Effect of overreaching on cognitive performance and related cardiac autonomic control

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The purpose of this study was to characterize the effect of a 2-week overload period immediately followed by a 1-week taper period on different cognitive processes including executive and nonexecutive functions, and related heart rate variability. Eleven male endurance athletes increased their usual training volume by 100% for 2 weeks, and decreased it by 50% for 1 week. A maximal graded test, a constant speed test at 85% of peak treadmill speed, and a Stroop task with the measurement of heart rate variability were performed at each period. All participants were considered as overreached. We found a moderate increase in the overall reaction time to the three conditions of the Stroop task after the overload period \( (816 \pm 83 \text{ vs } 892 \pm 117 \text{ ms}, P = 0.03) \) followed by a return to baseline after the taper period \( (820 \pm 119 \text{ ms}, P = 0.013) \). We found no association between cognitive performance and cardiac parasympathetic control at baseline, and no association between changes in these measures. Our findings clearly underscore the relevance of cognitive performance in the monitoring of overreaching in endurance athletes. However, contrary to our hypothesis, we did not find any relationship between executive performance and cardiac parasympathetic control.

Nonfunctional overreaching (NFOR) in sport is a complex state, which appears when an imbalance exists between training/non-training stress and recovery. It is characterized by a transitory decrease in sport performance and may eventually lead to the development of an overtraining syndrome (OTS) if training load is not adjusted to the level of fatigue. Early detection represents therefore a cornerstone in the monitoring of NFOR. Unfortunately, the etiology is still poorly understood and there is no pathognomonic marker that is widely accepted by physicians and sport scientists (Meeusen et al., 2006).

Besides the decrease in sport performance, one of the most accessible and relevant symptoms of NFOR or OTS is a psychological disturbance characterized by negative affective states (Morgan et al., 1987; O’Connor et al., 1989; Raglin et al., 1991). The Profile Of Mood States (POMS) (Mac Nair et al., 1971) and the Recovery–Stress Questionnaire (RESTQ) are two valid and commonly used psychological tools (Kellmann & Kallus, 2001) that consistently showed a dose–response relationship between observed scores and training load as well as a close association with performance (Dupuy et al., 2010). While psychological symptoms have been early recognized as possible signs of training maladaptation, the role of the central nervous system and higher brain centers in the development of fatigue and NFOR has received little attention (Meeusen, 1999).

Psychomotor speed and cognitive performance are considered as indirect measures of cerebral functioning, and have been proposed as early markers of NFOR and OTS (Nederhof et al., 2006). The study by Rietjens et al. (2005), provided some support to this hypothesis, because they found increased reaction time (RT) in seven well-trained cyclists after a 2-week period of overload. However, these cyclists could not be considered as overreached, because their performance during the graded exercise test or during the constant intensity test was not altered by the overload period. Nederhof et al. (2007) measured RT before and after a ~9-day training camp in 12 well-trained cyclists. Five of them were considered as functional overreached based on physiological and subjective measures, while the seven remaining cyclists were considered as well-trained. Nederhof et al. (2007), observed an increased RT in overreached cyclists, but the difference was not statistically significant. Hynynen et al. (2008), reported a larger number of errors during the Stroop color word test in 12 athletes suffering from NFOR or OTS when compared with their 12 well-trained counterparts.
Despite compelling findings, the cross-sectional nature of this study limits the interpretability of the data, because it is not possible to determine whether the lower cognitive performance observed in athletes suffering from NFOR or OTS was a consequence of fatigue, or rather a consequence of lower cognitive performance at baseline, which eventually made them more sensitive to fatigue. In line with these findings, recent research by Dupuy et al. (2010), reported a lower psychomotor speed during a simple RT task and lower executive performance during the most complex condition of a computerized modified Stroop task in five athletes who were classified as overreached after an unaccustomed increase of 100% of volume training. Some studies thus suggest a consistent trend appears to exist between cognitive function and training intolerance. However, it seems premature to consider cognitive performance as an important tool in the monitoring of NFOR. The general knowledge of NFOR/OTS continues to grow, but specific information on cognitive changes remains scant and this knowledge has important implications for both basic and applied issues. Executive functions generally refer to a “high-level” cognitive function involved in the control and regulation of cognitive processes such as planning, inhibiting routine behavior or updating working memory, and are largely under the influence of prefrontal cortex. Thayer et al. (2009) proposed a neurovisceral model, which supports a close relationship between prefrontal cortex and cardiac autonomic regulation, and more especially between executive functions and cardiac parasympathetic control. In fact, several authors have reported that subjects who performed better in cognitive tasks often presented greater heart rate variability (HRV) than others subjects, particularly in the high-frequency band of the spectrum, which is specific to the parasympathetic control of the heart (Hansen et al., 2003; Kim et al., 2006). In line with Thayer et al.’s (2009) proposal that HRV represents a measure of mental effort, it would be relevant to measure HRV during an executive task to improve our understanding of the relationship between executive and physical performance in overreached athletes (Hynynen et al., 2008; Dupuy et al., 2010).

The primary purpose of this study was to characterize the effect of a 2-week overload period immediately followed by a 1-week taper period on different cognitive processes including executive and nonexecutive functions. A secondary purpose was to examine the possible implication of the cardiac autonomic control in cognitive performance alterations. We hypothesized that (a) a 2-week overload period would alter specifically executive functions because of a decreased cardiac parasympathetic control during the cognitive task and that (b) cognitive performance would return to baseline after a 1-week taper period owing to the normalization of the cardiac autonomic control.

**Material and methods**

**Participants**

Eleven male endurance athletes participated in this study. They were competing at a provincial-standard in road running (n = 6), road cycling (n = 2) or triathlon (n = 3). Their mean ± standard deviation age, stature, and body mass were 29.5 ± 9.3 years, 177.0 ± 6.2 cm, and 71.6 ± 7.5 kg. The protocol was reviewed and approved by the Research Ethics Board in Health Sciences of the University of Montreal (Canada), and has been conducted in accordance with recognized ethical standards and national/international laws.

**Experimental design**

Following a thorough briefing all participants signed a written statement of informed consent. Subsequently, they completed three experimental sessions including a POMS questionnaire, a RESTQ-sport questionnaire, and a maximal continuous graded exercise test (session 1), and a computerized version of the Stroop color word test with the measurement of HRV (session 2), and a constant speed test (session 3). All sessions were separated by at least 48 h and were performed within a 7-day period, before and after a 2-week overload period consisting in a 100% increase of the baseline training volume (i.e., the training volume that is usually used by participants in their training plan), and after a 1-week taper period consisting in a 50% decrease of the baseline training volume. To avoid any residual fatigue induced by recent training, participants were asked to refrain from strenuous exercise the day before each session.

**Computerized modified Stroop task**

The computerized modified Stroop task was based on the modified Stroop color test (Bohnen et al., 1992). This test includes three conditions. In the first condition (Denomination), the participant had to identify the color of unrelated words, which were “MAIS” (but), “POUR” (for), “QUAND” (when), “DONC” (then). The answers were mapped to the letters “u,” “i,” “o,” and “p” on a QWERTY keyboard, which participants used to give their answers with the right and the left hand. The mapping remained the same throughout the task. The order was for the right hand “index finger – red,” “middle finger – green,” and for the left hand, “index finger – blue,” and “middle finger – yellow.” The order of this response procedure was counterbalanced across participants. The second block consisted in a classic Interference task, which requires naming the color of a color-word, the meaning of the color being incongruent with the color itself (the word BLUE written in green). In these two conditions (i.e., Denomination and Interference), a fixation cross appeared during 500 ms, followed by the word during 3000 ms. The third block consisted in a Switching task, which was identical to the Interference task, except that for 25% of the trials, a square appeared instead of the fixation cross, and participants were asked to read the color-word, instead of naming its color. The reading trials appeared randomly throughout the block. Each of the three blocks contained 60 trials and the screen was blank between the trials. Before each condition, participants completed practice trials; 12 for the Denomination condition, 12 for the Interference condition, and 20 for the Switching condition. During practice, the message “Error” was given on the screen for incorrect responses only.

**HRV analysis**

R–R intervals from each of condition of the Stroop test were edited separately and visually inspected so that ectopic beats could be replaced by interpolated data from adjacent normal-to-normal
(NN) intervals. HRV was assessed in the time and frequency domains. The mean HR, the standard deviation of NN intervals (SDNN) and the root mean square difference of successive normal NN intervals (RMSSD) were calculated from a segment of 256 s taken in the five last-minute period retained for HRV analysis. The same segment of 256 s was resampled at 2 Hz and detrended for subsequent analyses in the frequency domain. As recommended by the Task Force (1996), spectral analysis was performed with a fast Fourier transform to quantify the power spectral density of the low-frequency (LF 0.04–0.15 Hz) and the high-frequency (HF 0.15–0.40 Hz) bands. Additional calculations included LF + HF, LF, and HF expressed in normalized unit (i.e., in a percentage of LF + HF), and the LF/HF ratio.

Profile of mood states
The POMS (Mac Nair et al., 1971) is a 65-item Likert format questionnaire, which provides measures of six specific mood states: vigor, depression, fatigue, anger, anxiety, and confusion. These factors can also be combined to create composite measures of mood or fitness. Mood state index was obtained by adding the five negative factors together and subtracting the positive factor of vigor. Energy index represented the difference between the scores of vigor and fatigue (Kentta et al., 2006).

RESTQ-sport questionnaire
The RESTQ-sport (Kellmann & Kallus, 2001) is a 76-item Likert format questionnaire, which consists of 19 scales, of which seven assess general stress, five assess general recovery, three assess sport-specific stress, and four assess sport-specific recovery. Each scale consists of four questions.

Maximal continuous graded exercise test
This test was performed on a motorized treadmill (Quinton, Bothell, Washington, USA), which was calibrated at 8 and 16 km/h (gradient = 0) before each session with an “in-house” system using an optical sensor connected to an acquisition card. Initial speed was set at 12 km/h for 6 min, and increased by 1 km/h every 2 min until exhaustion. The grade was set at zero throughout the test. The speed of the last completed stage was considered as the peak treadmill speed (PTS). Perceived exertion was assessed at the end of the test, with the 10-point Borg scale (Borg, 1982). Oxygen uptake ($VO_2$) was determined continuously on a 15-s basis using an automated cardiopulmonary exercise system (Moxus, AEL Technologies, Naperville, Illinois, USA). Gas analyzers (S3A and CD3A, AEL Technologies) were calibrated before each test, using a gas mixture of known concentration (15% O$_2$ and 5% CO$_2$) and ambient air. Their accuracy was ±0.003% for oxygen and ±0.02% for carbon dioxide (data provided by the manufacturer). The turbine was calibrated before each test using a motorized syringe (Vacu-Med, Ventura, California, USA) with an accuracy of ±1% (Huszczyk et al., 1990). The tidal volume was set at 3 liters and the stroke rate at 40 cycles/min. Mean $VO_2$ over the last 2 min of the initial 6-min bout was divided by speed to calculate the energy cost of running (C$_{ER}$, in mL/kg/km). The highest $VO_2$ over a 15-s period during the test was considered as peak oxygen consumption ($VO_{2peak}$, in mL/kg/min). Heart rate was measured continuously on a 5-s basis using a heart rate monitor (S810, Polar Electro Oy, Kempele, Finland). The highest heart rate during the test was considered as peak heart rate ($HR_{peak}$, in b/min).

Constant speed exercise test
This test was performed on the same motorized treadmill than the maximal continuous graded exercise test. The instruction given to the participants was to maintain the required speed (85% of PTS) to the point of volitional exhaustion. Each test was preceded by a standardized warm-up consisting of a 10-min run at a self-determined speed; a set of three 10-s repetitions at the speed of the test, interspersed by 1 min of passive recovery, to accustomed themselves to the running speed; and a 5-min period of passive recovery. The test began with the participant’s feet astride the moving belt and hands holding the handrail. Time was measured to the nearest second from the moment the participant released the handrail (usually less than 3 s) until he grasped it again to signal exhaustion. Perceived exertion was assessed at the end of the test with the 10-point Borg scale (Borg, 1982). In order to increase reliability of this test (Currell & Jeukendrup, 2008), no verbal encouragement was given throughout the test, and participants were not informed about elapsed time.

Data analysis

Criteria for overreaching
A participant was considered as overreached when he gathered all the following criteria after the overload period: a decrease in physical performance evidenced by a decrease in PTS during the maximal continuous graded test or a decrease in time to exhaustion during the constant speed test; a decrease in $HR_{peak}$ during the maximal continuous graded test; psychological disturbances evidenced by a change in the Energy Index of the POMS and the RESTQ. The evolution of all these criteria after the taper period was used to assess the severity of overreaching. Short-term overreaching was characterized by a return to baseline after the taper period and could be assimilated to functional overreaching; long-term overreaching was characterized by maintenance of observed alterations after the taper period and could be assimilated to NFOR.

Statistical analysis
Standard statistical methods were used for the calculation of means and standard deviations. Normal Gaussian distribution of the data was verified by the Shapiro–Wilk test. A one-way within-group analysis of variance was performed to test the null hypothesis that dependant variables were not affected by the overload period. The compound symmetry, or sphericity, was checked by the Mauchly test. When the assumption of sphericity was not met, the significance of $F$-ratios was adjusted according to the Greenhouse–Geisser procedure when the epsilon correction factor was < 0.75, or according to the Huyn–Feld procedure when the epsilon correction factor was > 0.75. Multiple comparisons were made with the Newman–Keuls post-hoc test. The magnitude of difference was assessed by the Hedges’ $g$ (g), calculated as follows:

$$ g = J \times d $$

where $J$ is a correction factor calculated according to eqn. [2], and $d$ is Cohen’s $d$, calculated according to eqn. [3]

$$ J = 1 - \frac{3}{4 \cdot \text{d.f.} - 1} $$

where d.f. represents the degrees of freedom (d.f. = n–1 in the case of dependant groups)

$$ d = \frac{M_1 - M_2}{S_{\text{within}}} $$
where $M_1$ and $M_2$ are the mean of the first and the second trials, and $S_{\text{within}}$ is the standard deviation within groups, calculated as follows:

$$S_{\text{within}} = \sqrt{\frac{S_{\text{diff}}}{2(1-r)}}$$ [4]

where $S_{\text{diff}}$ is the standard deviation of differences between pairs and $r$ is the correlation between pairs. The magnitude of the difference was considered either small (0.2 < $r$ ≤ 0.5), moderate (0.5 < $r$ ≤ 0.8), or large ($r$ > 0.8). Statistical significance was set at $P < 0.05$ for all analyses.

**Results**

**Physiological response**

Mean responses during the maximal continuous graded exercise test are presented in Table 1. PTS, VO$_{\text{peak}}$ and Cr were not altered by the overload period. Nevertheless, we found a moderate decrease in maximal heart rate ($P = 0.003$, $g = -0.72$), with a return to baseline after the taper period. Perceived exertion was not affected by the period.

We found a moderate decrease in time to exhaustion after the overload period (29.8 ± 9.3 vs 22.1 ± 10.4 min, $P = 0.02$, $g = -0.71$), followed by a return to baseline after the taper period (31.0 ± 11.5 min, $P = 0.006$, $g = 0.75$). Perceived exertion was not affected by the period (8.6 ± 0.8, 8.7 ± 0.7, and 8.5 ± 1.1 after Baseline, Overload, and Taper, respectively).

**Psychological response**

Mean results for the POMS are presented in Fig. 1. We found a large and systematic increase in the Fatigue subscale (104 ± 4 vs 110 ± 5, $P = 0.0006$, $g = 1.33$) after the overload period, as well as a large and systematic decrease in the Vigor subscale (122 ± 3 vs 116 ± 6, $P = 0.001$, $g = -0.96$) and the Energy index (118 ± 6 vs 105 ± 10, $P = 0.0003$, $g = -1.29$). All these measures returned to baseline after the taper period (103 ± 4, 122 ± 4, and 119 ± 8 for Fatigue, Vigor, and Energy index, respectively).

### Table 1. Acute response to the maximal continuous graded exercise test

<table>
<thead>
<tr>
<th>Measure</th>
<th>Baseline</th>
<th>Overload</th>
<th>Taper</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO$_{\text{peak}}$ (mL/min/kg)</td>
<td>58.9 ± 4.3</td>
<td>57.4 ± 3.6</td>
<td>59.0 ± 3.4</td>
</tr>
<tr>
<td>PTS (km/h)</td>
<td>17.2 ± 1.3</td>
<td>17.0 ± 1.3</td>
<td>17.3 ± 1.3</td>
</tr>
<tr>
<td>HR$_{\text{peak}}$ (b/min)</td>
<td>186 ± 9</td>
<td>179 ± 8*</td>
<td>184 ± 10</td>
</tr>
<tr>
<td>RPE</td>
<td>8.5 ± 0.8</td>
<td>9.0 ± 1.0</td>
<td>8.8 ± 1.1</td>
</tr>
<tr>
<td>C$_{\text{r}}$ (mL/kg/m)</td>
<td>0.204 ± 0.020</td>
<td>0.202 ± 0.013</td>
<td>0.201 ± 0.018</td>
</tr>
<tr>
<td>HR$_{\text{r}}$ (b/min)</td>
<td>153 ± 13</td>
<td>147 ± 11</td>
<td>148 ± 13</td>
</tr>
</tbody>
</table>

VO$_{\text{peak}}$, peak oxygen uptake; PTS, peak treadmill speed; HR$_{\text{peak}}$, peak heart rate; RPE, rating of perceived exertion; C$_{\text{r}}$, energy cost of running at 12 km/h; HR$_{\text{r}}$, heart rate at 12 km/h; a, different from other values ($P < 0.05$).

Data are reported as mean ± standard deviation.

Mean results for the RESTQ are presented in Fig. 2. The main results are a large increase in the Fatigue subscale after the overload period (0.89 ± 0.7 vs 1.86 ± 1.33, $P = 0.02$, $g = 0.83$) and a moderate increase in the Lack of energy subscale (1.21 ± 0.72 vs 1.89 ± 0.98, $P = 0.02$, $g = 0.73$), as well as a large decrease in the Physical recovery subscale (3.80 ± 1.08 vs 2.20 ± 0.80, $P = 0.0002$, $g = -1.52$) and the Being in shape subscale (4.68 ± 0.86 vs 2.48 ± 1.18, $P = 0.0001$, $g = -1.91$).

**Cognitive response**

We found a moderate increase in the overall RT to the Stroop tasks (816 ± 83 vs 892 ± 117 ms, $P = 0.03$, $g = 0.60$) after the overload period followed by a return to baseline after the taper period (820 ± 119 ms, $P = 0.013$, $g = -0.56$). Results for separate conditions are presented in Fig. 3. We found a small to moderate increase in RT for denomination (701 ± 61 vs 784 ± 127 ms, $P = 0.04$, $g = 0.71$) and interference conditions (806 ± 131 vs 885 ± 154 ms, $P = 0.01$, $g = 0.47$) after the overload period followed by a return to baseline after the taper period. Concerning the switching condition, we observed a tendency toward a moderate increase in RT (942 ± 114 vs 1008 ± 118 ms, $P = 0.07$, $g = 0.52$) also followed by a return to baseline after the taper period (940 ± 112, $P = 0.07$, $g = -0.55$).

**Cardiac autonomic response**

HRV measures during the Stroop task are presented in Table 2. We found no effect of overload or taper periods on cardiac parasympathetic indices, either in the tempo-ral (SDNN, RMSSD) or frequency [High Frequency in normalized units HFnu] domains. We found no association between mean response time to the executive
conditions of the Stroop task (i.e., Interference and Switching) and related cardiac parasympathetic indices. We found no relationship between changes in these cognitive and autonomic measures.

**Discussion**

The primary purpose of this study was to characterize the effect of a 2-week overload period immediately followed by a 1-week taper period on different cognitive processes including executive and nonexecutive functions. A secondary purpose was to examine the possible implication of the cardiac autonomic control in cognitive performance alterations. The trends in performance, mood, and cognitive performance exhibited consistent changes in response to the overload period. This finding clearly underscores the relevance of cognitive performance in the monitoring of NFOR. However, contrary to our
Table 2. Heart rate variability in the time and frequency domains for the three separate conditions of the Stroop task at baseline, and after overload and taper

<table>
<thead>
<tr>
<th>Denomination</th>
<th>Time domain</th>
<th>Inhibition</th>
<th>Switching</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline</td>
<td>Overload</td>
<td>Taper</td>
</tr>
<tr>
<td>HR</td>
<td>69.6 ± 9.9</td>
<td>64.1 ± 9.4</td>
<td>64.6 ± 9.1</td>
</tr>
<tr>
<td>NN</td>
<td>888 ± 120</td>
<td>982 ± 145</td>
<td>912 ± 125</td>
</tr>
<tr>
<td>SDNN</td>
<td>56.4 ± 16.0</td>
<td>61.6 ± 23.3</td>
<td>59.0 ± 14.7</td>
</tr>
<tr>
<td>RMSSD</td>
<td>49.1 ± 18.8</td>
<td>61.2 ± 32.9</td>
<td>56.2 ± 20.8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Frequency domain</th>
<th>HR (ms²)</th>
<th>LF (ms²)</th>
<th>LF/HF</th>
<th>HF (ms²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>889 ± 689</td>
<td>1355 ± 1187</td>
<td>2.9 ± 3.3</td>
<td>28.4 ± 13.7</td>
</tr>
<tr>
<td>Overload</td>
<td>1304 ± 1320</td>
<td>1226 ± 959</td>
<td>3.5 ± 3.6</td>
<td>36.9 ± 18.4</td>
</tr>
<tr>
<td>Taper</td>
<td>1088 ± 816</td>
<td>1326 ± 959</td>
<td>3.6 ± 3.1</td>
<td>31.6 ± 15.2</td>
</tr>
<tr>
<td>Baseline</td>
<td>2247 ± 1995</td>
<td>1770 ± 934</td>
<td>2.9 ± 3.3</td>
<td>36.9 ± 18.4</td>
</tr>
<tr>
<td>Overload</td>
<td>2931 ± 2871</td>
<td>2427 ± 1355</td>
<td>3.6 ± 3.1</td>
<td>31.6 ± 15.2</td>
</tr>
<tr>
<td>Taper</td>
<td>2054 ± 1115</td>
<td>2421 ± 1416</td>
<td>3.6 ± 3.1</td>
<td>31.6 ± 15.2</td>
</tr>
</tbody>
</table>

| HF nu (%)        | 28.4 ± 13.7 | 36.9 ± 18.4 | 31.6 ± 15.2 |

<table>
<thead>
<tr>
<th>Time domain</th>
<th>Baseline</th>
<th>Overload</th>
<th>Taper</th>
</tr>
</thead>
<tbody>
<tr>
<td>HR</td>
<td>72.2 ± 10.9</td>
<td>64.5 ± 8.4</td>
<td>65.6 ± 8.4</td>
</tr>
<tr>
<td>NN</td>
<td>857 ± 123</td>
<td>972 ± 133</td>
<td>919 ± 109</td>
</tr>
<tr>
<td>SDNN</td>
<td>63.5 ± 32.7</td>
<td>67.10 ± 26.4</td>
<td>70.84 ± 28.9</td>
</tr>
<tr>
<td>RMSSD</td>
<td>57.0 ± 40.4</td>
<td>63.3 ± 35.4</td>
<td>69.2 ± 44.5</td>
</tr>
</tbody>
</table>

HF, high-frequency bands; HR, heart rate; LF, low-frequency bands; NN, normal-to-normal RR intervals; RMSSD, root mean square difference of successive normal NN intervals; SDNN, standard deviation of NN intervals;
a, different from baseline (P < 0.05).

Data are reported as mean ± standard deviation.

Energy index computed from the Vigor and Fatigue subscales of the POMS. The decrement in the monitoring of overreaching, the RESTQ, and confirms the usefulness of these questions.

A prerequisite to compare physical performances before and after an intervention such as the overreaching or taper period, is to make sure that all performances were indeed maximal. We did not find any effect of period on the rating of perceived exertion, whatever the exercise test, thus suggesting that this criterion was fulfilled in our case. The absence of alteration in VO₂peak and PES was implemented to complete the assessment of physical performance. The moderate decrease observed after the overload period, compared to the controls, suggests that aerobic endurance is more sensitive to overreaching than anaerobic power. The modified profile in the Vigor and Fatigue subscales of the POMS reported by Konta et al. (2010) and confirmed by others, reflects the usefulness of these questions in the monitoring of overreaching during an overreaching period. The observation is typical of overreaching, because the psychological impairment has been consistently described in the literature (Amar, 1999; Raglin et al., 1991; Dupuy et al., 1999). O'Connor et al. (2002) showed a small to moderate decrease in HRpeak in overreached athletes (Callister et al., 1990; Fry et al., 1992; Urhausen et al., 1998) when the aerobic endurance was not maximal. We did not find any effect of period on the rating of perceived exertion, whatever the exercise test, thus suggesting that this criterion was fulfilled in our case.
that could be assimilated in terms of severity to the previously described functional overreaching (Meeusen et al., 2006).

Cognitive and cardiac autonomic responses

The slowing down in cognitive performance induced by the overload period is consistent with previous reports (Rietjens et al., 2005; Nederhof et al., 2007, 2008; Dupuy et al., 2010), thus highlighting the central impact of overreaching and the interest of cognitive measures in the follow-up of athletes. Nevertheless, two findings that were not documented until now emerge from our study: (a) both executive and nonexecutive functions are affected by overreaching and (b) a 1-week taper period is an effective intervention to restore initial level. An important issue is to determine whether these changes are specific to the changes in training load or to the changes in performance capacity. Dupuy et al. (2010) provided some data suggesting that performance capacity is the keypoint. In this study, participants were classified as overreached or well-trained according to their performance capacity after a 2-week overload period. These authors reported a time by group interaction in physiological, psychological, and cognitive responses, which would not have been the case if training load was the major determinant of cognitive changes. Beyond their practical implications in terms of tests selection and interventions with overreached athletes, these findings raise some questions about the mechanisms involved in this response. In accordance with the neurovisceral model of Thayer et al. (2009), we hypothesized that these cognitive alterations were closely linked to the cardiac parasympathetic control during the Stroop task. Considering the evolution of cognitive performances in our participants, a decrease of the parasympathetic indices of HRV (i.e., SDNN, RMSSD, and HFnu) was expected after the overload period, followed by a return to baseline after the taper period. As shown in Table 2, we did not find any alteration in these markers of cardiac autonomic control. Hynynen et al. (2008) measured HRV during a Stroop task in 12 athletes suffering from NFOR or OTS and compared their results with 12 well-trained athletes. They reported a larger number of errors during the Stroop task in athletes suffering from NFOR or OTS, but the effect of fatigue on the measures of HRV was not convincing. It is worth noting that the effect of aerobic training on the sympathetic response to mental stress is itself inconsistent, because it has been found that sympathetic activity could be decreased or unchanged after the training period (Forcier et al., 2006; Jackson & Dishman, 2006; Hamer & Steptoe, 2007; Ray & Carter, 2010; Sloan et al., 2011). All together, these observations and the results of our study suggest that overload-induced changes in executive or nonexecutive performances during a Stroop task are not related to changes in cardiac autonomic control. Even if this conclusion remains to be confirmed with larger sample sizes, this absence of relationship also questions the validity of measuring autonomic regulation at the heart level to make inferences on autonomic regulation at the brain level during a cognitive task. Mechanistic studies should be implemented to address this important issue for the validity of the neurovisceral model of Thayer et al. (2009).

Other mechanisms can be involved in this cognitive impairment. A decrease in cerebral oxygenation, an upregulation of brain neurotransmitters such as serotonin or a dysregulation of neurotrophic factors such as the BDNF can potentially affect cerebral functioning and in turn executive and nonexecutive functions (Ploughman, 2008). However, none of these hypotheses has been clearly validated in overreached athletes. An alteration of motor control can eventually be involved, since the increase in the mean response time to a cognitive challenge such as the modified Stroop task we used in this study can also be the consequence of a peripheral impairment. This possible alteration of the motor tract, including the pyramidal tract, alpha motoneurons and the neuromuscular junction, is supported by some reports showing an alteration of the Hoffman reflex (Raglin et al., 1996) or a decrease in neuromuscular excitability (Lehmann et al., 1997) in overreached athletes. Futures studies involving more severe training paradigms and cases of OTS would be needed in order to adequately test these hypothetical mechanisms.

Limitations

This study suffers some limitations related to the experimental design that may affect the generalization of the conclusions. The first one concerns the hypothesis that the fatigue induced by a 2-week period of overload training is similar to the fatigue that characterizes FOR/NFOR when they are observed in a more ecological environment. Although we proposed a diagnostic approach that should improve the external validity of the results, it is acknowledged that the experimental model used to study the effect of FOR/NFOR on executive performance is not optimum and may have led to some shortcomings. A second limit concerns the lack of a control group. It is well established that the mean response time to the computerized modified Stroop tasks we used in this study improves with practice (Lemay et al., 2004). Because our participants were tested three times, a learning effect was expected after overload and taper periods. We observed this learning effect in a previous report using a comparable experimental design (Dupuy et al., 2010). Mean response time improved after the overload period in all conditions of the computerized Stroop tasks used in this study can also be the consequence of a peripheral impairment. This possible alteration of the motor tract, including the pyramidal tract, alpha motoneurons and the neuromuscular junction, is supported by some reports showing an alteration of the Hoffman reflex (Raglin et al., 1996) or a decrease in neuromuscular excitability (Lehmann et al., 1997) in overreached athletes. Futures studies involving more severe training paradigms and cases of OTS would be needed in order to adequately test these hypothetical mechanisms.
faster in participants who improved their performance capacity. These results suggest that the magnitude of effect of the overload period exceeds the magnitude of the learning effect in overreached participants. Considering the results of Dupuy et al. (2010) and the fact that mean response time was slower after the overload period in the present study, one may argue that the absence of a control group probably led to an underestimation of the effect of FOR on executive performance, which does not fundamentally change the conclusions of this study.

Conclusion

The purpose of this study was to characterize the effect of a 2-week overload period immediately followed by a 1-week taper period on different cognitive processes including executive and nonexecutive functions. A secondary purpose was to examine the possible implication of the cardiac autonomic control in cognitive impairment. We found an alteration of both cognitive and physical performances after the overload period, followed by a return to baseline after the taper period. This finding clearly underscores the relevance of simple computerized tests to assess cognitive performance in the monitoring of NFOR. However, contrary to our hypothesis, we did not find any relationship between cognitive performance and cardiac parasympathetic control. Future studies should therefore focus on the mechanisms involved in the cognitive impairment observed in overreaching.

Key words: overreaching, overload, tapering, Stroop task, heart rate variability.

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References


Overreaching and cognitive performance


