction between cerebral vasculature and the regulation of cerebral
17 blood flow (CBF) but also by the availability of oxygen in the environment as suggested by studies
18 showing cognitive performance impairments during hypoxia [31]–[33]. Differences in CRF seem to
19 play a key role in cerebral oxygenation since high-fit older adults display higher cerebral
20 oxygenation during a cognitive task [11], [34], [35]. In parallel, some evidence has suggested that
21 blood pressure is involved in the association between CRF and executive performance, including
22 WM [36]. In fact, both hypertension and hypotension have been associated with alterations in CBF
23 which may lead to a decrease in perfusion and oxygenation of the brain, a decrease in a vascular
24 reserve capacity, and ultimately a decrease in executive performance capacity [36]. This potential
25 role of blood pressure has also been supported by the association between blood pressure and

1 cognitive impairment, even in normotensive individuals [37]. Finally, some studies reported that a
2 higher CRF predicted a lower mean arterial pressure (MAP) [38] and CBF regulation [39] in healthy
3 young adults. However, the degree to which CRF and MAP associated with the PFC oxygenation
4 and dual-task performance still remains to be determined, particularly in younger adults.

5 Therefore, the purpose of this study was to determine the interactions between CRF, MAP
6 and PFC oxygenation during dual-task walking in healthy young males. Considering the literature
7 and previous studies, we expected that a higher CRF level would be associated with a better 2-back
8 accuracy in healthy young males, especially in the dual-task condition. Secondly, we expected that a
9 higher CRF level would also be associated with a greater change in ΔHbO_2 and ΔHHb during 2-back
10 task performance, especially in dual-task condition. Thirdly, we expected that MAP would influence
11 the relationship between CRF, cerebral oxygenation and WM in healthy young males. We
12 hypothesized that: 1) WM assessed in dual-task would be better in high-fit individuals compared to
13 low-fit, 2) PFC oxygenation would be greater in individuals with better WM, and 3) MAP would
14 affect the link between WM, cerebral oxygenation, and CRF.

15

16 **2. MATERIAL AND METHODS**

17 2.1 Participants

18 In this study, considering the influence of estrogen on PFC, we decided to focus specifically
19 on males [40]–[42]. Young healthy males aged between 18 and 35 years old were considered for
20 inclusion in this study. Thirty-nine young males were recruited for this study. All participants were
21 university students in Poitiers (France) and were recruited via announcements in the university's
22 media. Participants were excluded if they had cardiovascular, musculoskeletal or rheumatoid
23 disorders that are exacerbated by exercise, a psychiatric disorder, a gait abnormality or were
24 currently being treated for cardiovascular disease or psychiatric disorder. After inclusion, 2

1 participants were unable to perform the dual-task correctly and one participant did not complete the
2 study. Therefore, the final sample of participants is thirty-six young males who have completed this
3 protocol. All participants provided written informed consent under an approved ethical board
4 protocol from the research ethics board in physical activity and sports sciences (CERSTAPS #2017-
5 231117).

6 2.2 Experimental design

7 On day one, participants came to the lab and completed the informed consent form.
8 Afterward, a Beck's Depression Inventory-II questionnaire was given and all participants underwent
9 cognitive screening (Montreal Cognitive Assessment). Then, participants completed anthropometry
10 measurements to measure height, weight, body fat percentage using the Leicester height measure and
11 a bioelectric impedance device (Tanita BC418, Tanita Corp., Tokyo, Japan). Following, these
12 questionnaires and measures, the dual-task protocol was performed by the participants. At the end of
13 the first session, all participants were given a 24-h ambulatory blood pressure monitor. The arm cuff
14 was attached and instructions were provided so that 24-h blood pressure monitoring could be started.
15 On day two, participants completed the maximal continuous graded exercise test. To avoid any
16 residual fatigue induced by recent workout, participants were asked to refrain from strenuous
17 exercise the day before each session. They were also asked to abstain from alcohol and caffeine-
18 containing beverages 24 hours before the test in order to avoid any influence of these beverages on
19 the regulation of the cardiovascular system. All sessions were administered between 8:00 a.m. to
20 4:00 p.m.

21 Once the experimental sessions were completed, participants were sorted according to their
22 peak oxygen uptake ($\dot{V}O_{2\text{peak}}$). Based on the participants' $\dot{V}O_{2\text{peak}}$, the sample was split into
23 tertiles. The second tertile was excluded to generate two groups of different physical fitness (high
24 and low-fit). Then, a median split was performed to generate two subgroups with different MAP

1 (higher and lower-MAP) within each physical fitness group. In the end, 4 groups (higher-MAP low-
2 fit; lower-MAP low-fit; higher-MAP high-fit; and lower-MAP low-fit) of 6 participants were
3 generated to test our hypotheses. Their characteristics are presented in Table 1.

4 2.3 Maximal continuous graded exercise test

5 This test was performed on a motorized treadmill (Valiant 2 sport, Lode B.V., Groningen,
6 Netherlands). Modified Balke walking protocol was used to measure peak oxygen consumption
7 ($\dot{V}O_{2peak}$). Walking protocol was chosen because it does not require running and has a slow
8 increase in workload. This test is well suited to evaluate aerobic fitness in heterogeneous populations
9 that vary in terms of fitness level, age, adiposity or health status in general [43]. The velocity was set
10 at 5.6 km/h throughout the test, with an initial 0% grade. The inclination was increased by 6% after
11 the first minute, and then by 2% every minute until voluntary exhaustion. Verbal encouragement was
12 given every minute throughout the test [44]. Oxygen uptake ($\dot{V}O_2$, in $ml.kg^{-1}.min^{-1}$) was determined
13 continuously on a 30-s basis using a portable cardiopulmonary exercise testing system (MetaMax
14 Cortex 3B, CORTEX Biophysik GmbH, Germany). Gas analyzers were calibrated before each test
15 using ambient air and a gas mixture of known concentration (15% O_2 and 5% CO_2). The turbine was
16 calibrated before each test using a 3-l syringe at several flow rates. The highest $\dot{V}O_2$ over a 30-s
17 period during the test was considered as the peak oxygen uptake ($\dot{V}O_{2peak}$, in $ml.kg^{-1}.min^{-1}$).
18 Perceived exertion (RPE) was assessed at the end of the test with the 15-point Borg scale (in which
19 higher scores represent higher perceived exertion) [45].

20 2.4 Blood pressure measurement

21 Blood pressure parameters were measured with an ambulatory blood pressure measurement
22 device (Mobil-O-Graph, I.E.M GmbH, Stolberg, Germany). Systolic blood pressure (SBP), diastolic
23 blood pressure (DBP) and mean arterial pressure (MAP; $MAP = 1/3 SBP + 2/3 DBP$) were measured

1 every 20 minutes during a 24-h period and were divided into daytime (8 am to 10 pm) and night-time
2 (from 10 pm to 8 am) periods.

3 2.5 Measurement of motor and cognitive performances

4 The n-back task is a cognitive task which frequently used to measure working memory [46].
5 A series of numbers (0-9) were presented auditorially, and the participants were asked to respond to
6 the stimuli that they heard "n" items-back (0-back or 2-back). In the lowest load version (0-back),
7 participants were asked to remember and say the number they just heard. As the number of items-
8 back increases, the working memory load increases the attentional demands of the individual [47].
9 The dual-task condition with a 2-back version of the n-back task has better reliability than the 1-back
10 or 3-back version [20]. Previous work with this task [24] has shown that the 2-back version of this
11 task adequately challenges younger adults and therefore this was the version used in this study. In
12 this study, the cognitive load was manipulated by using two different conditions: single- and dual-
13 task, and not by manipulating the n-back load. In the single-task condition, participants were
14 instructed to perform either a self-paced walk (motor task) or the 2-back task (cognitive task). In the
15 dual-task condition, participants performed both self-paced walking and 2-back task simultaneously.

16 The numbers were pseudo-randomly ordered to ensure that there were no repeats (1–1) and
17 no sequenced series (1–2–3). The numbers were recorded with a female voice, and sound files (wav
18 files) of lists of numbers were created with Audacity version 2.2.6 (general public license). The
19 numbers were presented through wireless headphones (RS 165, Sennheiser Electronic, Wedemark,
20 Germany). In the 2-back version, a participant might hear the series "0 – 4 – 1 – 5.....", once they
21 heard "1", they would have to say "0", and once they heard "5" they would have to say "4", always
22 keeping in mind the digit heard two positions back. The experimenter noted the participants'
23 responses and their accuracy. A 0-back version of the task with 12 items was used in a single-task
24 condition and only in practice session to ensure an adequate hearing for testing. All participants were
25 given instructions before each task condition (0-back single-task, 2-back single-task, self- paced

1 walking, and 2-back dual-task walking). The practice trial consisted of two trials for each task
2 condition. All participants reached 100% accuracy on a 0-back version during practice. Then, the
3 experimental test consisted of 10 blocks organized as follows: single-task 2-back (2 blocks), single-
4 task (self-selected pace) walking (1 block), dual-task 2-back (4 blocks), single-task (self-selected
5 pace) walking (1 block), and single-task 2-back (2 blocks). Each block of single and dual-task 2-back
6 consisted of 12 items. Each item was presented in 1.5 s, and there was a 1 s response interval (total
7 trial time 2.5 s) before the next item was presented. Each block lasted 40 seconds with a 60-second
8 rest period between blocks. The protocol for the 2-back task and the general experimentation are
9 presented in Figure 1.

10 Cognitive performance was measured as a percentage of correct responses out of all possible
11 responses on the 2-back task. Single-task cognitive performance is the percentage of participants'
12 correct responses on the 2-back tasks while seated on a chair. The dual-task cognitive performance is
13 the percentage of participants' correct responses on the 2-back tasks while walking at their self-
14 selected pace. In this study, participants were given instructions to give equal priority for both
15 cognitive and motor tasks.

16 Temporal and spatial parameters of motor performances of walking were studied using an
17 instrumented walkway system (GAITRite system; CIR Systems Inc, Clifton, NJ, USA). This system
18 consists of a 4.6 m electronic walkway with sensors arranged in a grid-like pattern to identify
19 footsteps contacts. Participants stood a distance of 5 meters away from the beginning of the walkway
20 and were instructed to walk at their self-selected pace across the instrumented walkway. Participants
21 began and finished walking according to the sound cues from the headphones.

22 Walk speed and stride length variability were quantified to represent motor performances.
23 Single-task motor performance was the speed and stride length variability of their self-selected-pace
24 walk (alone). The dual-task motor performances were the walking speed and stride length variability
25 at their self-selected-pace walk while responding to the 2-back task.

1 2.6 Measurement and analysis of PFC oxyhemoglobin (HbO₂) and deoxyhemoglobin (HHb)

2 The concentration changes of HbO₂ (Δ HbO₂) and HHb (Δ HHb) were measured with the
3 PortaLite fNIRS system (Artinis Medical Systems, Elst, Netherlands). This system utilizes
4 continuous-wave near-infrared lights, which penetrates the skull and brain but is absorbed by
5 hemoglobin (Hb) chromophores in the cortical layer. The lights were transmitted with two different
6 wavelengths, 760 and 850 nm. Based on different Hb absorption spectra, concentration changes of
7 HbO₂ and HHb in the PFC area are calculated from the changes in detected light intensity. The
8 calculation was done using the modified Lambert-Beer law, assuming constant light scattering [48].
9 A probe of PortaLite has three transmitters and one receiver, with transmitter-receiver distances of
10 30, 35, and 40 mm. The differential pathlength factor (DPF) was specified for DPF807, which is
11 determined using the formula: $DPF807 = 4.99 + (0.067 \times Age^{0.814})$ [49], and data were sampled with
12 a frequency of 10 Hz.

13 Two probes were placed on the forehead of the participants, at a height corresponding to 10
14 % of the nasion-inion distance from nasion, and the middle of the device was placed at 5 % of the
15 head circumference to the left and right from midline, corresponding to the Fp1 and Fp2 according to
16 the international EEG 10–20 system. These locations roughly target left and right Brodmann's areas
17 9 and 10, which represent the dorsolateral and anterior PFC. Probes were shielded from ambient light
18 with a black cloth fixed by an elastic strap. Oxysoft version 3.0 (Artinis Medical Systems, Elst,
19 Netherlands) was used for data collection.

20 Measurement started with a measure of resting PFC oxygenation in a sitting condition for 2
21 minutes. During the practice phase, no PFC oxygenation data was acquired. The resting PFC
22 oxygenation values were subtracted in single-task condition. During the 2-back task conditions, the
23 last 30 s of each block was used as a measurement of PFC oxygenation. In the dual-task condition,
24 the PFC oxygenation values from the self-selected pace walking block were subtracted to isolate the
25 dual-task condition. The PortaLite uses wireless technology (Bluetooth), which gives a possibility to

1 measure the cerebral oxygenation during walking without restriction of wires. During the
2 experimentation, a tight-fitting band and no long wires pulling on optodes were applied in order to
3 minimize noise in the hemodynamic signals. For the same objective, our participants were asked to
4 always facing forward during the test, avoid making a sudden head movement, clenching their jaw,
5 frowning, and other facial expressions.

6 NIRS data analysis was performed on unfiltered data as an average of each task condition.
7 The artifacts in the signal were identified by visual inspection and replaced by interpolation of
8 adjacent data. Conversion of optical density to HbO₂ and HHb signals occurred in the Oxysoft
9 software with the modified Beer-Lambert law. The change in prefrontal oxygenation was calculated
10 as the average of the three channels of NIRS on the same side of the prefrontal cortex. As in all
11 fNIRS calculations, the experimental condition activity was subtracted from the baseline activity in
12 order to have a change in cerebral oxygenation for each condition.

13 2.7 Statistical Analysis

14 Normal Gaussian distribution of the data was verified by the Shapiro-Wilk test, and
15 homogeneity of variance by a modified Levene test. Independent t-test was used to compare means
16 between characteristics of groups and subgroups. Mann-Whitney test was used when homogeneity of
17 variance or normality of distribution between groups or subgroups was violated. The magnitude of
18 the difference for each test was assessed by Cohen's *d*. The scale proposed by Cohen [50] was used
19 for interpretation. The magnitude of the difference was considered small (0.2), moderate (0.5), or
20 large (0.8). Three-way 2 x 2 x 2 ANOVAs with the following design: fitness (high-fit vs. low-fit) x
21 MAP (higher-MAP vs. lower-MAP) x 2-back conditions (single-task vs. dual-task) as independent
22 variables, with 2-back accuracy and PFC oxygenation parameters (HbO₂, HHb, and tHb) as
23 dependent variables. Tukey's post-hoc test was conducted for cognitive performance, motor
24 performance, and PFC oxygenation data. Since there was no control group, the pooled standard

1 deviation was used to compute this statistic. The association between CRF or MAP and cognitive
2 performance was tested using nonparametric Spearman's rank correlation test using the data from all
3 participants as a continuum. Statistical significance was set at $\alpha \leq 0.05$ level for all analyses. All
4 calculations were made with Statistica 7.0 (StatSoft, Tulsa, USA). The values are presented as mean
5 \pm SD.

6

7 **3. RESULTS**

8 Characteristics of our participants are presented in Table 1. As expected, we found a large
9 difference in the $\dot{V}O_{2\text{peak}}$ for high-fit ($M = 56.0$, $SD = 6.7$) and low-fit ($M = 36.7$, $SD = 4.1$) group,
10 $t(22) = 8.54$, $p < .001$, $d = 3.5$. Average $\dot{V}O_{2\text{peak}}$ of the high-fit group corresponded to the 90th
11 percentile of the ACSM norm [51], while the low-fit group was ranked in the 20th percentile.
12 Although both groups could be considered as normotensive (i.e., 24-hour APBM $< 130/80$ mmHg),
13 low-fit individuals had higher MAP levels ($M = 90.8$, $SD = 6.1$) than high-fit individuals ($M = 82.8$,
14 $SD = 5.9$), $t(22) = -3.23$, $p = .003$, $d = 1.3$. More precisely, the difference was reported in the
15 diastolic blood pressure in high-fit ($M = 67.6$, $SD = 6.8$) and low-fit ($M = 80.3$, $SD = 7.9$) group,
16 $t(22) = -4.18$, $p < .001$, $d = 1.7$, but not in the systolic blood pressure. The characteristic differences
17 between CRF groups were also found in weight; high-fit ($M = 68.3$, $SD = 5.8$) and low-fit ($M = 79.8$,
18 $SD = 16.8$), $t(22) = -2.23$, $p = .04$, $d = 0.9$, and in body mass index (BMI); high-fit ($M = 21.9$, $SD =$
19 2.4) and low-fit ($M = 26.2$, $SD = 5.3$), $t(22) = -2.52$, $p = .02$, $d = 1.0$.

20 Within the CRF category, in the high-fit group, we found a large MAP difference between
21 lower-MAP ($M = 78.3$, $SD = 4.7$) and higher-MAP ($M = 87.3$, $SD = 2.9$) group, $t(10) = -3.95$, $p <$
22 $.002$, $d = 2.3$. Also a large difference in systolic blood pressure; lower-MAP ($M = 110.0$, $SD = 4.8$)
23 and higher-MAP ($M = 116.2$, $SD = 3.1$), $t(10) = -2.66$, $p = .02$, $d = 1.5$, and in diastolic blood
24 pressure; lower-MAP ($M = 62.5$, $SD = 5.0$) and higher-MAP ($M = 72.8$, $SD = 3.7$), $t(10) = -4.06$, $p <$

1 .002; $d = 2.3$. In the low-fit group, we found a large MAP difference between lower-MAP ($M = 86.9$,
2 $SD = 1.8$) and higher-MAP ($M = 94.6$, $SD = 6.6$) group, $t(10) = -2.73$, $p = .02$, $d = 1.6$. As well a
3 large difference in the diastolic blood pressure, lower-MAP ($M = 75.2$, $SD = 4.6$) and higher-MAP
4 ($M = 85.5$, $SD = 7.3$), $t(10) = -2.91$, $p = .01$, $d = 1.7$, but not in the systolic blood pressure.

5 No differences were found in age, height, MoCA score and years of education both between
6 CRF groups and MAP subgroups.

7 Characteristics of the CRF groups and MAP subgroups are presented in Table 1. Cognitive
8 and motor performances during single-task and dual-task conditions are presented in Table 2, Figure
9 2 and Figure 3, while PFC oxygenation characteristics are shown in Table 3.

10 *Motor Performance*

11 There was a main effect of task condition on motor performance ($F_{(1,20)} = 68.02$, $p = .001$),
12 indicating that the stride length variability (CoV) for single-task motor condition ($M = 0.9$, $SD = 0.2$)
13 was significantly lower than the dual-task condition ($M = 1.4$, $SD = 0.4$). No interaction was found
14 between cognitive task condition and CRF on the stride length variability. Neither main effect nor
15 interaction was found between walking speed and CRF.

16 *CRF and Cognitive Performance*

17 The ANOVA revealed a main effect of condition on 2-back accuracy ($F_{(1,20)} = 4.45$, $p = .047$),
18 indicated that the accuracy for the single-task condition ($M = 97.73\%$, $SD = 3.03$) was significantly
19 greater than the dual-task condition ($M = 95.73\%$, $SD = 5.84$). Also, there was a main effect of CRF
20 on 2-back accuracy ($F_{(1,20)} = 8.49$, $p = .009$), showing that the overall accuracy for the high-fit
21 participants ($M = 98.58\%$, $SD = 3.07$) was significantly greater than the low-fit participants ($M =$
22 94.88% , $SD = 5.36$). The ANOVA also revealed a significant interaction between the cognitive task
23 condition and CRF on 2-back accuracy ($F_{(1,20)} = 8.93$, $p = .007$). Post-hoc analyses indicated that

1 low-fit participants were significantly less accurate in dual-task condition, as compared to single-task
2 condition ($p = .02$), but there was no difference between conditions in high-fit participants. Also,
3 post-hoc analyses revealed that dual-task performance is better for higher fit participants compared to
4 lower fit participants ($p = .04$). These results are presented in Figure 2. No significant correlation was
5 found between $\dot{V}O_2$ peak and dual task cognitive performance.

6 *CRF and Cerebral Oxygenation*

7 Neither main effect nor interaction was found on both sides of PFC on ΔHbO_2 . The ANOVA
8 performed on relative changes in ΔHHb showed a main effect of CRF on ΔHHb ($F_{(1,20)} = 7.98$, $p =$
9 $.01$) in the right PFC, indicating that the ΔHHb for the high-fit participants ($M = -0.31$, $SD = 0.28$)
10 was significantly greater than the low-fit participants ($M = -0.11$, $SD = 0.21$). A correlation between
11 $\dot{V}O_2$ peak and ΔHHb was confirmed ($r = -.43$, $p = .03$) but no significant correlation was found
12 between accuracy and ΔHbO_2 nor between accuracy and ΔHHb ($r = -.29$, $p = .07$). In the left PFC,
13 there was a main effect of CRF on ΔHHb ($F_{(1,20)} = 4.43$, $p = .048$), indicating that the ΔHHb for the
14 high-fit participants ($M = -0.21$, $SD = 0.15$) was significantly greater than the low-fit participants (M
15 $= -0.12$, $SD = 0.13$). A correlation between $\dot{V}O_2$ peak and ΔHHb was also confirmed ($r = -.36$, $p =$
16 $.04$). However, no significant correlation was found between accuracy and ΔHbO_2 nor accuracy and
17 ΔHHb ($r = -.32$, $p = .06$).

18 *MAP and Cognitive Performance*

19 The ANOVA reported a significant interaction between the cognitive task condition and
20 MAP on 2-back accuracy ($F_{(1,20)} = 4.27$, $p = .04$) in healthy younger adults, in which higher-MAP
21 participants were significantly less accurate in dual-task condition, compared to single-task condition
22 ($p = .03$), but there were no differences between conditions in lower-MAP participants. The results

1 are presented in Figure 2. Again, these results were further supported by a significant correlation
2 between MAP and dual-task 2-back accuracy ($r = -.47, p = .01$).

3 Finally, we performed an exploratory analysis to test the possible interaction between CRF,
4 MAP and cognitive task conditions on 2-back accuracy. The results are presented in Figure 3.
5 Although the interaction does not reach statistical significance ($F_{(1,20)} = 3.91, p = .06$), it seems that
6 MAP modulates the general effect described previously between CRF and cognitive performance.
7 This result seems to support that lower-fit with higher-MAP group have poorer dual-task
8 performance compared to other groups. The small sample size does not allow to provide a definitive
9 answer, but these results underscore the need for further investigations.

10

11 *MAP and Cerebral Oxygenation*

12 The ANOVA revealed no effect of MAP on cerebral oxygenation.

13

14 **4. DISCUSSION**

15 The study investigated the interactions between CRF, MAP, PFC oxygenation and WM
16 performances in healthy young males. Based on the literature, we hypothesized that individuals with
17 high-CRF would have better WM performances than individuals with low-CRF. Our main findings
18 were that 1) only lower fit participants demonstrated dual-task performance costs in WM (Dual-task
19 < Single), while higher-fit participants maintained their performance level and 2) PFC oxygenation
20 during the dual-task condition, specifically in ΔHHb , was greater in high-fit participants compared to
21 lower fit. 3) Neither walking speed nor stride length variability during the 2-back task was associated
22 with CRF. 4) MAP did not significantly change the association between CRF and WM
23 performances.

1 Regarding motor performance, although there was a main effect of conditions that both
2 groups had better motor control in single-task condition than in dual-task condition, no significant
3 main effects of CRF or interactions with CRF and conditions were found suggesting that task
4 conditions had the same effect in both CRF-group. The increased stride length variability in the dual-
5 task condition in both groups suggests that, even in healthy young males, walking is not a purely
6 motor task. A dual-task study by Bloem et al. (2001) in 50 healthy young and 13 healthy elderly
7 participants showed that healthy participants prioritize performance of motor tasks over performance
8 of cognitive tasks [52]. Moreover, the younger participants were more likely to use this strategy than
9 older adults. Based on this finding, it seems that in healthy young individuals, a self-paced motor
10 task may be a less sensitive parameter than cognitive task performance when examining the
11 influence of CRF on dual-task performance.

12 Regarding 2-back accuracy, we found a main effect of CRF, since high-fit individuals were
13 more accurate than low-fit individuals. We also found an interaction between CRF and 2-back
14 conditions, suggesting that this effect of CRF was specific to the dual-task condition. Specifically,
15 the increased the complexity of the task (i.e., from a seated single-task to dual-task walking) resulted
16 in a higher error rate in low-fit individuals than high-fit individuals. This finding is in line with the
17 literature on CRF-related differences in working memory in Agbangla et al. (2019), in which high-fit
18 older adults showed were more accurate in the 3-back condition but not in 1- or 2-back condition
19 [28]. This higher sensitivity of highly demanding cognitive tasks to CRF has already been
20 underscored in older adults [53]. Indeed, Dupuy et al [53], reported that higher fit older adults had
21 better cognitive performance and lesser error rate in visual-auditory dual-task performance than
22 lower fit counterparts. All these results suggest that a good CRF allows for better cognitive
23 performance in cognitively demanding tasks that involve executive functions. These results support
24 the hypothesis, that executive function is the most sensitive cognitive function to CRF [54].

1 Several underlying neurophysiological mechanisms could explain our results. The CRF is
2 associated with greater white and grey matter of the brain and more particularly of the PFC [28].
3 Also, structural modifications in the blood vessels are observed in subjects with better CRF [55].
4 These changes are often accompanied by increased cerebral blood flow and brain oxygenation in
5 older subjects [32], [35], [53]. Neuronal activation consumes energy which is met by oxidation of
6 lactate present in the extracellular space, resulting in a temporary decrease in lactate levels and
7 oxygen concentrations [56]. Neurovascular response resulting in larger arteriole dilation and greater
8 blood flow at the activated brain regions, consequently providing a temporary increase in HbO₂ and a
9 relative decrease in HHb, due to the increased HbO₂ concentration [57].

10 It is a continuing discussion in the fNIRS studies to determine which parameter (HbO₂ or
11 HHb) is best for capturing relevant cerebral hemodynamic changes. HbO₂ is reported producing
12 higher signal-to-noise ratio [58], higher reproducibility [59], [60], and be more sensitive to the
13 changes in regional blood flow [61] especially in participants with pathologies [62] than HHb. HHb
14 described to have less physiological noise [30], [63] and spatially more focused than HbO₂ [64],
15 [65]. Also, the inverse relationship between HHb and blood oxygenation level dependent (BOLD)
16 signal of fMRI has been reported by Ekkekakis (2009) and Strangman et al. (2002) [58], [66].

17 In our study, concerning the changes in PFC oxygenation, we found that high-fit individuals
18 had a greater decrease in Δ HHb than low-fit individuals in both hemispheres. The absence of
19 interaction between CRF and task conditions Δ HHb suggested that this difference was true for both.
20 single-task and dual-task. This observation was supported by the association between $\dot{V}O_2$ peak and
21 dual-task Δ HHb in the right and left PFC. Altogether, these results showed that healthy young males
22 with greater CRF displayed a greater decrease of Δ HHb in both hemispheres of PFC during a dual-
23 task. Moreover, this relation supports the CRF hypothesis that PFC hemodynamic is influenced by
24 the regulation of the cardiovascular system [67]. According to this hypothesis, high-fit individuals

1 have a greater regional cerebral blood flow and therefore a greater potential for PFC activation,
2 which could contribute to their better executive performances [32].

3 Using fNIRS technique, this study confirms that higher fit participants displayed greater
4 cortical activation during executive task [68]. Furthermore, in contrast to a recent study that reported
5 a greater ΔHbO_2 during n-back task in higher-fit older adults compared to their lower-fit counterpart
6 [11], our study reports no difference in ΔHbO_2 between groups in both task conditions. Aside from a
7 difference in age group, it should be noted that the change in PFC hemodynamics in this study was
8 measured in the dual-task walking paradigm whereas the participants were sitting in the study of
9 Agbangla et al. [11]. An alternate explanation for these differences between studies is the duration of
10 our dual-task condition. Indeed, Agbangla et al [11], reported the evolution of PFC hemodynamics
11 during 0-,1-,2 and 3-back tasks and showed that ΔHbO_2 concentration increased progressively from
12 the beginning to the end of their task, which lasted 140-seconds [11]. Considering these results, the
13 shorter duration (30 seconds) of the 2-back task in this study may not allow us to observe the
14 complete kinetics of HbO_2 concentration. It is clear from literature that many of the changes in
15 working memory performance (i.e., accuracy) are related to age-related changes in executive
16 functions and depend on the type of cognitive domain and the individual being assessed [69] In
17 addition, accuracy (in our sample of younger adults) was quite high (Mean of full sample = 96.73%)
18 with only the LFHM group demonstrating a single-dual difference. This may have limited our ability
19 to find a correlation between the cognitive accuracy measure and cerebral oxygenation. In cases
20 where accuracy is high, it has been proposed that response times might be a more accurate reflexion
21 of working memory processing [70]. Future studies utilizing this paradigm in younger adults should
22 measure both accuracy and response times to the n-back task in order to capture the variability that is
23 likely present even in younger adult samples.

24 In our study, we were also interested in determining the effect of MAP on cognitive
25 performance during a dual-task. We observed that participants with a lower-MAP had a better WM

1 performance during the dual-task than those with a higher-MAP. This result supports previous
2 studies examining the relationship between elevated resting blood pressure and poorer cognitive
3 performance on attention [71] and visualization/fluid score of the Wechsler Adult Intelligence Scale
4 (WAIS) [72] in young adults. One of the potential physiological mechanisms involved in this
5 relationship is an altered cerebrovascular reactivity [73]. In the study of Settakis et al. (2003) which
6 investigated 113 hypertensives and 58 normotensive young adults, the investigators reported that the
7 hypertensive group has smaller changes in mean and diastolic blood flow velocities after breath-
8 holding compared to the normotensive group [74]. This result suggesting decreased cerebrovascular
9 reactivity in hypertensive young adults compared to their normotensive counterparts. Another study
10 by Wong et al. (2011) investigated the relationship between blood pressure and cerebral
11 vasoreactivity in 56 children and adolescents [75]. All of the subjects in this study were examined by
12 transcranial Doppler in the middle cerebral artery while rebreathing carbon dioxide with a plastic bag
13 [75]. The result showed that baseline diastolic blood pressure (DBP) was inversely related to cerebral
14 vasoreactivity [75]. All of those results displayed evidence of a relationship between hypertension
15 and altered cerebrovascular reactivity in young adults. However, we also observed that CRF could
16 modulate this effect of MAP on WM. Although these results should be viewed as exploratory
17 considering the small sample size of subgroups (n=6), we found a tendency toward an interaction
18 between CRF, MAP and cognitive performance. Low-fit participants with a higher MAP displayed
19 poorer 2-back accuracy than all other profiles. Taken together, our results suggest that high CRF in
20 young males is associated with greater PFC oxygenation (ΔHHb) and better WM performance in a
21 dual-task condition.

22 4.1 Limits and perspectives

23 The focus of this study on a single sex (males) is to limit the gender bias due to the influence
24 of estrogen on PFC, but we aware that this limits the generalizability of findings in younger adults. A

1 replication of this study with young females is needed. The small sample size of subgroups (n=6)
2 necessitates caution in interpreting the results of the 3-way ANOVA. However, they provide very
3 interesting outcomes that should be tested in a larger sample. CRF is determined by life habits,
4 including physical activity (PA), and genetic factors. Since we have no direct measure of both PA
5 and genetic factors, it is not possible to determine the extent by which they contribute to the observed
6 differences in cognition. Regarding cognitive performance, there is a possibility that CRF and/or
7 MAP could also influence the reaction time in the 2-back task. Therefore, we highly recommend
8 future studies using a 2-back task to investigate both reaction time and accuracy. In addition, NIRS is
9 an indirect measure of brain or neuronal activities. It has several limitations such as lower spatial
10 resolution and lack of sensitivity to deeper brain areas.

11 The fNIRS signal pre-processing that was used in this study may have underestimated the
12 impact of motion artifacts. In this study, we have not performed the filtering of the NIRS signals and
13 detrending of segments that could lead to contamination of the fNIRS data with physiological or
14 body movement noise. Converging evidence from NIRS with EEG and fMRI is needed to provide a
15 more comprehensive understanding of the dynamics of cerebral activation. Also, the utilization of a
16 multi-channel NIRS setup can also help to observe the oxygenation profiles and activities of other
17 brain regions compared to the two-channel setup in this study. Analyzing PFC hemodynamic in dual-
18 task walking with longer duration (> 3 minutes) is needed to understand the complete hemodynamic
19 profile of this paradigm. As differences in PFC oxygenation could be interpreted as a difference in
20 concentration of oxyhemoglobin (ΔHbO_2) and deoxyhemoglobin (ΔHHb), their values are relative to
21 their total concentration in blood and CBF. Therefore, measurements of total hemoglobin and CBF
22 are needed in further studies to obtain a comprehensive understanding of the role of cerebral
23 oxygenation. We did not have a wide range of blood pressure levels (from hypotension to
24 hypertension) in participants of our study. This may underestimate the effect of blood pressure on
25 brain activation and cognitive performance. In future studies, it would be beneficial to include a

1 broader range of blood pressure levels in young adults to observe the relationship between blood
2 pressure and cognitive performance on dual-task condition.

3

4 **5. CONCLUSION**

5 This study supports the positive effect of higher CRF on WM performance in healthy young
6 males. The results indicated that the high-fit individuals performed better in dual-task conditions than
7 low-fit individuals. Moreover, greater PFC oxygenation in the ΔHHb measure was demonstrated in
8 higher CRF group. Also, lower blood pressure tends to be associated with better dual-task
9 performance. Consequently, healthy young males with high cardiorespiratory fitness may be able to
10 perform better in the activities that require working memory, especially while walking.

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1

2 Figure caption

3

4 Figure 1: Experimentation protocol and information of methods

5

6 Figure 2: Impact of cardiorespiratory fitness (A) and mean arterial pressure (B) on cognitive
7 performance (% correct responses) during single and dual-task conditions. Data are presented as
8 mean and SD. *: $p < 0.05$. (HF: High-fit; LF: Low-fit; LM: Low mean arterial pressure; HM: High
9 mean arterial pressure)

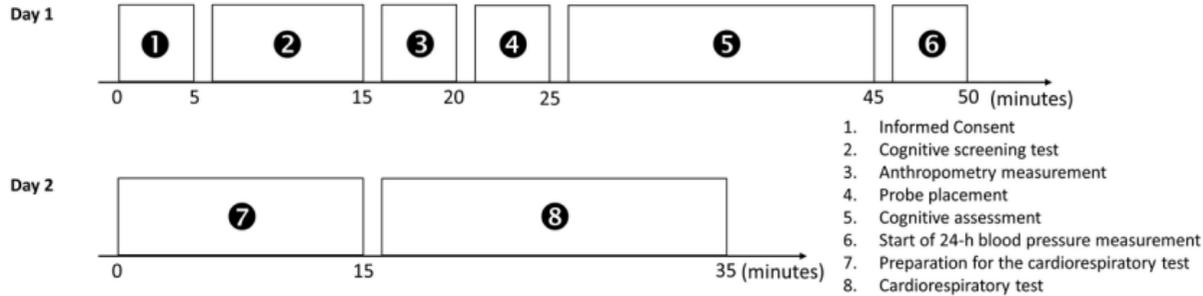
10

11 Figure 3: Cognitive performance (% correct responses) during single and dual-task for HFLM,
12 HFHM, LFHM, LFLM participants. Data are presented as mean and SD. *: $p < 0.05$. (HFLM: High-
13 Fit Low-MAP; HFHM: High-Fit High-MAP; LFLM: Low-Fit Low-MAP; LFHM: Low-Fit High-
14 MAP)

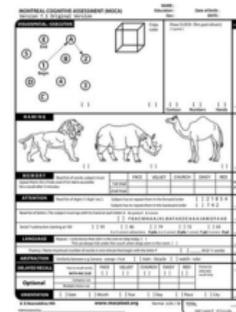
15

16 Figure 4: Conceptual framework for links between fitness level, cognitive performance in dual-task
17 condition, mean arterial blood pressure and PFC oxygenation.

Experimental Protocol



Cognitive screening test



Montreal Cognitive Assessment (MOCA)

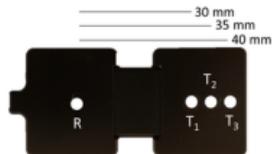
Exclusion from the study with cutoff score < 26

(Nasreddine *et al.* 2005)

Probe placement and characteristics (PortaLite - Artinis)



Fp1 and Fp2 are regions of interest on the pre-frontal cortex (10/20 system)

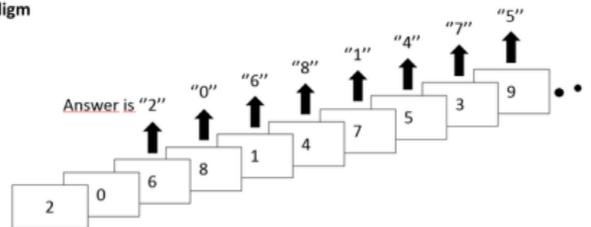


The variables of interest (ΔHbO_2 , ΔHHb , ΔtHb) are calculated from the mean of the 3 channels.

R = Receptor; T = Transmitter

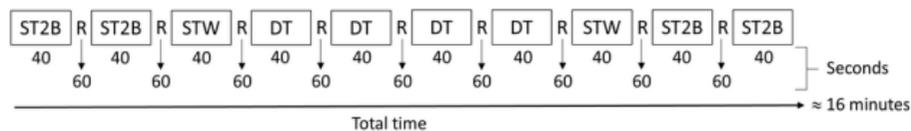
Cognitive assessment

2-back task paradigm



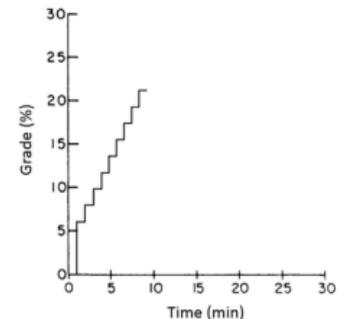
(Fraser *et al.*, 2016)

Experimentation blocks



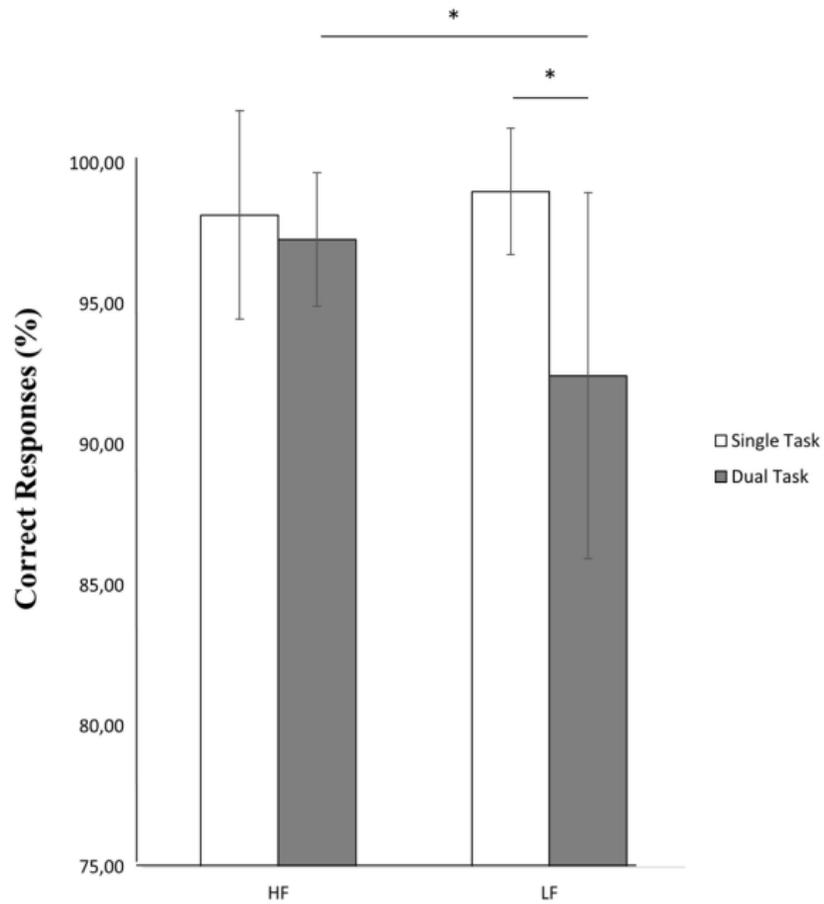
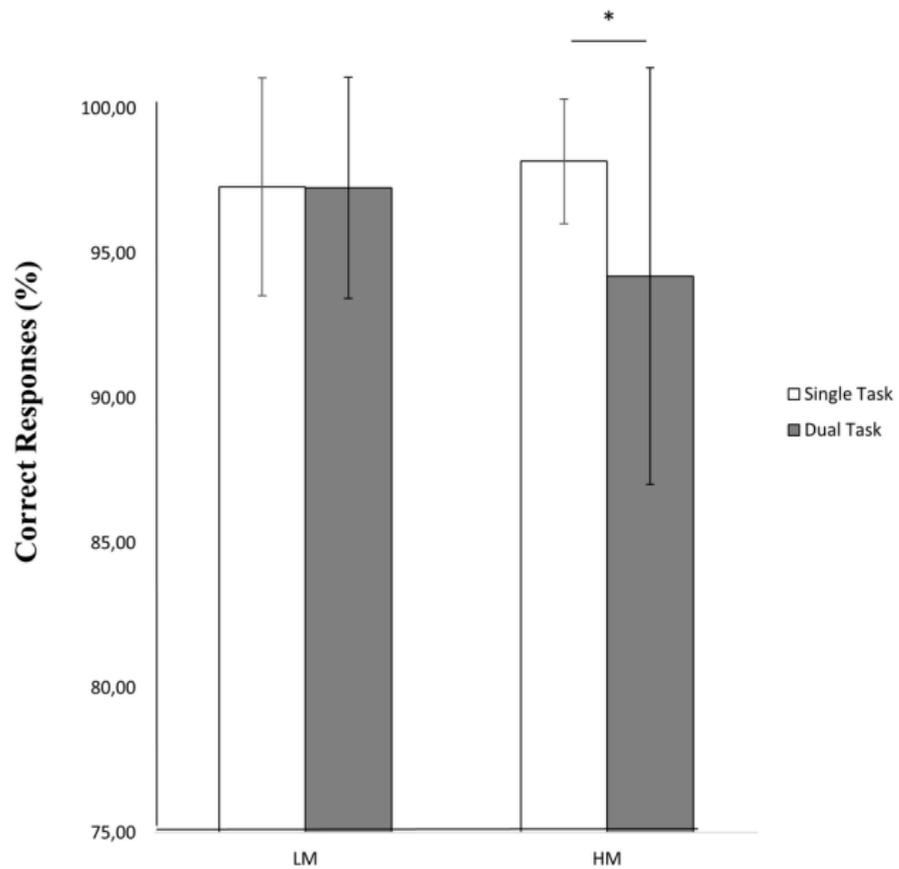
R = Rest; ST2B = single task 2-back, STW = single task walking; DT = dual task

Cardiorespiratory test

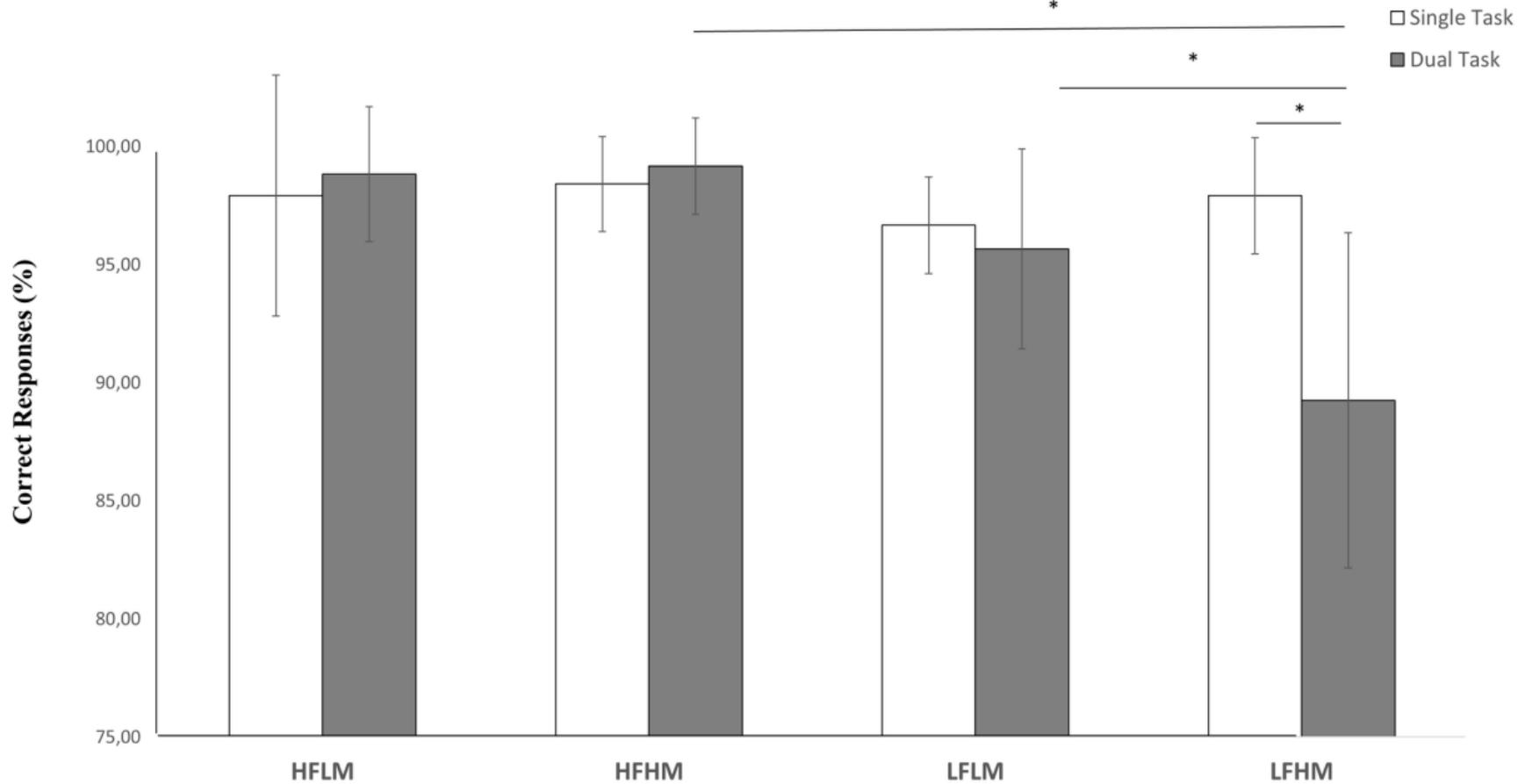


consisting of nine stages per 1 min at a constant velocity of 5.6 km/h and increasing elevation from 6% to 22% in 2% increments each minute.

(Marinov *et al.* 2002)

A**B**

Interaction between Fitness x MAP x Condition : $p=0.06$



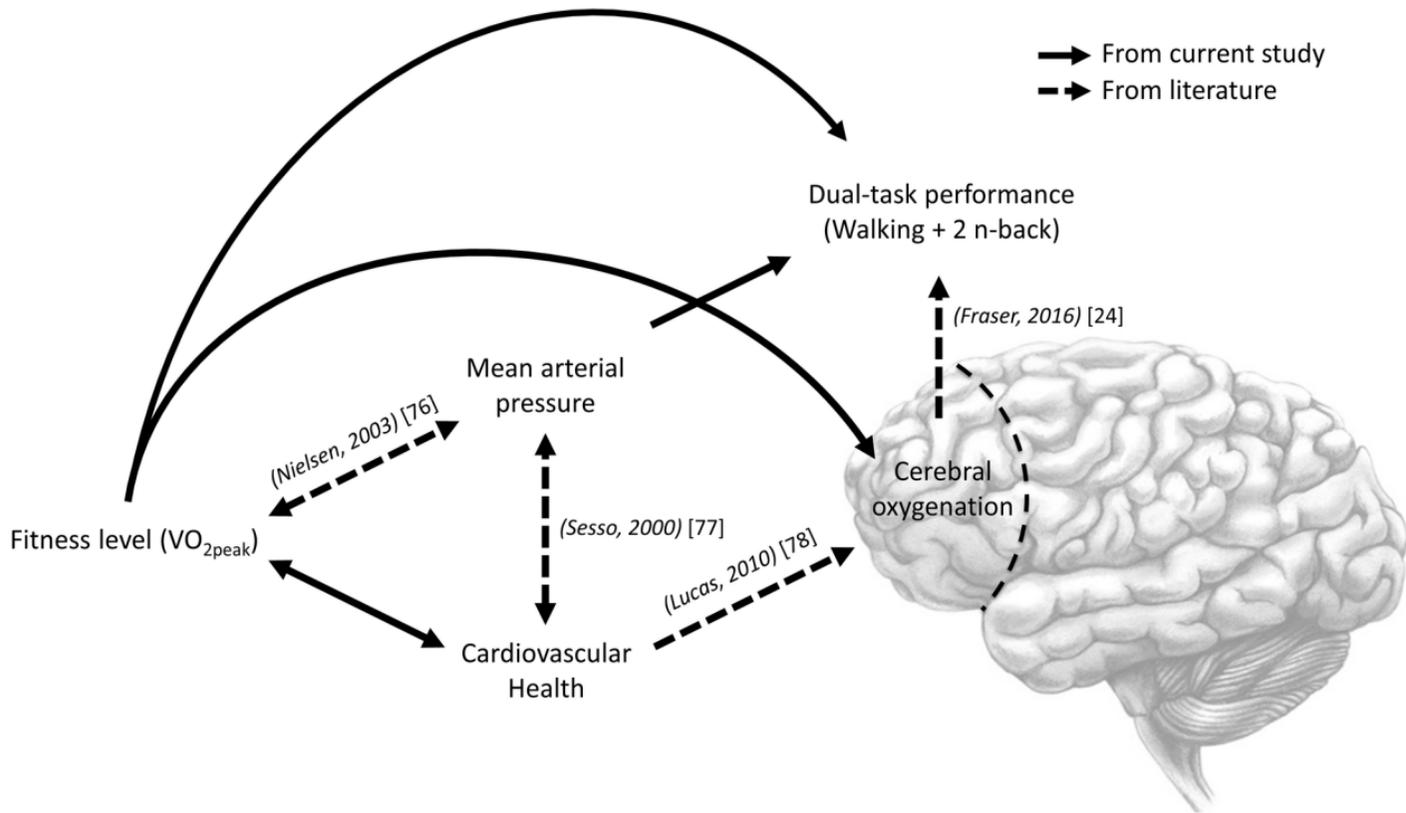


Table 1. Characteristics of study participants. Data are presented as means and standard deviations (SD)

	Overall (n=24)	High-Fit		Cohen's d +	High-Fit (n=12)		Cohen's d	Low-Fit (n=12)		Cohen's d
		High-Fit (n=12)	Low-Fit (n=12)		Lower MAP (n=6)	Higher MAP (n=6)		Lower MAP (n=6)	Higher MAP (n=6)	
Age (yr)	23.8 (4.8)	22.8 (4.2)	24.8 (5.1)	0.4	23.8 (5.3)	21.7 (2.7)	0.5	22.7 (4.7)	26.8 (5.0)	0.8
Height (cm)	175.5 (6.5)	176.6 (6.5)	174.5 (6.7)	0.3	178.3 (7.0)	174.8 (6.0)	0.5	173.3 (6.5)	175.7 (7.2)	0.3
Weight (kg)	74.1 (13.6)	68.3 (5.8)	79.8 * (16.9)	0.9	70.4 (3.9)	66.2 (6.9)	0.8	70.7 (9.7)	88.9 (18.2)	1.2
BMI (%)	24.1 (4.0)	22.0 (2.4)	26.2 * (5.3)	1.0	22.2 (1.3)	21.7 (3.3)	0.2	23.5 (3.0)	28.9 (6.0)	1.1
Overweight & Obese (n;%)	(3;13%)	(0;0%)	(3;25%)		(0;0%)	(0;0%)		(1;17%)	(2;33%)	
$\dot{V}O_2$ peak (ml.kg ⁻¹ .min ⁻¹)	46.1 (9.9)	56.0 (6.7)	36.7 * (4.1)	3.5	58.8 (6.4)	53.2 (6.2)	0.9	37.7 (3.0)	35.7 (5.0)	0.5

RER	1.19	1.23	1.18	0.6	1.25	1.21	0.5	1.17	1.19	0.2
()	(0.09)	(0.08)	(0.08)		(0.08)	(0.07)		(0.09)	(0.07)	
RPE	16.2	16.6	15.9	0.5	17.0	16.7	0.5	15.3	16.3	0.8
()	(1.4)	(1.6)	(1.3)		(1.8)	(1.5)		(0.8)	(1.6)	
MAP24h	86.9	82.8	90.8 *	1.3	78.3	87.3 #	2.3	86.9	94.6 #	1.6
(mmHg)	(7.0)	(6.0)	(6.1)		(4.7)	(3.0)		(1.8)	(6.6)	
Systolic Pressure	112.4	113.8	111.7	0.2	110.0	116.2 #	1.5	110.5	112.8	0.3
(mmHg)	(6.7)	(5.0)	(7.7)		(4.8)	(3.1)		(7.4)	(8.5)	
Diastolic Pressure	74.0	67.7	80.3 *	1.7	62.5	72.8 #	2.3	75.2	85.5 #	1.7
(mmHg)	(9.2)	(6.8)	(8.0)		(5.0)	(3.7)		(4.6)	(7.3)	
MoCA	28.6	28.4	28.8	0.3	28.8	28.0	0.6	28.3	29.2	0.8
(points)	(5.4)	(1.5)	(1.1)		(1.6)	(1.4)		(1.2)	(1.0)	
Education	14.5	13.9	15.1	0.5	14.2	13.7	0.1	14.2	16.0	0.6
(years)	(2.3)	(2.2)	(2.2)		(2.5)	(2.2)		(2.2)	(2.0)	
0-back	100	100	100	0.0	100	100	0.0	100	100	0.0
(% correct)	(0)	(0)	(0)		(0)	(0)		(0)	(0)	

$\dot{V}O_2$ peak, peak oxygen uptake; RER, respiratory exchange ratio; RPE, rated perceived exertion; MAP24h, mean arterial pressure over 24-hour.

* different from High-Fit ($p < 0.05$); # different from Lower-MAP in same group ($p < 0.05$); + effect size of the difference between high-fit and low-fit groups

Table 2. Cognitive and motor performance during single task and dual-task conditions. Data are presented as mean (SD)

	Overall (n=24)	High-Fit (n=12)	Low-Fit (n=12)	Cohen's d ⁺
2-back accuracy (% of correct responses)				
Single task	97.9 (2.9)	98.2 (3.7)	97.3 (2.3)	0.3
Dual task	95.9 (5.5)	99.0 (2.4)	92.5 (6.5) *	1.3
Walking speed (m.s⁻¹)				
Single task	1.42 (2.9)	1.45 (3.7)	1.41 (2.3)	0.5
Dual task	1.37 (5.5)	1.39 (2.4)	1.36 (6.5) *	0.7
CoV of stride length				
Single task	0.9 (0.2)	1.0 (0.2)	0.9 (0.1)	0.5
Dual task	1.4 (0.4)	1.4 (0.3)	1.4 (0.3)	<0.2

m.s⁻¹, meter per second; CoV, coefficient of variation

* different from High-Fit ($p < 0.05$);

Table 3. Cerebral oxygenation changes from baseline during the 2-back task in single and dual-task conditions. Data are presented as mean (SD).

	Overall (n=24)	High-Fit (n=12)	Low-Fit (n=12)	Cohen's d ⁺	High-Fit (n=12)		Cohen's d	Low-Fit (n=12)		Cohen's d
					Lower MAP (n=6)	Higher MAP (n=6)		Lower MAP (n=6)	Higher MAP (n=6)	
Single Task										
Right PFC										
ΔHbO_2 (umol.L ⁻¹)	0.64 (0.89)	0.52 (1.24)	0.67 (0.57)	0.2	0.84 (1.63)	0.19 (0.69)	0.5	0.90 (0.56)	0.45 (0.52)	0.8
ΔHHb (umol.L ⁻¹)	-0.25 (0.23)	-0.29 (0.27)	-0.15 (0.20)	0.6	-0.37 (0.33)	-0.22 (0.19)	0.6	-0.22 (0.08)	-0.07 (0.25)	0.8
ΔHbDiff (umol.L ⁻¹)	0.79 (1.04)	0.81 (1.45)	0.82 (0.65)	<0.2	1.21 (1.94)	0.41 (0.66)	0.6	1.13 (0.64)	0.52 (0.55)	1.0
Left PFC										
ΔHbO_2 (umol.L ⁻¹)	0.35 (0.44)	0.24 (0.54)	0.42 (0.46)	0.4	0.31 (0.71)	0.17 (0.36)	0.2	0.58 (0.58)	0.27 (0.26)	0.7
ΔHHb (umol.L ⁻¹)	-0.19 (0.14)	-0.19 (0.12)	-0.14 (0.16)	0.4	-0.24 (0.13)	-0.15 (0.10)	0.7	-0.20 (0.16)	-0.08 (0.15)	0.8
ΔHbDiff (umol.L ⁻¹)	0.54 (0.53)	0.43 (0.61)	0.56 (0.59)	0.2	0.55 (0.78)	0.32 (0.41)	0.4	0.78 (0.72)	0.34 (0.36)	0.7
Dual Task										

Right PFC																	
ΔHbO_2 (umol.L ⁻¹)	0.50	(0.90)	0.30	(1.07)	0.99	(0.54)	0.8	-0.10	(1.02)	0.70	(1.05)	0.7	1.20	(0.66)	0.77	(0.32)	0.8
ΔHHb (umol.L ⁻¹)	-0.17	(0.27)	-0.33	(0.29)	-0.06	(0.21) *	1.1	-0.28	(0.25)	-0.38	(0.34)	0.3	-0.22	(0.11)	0.09	(0.17) #	2.1
ΔHbDiff (umol.L ⁻¹)	0.67	(1.00)	0.63	(1.21)	1.05	(0.69)	0.4	0.18	(1.20)	1.08	(1.15)	0.7	1.42	(0.73)	0.68	(0.42)	1.2
Left PFC																	
ΔHbO_2 (umol.L ⁻¹)	0.21	(0.47)	0.16	(0.59)	0.50	(0.27)	0.7	-0.09	(0.48)	0.40	(0.62)	0.9	0.60	(0.32)	0.39	(0.17)	0.8
ΔHHb (umol.L ⁻¹)	-0.15	(0.16)	-0.23	(0.17)	-0.09	(0.14) *	0.9	-0.21	(0.18)	-0.25	(0.19)	0.2	-0.17	(0.11)	0.00	(0.12) #	1.5
ΔHbDiff (umol.L ⁻¹)	0.35	(0.54)	0.39	(0.70)	0.58	(0.36)	0.3	0.13	(0.58)	0.65	(0.75)	0.7	0.77	(0.36)	0.39	(0.26)	1.2

MAP, mean arterial pressure over 24-hour; PFC, Pre-frontal cortex; ΔHbO_2 , changes in oxyhemoglobin concentrations; ΔHHb , changes in deoxyhemoglobin concentrations; ΔHbDiff , ($\Delta\text{HbO}_2 - \Delta\text{HHb}$) as an index of brain oxygenation.

* different from Higher-Fit ($p < 0.05$); # different from lower MAP in same group ($p < 0.05$); + between Higher-Fit and Lower-Fit