Influence of training load on upper respiratory tract infection incidence and antigen-stimulated cytokine production

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This study examined the effect of training load on upper respiratory tract infection (URTI) incidence in men and women engaged in endurance-based physical activity during winter and sought to establish if there are training-associated differences in immune function related to patterns of illness. Seventy-five individuals provided resting blood and saliva samples for determination of markers of systemic immunity. Weekly training and illness logs were kept for the following 4 months. Comparisons were made between subjects (n = 25) who reported that they exercised 3–6 h/week (LOW), 7–10 h/week (MED) or ≥ 11 h/week (HIGH). The HIGH and MED groups had more URTI episodes than the LOW group (2.4 ± 2.8 and 2.6 ± 2.2 vs 1.0 ± 1.6, respectively; P < 0.05). The HIGH group had approximately threefold higher interleukin (IL)-2, IL-4 and IL-10 production (all P < 0.05) by antigen-stimulated whole blood culture than the LOW group and the MED group had twofold higher IL-10 production than the LOW group (P < 0.05). Other immune variables were not influenced by training load. It is concluded that high levels of physical activity are associated with increased risk of URTI and this may be related to an elevated anti-inflammatory cytokine response to antigen challenge.

Exercise, depending on its intensity, can have either positive or negative effects on immune function and general health (Pedersen & Hoffman-Goetz, 2000). Regular moderate-intensity exercise enhances immune functions above those typically found in sedentary individuals. These functions include the potentiation of T-cell-mediated immunity, natural killer (NK) cell cytotoxicity, pro-inflammatory cytokine production, and the Th1 reaction in human or animal models (Sugiura et al., 2001; Davis et al., 2004; Murphy et al., 2004; Okutsu et al., 2008; Wang et al., 2012). These effects may explain why regular moderate exercise reduces upper respiratory tract infection (URTI) incidence by ~20–45% compared with a sedentary lifestyle (Matthews et al., 2002; Nieman et al., 2011). In contrast, very prolonged strenuous bouts of exercise and periods of intensive training and competition may impair immune function, increasing susceptibility to URTI by decreasing salivary secretory immunoglobulin A (S-IgA) secretion, NK cell activity, and pro-inflammatory cytokine production (Peters & Bateman, 1983; Nieman et al., 1990; Heath et al., 1992; Gleeson et al., 1999; Nieman, 2000; Steensberg et al., 2001; Suzuki et al., 2002; Bishop, 2005; Fahlman & Engels, 2005). However, not all studies on high-level athletes have found significant associations between training load and URTI incidence (e.g., Fricker et al., 2005).

The aims of the present study were to examine URTI incidence and its possible associations with resting immune variables including salivary and plasma Ig concentrations, numbers of circulating leukocyte subsets and cytokine production by antigen-stimulated whole blood culture in an athletic population. In particular, we wished to determine if whether URTI incidence and any immune variables differed between subjects who practiced regular moderate amounts of exercise (defined as 3–6 h of exercise per week) and those who engaged in substantially more hours of endurance-based training. Differences in saliva and blood immune parameters were examined, and one measure of immune function was antigen-stimulated cytokine production by whole blood culture in order to simulate exposure to a pathogen challenge. We hypothesized that high-volume training would be associated with a higher incidence of URTI and an impaired pro-inflammatory cytokine response and/or an elevated anti-inflammatory cytokine response to the multi-antigen challenge compared with subjects engaged in lower levels of physical activity. Our study population was a group of university students on a single campus site so that environment and pathogen exposure were likely to be similar for all subjects.
Materials and methods

Subjects

Ninety healthy university students who were engaged in regular sports training (predominantly endurance-based activities such as running, cycling, swimming, triathlon, team games, and racquet sports) volunteered to participate in the study. Subjects ranged from recreationally active to Olympic triathletes. Of these 90 subjects, 40 were women and 50 were men with baseline characteristics [mean ± standard deviation (SD)] as follows: age 22.5 ± 4.0 years, body mass 71.5 ± 11.6 kg, height 175 ± 9 cm, body mass index 23.2 ± 2.6 kg/m² and self-reported weekly training load 9.3 ± 4.3 h/week. Subjects were required to complete a comprehensive health-screening questionnaire prior to starting the study; they were free of URTI symptoms for at least 2 weeks and had not taken any medication in the 4 weeks prior to the study. All subjects were fully informed about the rationale for the study and of all experimental procedures to be undertaken. Subjects provided written consent to participate in the study, which had earlier received the approval of Loughborough University ethical advisory committee. Subjects were enrolled after having fulfilled all inclusion criteria, and presenting none of the exclusion criteria (determined by both questionnaire and interview).

Subjects could be included if they were currently healthy, aged 18–35 years, had been involved in endurance training for at least 2 years, and engaged in at least three sessions and at least 3 h of total moderate/high-intensity training time per week. For data analysis, subjects were allotted to one of three groups according to their self-reported hours of weekly training: 3–6 h/week, designated as low- (LOW), medium- (MED), and high- (HIGH) volume training groups, respectively.

Subjects representing one or more of the following criteria were excluded from participation: Smoking or use of any regular medication, abnormal hematology (e.g., erythrocyte or leukocyte counts outside the normal range), suffered from or had a history of cardiac, hepatic, renal, pulmonary, neurological, gastrointestinal, hematological, or psychiatric illness.

Seventy-five subjects (44 males and 31 females) completed the 4-month study period. Reasons for dropout were given as foreign travel, injury, or persistent non-respiratory illness (preventing subjects from performing training) or because of undisclosed reasons. There were 25 subjects in the LOW group (10 females, 15 males), 25 in the MED group (14 females, 11 males) and 25 in the HIGH group (7 females, 18 males). The anthropometric characteristics of the groups were similar, although subjects in the LOW group were slightly older than in the other two groups (Table 1).

Laboratory visit

The study began in the month of November. Subjects arrived at the laboratory in the morning at 08:30–10:30 a.m. following an overnight fast of approximately 12 h. Each subject was asked to empty their bladder before body mass and height were recorded. Subjects then sat quietly for 10 min and completed health and training questionnaires before providing a saliva sample. With an initial swallow to empty the mouth, unstimulated whole saliva was collected by expectoration into a vial for 2 min with eyes open, head tilted slightly forward and making minimal orofacial movement. All saliva samples were stored at −20°C until analysis. Subsequently, a venous blood sample (11 mL) was obtained by venepuncture from an antecubital vein and blood was collected into two Vacutainer tubes (Becton Dickinson, Oxford, UK) containing either K₁ ethylenediaminetetraacetic acid (EDTA) or heparin. Hematological analysis was immediately carried out on the EDTA sample as detailed later.

Questionnaires

During the 4-month subsequent study period, subjects were requested to continue with their normal training program and they completed a health (URTI symptoms) questionnaire on a weekly basis. Supplements (vitamins and minerals, etc.) were not permitted during this period. Subjects were not required to abstain from medication when they were suffering from illness symptoms but they were required, on a weekly basis, to report any unscheduled medications taken, visits to the doctor and any prescribed medications.

The illness symptoms listed on the questionnaire were: sore throat, catarrh in the throat, runny nose, cough, repetitive sneezing, fever, persistent muscle soreness, joint aches and pains, weakness, headache, and loss of sleep. The non-numerical ratings of light, moderate, or severe (L, M, or S, respectively) of severity of symptoms were scored as 1, 2 or 3, respectively to provide a quantitative means of data analysis (Fricker et al., 2005; Gleeson et al., 2011a, b), and the total symptom score for every subject each week was calculated by multiplying the total number of days each symptom was experienced by the numerical symptom severity rating. In any given week a total symptom score of ≥12 was taken to indicate that a URTI was present. This score was chosen as to achieve it a subject would have to record at least three moderate symptoms lasting for 2 days or two moderate symptoms lasting for at least 3 days in a given week. A single URTI episode was defined as a period during which the weekly total symptom score was ≥12 and

Table 1. Anthropometric and hematological characteristics of the low- (LOW), medium- (MED), and high- (HIGH) volume training groups

<table>
<thead>
<tr>
<th></th>
<th>LOW (n = 25)</th>
<th>MED (n = 25)</th>
<th>HIGH (n = 25)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Females (F), males (M)</td>
<td>10F, 15 M</td>
<td>14F, 11 M</td>
<td>7F, 18 M</td>
</tr>
<tr>
<td>Age (years)</td>
<td>24.6 ± 5.1</td>
<td>21.2 ± 2.4**</td>
<td>22.0 ± 3.3*</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>1.74 ± 0.10</td>
<td>1.75 ± 0.08</td>
<td>1.77 ± 0.08</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>71.7 ± 12.1</td>
<td>70.9 ± 11.2</td>
<td>72.2 ± 12.5</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>23.5 ± 2.8</td>
<td>23.1 ± 2.2</td>
<td>23.0 ± 2.7</td>
</tr>
<tr>
<td>Training load (h/week)</td>
<td>5.1 ± 0.9</td>
<td>8.5 ± 1.0**</td>
<td>14.5 ± 3.4**</td>
</tr>
<tr>
<td>IPAQ (MET-h/week)</td>
<td>45.5 ± 22.1</td>
<td>58.8 ± 23.0</td>
<td>86.0 ± 33.4**</td>
</tr>
<tr>
<td>RBC count (x10⁹/L)</td>
<td>4.76 ± 0.49</td>
<td>4.61 ± 0.43</td>
<td>4.79 ± 0.44</td>
</tr>
<tr>
<td>Hematocrit (%)</td>
<td>41.2 ± 3.6</td>
<td>41.3 ± 4.0</td>
<td>41.4 ± 2.8</td>
</tr>
<tr>
<td>Hemoglobin (g/L)</td>
<td>140 ± 13</td>
<td>139 ± 14</td>
<td>141 ± 10</td>
</tr>
</tbody>
</table>

Values are expressed as mean (± SD).

Significantly different from LOW: *P < 0.05; **P < 0.01.

Significant difference between HIGH and MED: *P < 0.01.

BMI, body mass index; IPAQ, international physical activity questionnaire; MET, metabolic equivalent; RBC, red blood cell; SD, standard deviation.
separated by at least 1 week from another week with a total symptom score ≥ 12. Subjects were also asked to rate the impact of illness symptoms on their ability to train (normal training maintained, training reduced, or training discontinued: L, M, or S, respectively). The same questionnaire was used in two previous studies that examined sex differences in URTI incidence in athletes (Gleeson et al., 2011a) and the influence of probiotic supplementation on URTI incidence in an endurance athlete cohort (Gleeson et al., 2011b). Subjects were also asked to fill in a standard short form international physical activity questionnaire (IPAQ: http://www.ipaq.ki.se/downloads.htm) at weekly intervals, thus providing quantitative information on training loads in metabolic equivalent (MET)-h/week (Craig et al., 2003).

Blood cell counts
Blood samples in the K$_3$EDTA vacutainer (4 mL) were used for hematological analysis (including hemoglobin, hematocrit, and total and differential leukocyte counts) using an automated cell-counter (A$_v$T$	extsuperscript{TM}$5diff hematology analyzer; Beckman Coulter, High Wycombe, UK). The intra-assay coefficient of variation for all measured variables was less than 3.0%.

Lymphocyte subsets
Lymphocyte subsets (CD3$, CD4$, CD8$, CD19$, CD56$) to enumerate total T-cells, T-helper cells, T-cytotoxic cells, B cells, and NK cells, respectively were determined by three-color flow cytometry (Becton Dickinson FACSCalibur) with CellQuest analysis software (Becton Dickinson Biosciences, Oxford, UK) as described previously (Lancaster et al., 2004). Forward scatter vs side scatter plots were used to gate on the lymphocyte population by morphology and 10,000 lymphocyte events were acquired per analysis. Estimations of the absolute CD3$, CD3$+CD4$, CD3$+CD8$, NK cell (CD3$-CD56$), and B cell (CD3$-CD19$) numbers were derived from the total lymphocyte count.

Monocyte toll-like receptor 4 (TLR4) expression
The cell surface expression of TLR4 on CD14$^+$ monocytes (geometric mean fluorescence intensity) corrected for nonspecific binding using an isotype control) was determined according to Oliveira and Gleeson (2010).

Antigen-stimulated cytokine production
Stimulated whole blood culture production of cytokines [interferon (IFN)-γ, tumor necrosis factor (TNF)-α, interleukin (IL)-1β, IL-2, IL-4, IL-6, IL-8, and IL-10] was determined as described previously (Gleeson et al., 2011a, b). The stimulant was a commercially available multi-antigen vaccine (Pediacel Vaccine; Sanofi Pasteur, Maidenhead, UK) containing diphtheria, tetanus, acellular pertussis, poliomyelitis, and hemophilus influenzae type b antigens. Briefly, heparinized whole blood was cultured with vaccine at 37°C and 5% CO2 for 24 h. After centrifugation at 1500 g for 10 min at 4°C, supernatants were collected and stored frozen at −80°C prior to analysis of cytokine concentrations using an Evidence Investigator System using the cytokine biochip array EV3513 (Randox, County Antrim, UK). The intra-assay coefficient of variation for all measured cytokines was less than 5.0%.

Plasma immunoglobulins
The remaining blood in the K$_3$EDTA tube was centrifuged at 1500 g for 10 min at 4°C within 10 min of sampling. The plasma obtained was immediately stored at −80°C prior to analysis of IgA, IgG, and IgM (immunoturbidimetric assay on Pentra 400 autoanalyser, Horiba, France using the manufacturer’s calibrators and controls). The intra-assay coefficient of variation for IgA, IgG, and IgM was 3.2%, 1.9%, and 2.3%, respectively.

Saliva IgA
Duplicate saliva samples were analyzed for secretory IgA using an enzyme-linked immunosorbent assay kit (Salimetrics, Philadelphia, USA). The intra-assay coefficient of variation for IgA was 3.6%.

Statistical analysis
The number of URTI episodes, blood leukocyte, neutrophil, monocyte, eosinophil, and lymphocyte counts, lymphocyte subset counts, concentrations of secreted cytokines, plasma, and saliva Ig concentrations were compared between the groups using one-way analysis of variance (ANOVA) for normally distributed data. Where significant F-values were found, Newman–Keuls tests were used for comparisons between groups. The cytokine and saliva IgA data were not normally distributed and these data were analyzed using the Kruskal–Wallis test (nonparametric equivalent of one-way ANOVA) with post-hoc Dunns test. Relationships between variables were examined using Pearson’s product moment correlation coefficient. Statistical significance was accepted at P < 0.05. Data are expressed as mean ± SD or median and 25% and 75% percentiles as appropriate.

Results
Training loads and URTI incidence
The LOW, MED and HIGH groups reported participating in moderate-vigorous exercise for 5.1 ± 0.9, 8.5 ± 1.0, and 14.5 ± 3.4 h/week, respectively (P < 0.001). Analysis of the IPAQ questionnaires confirmed that the weekly training loads were substantially higher in the HIGH group compared with the MED and LOW groups (Table 1). The IPAQ scores in MET-h/week significantly correlated with subjects’ self-reported training loads at the start of the study (r = 0.583, P < 0.001, n = 75).

Analysis of the URTI symptom questionnaires indicated that the HIGH and MED groups experienced 2.4 ± 2.6 and 2.6 ± 2.2 episodes, respectively during the 4-month period, which were both significantly more than the LOW group (1.0 ± 1.7 episodes, P < 0.05). The proportion of subjects who suffered one or more episodes of URTI was also higher in the HIGH (0.72) and MED (0.84) groups compared with the LOW (0.36) group. The proportion of all subjects who stated that training was negatively affected when suffering URTI symptoms (N = 48) was 0.81. When an URTI episode was present, the proportion of subjects who took medication was 0.65 and the proportion of subjects who visited their doctor was 0.22.

Influence of training load on blood and saliva immune variables
There were no differences in hematological variables (Table 1), circulating numbers of leukocytes, neutrophils,
The main findings of the present study were that athletes engaged in high training loads had higher URTI incidence and higher IL-2, IL-4, and IL-10 production in response to antigen challenge than subjects who were only moderately active. Thus, our hypothesis was only partially correct in that high-volume training was associated with a higher incidence of URTI and an elevated anti-inflammatory cytokine response to antigen compared with subjects engaged in lower levels of physical activity but there was no statistically significant effect of training load on the pro-inflammatory cytokine response to antigen (other than a tendency for IFN-γ production to be higher in the HIGH group). Other studies have reported increased URTI incidence following marathon and ultramarathon events (Peters & Bateman, 1983; Nieman et al., 1990) or during periods of intensive training and competition (Fahlman & Engels, 2005) and some (Nieman et al., 1990; Heath et al., 1992; Nieman, 2000) but not all (Matthews et al., 2002; Fricker et al., 2005) studies have reported a positive association between URTI incidence and training load. Our data, in combination with the findings of studies by Matthews et al. (2002) and Nieman et al. (2011) support the notion of a ‘J-shaped’ relationship between URTI incidence and
exercise training load (Nieman, 2000) although a limitation of the present study was that a sedentary control group was not included. These previous studies indicated that URTI risk is reduced in adults performing regular moderate exercise compared with those having a sedentary lifestyle and our findings indicate that exercise training loads above that which could be considered to be moderate levels of physical activity result in increased URTI risk.

Associations between URTI risk and blood immune parameters have not been extensively examined, although an impaired IFN-γ production in unstimulated whole blood culture has been reported in fatigued and illness-prone endurance athletes (Clancy et al., 2006). However, the relevance of this measure of immune function to infection risk is unclear as cytokine production in the unstimulated state is very low compared with the response to an infectious agent or antigen challenge. In the present study, we examined cytokine production in response to an in vitro multi-antigen challenge in order to simulate the response to an infection. We observed significant differences in the production of IL-2, IL-4, and IL-10 between the LOW and HIGH training volume groups. Similarly, Sugiura et al. (2002) observed a twofold higher mitogen-stimulated IL-2 production by splenic lymphocytes in exercise trained mice compared with sedentary counterparts. None of the other immune variables measured in the present study were significantly influenced by training load.

A difference in TLR expression on monocytes was considered as one possible reason for a difference in cytokine production in response to an antigen challenge (Lancaster et al., 2005) and others have reported lower TLR4 expression in trained compared with sedentary subjects in both cross-sectional (McFarlin et al., 2006) and longitudinal training studies (Stewart et al., 2005). However, in the present study, we found no influence of training load on monocyte TLR4 expression and production of none of the measured cytokines correlated with monocyte TLR4 expression. Specific differences in the expression of cytokine genes could also account for differences in susceptibility to URTI (and other infectious diseases) by influencing the function of immune cells or the cytokine response to pathogens (Ollier, 2004). In a recent study, IL-2 and IL-10 polymorphisms were associated with respiratory tract infection incidence in elderly humans (Besisle et al., 2010). However, the present study suggests that training volume may have a direct influence on the pattern and the magnitude of cytokine production in response to antigen challenge and that a high anti-inflammatory cytokine (IL-4 and IL-10) response may make individuals more susceptible to URTI.

IL-10 is known to be produced by both innate and adaptive immune cells and its principal role appears to be containment and suppression of inflammatory responses so as to downregulate effector adaptive immune responses and minimize tissue damage in response to microbial challenges (Moore et al., 2001; Fujio et al., 2010). Accordingly, IL-10 induces downregulation of major histocompatibility complex (MHC) antigens, the intercellular adhesion molecule-1, as well as the costimulatory molecules CD80 and CD86 on antigen-presenting cells, and it has been shown to promote differentiation of dendritic cells expressing low levels of MHC class II, CD80, and CD86 (Maynard & Weaver, 2008). Thus, IL-10 is able to limit the ability of antigen-presenting cells to promote the differentiation and/or proliferation of CD4+ T-cells, thereby regulating both initiation and perpetuation of adaptive T-cell responses.

There is now extensive evidence from both murine and human studies that IL-10 production usually imposes some limits on the effectiveness of antipathogen immune responses, especially innate immunity and adaptive Th1 responses (van der Sluijs et al., 2004; Blackburn & Wherry, 2007). The Th2 cytokine IL-4, which was also secreted in higher amounts in the HIGH subjects also exerts inhibitory effects on Th1 differentiation. Th1 cells drive cell-mediated immunity, which is important in the defense against viral infections. Therefore, we suggest that decreased Th1 responses, mediated by high IL-10 responsiveness in particular, may be partly responsible for the higher incidence of URTI symptoms in the HIGH and MED athletes. In the present study, the higher URTI incidence in the HIGH and MED subjects could not be attributed to decreased production of pro-inflammatory cytokines but rather to an increased production of IL-10 and/or IL-4.
T-regulatory (Treg) cells (Fujio et al., 2010) and B-regulatory (Breg) cells (Blair et al., 2010) are thought to be the main secretors of IL-10 and one possibility is that heavy exercise training induces an increase in the number of Treg and/or Breg cells. Indeed, several recent human (Yeh et al., 2006; Teixeira et al., 2011) and animal (Wang et al., 2012) studies have reported higher circulating Treg cell numbers following increases in training load. The study by Yeh et al. (2006) reported an increase in the numbers of circulating CD4+CD25+ Treg cells following a 12-week exercise training program, which was associated with a 1.8-fold increase in antigen-stimulated IL-10 production by cultured mononuclear leukocytes. Interestingly, Treg cells respond to the presence of IL-2 by rapid proliferation (Malek, 2003) and plasma levels of IL-2 are increased for several hours after prolonged exercise (Castell et al., 1997).

Limitations of the present study were that an unvalidated questionnaire was used to assess URTI incidence and the immune measures were made on only a single baseline sample. However, we had established from an earlier unpublished study of 48 healthy active subjects that differential leukocyte counts and antigen-stimulated cytokine production were reasonably consistent in resting blood samples collected 2 months apart. The same immune variables were measured and we found that coefficients of variation for were <20% for total leukocytes, neutrophils, monocytes, lymphocytes, T-cells, and antigen-stimulated IL-2, IL-4, IL-6, IL-10, TNF-α, and IFN-γ production by whole blood culture. Furthermore, rank correlations among the 48 subjects for the relationship between 0-month and +2-month samples for these same variables had r-values of 0.70–0.98.

It is concluded that high training loads are associated with increased risk of URTI and that alterations in the cytokine response to antigens—in particular elevated production of the anti-inflammatory cytokines IL-4 and IL-10—with heavy training may, at least in part, account for the greater susceptibility to URTI in highly physically active individuals.

Perspectives

The present study confirms that high training loads are associated with increased incidence of URTI during the winter months. This study is the first, to our knowledge, to report that IL-10 responsiveness to antigen challenge is influenced by training load and presumably this is due to higher numbers of IL-10-producing cells in the circulation. Although this may impair immune response effectiveness against the common cold it could also be a contributing factor to the anti-inflammatory effects of regular exercise, which are seen to be beneficial to long-term health (Gleeson et al., 2011c).

Key words: exercise, immunity, leukocytes, illness, interleukins.

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