

# Metabolic Profile of Military Personnel as a Predictor of Immune Response Under Physical Load

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**Abstract** Regular physical activity influences the immune system both acutely and chronically. In this study, we assessed key metabolic and nutritional biomarkers – including glucose, lipid profile, iron stores, and vitamin D status – in different categories of military servicemen to evaluate their impact on immune responsiveness to physical exertion. A total of 257 healthy male servicemen were divided into four groups (young conscripts, contract soldiers, high physical load units, and officers/instructors). Baseline biochemical indicators were measured for all participants and analyzed alongside immunological parameters. Results showed that serum lipid levels (total cholesterol and low-density lipoprotein cholesterol) increased progressively with age and service duration (from conscripts to officers), accompanied by a higher frequency of subclinical dyslipidemia. High-load personnel and officers also exhibited less favorable high-density lipoprotein and triglyceride profiles compared to younger servicemen. Ferritin levels indicated latent iron deficiencies in a subset of younger troops, while vitamin D deficiency or insufficiency was widespread in all groups, with only about one-quarter of servicemen having optimal 25(OH)D levels. These metabolic trends correlated with immune findings: servicemen with less favorable metabolic profiles tended to have higher baseline inflammatory indexes. Our findings suggest that the metabolic profile of servicemen – including dyslipidemia, iron status, and vitamin D levels – may serve as important predictors of the magnitude and balance of immune responses to physical stress.

**Keywords** Exercise immunology, Military personnel, Metabolic syndrome, Vitamin D, Immune readiness, Lipid profile, Inflammation

## 1. Introduction

It is known that regular physical exercise exerts complex effects on both innate and adaptive immunity. Moderate-intensity exercise has been demonstrated to enhance immune surveillance and reduce the risk of infection, whereas excessive workloads can transiently suppress certain immune functions [1] [2]. For example, the classic “J-shaped” curve hypothesis proposed by Nieman suggests that while moderate exercise lowers infection risk, very intense or prolonged exercise may increase short-term susceptibility to infections, especially upper respiratory tract infections in endurance athletes. Recent research has refined this view: many apparent post-exercise immune deficits may actually reflect other stressors (lack of sleep, energy deficit, extreme environment) rather than exercise alone [3]. Indeed, current consensus holds that an active lifestyle generally benefits immune defense, with well-periodized training enhancing immune competence and reducing inflammation in the long term.

It is known that the nutritional and metabolic status of an individual significantly modulates immunity. For example, obesity and dyslipidemia are associated with a chronic

low-grade inflammatory state that can impair immune response effectiveness. Conversely, maintaining adequate micronutrient levels (such as iron and vitamin D) is critical for optimal immune function. Vitamin D in particular has gained attention as an immunomodulator; deficiency in 25(OH)D is widespread in many populations and has been linked to higher incidence of respiratory infections and poorer immune regulation. Military personnel often face unique challenges, including high physical demands and environmental stressors, which can affect both their metabolic profile and immune status. However, baseline metabolic health metrics (like lipid profile, glucose, iron stores, etc.) are not routinely monitored in young servicemen, even though these factors might explain inter-individual variability in adaptation to training loads.

For example, it is known that elevated serum cholesterol and other atherogenic lipid markers can promote systemic inflammation and may predispose individuals to exaggerated immune responses under stress. On the other hand, deficiencies such as low iron stores or hypovitaminosis D could weaken immune defenses and impair recovery. Given the multi-layered interaction between metabolism and immunity, this study aimed to evaluate the biochemical profile of different groups of military servicemen and to determine how these metabolic indicators relate to their immune responses to

physical load. We hypothesized that older and more experienced servicemen (e.g. officers) might exhibit less favorable metabolic profiles (due to longer service and lifestyle factors) which could correlate with distinctive immune parameters, compared to younger recruits.

## 2. Methods

**Study design and participants:** This cross-sectional study included 257 male military personnel of the Armed Forces, categorized into four groups based on service status and typical physical load: Group 1 – young servicemen in initial training (n=67, newly enlisted conscripts); Group 2 – active duty soldiers on regular service training (contract servicemen, n=64); Group 3 – high physical load units (mountain troops, reconnaissance and airborne units with intensive exercise routines, n=66); Group 4 – officers and instructors with stable routine activity, serving as a reference group (n=60). All participants were 18–40 years old (mean age  $25.5 \pm 5.8$  years) and clinically healthy at the time of inclusion. Key exclusion criteria were any acute illness in the 4 weeks prior or decompensated chronic conditions. The study was conducted in 2022–2025 under real military training conditions. Written informed consent was obtained from all servicemen, and the protocol was approved by the Defense Health Research Ethics Committee.

**Anthropometry and physical load assessment:** Basic anthropometric measurements were recorded, including body mass index (BMI), waist circumference, and waist-to-height ratio (WHtR). A standardized 20-meter shuttle run test (Léger's beep test) was used to evaluate fitness and induce acute physical load in a controlled manner. All participants performed the shuttle run to volitional exhaustion in the morning (08:00–10:30) after abstaining from heavy exercise for 24 hours. Heart rate was monitored (chest belt, recorded every second) to obtain peak heart rate (HR<sub>max</sub>). Rating of perceived exertion (RPE) was collected 20–30 minutes post-exercise and used to calculate session training load (session-RPE  $\times$  duration). For all participants, blood samples were taken at three time points relative to the shuttle test: immediately before exercise (T0, baseline), immediately after exercise (T1), and 24 hours post-exercise (T2). This design allowed assessment of acute immune changes and recovery dynamics.

**Laboratory measurements:** Venous blood was drawn from the antecubital vein at each time point under fasting, resting conditions. A complete blood count was performed using an automated hematology analyzer, with manual smear review for differential when needed. Total leukocyte count and differential counts (neutrophils, lymphocytes, monocytes) were recorded. From these, the neutrophil-to-lymphocyte ratio (NLR) was calculated for each sample as an integrated inflammation index. Saliva samples were collected to assess mucosal immunity: unstimulated saliva was obtained over 5 minutes before exercise (T0) and at T1 and T2, then centrifuged and stored at  $-20$  °C. Secretory immunoglobulin

A (sIgA) concentration in saliva was measured by ELISA (enzyme-linked immunosorbent assay), and salivary flow rate was noted to compute total sIgA secretion if needed. In a subset of participants (n $\approx$ 25–30 per group), serum interleukin-6 (IL-6) was measured as a key pro-inflammatory cytokine using a high-sensitivity chemiluminescent immunoassay (Abbott Architect i2000SR). All immunological assays were conducted in the same certified laboratory with proper quality controls in place.

**Biochemical assays:** Fasting blood samples (collected at baseline T0) were also analyzed for metabolic parameters. Serum glucose was measured by the glucose oxidase enzymatic colorimetry method. Lipid profile included total cholesterol (Total-C), high-density lipoprotein cholesterol (HDL-C), low-density lipoprotein cholesterol (LDL-C), and triglycerides, all determined via enzymatic methods on a Roche Cobas c311 autoanalyzer. High-sensitivity C-reactive protein (hs-CRP) was measured immunoturbidimetrically as a systemic inflammation marker. Iron stores were evaluated by serum ferritin concentration using electrochemiluminescent immunoassay (Cobas e411 analyzer). In a partial sample of participants (n=96), vitamin D status was assessed by measuring 25-hydroxyvitamin D [25(OH)D] levels (chemiluminescent assay, Abbott Architect) with samples stored at  $-80$  °C until batch analysis. Vitamin D status was classified as deficient (<20 ng/mL), insufficient (20–30 ng/mL), or sufficient (>30 ng/mL) for descriptive analysis. All assays underwent rigorous internal and external quality control, and results were recorded for statistical analysis.

**Statistical analysis:** Data were analyzed with SPSS 25.0. Continuous variables are presented as mean  $\pm$  standard deviation (M  $\pm$  SD). Group comparisons for baseline biochemical parameters were performed by one-way ANOVA with Tukey's post hoc tests. The distribution of abnormal values (e.g. % of subjects above or below clinical cut-offs) was compared using Chi-square test. Repeated-measures ANOVA was used to assess changes in immune parameters over time (T0, T1, T2) and interactions with group. Pearson correlation analysis was applied to explore associations between baseline metabolic markers and immune indices (e.g. cholesterol vs NLR, 25(OH)D vs sIgA). A significance threshold of  $p < 0.05$  was used.

## 3. Results

### Baseline Metabolic Characteristics

It is known that lipid levels tend to increase with age and prolonged service. For example, **Table 1** summarizes the baseline lipid profile across the four groups of servicemen. Total cholesterol (TC) showed a stepwise increase from the youngest group to the officers: mean TC was  $4.4 \pm 0.6$  mmol/L in young conscripts, rising to  $5.1 \pm 0.8$  mmol/L in officers ( $p < 0.01$  vs Group 1). Similarly, mean LDL-C increased from  $2.7 \pm 0.5$  mmol/L to  $3.3 \pm 0.7$  mmol/L ( $p < 0.01$ ). The proportion of individuals with borderline-high cholesterol (>5.0 mmol/L) or elevated LDL (>3.0 mmol/L) was significantly

greater in the high-load and officer groups than in young servicemen (e.g. one-third of officers had LDL >3.0 mmol/L, vs 11.9% of conscripts). These data indicate an unfavorable shift in lipid profile with increasing service duration and training load intensity.

It is known that HDL cholesterol and triglycerides have inverse implications for metabolic health. **Table 2** shows that mean HDL-C levels were highest in young servicemen (1.35 ± 0.26 mmol/L) and progressively decreased in groups with higher loads and older age (down to 1.18 ± 0.23 mmol/L in officers, p<0.01 vs Group 1). Conversely, triglyceride (TG) levels increased from 1.2 ± 0.3 mmol/L (Group 1) to 1.6 ± 0.5 mmol/L (Group 4, p<0.01). The percentage of individuals with low HDL (<1.0 mmol/L) or high TG (>1.7 mmol/L) was modest in the youngest group (~6–7%) but rose to ~18% (low HDL) and 25% (high TG) in officers. Thus, those in the high-load and officer categories showed a trend toward a pro-atherogenic lipid profile (lower HDL, higher TG) compared to younger peers.

For example, **Figure 1** illustrates the upward trend in average total cholesterol across the groups, alongside the corresponding rise in LDL cholesterol. Both Total-C and LDL-C were significantly higher in the high-load and officer groups compared to young servicemen (p<0.01), consistent with an age- and training-related accumulation of metabolic

risk factors. These differences remained significant even after adjusting for BMI in a post hoc analysis (data not shown).

In terms of glycemic status, all groups had mean fasting glucose within reference range (~4.9–5.2 mmol/L) with no significant differences between groups (data not shown). Only 4.7% of individuals had fasting glucose above 5.5 mmol/L (pre-diabetic range), with no clear group pattern. Thus, overt dysglycemia was not observed in this generally young cohort.

It is known that iron storage and vitamin D status are important for immune function. At baseline, the mean serum ferritin was 50.1 ± 14.5 ng/mL overall. **Table 3** shows ferritin levels by group. Young servicemen (Group 1) had the lowest mean ferritin (42.5 ± 12.8 ng/mL), and notably 17.9% of them had ferritin <30 ng/mL, indicating latent iron deficiency. In contrast, contract soldiers had significantly higher ferritin on average (56.3 ± 14.5 ng/mL, p<0.05 vs Group 1) and the lowest proportion with ferritin <30 (only 9.4%). High-load troops and officers had intermediate ferritin values (~49–53 ng/mL) and about 12–15% with low ferritin. These results suggest that young new recruits were most prone to suboptimal iron stores, whereas those in steady service had repleted levels, possibly due to regular diet and routine.

**Table 1.** Baseline total cholesterol and LDL cholesterol in servicemen (mean ±SD, and % of group above risk thresholds)

Group	Total Cholesterol (mmol/L)	% >5.0 mmol/L	LDL Cholesterol (mmol/L)	% >3.0 mmol/L
1 – Young conscripts (n=67)	4.4 ± 0.6	9.0%	2.7 ± 0.5	11.9%
2 – Contract soldiers (n=64)	4.7 ± 0.7	17.2%	2.9 ± 0.6	20.3%
3 – High-load units (n=66)	4.9 ± 0.7*	22.7%*	3.1 ± 0.6*	25.8%*
4 – Officers/Instructors (n=60)	5.1 ± 0.8**	28.3%**	3.3 ± 0.7**	33.3%**

p < 0.05 vs Group 1; \*p < 0.01 vs Group 1 (and vs Group 2 for officers).

**Table 2.** Baseline HDL cholesterol and triglycerides in servicemen (mean ±SD, and % of group outside normal range)

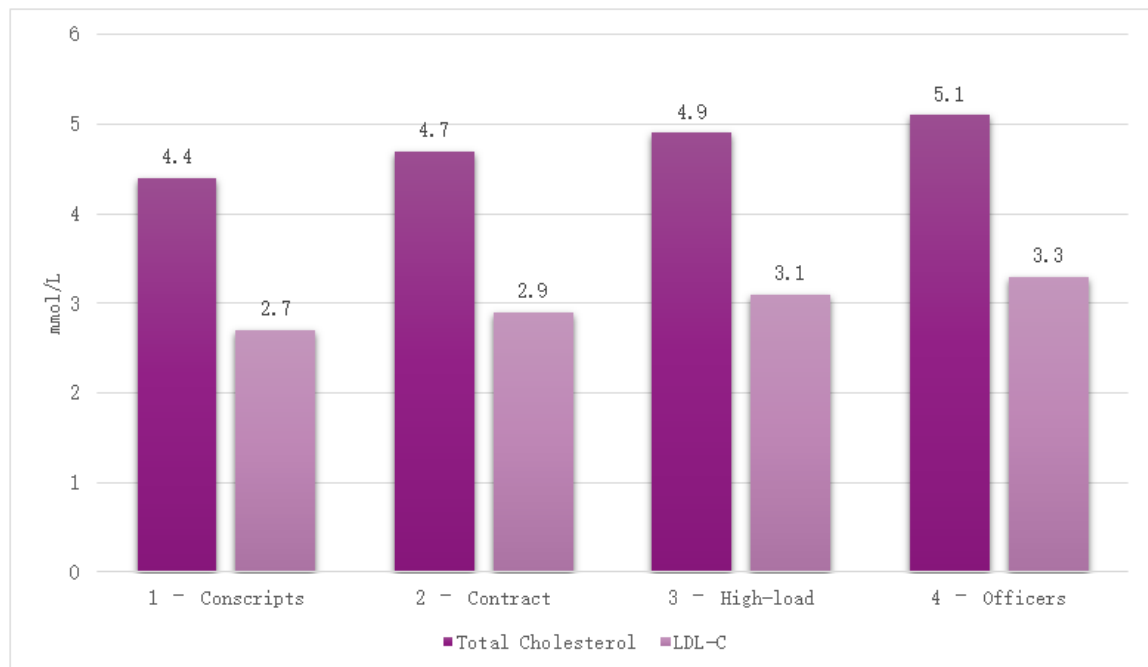
Group	HDL-C (mmol/L)	% <1.0 mmol/L	Triglycerides (mmol/L)	% >1.7 mmol/L
1 – Young conscripts (n=67)	1.35 ± 0.26	6.0%	1.2 ± 0.3	7.5%
2 – Contract soldiers (n=64)	1.28 ± 0.25	10.9%	1.3 ± 0.4	12.5%
3 – High-load units (n=66)	1.22 ± 0.24*	15.2%*	1.5 ± 0.4*	19.7%*
4 – Officers/Instructors (n=60)	1.18 ± 0.23**	18.3%**	1.6 ± 0.5**	25.0%**

p < 0.05 vs Group 1; \*p < 0.01 vs Group 1 (and vs Group 2).

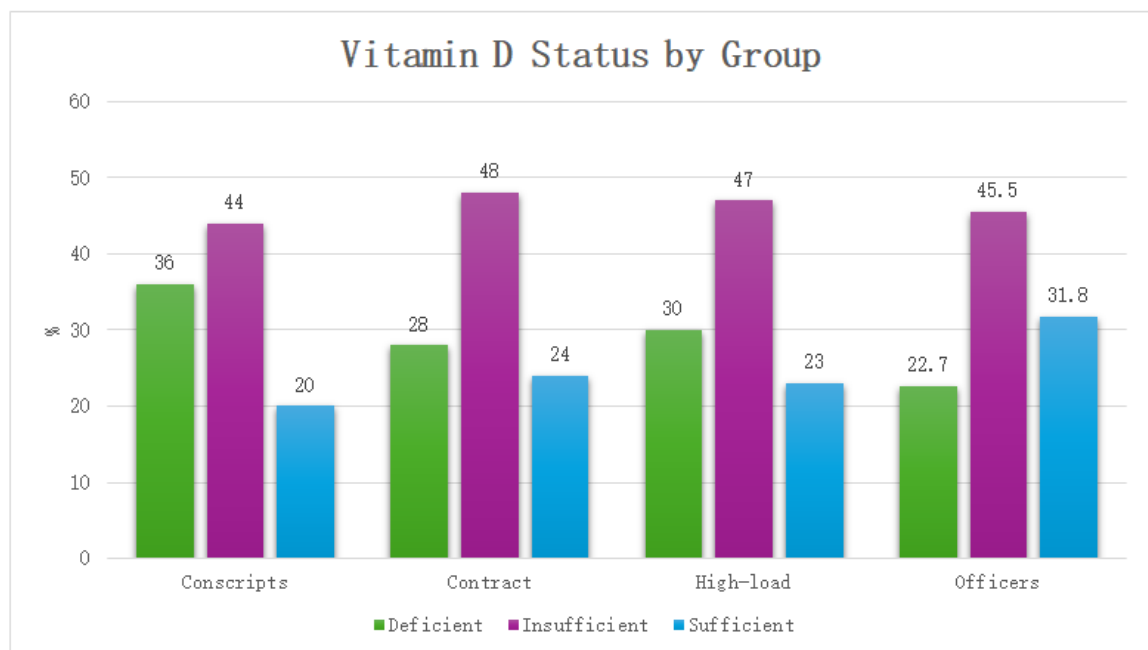
**Table 3.** Baseline serum ferritin in servicemen (ng/mL, mean ±SD, with range and % <30 ng/mL)

Group	Ferritin (ng/mL)	Range (min–max)	% <30 ng/mL
1 – Young conscripts (n=67)	42.5 ± 12.8	18 – 70	17.9%
2 – Contract soldiers (n=64)	56.3 ± 14.5 *	25 – 85	9.4% *
3 – High-load units (n=66)	49.1 ± 13.6	21 – 80	15.2%
4 – Officers/Instructors (n=60)	53.4 ± 15.1	24 – 88	11.7%
<b>Total (n=257)</b>	<b>50.1 ± 14.5</b>	<b>18 – 88</b>	<b>13.6%</b>

• p < 0.05 vs Group 1 (Young conscripts).



**Figure 1.** Mean total cholesterol and LDL cholesterol by group of servicemen. Bars represent mean  $\pm$ SD. Older and higher-load groups show significantly higher levels of Total-C and LDL-C compared to young conscripts



**Figure 2.** Proportion of servicemen with deficient (<20 ng/mL), insufficient (20–30 ng/mL), and sufficient (>30 ng/mL) vitamin D status in each group. Vitamin D deficiency or insufficiency was common in all groups, with only about one-quarter of personnel achieving optimal levels

It is known that vitamin D deficiency is prevalent in many populations, and our cohort was no exception. For example, **Figure 2** shows the distribution of vitamin D status in a subset of 96 servicemen tested (approximately 22–25 per group). Overall, the mean 25(OH)D level was  $22.9 \pm 5.5$  ng/mL, falling in the insufficient range. About 29% of the tested servicemen had frank vitamin D deficiency (<20 ng/mL) and an additional 47% had 20–30 ng/mL (insufficiency), leaving only 24% with sufficient levels. Young conscripts had the

highest rate of deficiency (36% <20 ng/mL), while officers showed a slightly better profile (only 22.7% deficient and ~31.8% sufficient). Nevertheless, even among officers, a quarter remained deficient. These findings suggest that vitamin D insufficiency is widespread across military personnel, potentially attributable to limited sun exposure during winter training and other lifestyle factors.

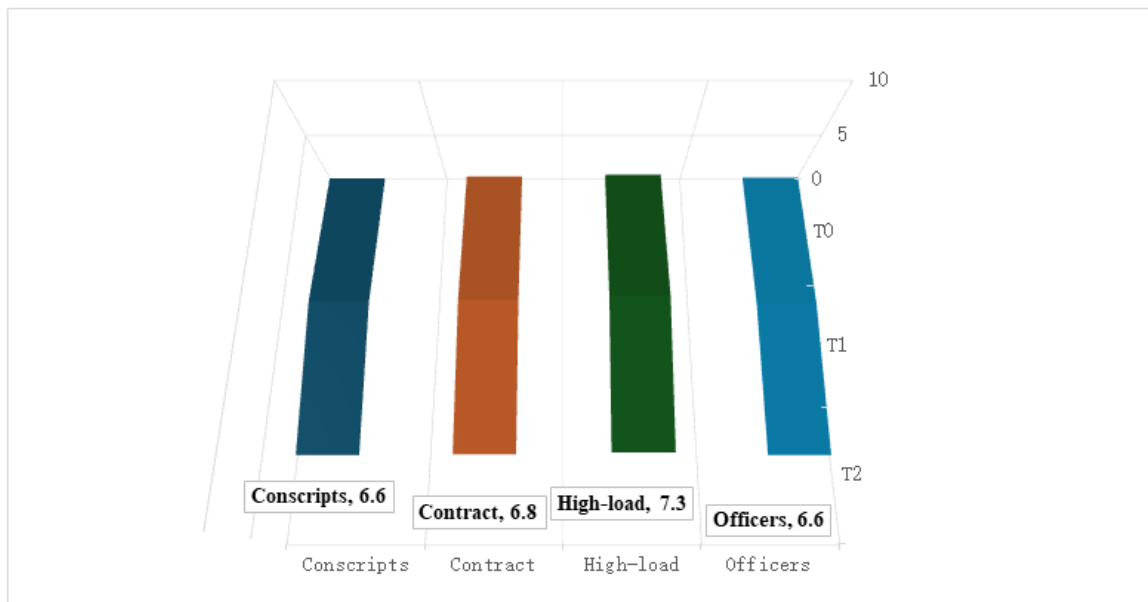
In summary, the baseline metabolic assessment revealed that the army contingent exhibits a characteristic metabolic

profile: subtle impairments in carbohydrate and lipid metabolism (e.g. borderline dyslipidemia), a notable prevalence of latent iron deficiency among younger troops, and a high prevalence of vitamin D insufficiency in all groups. These factors can act as modifiers of immune responses. Next, we examined how these metabolic differences might relate to immune parameters and their changes under physical load.

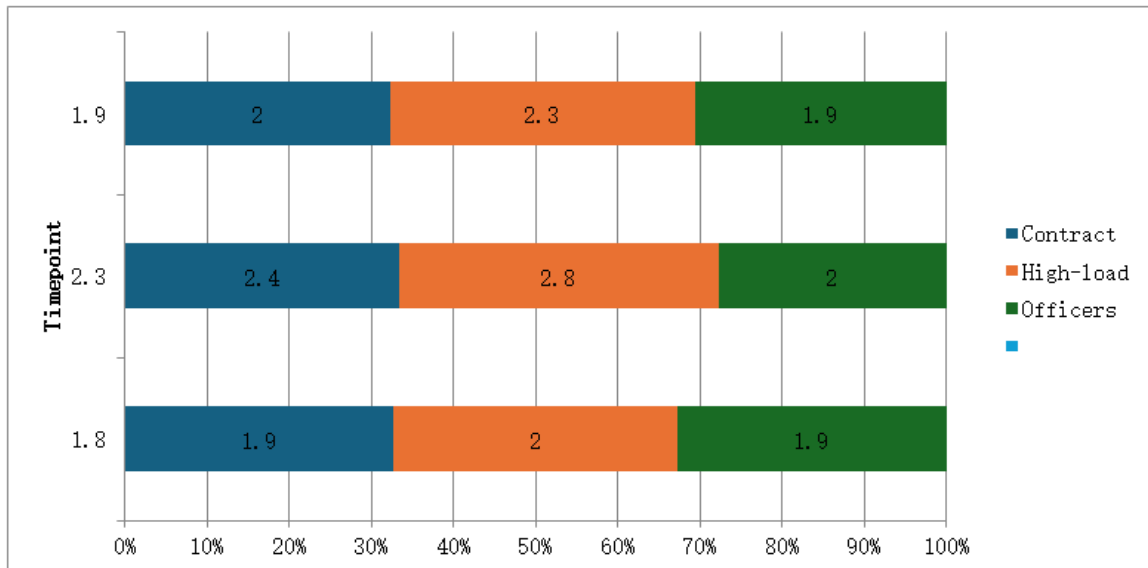
**Immune Responses to Acute Physical Load**

Before exercise, all groups had comparable baseline total leukocyte counts (around  $6.5 \times 10^9/L$  on average). It is known that acute exercise typically induces leukocytosis via stress hormone-mediated demargination of leukocytes. For example, **Figure 3** illustrates the dynamic change in blood leukocyte count (WBC) from before exercise (T0) to immediately after (T1) and 24 h after (T2). All groups

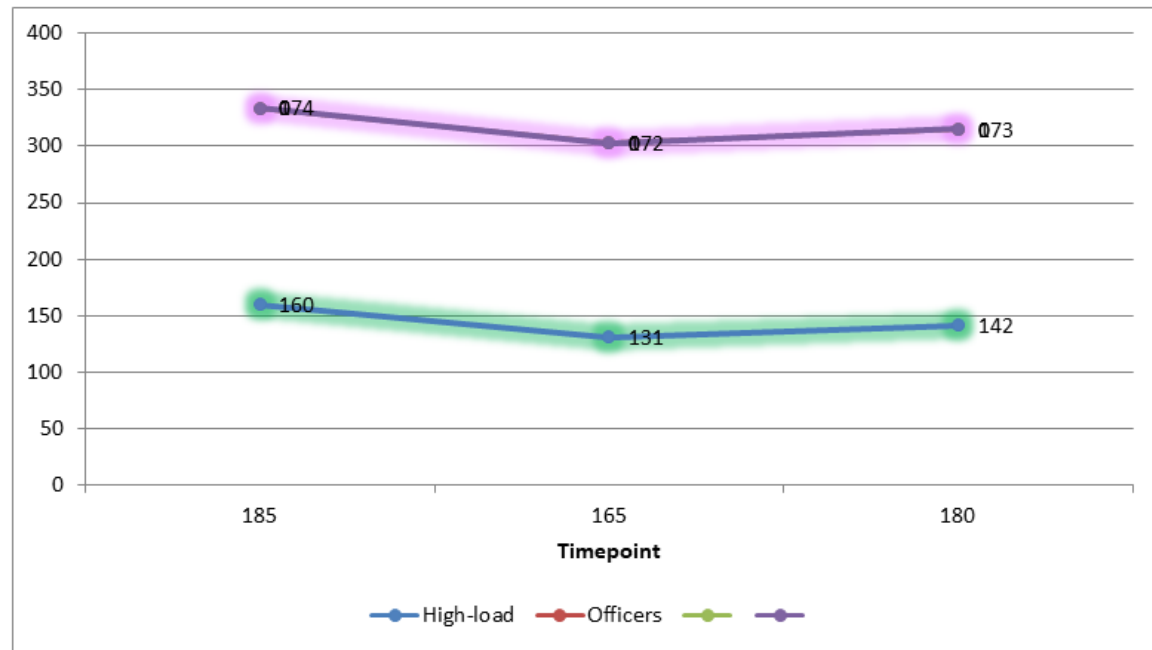
experienced a significant increase in WBC at T1 ( $p < 0.05$  vs T0). The rise was most pronounced in the high-load group, where mean WBC jumped from  $6.9$  to  $8.2 \times 10^9/L$  (an increase of  $\sim 19\%$ ,  $p < 0.01$ ). Even after 24 hours, this group had not fully returned to baseline (WBC  $7.3$ , still  $6\text{--}7\%$  above initial,  $p < 0.05$  vs T0). In contrast, young conscripts and contract soldiers showed a more moderate leukocyte rise ( $10\text{--}15\%$ ) that subsided by 24 h (T2  $\sim$  equal to baseline). Officers had the smallest change in WBC (a mild  $0.5 \times 10^9/L$  increase at T1 that normalized by T2). These patterns suggest that individuals from high-load units mount a stronger and more prolonged leukocyte response to acute exercise stress, whereas officers (with presumably higher fitness and adaptation) maintain homeostasis more effectively.



**Figure 3.** Leukocyte count dynamics (mean  $\pm$  SD) before (T0), immediately after (T1), and 24 h after (T2) exercise in different groups. All groups show post-exercise leukocytosis, most marked and sustained in Group 3 (high-load), while Group 4 (officers) shows minimal change



**Figure 4.** Neutrophil-to-Lymphocyte Ratio (NLR) before and after exercise. NLR increased in all groups post-exercise, with the largest and longest-lasting rise in Group 3 (high-load). Group 4 (officers) showed negligible NLR change, indicating a stable immune balance



**Figure 5.** Secretory IgA (sIgA) in saliva at baseline, immediately after, and 24 h after exercise. A significant post-exercise sIgA reduction is seen in Groups 1–3 (particularly pronounced in high-load servicemen), whereas Group 4 maintains sIgA levels. Recovery to baseline by 24 h occurs in Groups 1–2, but not fully in Group 3

To further analyze leukocyte subpopulation shifts, we evaluated neutrophil and lymphocyte counts. It is known that acute stress triggers a “neutrophil surge” and relative lymphopenia (stress leukogram). At T1, neutrophil percentages increased in all groups (e.g. from ~58% to ~63% in young soldiers, and up to ~65% in high-load troops), with reciprocal drops in lymphocyte percentages. The absolute neutrophil count roughly doubled in high-load individuals at T1 (from  $3.6$  to  $4.5 \times 10^9/L$ ) and remained slightly elevated at T2, whereas officers had minimal neutrophil changes. These shifts resulted in notable changes in the neutrophil-to-lymphocyte ratio (NLR).

For example, **Figure 4** shows the NLR dynamics. At baseline, the average NLR was around 1.7–2.0 in all groups. Immediately post-exercise, NLR rose significantly: by ~28% in young and contract soldiers ( $p < 0.05$ ) and by ~40% in the high-load group (from 2.02 to 2.85,  $p < 0.01$ ). The high-load group also retained an elevated NLR at 24 h (2.34, still above baseline,  $p < 0.05$ ), whereas in groups 1 and 2, NLR returned to pre-exercise values by 24 h. Officers showed little change in NLR (stayed ~1.7–2.0 throughout). This pattern mirrors the total WBC results and indicates that those under chronic higher physical strain (Group 3) experience a stronger innate immune activation (neutrophil-dominant response) that is slower to normalize. In contrast, well-adapted individuals (Group 4) maintain a stable NLR, reflecting more resilient immune equilibrium.

Mucosal immunity, represented by secretory IgA in saliva, is an important first-line defense that can be transiently suppressed by intense exercise. For example, **Figure 5** demonstrates the change in salivary sIgA levels. At T0, baseline sIgA concentrations were similar across groups (approximately 160–187 mg/L). After exercise (T1), sIgA

significantly declined in Groups 1 and 2 by about 10–15% ( $p < 0.05$ ), then returned to near baseline by 24 h. In the high-load group, sIgA drop was more pronounced: from 160 mg/L to 131 mg/L at T1 (–18%,  $p < 0.01$  vs baseline) and remained lower than initial even at 24 h (142 mg/L,  $p < 0.05$ ). Officers again showed no significant sIgA change (values ~174 mg/L pre and post). Thus, heavy acute exertion led to a temporary suppression of mucosal immunity in most servicemen, especially those in high-load units, whereas those with higher adaptation (officers) maintained stable mucosal IgA. This finding is consistent with literature on exercise-induced decrease in sIgA, which has been linked to increased infection risk during recovery.

Serum IL-6 (a pro-inflammatory cytokine and myokine) was measured in a subset and showed a phase response to exercise. At T1, IL-6 levels rose in all groups (mean increase from ~2.2 to 2.6–3.0 pg/mL in Groups 1–2, and from 3.0 to 4.5 pg/mL in Group 3). By 24 h, IL-6 subsided toward baseline but in the high-load group it remained elevated (3.6 pg/mL vs 3.0 at baseline,  $p < 0.05$ ), whereas in others it returned to ~2.1–2.5. Officers had almost no IL-6 change (2.0 → 2.3 pg/mL). The IL-6 pattern closely paralleled NLR and sIgA findings, reinforcing that intense exercise evokes stronger inflammatory signaling in high-load troops. Notably, those same individuals had the poorest vitamin D status, suggesting a possible link between vitamin D deficiency and heightened inflammatory response, as reported in other studies [4].

In summary, the acute exercise trial revealed that military personnel exhibit varied immune responses depending on their training background: young and moderately trained soldiers have a moderate immune activation that resolves within a day, highly trained but heavily burdened servicemen

show an exaggerated and prolonged response (elevated WBC, NLR, IL-6 and depressed sIgA), and the most adapted officers show minimal perturbation. The next step was to analyze how baseline metabolic differences might explain some of these immune response patterns.

#### Association of Metabolic Factors with Immune Measures

At baseline, we observed several significant correlations between metabolic markers and immune/inflammatory indicators across the combined sample of servicemen. Higher total cholesterol and LDL levels were weakly but significantly associated with higher hs-CRP and NLR (for LDL, Pearson  $r \approx +0.21$  with NLR,  $p=0.002$ ), suggesting that an atherogenic lipid profile correlates with a pro-inflammatory immune status. In contrast, HDL cholesterol had inverse correlations with inflammatory markers and showed a positive correlation with salivary sIgA ( $r \approx +0.17$ ,  $p<0.05$ ), aligning with the concept that HDL has anti-inflammatory properties. Fasting glucose also correlated positively with CRP and IL-6 ( $r \approx +0.24$ ,  $p<0.01$ ), and higher glucose was associated with lower sIgA ( $r = -0.20$ ,  $p=0.002$ ), even though mean glucose levels were normal. These findings indicate that even within normoglycemic ranges, individuals with relatively higher glucose might have slight immune impairments (possibly reflecting early “prediabetic” immune changes).

It is known that low iron stores can impair immune function. In our data, subjects with ferritin  $<30$  ng/mL tended to have higher baseline NLR and lower sIgA secretion, though the correlation between ferritin and CRP did not reach significance. More strikingly, vitamin D showed multiple significant associations: 25(OH)D levels were inversely correlated with CRP ( $r = -0.27$ ,  $p=0.007$ ) and IL-6 ( $r = -0.25$ ,  $p=0.02$ ), and positively correlated with sIgA ( $r = +0.23$ ,  $p=0.03$ ). In other words, servicemen with lower vitamin D tended to have higher systemic inflammation and lower mucosal immunity, which is in line with published research linking vitamin D deficiency to heightened inflammatory tone and infection risk. The NLR had a borderline negative correlation with 25(OH)D ( $r \approx -0.19$ ,  $p=0.06$ ), suggesting a trend that did not reach statistical significance but is clinically coherent (since vitamin D has immunoregulatory effects on neutrophils and lymphocytes).

For example, **Table 4** summarizes selected correlations between key metabolic markers and immune/inflammation indicators in our cohort. These relationships paint a consistent

picture: a “metabolically healthy” profile (normal glucose, normal lipids, sufficient vitamin D) is associated with a more balanced, anti-inflammatory immune status (lower CRP, IL-6, NLR and higher sIgA). Conversely, features of a metabolic risk profile – dyslipidemia, insulin resistance, micronutrient deficiencies – coincide with signs of immune dysregulation (higher innate activation and weakened mucosal defense).

These data suggest that the metabolic background directly relates to systemic inflammatory status in this military cohort. In particular, a cluster of “unfavorable” metabolic factors – higher LDL and triglycerides, borderline high glucose, low vitamin D (and to some extent low ferritin) – was associated with a heightened baseline inflammation (higher CRP, IL-6, NLR) and reduced mucosal immunity (lower sIgA). This metabolic-immune profile could potentially predispose to greater immune perturbations during physical stress.

## 4. Discussion

In this study of healthy military personnel, we found that distinct metabolic profiles correspond to differences in immune status and responses to physical load. The key findings can be summarized as follows: (1) Older and more experienced servicemen (especially those in high-load roles and officers) showed a trend toward metabolic changes such as higher cholesterol, LDL, and triglycerides, along with lower HDL. These changes, while mostly within subclinical ranges, were associated with a pro-inflammatory shift in immune indicators. (2) Micronutrient status varied by group – young recruits had more latent iron deficiency, and vitamin D insufficiency was pervasive in all groups. Importantly, those with poorer vitamin D status exhibited signs of elevated inflammation and weaker mucosal immunity. (3) Acute exercise induced significant immune changes (leukocytosis, neutrophilia, sIgA reduction, IL-6 surge) in all servicemen, but the magnitude and duration of these changes were greatest in individuals from high physical load units. Officers, presumably benefiting from long-term adaptation and possibly healthier lifestyles, had the most stable immune response with minimal perturbation. (4) There were significant correlations linking metabolic risk markers (e.g. LDL, glucose) to higher inflammatory markers at baseline. Collectively, these findings underscore the interplay between metabolic health and immune resilience in physically active populations.

**Table 4.** Correlation between metabolic markers and immune indicators (Pearson  $r$ , all servicemen)

Metabolic Marker	hs-CRP	IL-6	NLR	Salivary sIgA
Fasting glucose	+0.29 ( $p<0.001$ )	+0.24 ( $p=0.009$ )	+0.22 ( $p<0.001$ )	-0.20 ( $p=0.002$ )
Total cholesterol	+0.21 ( $p=0.001$ )	+0.17 ( $p=0.07$ )	+0.18 ( $p=0.004$ )	-0.12 ( $p=0.06$ )
LDL cholesterol	+0.26 ( $p<0.001$ )	+0.22 ( $p=0.02$ )	+0.21 ( $p=0.002$ )	-0.15 ( $p=0.02$ )
HDL cholesterol	-0.24 ( $p<0.001$ )	-0.18 ( $p=0.05$ )	-0.19 ( $p=0.003$ )	+0.17 ( $p=0.01$ )
Triglycerides	+0.28 ( $p<0.001$ )	+0.20 ( $p=0.03$ )	+0.23 ( $p=0.001$ )	-0.16 ( $p=0.015$ )
Ferritin	-0.10 ( $p=0.09$ )	-0.12 ( $p=0.21$ )	-0.18 ( $p=0.004$ )	+0.21 ( $p=0.001$ )
25(OH)D (vitamin D)	-0.27 ( $p=0.007$ )	-0.25 ( $p=0.02$ )	-0.19 ( $p=0.06$ )	+0.23 ( $p=0.03$ )

Our results are in line with the concept of an “immuno-metabolic” profile influencing exercise outcomes. Prior research has shown that obesity and central adiposity act as chronic inflammatory stimuli, accelerating immunosenescence and impairing vaccine responses [5] [6]. Although our participants were generally young and not obese on average, even modest elevations in BMI or waist circumference in some individuals could have contributed to elevated NLR and CRP. Kondrat’ev et al. (2021) reported that NLR is a reliable marker of systemic inflammation in obesity, and we similarly observed higher NLR in subjects with metabolic irregularities (e.g. dyslipidemia or low HDL often co-occurring with higher BMI). Furthermore, Lazarev et al. (2022) demonstrated strong correlations between visceral fat and inflammatory markers like IL-6 and CRP. Our finding that waist/height ratio correlated more strongly with CRP and NLR than BMI supports the idea that central fat distribution is critical in immune modulation, even in a non-obese range.

One novel aspect of this study is highlighting the high prevalence of vitamin D insufficiency in military personnel and its possible impact on immunity. Nearly 75% of tested servicemen had suboptimal 25(OH)D levels, which is consistent with other reports of widespread vitamin D deficiency in Central Asian populations despite abundant sunlight. Gorelov et al. (2023) in a systematic review confirm that vitamin D plays an important role in preventing respiratory infections. In our data, lower vitamin D was associated with higher CRP/IL-6 and lower sIgA, suggesting a more inflammation-prone and infection-prone immune status, which aligns with the immunoregulatory function of vitamin D noted in athletes and soldiers by various authors. This finding has practical implications: correcting vitamin D deficiency (through supplementation or diet) could be a simple measure to improve immune readiness in the military, as also recommended by recent military medicine guidelines [7].

The acute exercise findings also deserve discussion. We observed that high physical load personnel had an exaggerated leukocyte and cytokine response to the shuttle run compared to others. While a certain level of post-exercise immune activation is normal, the sustained elevation at 24 h in this group might indicate incomplete recovery or an “open window” of increased susceptibility to infections. Vasilenko (2015) and Didenko & Aleksanyants (2015) both documented that intense training blocks can cause transient drops in salivary IgA and spikes in cortisol, correlating with higher incidence of upper respiratory tract infections in athletes [8]. Our data similarly showed a ~18% sIgA drop in high-load servicemen and only partial rebound by next day, which could translate to higher URTI risk. Indeed, there is evidence that soldiers undergoing heavy training (e.g. special forces) report more frequent respiratory illnesses, likely due to this immune suppression combined with operational stress. The more tempered response in officers suggests that long-term adaptation or possibly lifestyle factors (better nutrition, routine) confer a protective effect—this resonates with studies showing that well-conditioned individuals have less dramatic

“post-exercise immune depression” [3] and a quicker return to homeostasis.

Notably, the groups with more robust immune perturbations (high-load units) were also those with slightly worse metabolic profiles on average (higher LDL, more vitamin D deficiency). This raises the question: are their heightened inflammatory responses a consequence purely of acute exertion, or are they primed by underlying metabolic/inflammatory status? It is plausible that chronic training stress combined with marginal nutrition (e.g. insufficient vitamin D, iron) creates a pro-inflammatory baseline that amplifies acute responses. On the other hand, the officers’ favorable metabolic status (e.g. relatively lower triglycerides and higher vitamin D sufficiency) could be contributing to their stable immune responses. Simpson et al. (2020) emphasize that maintaining good general health and nutrition is key to an effective immune system in athletes [9]. Our findings support that recommendation in a military context: attention to metabolic health — treating dyslipidemia, correcting micronutrient deficiencies, etc. — may improve soldiers’ immunological resilience to training and deployment stress.

Some limitations of this study should be noted. The research was cross-sectional in metabolic measurements, so we cannot infer causality between metabolic factors and immune differences. Unmeasured confounders (diet, sleep, genetics) might also influence both metabolism and immunity. The vitamin D and IL-6 data were obtained in subsets of participants, which limits generalization. Additionally, while we stratified by broad service categories, there is individual variability within groups (some conscripts may be very fit, some officers less so). Nevertheless, the significant trends observed suggest real physiological differences that align with group roles. Future longitudinal studies or interventions (e.g. vitamin D supplementation trials, tailored nutrition programs) in military populations could more directly test the causative links between improving metabolic health and enhancing immune function.

In conclusion, this study demonstrates that even in young, non-obese military men, there are gradations of metabolic health that correlate with immune readiness. Servicemen with optimum metabolic profiles (healthy lipid levels, adequate iron and vitamin D) tended to exhibit balanced immune responses to physical exertion, whereas those with emerging metabolic risk factors showed heightened inflammation and transient immune suppression after exertion. These findings highlight the importance of monitoring and managing metabolic health as part of military medical readiness programs. Simple measures such as nutritional supplementation (vitamin D, iron when needed) and lifestyle interventions to improve lipid profiles could confer immunological benefits, potentially reducing illness rates and improving performance. In the modern military setting, where personnel are expected to withstand significant physical and environmental stress, maintaining metabolic fitness is as crucial as physical fitness for ensuring an optimal, resilient immune system [10].

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