

MODELING THE ASSOCIATION BETWEEN HEART RATE VARIABILITY AND ILLNESS IN ELITE SWIMMERS

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ABSTRACT

Purpose: To determine whether heart rate variability, an indirect measure of autonomic control, is associated with upper respiratory tract and pulmonary infections, muscular affections and all-type pathologies in elite swimmers. **Methods:** Seven elite international and 11 national swimmers were followed weekly for two years. The indexes of cardiac autonomic regulation in supine and orthostatic position were assessed as explanatory variables by time-domain (SD1, SD2) and spectral analyses (high frequency- HF; 0.15 Hz-0.40Hz, low frequency-LF; 0.04-0.15 Hz and HF/LF ratio) of heart rate variability. Logistic mixed models described the relationship between the explanatory variables and the risk of upper respiratory tract and pulmonary infections, muscular affections and all-type pathologies. **Results:** The risk of all-type pathologies was higher for national swimmers and in winter ($p<0.01$). An increase in the parasympathetic indexes (HF, SD1) in supine position assessed one week earlier was linked to a higher risk of upper respiratory tract and pulmonary infections ($p<0.05$), and to a higher risk of muscular affections (increase in HF, $p<0.05$). Multivariate analyses showed: (1) a higher all-type pathologies risk in winter, and for an increase in the total power of heart rate variability associated with a decline SD1 in supine position; (2) a higher all-type pathologies risk in winter associated with a decline in HF assessed one week earlier in orthostatic position; and (3) a higher risk of muscular affections in winter associated with a decrease SD1 and an increase LF in orthostatic position. **Conclusion:** Swimmers' health maintenance requires particular attention when autonomic balance shows a sudden increase in parasympathetic indices in supine position assessed one week earlier evolving toward sympathetic predominance in supine and orthostatic positions.

Key Words: Swimming, upper respiratory tract and pulmonary infections, muscular affections, mixed-effects logistic regression models.

Running title: HRV and risk of illness in elite swimmers.

INTRODUCTION

Paragraph Number 1 International and Olympic swimming competition can be characterized by a rise in the level of the performances (28,37). Moreover, the higher the performance level, the smaller the differences in performance. For example, during the Rome World Championships in 2009, the mean difference for all the swimming finals was $2.9 \pm 0.9\%$ between the World Champion and the poorest (8th) performance, while for the national championships this difference was $5.1 \pm 2.8\%$. In such a competitive context, the training must be optimized to reach the highest level of performance, and the risk of infection must be carefully monitored during the most intensive training periods and actual competition (17,27,29). For example, the swimmers from the Australian team who fell ill in the six weeks preceding the Commonwealth Games were found to have a 60% greater risk of turning in a poor performance (29).

Paragraph Number 2 Yet reducing the risk of infection during prolonged and intensive training and competition periods depends on several factors (17,21,29). High-level swimmers like many international athletes encounter many sources of stress in addition to the physiological and biological stress of intensive training. These include stresses due to environmental conditions (e.g., heat and humidity, altitude, air pollution, traveling great distances and through several time zones), lifestyle factors (e.g., professional obligations, cohabitating, dietary practices), and psychological factors (e.g., personal and psychosocial factors, competition and training stresses) (17,21,29). This accumulation of acute and chronic stress factors has been shown to disturb several immune parameters, which in turn lowers resistance to common minor illnesses like upper respiratory tract infection (12,13,17,35).

Paragraph Number 3 Several studies have also established that physical and psychological stresses disturb autonomic regulation (2,18,21,25,31). These authors observed disturbances in autonomic regulation during periods of long and intensive training overload, manifesting first

by a shift in autonomic balance toward sympathetic predominance (sympathetic form of overtraining) (18,21,25,31), which then progressed to complete exhaustion of the neuroendocrine system (parasympathetic form of overtraining) when recovery periods were omitted from the training schedule (2,10,18,21).

Paragraph Number 4 Several lines of evidence suggest that autonomic imbalance compromises immune regulation and thus increases the risk of illness. For example, the hypothalamus is known to communicate with the immune system via the autonomic nervous system (4). Lymph organs like the spleen, lymph nodes and thymus are innervated by noradrenergic fibers from sympathetic neurons (8) and cholinergic fibers (4). Functionally, sedentary subjects with autonomic imbalance characterized by sympathetic predominance were found to be predisposed to gastrointestinal diseases like inflammatory bowel disease or active ulcerative colitis (34).

Paragraph Number 5 It is generally assumed that sympathetic control promotes the inflammatory response while the parasympathetic arm is protective (22,34). For instance, a study by Marsland et al. (2007) provided initial human evidence that vagal activity inhibits the production of proinflammatory cytokines by activated monocytes/macrophages and thus decreases local and systemic inflammation.

Paragraph Number 6 However, no study has yet investigated the effects of disturbed autonomic nervous activity on the incidence of infection in elite athletes under the intense stress of training and competition.

Paragraph Number 7 This study tested the hypothesis that a shift in autonomic balance toward sympathetic predominance would be associated with a higher risk of infection. The presence of infection and variations in autonomic activity as assessed by heart rate variability were thus assessed weekly in 18 elite swimmers over a two-year period.

MATERIAL AND METHODS

Subjects.

Paragraph Number 8 Eighteen elite swimmers (10 men and 8 women; 7 elite international and 11 national) aged 19-30 yr were followed longitudinally weekly between 2003 and 2005 (1508 weeks of observation for the whole cohort). The study was approved by the Institutional Review Board of the host site, and written informed consent was obtained from all athletes. These athletes all trained in the same location and followed the same training program.

Infections and affections.

Paragraph Number 9 The study was conducted in two Olympic preparation centers. Both centers have a medical service located 500 meters from the pool. The same two physicians followed the swimmers over the course of this study. These two physicians developed the questionnaire that was used to document all upper respiratory tract, pulmonary, gastrointestinal, gynecological and urological infections, and all neurological symptoms and muscular affections. The questionnaire was derived from the WURSS-44 and the questionnaire of Fricker et al. (2005). On a weekly basis, the physicians thus documented the following symptoms: for upper respiratory infections: sneezing, stuffy nose, runny nose, hoarseness, sore throat, sinus pain, sinus pressure, sinus drainage, swollen glands, ear infection, ear ache, plugged ear, ear discomfort, watery eyes, eye discomfort, headaches, sweats, chills, feeling feverish, feeling tired, irritability, and feeling depressed; for pulmonary infections: chest congestion, chest tightness, cough, and sputum. The term muscular affections referred to the following: muscle injury (violent pain requiring exercise cessation), pulled muscles (muscle pain during exercise insufficient to stop exercise), tendinopathies (tendon pain with swelling and altered function), delayed-onset muscle soreness persisting more than 24 hours after training, shoulder pain syndrome and knee pain syndrome. Upper respiratory

tract and pulmonary infections, muscular affections and all-type pathologies were only recorded if the swimmer showed signs or symptoms for more than 48 hours, required medication, and missed at least one training session as a result of illness. A recurring illness was defined as “any upper respiratory tract or pulmonary infections, muscular affections, or all-type pathologies occurring” within one week of a previously recorded episode and was not retained for analysis (9, 32). At the appearance of any signs or symptoms, the swimmers were immediately (within 1 to 6 hours) seen by one of the two physicians for a complete clinical examination. Once a diagnosis was made, the swimmer was asked to complete the questionnaire daily during the period of illness. For each episode of illness the following indices were noted: type, duration (number of days), and peak severity (mild=no change in training program, moderate=training program modified, severe=complete cessation of training). An illness was defined and taken into account for the study when a swimmer reported one or more signs or symptoms on two or more consecutive days or when the severity was rated as either moderate or severe (9).

Paragraph Number 10 For statistical reasons (small samples, rare events), the infections were grouped into three responses of primary interest for physicians and trainers: upper respiratory tract and pulmonary infections (URTPI), muscular affections (MA), and all types of pathologies (AP).

Heart rate variability (HRV) analysis.

Paragraph Number 11 All tests were conducted every Monday at 9 am in identical conditions. The swimmers did not train the day before testing to avoid the effects of exercise on the test results. They were also instructed not to ingest any medication, tea or coffee before the test.

Paragraph Number 12 After a 15-min rest, testing began, with each test lasting 16 min: 8 min in supine position (SUP) and 8 min in orthostatic position (OR). Recordings made during

the last six minutes of each position were retained for analysis. The time between two consecutive R waves of the recorded cardiac electrical activity (R-R interval) was measured with a Polar S810 HR monitor (Polar[®], Kempele, Finland).

Paragraph Number 13 The heart rate monitor signal was transferred to the Polar Precision Performance Software, version 4.03.040 (Electro Oy, Kempele, Finland), and the R-R intervals were exported under ASCII format. Prior to HRV analysis, raw R-R intervals from Polar S810 recordings were edited to discriminate error caused by S810 acquisition, nonsinus beats or artifacts. S810 artifacts were edited using the automated default protocols in the Polar software. This software corrected for artifacts using an error filter and beat protection zone function. A moderate filter power set at a minimum beat protection of six beats.min⁻¹ was used. Following removal of abnormal intervals, the Polar software linearly interpolated the removed intervals using system-specific algorithms. Each data file was again visually inspected for artifacts, which were manually corrected. The signal was then considered to be normal and to provide normal-to-normal (N-N) intervals. The stationarity of each R-R series was assessed with the paired t-test for equality of means and the Levene's test for equality of variances adapted to paired data. Samples characterized by means and variances that varied over time were excluded from the study (7.5% of the total data). The corrected files were then transferred under ASCII format to the Nevrokard HRV software (Nevrokard[®], Medistar, Ljubjana, Slovenia).

Paragraph number 14 An analysis of the R-R interval recordings was made with the Poincare method, which consists of plotting the length of each R-R interval against the length of the previous R-R interval. SD1 and SD2 are two standard Poincare plot descriptors (2). SD1 is a measure of instantaneous variability (successive beats) and is taken as an indicator of parasympathetic activity, whereas SD2 represents long-term variability and indicates both parasympathetic and sympathetic activities (2).

Paragraph Number 15 Two R-R segments of 360-s were selected during the last six minutes in the two positions, orthostatic and supine. These 360-s segments were detrended by interpolation of a polynomial function adjusted on a sliding window of 30 R-R intervals by an algorithm minimizing the residual sum of squares between the simulated curve and the experimental curve. The 30-point window size was chosen in order to achieve the correct trade-off between noise reduction and avoiding the introduction of bias. The new function (R-R interval vs. time) adjusted by the polynomial function was thus resampled at 2 Hz to obtain equidistant data (720 points). The segment was then windowed using a Hanning window to reduce the spectral leakage resulting from edge effects when using finite data periods. On this resampled R-R interval series, the first “integer power-of-two” points were selected (512 points) on which the Fast Fourier Transform (FFT) was applied. The spectral power was measured by frequency bands in ms.Hz according to the recommendations of the Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology (1996).

Paragraph Number 16 The following HRV indices were computed: total power and spectral power in the low-frequency (LF; 0.04-0.15 Hz) and high-frequency (HF; 0.15 Hz-0.40Hz) bands expressed in absolute values (ms^2) and normalized units (HFnu, LFnu), which represent the relative value of each power component in proportion to the total power minus the very low-frequency component (VLF; ≤ 0.01 -0.04 Hz).

Paragraph Number 17 The HF component primarily reflects the variability of vagal outflow (i.e., parasympathetic activity) to the heart, whereas the LF component reflects both sympathetic and parasympathetic influences. However, LF power often contains a substantial amount of parasympathetic influence, which would explain why HF power and LF power are frequently directly correlated (as seen in our subjects) and why decreased levels in HF power and LF power both predict cardiovascular outcome in the same direction (33). The LF/HF

power ratio quantifies the sympathovagal balance, with relatively higher ratios indicating relatively more sympathetic than parasympathetic modulation of the heart rhythm (33).

Statistical analysis.

Paragraph Number 18 The three outcome variables were the presence or absence of URTPI, MA or AP (for each subject at each observation time). The explanatory variables were the HRV measures performed during the same week and during the previous week (w-1). The adjustment variables were time variables (sport season: 2003-2004 and 2004-2005; and semi-season: winter, from September to March, and summer, from April to July) and individual characteristics such as age, sex, and competition level.

Paragraph Number 19 Analysis was conducted using mixed-effects logistic regression models. Logistic regression is a standard tool for analyzing the dependence of binary variables on explanatory variables. The logistic regression model, which assumes that all observations are independent of each other, is nevertheless not appropriate for analyzing several types of correlated data structures, particularly longitudinal data (i.e., repeated observations within subjects). For analysis of such data, random subject effects can be added into the (fixed effects) regression model to account for the correlation of the data. The resulting model is a mixed model including the usual fixed effects for the explanatory variables (thus, the effects common to the population are estimated using all the data) plus the random effects (to take into account individual heterogeneity) (38).

Paragraph Number 20 In particular, in random intercept models only the intercept parameter is assumed to vary independently from one subject to another according to a common distribution. Logistic random intercept models were fitted using the NLMIXED procedure of SAS version 9.1 (Cary, NC). Coefficients were interpreted in terms of the odds ratio of an average subject.

Paragraph Number 21 The recommendation is to rescale mixed models with random effects, which are expected to have small variability, in order to enlarge the covariance parameters and thus prevent algorithm convergence problems (38). Therefore, we expressed each HRV variable as a percentage of its maximum during the study period. This rescaling also facilitated comparison of HRV data from one individual to another.

Paragraph Number 22 A univariate analysis was performed: the time variables and individual characteristics were included alone as single fixed effects in a logistic random intercept model.

Paragraph Number 23 After the univariate pre-selection of variables, multivariate analysis was performed. All pertinent combinations of HRV indexes and significant adjustment variables were included in the models as fixed effects, as well as a subject-specific intercept.

Paragraph Number 24 For interpretability reasons, the HRV data from the supine and orthostatic positions were not included simultaneously in the models. Interactions were not statistically significant and were not included.

Paragraph Number 25 Model selection relied on the Akaike Information Criterion (AIC). Among the models with the smallest AIC, those with significant variables were selected. A significance level of 0.05 was used for all tests. In further analyses, receiver-operating characteristic (ROC) curves and the associated area under the curve (AUC) with its 95% confidence interval were calculated for each retained model to express the discriminating power of each model. Finally, a subject influence study was performed.

RESULTS

Time variables and individual characteristics.

Paragraph Number 26 Table 1 shows the percentage for each category of infection or affection for the 1508 weeks of observation.

Paragraph Number 27 Table 2 shows the effects of the time variables and the individual characteristics on the three outcome variables. The number of occurrences of each variable is also presented in terms of sex, competition level, season, and semi-season. The risk of URTPI was significantly lower for the international swimmers compared with the national swimmers. A significant negative effect of winter compared with summer was found for URTPI, MA and AP, especially for ORL or pulmonary infection.

Modeling results.

Paragraph Number 28 Eight HRV variables were quantified in supine and orthostatic positions. Table 3 summarizes the average HRV measures for each position as a function of the occurrence or absence of infection.

Paragraph Number 29 Univariate analyses showed that the increase in the parasympathetic indexes in SUP assessed one week earlier was linked to a higher risk of URTPI (increase in HF and SD1, $p < 0.05$, $AUC = 0.69$, $95\%CI(AUC) = [0.64, 0.75]$), and to a higher risk of MA (increase in HF, $p < 0.05$, $AUC = 0.78$ [$0.72, 0.85$]).

Paragraph Number 30 Concerning the results measured during the same week, the risk of MA in SUP was statistically linked with an increase in sympathetic (SD2) ($p < 0.05$, $AUC = 0.73$ [$0.68, 0.78$]) and parasympathetic (HF) autonomic regulation indexes ($p < 0.05$, $AUC = 0.67$ [$0.59, 0.75$]), as well as a gain in the LF/HF power ratio ($p < 0.05$). Concerning the OR position, our results showed that a decrease in HFnu was associated with an increased risk of MA measured during the same week, with excellent model discriminating power ($p < 0.05$, $AUC = 0.83$ [$0.76, 0.89$]). We also found that a gain in the LF/HF power ratio was statistically linked to an increase in URTPI ($p < 0.05$, $AUC = 0.68$ [$0.61, 0.75$]) and MA ($p < 0.05$, $AUC = 0.74$ [$0.69, 0.79$]).

Paragraph Number 31 Table 4 presents the parameter estimations for the three selected multivariate models. All models outline individual variability, with a significant random intercept standard deviation ($p < 0.05$).

All-type pathologies.

Paragraph Number 32 Multivariate analyses showed a higher AP risk in winter (model 1 in Table 4), and for an increase in the total power of HRV associated with a decline in SD1 in SUP ($p < 0.05$), AUC= 0.7 [0.64, 0.76].

Paragraph Number 33 In OR position in winter the decrease in HF during w_{-1} increased the risk of all-type pathologies, AUC=0.8 [0.73, 0.85], (model 2 in Table 4).

Muscular affection.

Paragraph Number 34 Increased LF and decreased SD1 in OR position were associated with an increased risk of muscular affection, AUC=0.89 [0.83, 0.96], (model 3 in Table 4).

DISCUSSION

Paragraph Number 35 The main results of this study were the following: (1) in winter, national-level swimmers showed a greater risk of pathology than international-level swimmers; (2) the weeks which preceded the appearance of upper respiratory tract and pulmonary infections but also muscular affections were characterized by an increase in autonomic parasympathetic activity in supine position. Conversely, in orthostatic position and in winter, the weeks which preceded the appearance of all-type pathologies were characterized by a drop in parasympathetic activity; (3) during weeks characterized by upper respiratory tract and pulmonary infections, a shift was noted in the autonomic balance toward sympathetic predominance in supine position and a drop in parasympathetic drive in orthostatic position; and (4) in winter and in orthostatic position, a drop in parasympathetic

drive associated with an increase in sympathetic drive was linked to an increased risk of muscular affection.

Paragraph Number 36 During and after intensive and stressful physical work (e.g., long and intensive competitive trials, long-term habitual intense exercise, altitude training), studies have shown both a shift in autonomic balance toward sympathetic predominance (25,31) and immunosuppression (12, 14,17), possibly linked (13,15,17) or not (14,16) to an increased risk of pathology.

Paragraph Number 37 To our knowledge, no study has yet associated the risk of illness with autonomic functioning as reflected by heart rate variability. We hypothesized that a shift in autonomic balance toward orthosympathetic predominance would increase the risk of pathology.

Paragraph Number 38 In agreement with earlier studies of athletes exposed to prolonged and/or intense stress, such as training overload or competition (9,12,17,24,31,32,35), upper respiratory tract infections (URTI) were the most frequent pathologies observed in this study. Only one of the 18 swimmers did not fall ill during the two-year study period, and 118 of the 1508 weeks were characterized by illness (7.82% of the total observation period). In comparison, Spence and colleagues (2007) observed 21 URTI episodes in 20 elite triathletes and cyclists studied for five months. Fricker et al. (2005) reported that 42 weeks (17.5%) were characterized by URTI episodes in 15 elite runners studied over 240 weeks. Gleeson et al. (2000) observed 22 elite swimmers for 12 weeks of summertime training in 1999 and diagnosed at least one infection in ten of the swimmers (45% of the study population).

Paragraph Number 39 An increased risk of URTI has been associated in athletes (32), and particularly swimmers (12,13,14), with a decrease in systemic antibodies (12,17,21) and laryngopharyngeal mucosal antibodies like salivary immunoglobulin A (S-IgA) (12,13,17). Some studies of the laryngopharyngeal mucosa questioned a direct causality between S-IgA

concentration and the risk of URTI (14,15,17). These authors hypothesized that the minor drop in general and local immunity induced by intensive training and stress did not directly cause illness but instead lowered resistance to potential viral (15) or nonviral pathogens, thus increasing the risk of URTI (16,17,32).

Paragraph Number 40 Lower viral resistance would explain the higher risk of infection in the winter observed in our study and often reported in the epidemiologic literature (3), as winter is characterized by a surge in viral outbreaks that increase the risk of infection, particularly in cases of lowered immune defense (3).

Paragraph Number 41 The frequency of gastrointestinal (GI) symptoms (1.26% of the reported illness) was much lower than that observed in runners during intensive training (9,14,24). In fact, twice as many GI infections were observed during running (reported by up to 20-50% of runners during heavy exercise) than during swimming (24). These findings were explained as the result of less mechanical bouncing during swimming, which has limited up and down movements (24). Although splanchnic blood flow is greatly reduced during high-intensity running, leading to ischemic damage associated with inflammatory response (24), the horizontal position of swimming prevents this phenomenon.

Paragraph Number 42 Of particular interest was the finding that pathology risk was lower in the international swimmers than in the national swimmers, despite similarities in age and training. Epidemiological studies will need to confirm this finding of lower susceptibility to pathology in high-level athletes and determine whether it is genetically determined, as observed in other populations (36), and/or due to the athletic lifestyle (emphasis on sleep quality and nutrition, immunonutrition supplementation) (17,23).

Paragraph Number 43 To our knowledge, this is the first report to point out a relationship between autonomic activity and the pathology potential in high-level athletes.

Paragraph Number 44 The interpretation of these results remains speculative because the autonomic control of potentially infected systems can only be inferred from the measure of heart rate variability (22). Future research will have to highlight the synergy between cardiac autonomic regulation and the autonomic regulation of respiratory, gastrointestinal and muscular systems, as seen in the studies on the autonomic regulation of three functional domains: sudomotor, cardiovagal, and adrenergic (20). Moreover, we did not measure immunological or neuroendocrine parameters, although this might have provided insight into the mechanisms of action of the autonomic regulation of immune system activity.

Paragraph Number 45 The results of the present study suggest a biphasic time-dependent relationship between autonomic activity and upper respiratory tract and pulmonary infections. The weeks which preceded the appearance of upper respiratory tract and pulmonary infections but also muscular affections were characterized by an increase in autonomic parasympathetic activity in supine position.

Paragraph Number 46 This period preceding the clinical expression of the illness could correspond to the incubation phase, for which the mean duration was estimated to be five days upper respiratory tract and pulmonary infections (3). During this first asymptomatic incubation phase, the increase in the vagal pathway could play a protective role by modulating the magnitude of early immune responses to inflammatory stimuli (3,22). Indeed, it is hypothesized that afferent vagal neurons relay sensory information regarding early inflammatory activity to the brain, which results in reflexive activation of the efferent vagal fibers leading to the suppression of proinflammatory cytokine release (39). This efferent pathway, termed the “cholinergic anti-inflammatory pathway” is proposed to play an important role in preventing excessive inflammatory responses and maintaining health (39). Experimental animal studies also showed that the increase in parasympathetic autonomic

activity could counterbalance an excessive sympathetic activity which down regulates the immune responses to viral and cellular antigens (30).

Paragraph Number 47 During the second phase corresponding to the symptomatic clinical expression of infections, the subjects of the present study were characterized by a shift of the autonomic balance towards a sympathetic dominance. The symptomatic phase shows a multiplication and then a scattering of viral and bacterial exogenous pathogenic agents into the blood stream. These pathogenic agents activate the macrophages which produce endogenous pyrogens (such as the proinflammatory cytokines IL-1 β , TNF- α et IL6) and migrate into the blood stream to the endothelial and perivascular cells of the blood-brain barrier, inducing the coding of a mediator, prostaglandin (PG) E2 (30). In various areas of the hypothalamus and brain stem, PGE2 mediates different components of the acute phase reaction such as the thermogenesis activation by the sympathetic nervous system (30).

Paragraph Number 48 Other investigators have found that disturbances in immune-neuroendocrine regulation and direct autonomic neural circuits can induce immune system alterations in the laryngopharynx (5,25,32). For example, nonviral infections of the laryngopharynx were more frequent when the mucosal lining of the nasopharynx or the normal comensal flora were altered due to autonomic-dependent vasomotor modifications (32). Animal studies have shown that long-term removal of parasympathetic (26) or sympathetic (5) nerve impulses in the submandibular glands reduced S-IgA concentration in saliva.

Paragraph Number 49 In active men, exercise intensity can provoke a shift toward orthosympathetic predominance in the salivary glands, which disturbs mouth and nasopharyngeal ecology (1). When S-IgA lowers and the mucus membranes dry out, bacteria proliferate, predisposing to mucosal damage and inflammation, which could compromise resistance to common minor illnesses, such as URTI (5,17,26).

Paragraph Number 50 This type of autonomic imbalance in elite swimmers could increase the impact of other risk factors, such as mucosal irritation caused by hyperventilation, high exposure to nonvirulent and virulent pathogenic and opportunistic microorganisms concentrated in the water surface film, and repeated exposure to chemical disinfectants like chlorine, which can cause mucosal irritation and inflammation (17).

Paragraph Number 51 Multivariate analysis revealed that the drop in parasympathetic control of heart rate and the concomitant rise in the orthosympathetic regulation were linked in winter to an increased risk of muscular affection.

Paragraph Number 52 In orthostatic conditions similar to our conditions, the increase in LF power indicated mostly sympathetic control predominance because cardiac autonomic balance favors vasomotor control through sympathetic dominance over parasympathetic influences (11,33).

Paragraph Number 53 An autonomic profile characterized by decreased parasympathetic regulation and higher sympathetic input has been suggested as one of the first responses to an overtraining stimulus, as previously reported for high-intensity training (10). This response, termed sympathetic overtraining syndrome, is characterized by complete abolition of the sympathetic regulation of skeletal muscle as manifested by a loss of strength and power, and delayed muscular recovery (10,40).

Paragraph Number 54 Fry et al. (2006) investigated the mechanisms by which this type of overtraining lowers performance and muscle recovery. They showed in eight overtrained weight-trained men that intense muscle stress provoked a 49% increase in nocturnal urinary epinephrine concentration and a decrease in the density of muscular β_2 -adrenergic receptors, indicating desensitization. They hypothesized that desensitization of β_2 -adrenergic receptors due to sympathetic overtraining affected the mitogen-activated protein kinases, a complex that relays extracellular stimuli to the nuclear domain of the muscle cell (10).

Paragraph Number 55 Moreover, muscular affections like delayed-onset muscle soreness, which is characteristic of cell damage, cause local tissue inflammation linked to the production of inflammatory mediators (6,7). Recent experimental studies have shown that local inflammation marked by increased of the inflammatory markers like C-reactive protein (CRP) and interleukin-6 (IL-6) can be regulated by autonomic influences through the cholinergic antiinflammatory pathway induced by vagal nerve stimulation (39).

Paragraph Number 56 Many reports have emphasized that exposure to multiple stressors (physical, psychological and environmental) acting in concert may have interactive or cumulative effects that disturb the neuroendocrine and immune systems and increase the risk of infection (16,17). For the first time to our knowledge, our study presents statistical evidence of the impact of several variables, such as wintertime, swimming level, and a shift in autonomic balance toward sympathetic predominance, on the risk of infection.

Paragraph Number 57 This study has some limitations. First, we were unable to measure biological parameters of mucosal or general immunity and inflammatory markers because of the long study period and the high number of subjects. Such measures would have provided insight into the mechanisms of autonomic regulation of immune and neuroendocrine systems and the effect on the risk of infection (16). Without these measures, our hypotheses remain essentially speculative. Second, we did not perform analyses to determine the etiology of illness and thus could not distinguish pathogens from inflammatory causes, as suggested by Spence et al. (2007).

Paragraph Number 58 Several tools have been proposed to monitor the effects of physical and psychological training stresses in high-level athletes and to prevent the risks of overtraining and infection (17,29,23). These include regular measures of maximal heart rate, the maximal blood lactate level corresponding to the perception of effort, plasma cortisol concentration, and fatigue and mood state as assessed by questionnaire (17,21).

Paragraph Number 59 The results of this study argue that HRV is a rapid and noninvasive tool to indicate autonomic function, which provides complementary information that may help to reduce the risk of infection in elite swimmers. Weekly HRV monitoring would indicate a drop in parasympathetic regulation, which increases the likelihood of pathology. The clinical recommendation in the case of signs or symptoms of illness and recovery from illness is to avoid or attenuate high-risk periods such as winter, overtraining with increased training volume and intensity (21,25,35), competition, travel through several time zones, and altitude training (31), all of which may induce a shift in the autonomic balance toward orthosympathetic predominance. Another recommendation is to intensify medical surveillance and institute prophylactic measures when autonomic balance shows a sudden increase in parasympathetic indices in the supine position, which progresses some days later toward sympathetic predominance in the supine and orthostatic positions.

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Table 1. Incidence of infectious disease during the study period.

Infection or affection type	Occurrence	%
URTPI	109	7.23
Gastrointestinal	19	1.26
Uro-genital	8	0.53
Neurological	3	0.20
Muscular	132	8.75
All-types	255	16.91

Over the 1508 weeks of observation, we counted the number of weeks in which each type of infection or affection was reported. The weeks characterized by infection/affection were then added to give the category of all types of infection/affection combined.

Table 2. Incidence (N), odds ratio and 95% confidence interval (CI) for the association between adjustment variables and pathologies for the 1508 weeks of follow-up of 18 subjects.

Variable	AP			URTP1			MA		
	N	Odds Ratio	95%CI	N	Odds Ratio	95%CI	N	Odds Ratio	95%CI
Age		0.96	[0.88, 1.05]		0.96	[0.86, 1.07]		0.95	[0.80, 1.13]
Sex									
Female	138	1.16	[0.60, 2.25]	52	0.91	[0.42, 1.99]	79	1.25	[0.37, 4.24]
Male	117			57			53		
Competition level									
International	74	0.65	[0.34, 1.25]	21	0.37	[0.19, 0.72]*	44	0.99	[0.28, 3.46]
National	181			88			88		
Season									
2003-2004	152	0.91	[0.65, 1.26]	80	1.72	[1.04, 2.85]*	56	0.41	[0.26, 0.64]*
2004-2005	103			29			76		
Semi-season									
Summer	64	0.25	[0.18, 0.36]*	24	0.25	[0.15, 0.42]*	36	0.31	[0.20, 0.49]*
Winter	191			85			96		

* $P < 0.05$.

Table 3. HRV data (ms²) in the supine and orthostatic positions as a function of all-type pathologies presence or absence.

HRV variable	Position	Infection presence			Infection absence		
		N	Mean	SD	N	Mean	SD
SD1	SUP	108	58.4	30.6	311	63.2	35.3
	OR	74	20.9	15.8	209	22.7	16.8
SD2	SUP	108	124.3	60.0	311	120.9	57.4
	OR	74	94.2	54.0	208	97.6	51.4
PT	SUP	108	28760.2	62417.0	311	25564.2	50243.4
	OR	75	23130.5	45939.6	212	27343.9	59571.8
VLF	SUP	108	23743.0	60007.9	311	20282.6	49116.0
	OR	75	20807.9	44762.1	212	24761.5	58556.5
LF	SUP	108	2551.7	2223.7	311	2560.4	2436.5
	OR	75	1930.7	1959.7	212	2108.0	2235.9
HF	SUP	108	2454.3	2470.1	311	2722.9	3213.4
	OR	75	399.9	647.8	212	474.4	963.0
LF/HF	SUP	108	1.5	1.3	311	1.5	1.5
	OR	74	11.6	10.4	211	12.2	12.2
HFnu	SUP	108	47.1	17.4	311	48.0	16.8
	OR	75	14.0	12.8	212	15.3	14.0

Table 4. Estimations of the multivariate models selected according to the statistical Akaike information criterion.

Model	Outcome variables	Explanatory variables	Estimation (SD)	<i>P</i>	Random effects <i>P</i>	AUC 95%IC
1	AP	intercept	-0.414 (0.379)	0.290	0.029	0.70 [0.64, 0.76]
		TP in SUP	0.013 (0.005)	0.022		
		SD1 in SUP	-0.015 (0.007)	0.036		
		Summer	-0.999 (0.321)	0.006		
2	AP	intercept	-0.630 (0.344)	0.084	0.005	0.79 [0.73, 0.85]
		HF in OR w_{-1}	-0.015 (0.007)	0.052		
		Summer	-1.188 (0.366)	0.005		
3	MA	intercept	-1.950 (0.771)	0.022	0.007	0.89 [0.83, 0.96]
		LF in OR	0.039 (0.015)	0.018		
		SD1 in OR	-0.044 (0.020)	0.039		
		Summer	-1.664 (0.678)	0.026		

Model 1: Probability of all-type pathologies (AP) presence as a function of total power of HRV in supine position (TP in SUP) and instantaneous variability in supine position (SD1 in SUP) adjusted by semi-season (reference category: Summer), number of observations n=419, for 18 subjects. Model 2: Probability of AP presence as a function of the high frequency component of HRV in orthostatic position assessed one week earlier (HF in OR w_{-1}), n=288, for 18 subjects. Model 3: Probability of muscular affection (MA) presence as a function of the low frequency component of HRV in orthostatic position (LF in OR) and instantaneous variability in orthostatic position (SD1 in OR) adjusted by semi-season, n=283, for 17 subjects. AUC, area under the curve.