Influence Of Haemoglobin Concentration On Physical Fitness And Performance: A Comparative Study

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Abstract
The present study examines the influence of haemoglobin concentration on physical fitness and performance among trained and untrained individuals. Haemoglobin plays a central role in oxygen transport, which directly affects aerobic metabolism, endurance, and muscular performance. A total of 60 male participants were examined and these were divided into two groups based on haemoglobin levels: Group X_1 (>12 gm/100 ml) and Group X_2 (<12 gm/100 ml). Various physiological and performance tests were carried out on these participants. These included basal pulse rate, post-exercise pulse rate, grip strength, persistence time, and 50-meter dash performance. Statistical analysis was carried out using mean, standard deviation, and t-test which revealed significant differences between groups. The results demonstrated that individuals with higher haemoglobin levels exhibited superior cardiovascular efficiency, faster recovery rates, enhanced muscular strength, and better speed performance. The findings of the study highlight the significance of maintaining optimal haemoglobin levels for improved physical fitness and athletic performance. The study contributes to understanding the physiological role of haemoglobin and suggests nutritional and training strategies to enhance performance.

1. Introduction

Haemoglobin is a vital iron-containing protein present in red blood cells (RBCs) and it plays a central role in oxygen transport and energy metabolism. It carries oxygen from the lungs to peripheral tissues and supports the elimination of carbon dioxide, thereby maintaining efficient physiological functioning during rest and exercise [1,2]. Adequate haemoglobin concentration is essential for sustaining aerobic metabolism, which is critical for physical fitness, endurance, and overall performance capacity [3]. Iron, a key component of haemoglobin, is an essential element which plays a role in several biochemical and physiological processes. In human body, the absorption of iron is regulated, as excretion mechanisms are limited [4]. Only a small fraction of dietary iron is absorbed, and its bioavailability is influenced by several dietary factors. Components such as phytates and calcium can inhibit iron absorption, whereas ascorbic acid enhances it [5]. Consequently, individuals consuming diets low in bioavailable iron have higher risk of developing iron deficiency, which may subsequently reduce haemoglobin levels and impair physiological function [6]. The role of haemoglobin in oxygen transport directly links it to physical performance. During exercise, the demand for oxygen increases significantly, and haemoglobin ensures adequate oxygen delivery to working muscles [7]. Efficient oxygen transport enhances aerobic energy production, delays the onset of fatigue, and improves muscular efficiency [8]. In contrast, reduced haemoglobin concentration limits oxygen availability, leading to decreased endurance, impaired muscular performance, and slower recovery following physical exertion [9].

Iron deficiency and low haemoglobin levels are commonly observed among physically active individuals and athletes. Increased physiological burdens, along with factors such as iron loss through sweat, gastrointestinal micro-bleeding, and, in some cases, inadequate dietary intake, contribute to this condition [10,11]. As a result, individuals with suboptimal haemoglobin levels often exhibit reduced work capacity, increased fatigue, and compromised physical performance [12]. Particularly in activities requiring sustained aerobic effort and muscular endurance, these effects are quite evident [13]. Previous research has established a strong correlation between concentration of haemoglobin and various components of physical fitness, including cardiovascular efficiency, muscular strength, endurance, and speed [14,15]. High levels of haemoglobin are known to improve oxygen-carrying capacity, better exercise tolerance, and enhanced recovery rates [16]. Conversely, lower haemoglobin levels are known to diminish aerobic capacity and reduced physical efficiency [17]. However, variability in findings across different populations highlights the need for further investigation into this relationship [18].

For physical fitness assessment, parameters such as pulse rate response, recovery patterns, muscular strength, and speed performance provide important information regarding individual's physiological efficiency. These parameters are closely influenced by oxygen availability and metabolic capacity, both of which are directly dependent on haemoglobin concentration [19]. The present study examines the influence of haemoglobin concentration on selected physical fitness variables, including cardiovascular responses, muscular strength, endurance, and speed performance. By comparing individuals with different haemoglobin levels, this study seeks to provide an understanding of the role of haemoglobin in determining physical performance and to emphasize the importance of maintaining optimal haemoglobin levels for improved fitness and athletic outcomes.

2. Materials and Methods

2.1 Study Design and Participants

The present investigation was designed as a comparative cross-sectional study to observe the effect of haemoglobin concentration on selected physiological and fitness parameters. The study focused on evaluating differences between individuals with relatively higher and lower haemoglobin levels, with particular emphasis on cardiovascular efficiency, muscular strength, speed, and endurance performance. For this study, a total of 60 male physical education students were selected from Punjabi University Campus schools and affiliated physical education institutions in Patiala. The participants were chosen from a similar age group and socio-economic background to ensure homogeneity and to minimize the influence of confounding variables such as lifestyle, diet, and training status. The chosen participants were medically screened prior to participation and it was ensured that they were free from cardiovascular, respiratory, metabolic, or hematological disorders. Participation was voluntary, and the participants were told about the purpose and procedures of the study. Based on haemoglobin concentration, the participants were divided into two groups: Group X_1 included participants which had haemoglobin levels greater than 12 gm/100 ml and Group X_2 included participants which had haemoglobin levels less than 12 gm/100 ml. This classification enabled a direct comparison of performance variables with regard to oxygen-carrying capacity.

2.2 Measurement of Haemoglobin

The concentration of haemoglobin was assessed using a standard hemometer under controlled laboratory conditions. The blood samples were taken by finger-prick method following strict hygienic protocols. The fingertip was first sterilized by cleaning with cotton soaked in hydrochloric acid. A sterile disposable pricking needle was used to obtain a blood sample. The blood was drawn into a capillary tube up to the marked level (0.02 ml) and immediately transferred into a titration tube containing the required reagents. Care was taken to prevent clotting by ensuring that all apparatus, including capillary tubes and titration tubes, were pre-cleaned with HCl. Fresh sterilized equipment was used for each participant to maintain accuracy and safety.

2.3 Physical fitness Measurements
Resting (basal) pulse rate of each participant was measured in a seated and relaxed condition using standard palpation techniques. Following baseline measurement, subjects performed a standardized exercise protocol. The measurement was made immediately after exercise and during recovery at intervals of 1 minute, 2 minutes, and 3 minutes. A battery of standardized tests was administered to assess different components of physical fitness:

Grip Strength Test: To measure muscular strength and endurance, a calibrated hand grip dynamometer was used. Subjects were asked to press the dynamometer handle with as great force as possible. Then the reading on dynamometer was recorded. The test was conducted first on right hand and then on left hand. Grip strength is measured in kg. The grip dynamometer is used to secure strength scores of the grip of each hand.

Persistence Time Test: To measure the time in which muscular endurance and strength as component of physical fitness remains constant. Persistence time was recorded in seconds. The subjects were asked to keep the needle of the grip dynamometer at one third of the grip strength. Muscular endurance was evaluated by measuring persistence time. The test was conducted first on right hand and then on left hand. The duration of persistence time was recorded in seconds.

Vertical Jump (Sargent Jump Test): The assessment of explosive power was made using the vertical jump test. The subjects were asked to stand with one side towards a wall, heels together and hold a 1 inch piece of chalk in the hand nearest to the wall. Keeping the heels on the floor the subject was asked to reach upward as high as possible and make a mark on the wall. Then the subjects were asked to perform a maximal vertical jump and mark the highest point reached. The difference between standing reach and jump height was recorded as the score. Three to five trials were allowed, and the best trial was recorded as the score.

Harvard Step Test: This test was used to evaluate cardiovascular endurance. The subjects were asked to step up and down on an 18-inch high bench for a duration of up to 3 minutes unless they feel exhausted before that and stop. The cadence was 30 steps per minute. As soon as the subject stopped, pulse rate was recorded at fixed intervals. The Physical Efficiency Index (PEI) was computed using the standard formula:

PEI = (Duration of exercise in seconds × 100) / (2 × sum of recovery pulse counts)
This index provided an estimate of cardiovascular fitness and recovery capacity.

50-Meter Dash: Speed was assessed through a 50-meter sprint test. The subjects were asked to stand behind the starting line already marked on the track for 50 m run. On a signal 'go' the subject was asked to run as fast as possible till the finish line of 50 m run. The minimum time taken by the subject to cover the distance between the starting and finishing line was recorded. Three trials were awarded and best one was recorded..

2.4 Experimental Procedure
The tests were conducted under uniform environmental conditions to ensure consistency. Subjects were familiarized with the testing procedures prior to data collection to minimize learning effects.

Adequate rest was provided between tests to prevent fatigue from influencing performance. Measurements were made by trained personnel using standardized protocols.

2.5 Statistical Analysis

Data analysis was carried out using descriptive and inferential statistical methods. The arithmetic mean was calculated to determine the central tendency of each variable, while standard deviation (SD) was used to assess variability within the data. Standard error of mean (SEM) was computed to estimate the precision of the sample mean. To evaluate the significance of differences between Group X_1 and Group X_2, an independent samples t-test was applied. A t-value greater than ±1.96 was considered statistically significant at 0.05 level. This statistical approach ensured a reliable comparison of physiological and performance variables between the two groups.

3. Results and Discussion

The results revealed substantial differences in physiological and physical fitness parameters between individuals with higher haemoglobin concentration (Group X_1) and those with lower haemoglobin concentration (Group X_2). The comparative analysis demonstrated that haemoglobin level is a key factor influencing cardiovascular efficiency, muscular strength, endurance, and speed performance. The data obtained for physiological and performance variables with statistical tests (Table 1).

Table 1: Physiological and performance variables with statistical tests

Variable	Group X1 Mean	Group X2 Mean	SD (X1)	SD (X2)	S.E.M. (X1)	S.E.M. (X2)	t-value
Haemoglobin (gm/100 ml)	13.34	10.72	0.8	1.0	0.1	0.2	11.9
Basal Pulse Rate	59.63	67.16	1.8	2.5	0.3	0.4	15.06
Pulse Rate after Exercise	145.66	166.46	3.2	4.3	0.6	0.8	20.8
Pulse Rate after 1 min Rest	124.13	132.7	2.1	1.9	0.4	0.4	15.30
Pulse Rate after 2 min Rest	103.33	122.4	1.5	1.8	0.3	0.3	45.46
Pulse Rate after 3 min Rest	90.26	98.06	1.6	1.8	0.3	0.3	18.57
Grip Strength (kg)	54.03	37.60	1.9	2.2	0.3	0.4	32.86
Persistence Time (sec)	29.63	23.76	1.0	2.0	0.2	0.4	13.34
50 m Dash (sec)	5.90	6.32	0.3	0.4	0.05	0.07	-1.23

A comparison of the mean values for group X_1 and X_2 is provided in Figure 1.

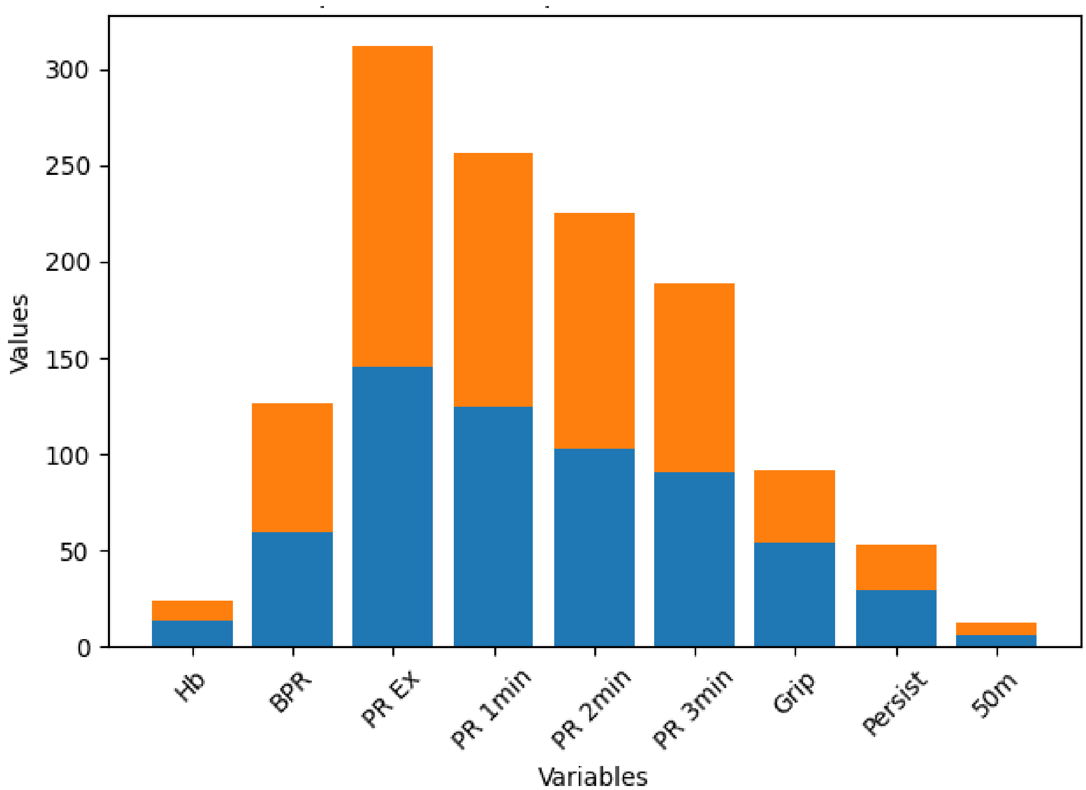

Fig. 1: A comparison of the mean values for group X_1 and X_2

As we can see from Fig. 1, the mean of haemoglobin concentration for Group X_1 was noticeably higher as compared to that of Group X_2, confirming the classification criteria adopted for the study. This difference in haemoglobin levels was associated with noticeable variations in performance outcomes. Individuals in Group X_1 exhibited a lower basal pulse rate compared to Group X_2, indicating more efficient cardiovascular functioning. A lower resting heart rate is generally considered a marker of better cardiac efficiency and improved aerobic fitness. Following exercise, pulse rate measurements further highlighted the differences between the two groups. Group X_1 showed comparatively lower post-exercise pulse rates and faster recovery within 1, 2, and 3 minutes. The results suggest that persons having higher haemoglobin levels possess enhanced oxygen transport capacity, enabling quicker restoration of physiological balance after exertion. Efficient recovery is a critical component of physical fitness, particularly in activities requiring repeated bouts of effort.

Muscular strength, as measured by grip strength, was considerably higher in Group X_1. It can be inferred that sufficient/higher haemoglobin levels contribute to improved muscle function which can be most likely due to better oxygen supply to muscle tissues during contraction. Similarly, persistence time was found to be greater in individuals with higher haemoglobin concentration. Persistence time reflects muscular endurance. Enhanced endurance in group X_1 can be attributed to continued aerobic metabolism and delay in onset of fatigue. Speed performance which was assessed through the 50-meter dash was also significantly different between the two groups. Participants in Group X_1 completed the sprint in less time compared to those in Group X_2. This indicates that participants having higher haemoglobin levels possess superior speed and power output. The improved overall efficiency could be attributed to adequate oxygen availability for recovery after high-intensity sprint activity which is primarily anaerobic.

The results of this study are in agreement with previous research results indicating that haemoglobin concentration plays a critical role in determining physical performance. Higher haemoglobin levels improve oxygen-carrying capacity, enable efficient energy production and contribute towards reducing fatigue. Conversely, lower haemoglobin levels limit oxygen carrying capacity which impairs both aerobic and anaerobic performance. The observed differences can be accounted for by the role of haemoglobin in maintaining oxygen homeostasis. During exercise, increased oxygen demand requires efficient transport mechanisms. Individuals with higher haemoglobin levels are better equipped to meet this demand, resulting in improved performance across multiple fitness parameters.

4. Conclusion

Overall, the study establishes a positive relationship between haemoglobin concentration levels and the physical fitness of the subjects. The results underscore the need for maintaining optimal haemoglobin levels for endurance activities, strength, speed, and recovery. These findings are of significance for athletes, coaches, and health professionals, highlighting the need for regular monitoring of haemoglobin levels and appropriate nutritional interventions to enhance fitness and performance.

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References

1. McArdle, W.D., Katch, F.I. and Katch, V.L., 2015. Exercise Physiology: Nutrition, Energy, and Human Performance. 8th ed. Philadelphia: Wolters Kluwer.
2. Powers, S.K. and Howley, E.T., 2018. Exercise Physiology: Theory and Application to Fitness and Performance. 10th ed. New York: McGraw-Hill.
3. Brooks, G.A., Fahey, T.D. and Baldwin, K.M., 2015. Exercise Physiology: Human Bioenergetics and Its Applications. 4th ed. New York: McGraw-Hill.
4. Ganz, T. and Nemeth, E., 2012. Iron homeostasis in host defence and inflammation. Nature Reviews Immunology, 12(8), pp.509–517.
5. Hurrell, R. and Egli, I., 2010. Iron bioavailability and dietary reference values. The American Journal of Clinical Nutrition, 91(5), pp.1461S–1467S.
6. Miller, J.L., 2013. Iron deficiency anemia: a common and curable disease. Cold Spring Harbor Perspectives in Medicine, 3(7), p.a011866.
7. Levine, B.D., 2012. VO2max: what do we know, and what do we still need to know? The Journal of Physiology, 586(1), pp.25–34.
8. Joyner, M.J. and Coyle, E.F., 2011. Endurance exercise performance: the physiology of champions. The Journal of Physiology, 586(1), pp.35–44.
9. Schumacher, Y.O. and Schmid, A., 2013. Hemoglobin, oxygen transport, and endurance performance. Sports Medicine, 43(2), pp.109–118.
10. Peeling, P., Dawson, B., Goodman, C., Landers, G. and Trinder, D., 2010. Athletic induced iron deficiency: new insights into the role of inflammation, cytokines and hormones. European Journal of Applied Physiology, 103(4), pp.381–391.
11. McClung, J.P., 2012. Iron status and the female athlete. Journal of Trace Elements in Medicine and Biology, 26(2–3), pp.124–126.
12. Dellavalle, D.M. and Haas, J.D., 2012. Iron status is associated with endurance performance in female athletes. Medicine & Science in Sports & Exercise, 44(8), pp.1552–1559.
13. Beard, J. and Tobin, B., 2010. Iron status and exercise. The American Journal of Clinical Nutrition, 72(2), pp.594S–597S.

14. Otto, J.M., Montgomery, H.E. and Richards, T., 2013. Haemoglobin concentration and exercise performance. Extreme Physiology & Medicine, 2(1), pp.1–9.
15. Schumacher, Y.O., 2010. Hemoglobin and sports performance. Sports Medicine, 40(6), pp.501–512.
16. Schmidt, W. and Prommer, N., 2010. Impact of alterations in total hemoglobin mass on VO2max. Exercise and Sport Sciences Reviews, 38(2), pp.68–75.
17. Burden, R.J., Pollock, N., Whyte, G.P., Richards, T., Moore, B., Busbridge, M. and Pedlar, C.R., 2015. Effect of iron supplementation on endurance capacity. British Journal of Sports Medicine, 49(21), pp.1389–1397.
18. McClung, J.P., 2012. Iron status and exercise performance. Current Sports Medicine Reports, 11(4), pp.199–204.
19. Bassett, D.R. and Howley, E.T., 2010. Limiting factors for maximum oxygen uptake and determinants of endurance performance. Medicine & Science in Sports & Exercise, 32(1), pp.70–84.
20. DellaValle, D.M., 2013. Iron supplementation for female athletes: effects on performance and recovery. Journal of Strength and Conditioning Research, 27(10), pp.2918–2925.