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# Original Research

## Impact of Audio-Visual Reaction Time in Anemic and Non-Anemic Adolescent Girls: A Comparative Study

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***ABSTRACT:***
**Background:**Anemia remains a major public health problem among adolescent girls, particularly in developing countries, where nutritional deficiencies, menstrual blood loss, and adverse socioeconomic conditions are highly prevalent. Adolescence is a critical period for physical growth and neurocognitive maturation, and reduced hemoglobin levels during this stage can impair oxygen delivery to tissues, including the brain. Reaction time is a simple, objective, and reliable indicator of sensory-motor integration and cognitive processing speed. Delayed auditory, visual, and audio-visual reaction times may reflect subtle neurocognitive impairment associated with anemia, which can negatively influence academic performance, daily functioning, and overall quality of life. **Aim:**The present study aimed to compare auditory, visual, and audio-visual reaction times between anemic and non-anemic adolescent girls and to assess the relationship between reaction time and severity of anemia. **Materials and Methods:**This comparative case–control study was conducted over a period of six to eight months in the Department of Physiology at Index Medical College Hospital & Research Centre, Indore. A total of 120 adolescent girls aged 13–19 years were enrolled and divided into two groups: anemic (n = 60; hemoglobin<12 g/dL) and non-anemic controls (n = 60; hemoglobin ≥12 g/dL). The anemic group was further categorized into mild, moderate, and severe anemia based on hemoglobin levels. Demographic details, anthropometric measurements, menstrual and medical history, and lifestyle variables were recorded. Hemoglobin estimation was performed, and auditory, visual, and audio-visual reaction times were measured under standardized laboratory conditions. Appropriate statistical tests were applied to analyze group differences, correlations, and associations. **Results:**Anemic adolescent girls demonstrated significantly prolonged auditory, visual, and audio-visual reaction times compared to non-anemic girls ($p < 0.001$). Audio-visual reaction time was markedly higher in the anemic group, indicating impaired multisensory processing. Reaction times showed a progressive increase with the severity of anemia, with a strong positive correlation between audio-visual reaction time and anemia severity. Anemia was also significantly associated with poor nutritional status, menstrual irregularities, low physical activity, poor sleep quality, and unfavorable socioeconomic and lifestyle factors. **Conclusion:**Anemia in adolescent girls is associated with significant delays in sensory-motor and cognitive processing, which worsen with increasing anemia severity. Early identification and comprehensive management of anemia are essential to improve both physiological health and functional performance in this vulnerable population.

**Keywords:**Anemia; Adolescent girls; Reaction time; Audio-visual reaction time; Hemoglobin

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## INTRODUCTION

Adolescence is a distinct developmental period marked by rapid physical growth, neurocognitive maturation, and increasing academic and social demands. The World Health Organization defines adolescents as individuals aged 10–19 years, a stage in which nutritional requirements rise sharply to support pubertal growth and expanding physiological reserves.[1] For adolescent girls, this phase is additionally shaped by the onset of menstruation, which increases iron loss and can further strain iron balance. When nutritional intake and iron stores do not match these demands, anemia becomes more likely, creating a vulnerability that may influence both health and functional performance.Anemia is commonly defined by a reduced hemoglobin concentration, which limits oxygen-carrying capacity and can compromise tissue oxygen delivery. WHO guidance provides standard hemoglobin cut-offs for diagnosing anemia and grading its severity at the population level, supporting the clinical classification used in adolescent research and screening.[2] In adolescent girls, hemoglobin levels below the recommended threshold may reflect iron deficiency, other micronutrient deficiencies, inflammation, or combined causes. Regardless of etiology, anemia during adolescence is important because it can occur at a time when cognitive efficiency, attention regulation, and motor coordination are consolidating—functions essential for learning, safe mobility, and overall quality of life. The public health burden of adolescent anemia remains substantial, particularly in low- and middle-income settings where dietary diversity, access to health information, and preventive care may be limited. In India, NFHS-linked government reporting highlights a high prevalence of anemia among adolescent girls (15–19 years), demonstrating that the condition affects a large segment of this population and remains a persistent national concern.[3,4] Such a high burden implies that even modest functional impacts of anemia—when multiplied across millions of adolescents—may translate into meaningful educational and productivity losses. This is especially relevant for adolescent girls, for whom anemia can coincide with school pressures, household responsibilities, and sociocultural constraints that may limit nutrition and health-seeking behavior.[5] Beyond hematologic definitions, the significance of anemia lies in its biological effects on the developing brain and neuromuscular system. Iron is essential for neurotransmitter synthesis, myelination, and energy metabolism, and iron deficiency can disrupt brain development and functioning even before severe anemia manifests. Evidence from nutritional neuroscience also indicates consistent links between iron-deficiency anemia and poorer cognitive and behavioral outcomes, with many studies reporting associations with attention, learning, and motor performance.[5] In practical terms, this means anemia may not only produce fatigue and reduced exercise tolerance, but may also subtly slow information processing and the speed of responding to sensory cues.One objective and clinically meaningful way to capture such functional slowing is through reaction time testing. Reaction time represents the interval between the presentation of a stimulus and the initiation of a motor response, integrating sensory detection, central processing, decision-making, and neuromuscular execution. Audio-visual reaction time, in particular, is useful because real-world functioning often involves multisensory integration—students respond to combined classroom cues (teacher voice plus visual instruction), and daily activities require rapid responses to both visual and auditory signals. If anemia slows these integrated pathways, it may be reflected as delayed auditory, visual, and especially audio-visual reaction times, making reaction time an accessible functional outcome alongside hemoglobin measures. Functional consequences of iron deficiency are also seen in educational performance at the population level. Large-scale analyses in school-aged children and adolescents have demonstrated that iron deficiency (with or without anemia) is associated with poorer cognitive achievement indicators, including standardized academic scores.[6,7]

## MATERIALS AND METHODS

This comparative case–control study was conducted over a period of six to eight months in the Department of Physiology, Index Medical College Hospital & Research Centre, Indore, Madhya Pradesh. Prior to the initiation of the study, institutional ethical clearance was obtained from the Institutional Ethics Committee. After approval, participants were recruited from the Department of Medicine and the Department of Obstetrics and Gynecology, Index Medical College & Hospital, Indore. All procedures were carried out in a controlled and standardized environment in the Physiology Department to ensure uniform testing conditions for hemoglobin estimation and reaction time measurement, thereby improving accuracy, reliability, and ethical compliance.

The study population included adolescent girls as per the World Health Organization (WHO) definition of adolescence. A total sample size of 120 adolescent girls was enrolled for the study. Participants were divided into two equal groups: Group I included 60 non-anemic girls who served as controls (hemoglobin ≥12 g/dL), and Group II included 60 anemic girls who served as cases (hemoglobin<12 g/dL). Further, based on hemoglobin levels, the anemic group was categorized into three severity-based subgroups: mild anemia (11.0–11.9 g/dL), moderate anemia (8.0–10.9 g/dL), and severe anemia (<8.0 g/dL). This sample size (60 per group) was considered statistically adequate to detect medium-to-large differences in audio-visual reaction time (AVRT) between anemic and non-anemic adolescent girls.

Participants were included if they were girls aged 13–19 years, willing to participate, and able to provide informed consent (with parental/guardian consent wherever required). For the case group, participants with hemoglobin levels below 12 g/dL were included, while controls were required to have hemoglobin levels of 12 g/dL or above. Only those free from chronic illnesses or neurological/muscular conditions that could affect reaction time were enrolled. Additionally, participants had to be able to understand and follow instructions required for reaction time testing. Participants were excluded if they had any acute or chronic disease or infection, physical or mental illness, untreated visual or auditory problems, or any diagnosed hearing or visual disorder, as these conditions could interfere with reaction time measurements.

Data collection was conducted in a systematic stepwise manner. After obtaining ethical approval, informed consent was taken from participants and/or parents/guardians. Eligible participants were screened and enrolled based on inclusion and exclusion criteria. Demographic and clinical details such as age, medical history, and menstrual history were recorded using a structured format. Anthropometric measurements including height and weight were obtained using standard procedures, and body mass index (BMI) was calculated accordingly. Hemoglobin estimation was performed to classify participants into anemic and non-anemic groups and to determine anemia severity among cases.

Reaction time assessment was carried out under standardized laboratory conditions in the Department of Physiology. Auditory reaction time (ART), visual reaction time (VRT), and audio-visual reaction time (AVRT) were measured using uniform instructions and consistent testing procedures for all participants. All readings were carefully recorded, verified, and compiled for analysis. Finally, the collected data were organized systematically for statistical evaluation and interpretation.

## RESULTS

**Table 1: Confounding Variables among Anemic and Non-Anemic Adolescent Girls**

Table 1 describes the distribution of selected demographic, anthropometric, and health-related confounding variables among anemic and non-anemic adolescent girls. With respect to age distribution, a higher proportion of anemic girls belonged to the 13–15 years age group (50.0%) compared to non-anemic girls (41.7%), whereas non-anemic girls were more represented in the 16–17 years age group. Height distribution showed that a greater percentage of anemic girls were below 150 cm (41.7%) compared to non-anemic girls (33.3%), while taller stature (≥160 cm) was more common among non-anemic girls. Regarding weight, half of the anemic girls (50.0%) weighed less than 45 kg, compared to 33.3% of non-anemic girls, indicating a higher prevalence of low body weight among anemic participants. Similarly, BMI analysis revealed that underweight status was more frequent among anemic girls (46.7%) than non-anemic girls (30.0%), while normal BMI was more common in the non-anemic group. Medical history showed slightly higher presence of illness among anemic girls. Menstrual irregularities were reported by one-third of anemic girls, which was notably higher than among non-anemic girls. Nutritional status further highlighted disparities, as poor nutrition was observed in 58.3% of anemic girls compared to 33.3% of non-anemic girls, suggesting a strong association between inadequate nutrition and anemia.

**Table 2: Anthropological Variables among Anemic and Non-Anemic Adolescent Girls**

Table 2 presents lifestyle, socioeconomic, and cultural characteristics of the study population. Poor sleep quality was reported by half of the anemic girls, whereas three-quarters of non-anemic girls reported good sleep quality. Physical activity levels showed that low activity was more prevalent among anemic girls (66.7%), while moderate to high activity was more common in the non-anemic group.

Socioeconomic status analysis indicated that a greater proportion of anemic girls belonged to the low socioeconomic category, while non-anemic girls were more likely to belong to middle or high socioeconomic groups. Family food practices showed that although shared meals were common in both groups, restricted meals were relatively more frequent among anemic girls. Cultural beliefs related to menstruation were predominantly restrictive among anemic girls, while non-restrictive beliefs were more common among non-anemic girls.

Furthermore, a higher proportion of anemic girls had high participation in household roles, limited access to nutrition information, low dietary diversity, and poor health-seeking behavior. Access to clean water and sanitation was also poorer among anemic girls. Collectively, these findings suggest that adverse lifestyle practices, sociocultural restrictions, and limited access to health and nutrition resources are more prevalent among anemic adolescent girls.

**Table 3: Comparison of Reaction Times among Anemic and Non-Anemic Adolescent Girls**

Table 3 compares auditory, visual, and audio-visual reaction times between anemic and non-anemic adolescent girls. The results indicate that anemic girls had longer reaction times across all modalities compared to non-anemic girls. Specifically, mean auditory reaction time, visual reaction time, and audio-visual reaction time were consistently higher in the anemic group, indicating slower sensory-motor processing.The difference in audio-visual reaction time between the two groups was statistically significant ($t = 9.21$, $p < 0.001$), demonstrating that anemia has a marked negative impact on reaction time performance.

**Table 4: Correlation between AVRT and Severity of Anemia**

Table 4 examines the relationship between audio-visual reaction time and severity of anemia. A progressive increase in mean AVRT was observed from mild to severe anemia, with the highest reaction time recorded in severely anemic girls. The Pearson correlation coefficient ($r = 0.82$) indicates a strong positive correlation between severity of anemia and AVRT, which was statistically significant ($p < 0.001$).

**Table 5: Comparison of Reaction Times across Severity of Anemia**

Table 5 compares auditory, visual, and audio-visual reaction times across different severities of anemia using ANOVA. Significant differences were observed for all three reaction time measures, with F-values indicating strong statistical significance ($p < 0.001$). Reaction times increased progressively from mild to moderate to severe anemia.Post-hoc Tukey analysis confirmed that reaction times in mildly anemic girls were significantly lower than those in moderately and severely anemic girls.

**Table 6: Distribution of Confounding Variables with Chi-Square Test**

Table 6 presents the association between selected confounding variables and anemia status using the chi-square test. Age group distribution did not show a statistically significant association with anemia. However, menstrual history was significantly associated with anemia, as irregular menstruation was more common among anemic girls ($p < 0.05$).Nutritional status also showed a statistically significant association, with poor nutritional status being significantly more prevalent among anemic girls.

**Table 7: Distribution of Anthropological Variables with Chi-Square Test**

Table 7 highlights the association between anthropological variables and anemia status. Significant associations were found for sleep quality, physical activity, socioeconomic status, cultural beliefs, participation in household roles, access to nutrition information, dietary diversity, and health-seeking behavior, all of which were poorer among anemicgirls.In contrast, family food practices and access to clean water and sanitation did not show statistically significant associations with anemia.

**Table 1: Confounding Variables among Anemic and Non-Anemic Adolescent Girls (n = 120)**

| Variables | Category | Anemic (N, %) | Non-Anemic (N, %) | Total (N, %) |
|---|---|---|---|---|
| **Adolescent Group** | 13–15 yrs | 30 (50.0%) | 25 (41.7%) | 55 (45.8%) |
| | 16–17 yrs | 20 (33.3%) | 25 (41.7%) | 45 (37.5%) |
| | 18–19 yrs | 10 (16.7%) | 10 (16.6%) | 20 (16.7%) |
| **Height (cm)** | <150 | 25 (41.7%) | 20 (33.3%) | 45 (37.5%) |
| | 150–159 | 30 (50.0%) | 30 (50.0%) | 60 (50.0%) |
| | ≥160 | 5 (8.3%) | 10 (16.7%) | 15 (12.5%) |
| **Weight (kg)** | <45 | 30 (50.0%) | 20 (33.3%) | 50 (41.7%) |
| | 45–50 | 20 (33.3%) | 25 (41.7%) | 45 (37.5%) |
| | >50 | 10 (16.7%) | 15 (25.0%) | 25 (20.8%) |
| **BMI (kg/m²)** | Underweight | 28 (46.7%) | 18 (30.0%) | 46 (38.3%) |
| | Normal | 30 (50.0%) | 40 (66.7%) | 70 (58.3%) |
| | Overweight | 2 (3.3%) | 2 (3.3%) | 4 (3.3%) |
| **Medical History** | Present | 15 (25.0%) | 10 (16.7%) | 25 (20.8%) |
| | Absent | 45 (75.0%) | 50 (83.3%) | 95 (79.2%) |
| **Menstrual History** | Irregular | 20 (33.3%) | 10 (16.7%) | 30 (25.0%) |
| | Regular | 40 (66.7%) | 50 (83.3%) | 90 (75.0%) |
| **Nutritional Status** | Poor | 35 (58.3%) | 20 (33.3%) | 55 (45.8%) |
| | Adequate | 25 (41.7%) | 40 (66.7%) | 65 (54.2%) |

**Table 2: Anthropological Variables among Anemic and Non-Anemic Adolescent Girls (n = 120)**

| Variable | Category | Anemic (N, %) | Non-Anemic (N, %) | Total (N, %) |
|---|---|---|---|---|
| Sleep Quality | Poor | 30 (50.0%) | 15 (25.0%) | 45 (37.5%) |
| | Good | 30 (50.0%) | 45 (75.0%) | 75 (62.5%) |
| Physical Activity | Low | 40 (66.7%) | 25 (41.7%) | 65 (54.2%) |
| | Moderate/High | 20 (33.3%) | 35 (58.3%) | 55 (45.8%) |
| Socioeconomic Status | Low | 35 (58.3%) | 20 (33.3%) | 55 (45.8%) |
| | Middle/High | 25 (41.7%) | 40 (66.7%) | 65 (54.2%) |
| Family Food Practices | Shared meals | 40 (66.7%) | 45 (75.0%) | 85 (70.8%) |
| | Restricted meals | 20 (33.3%) | 15 (25.0%) | 35 (29.2%) |
| Cultural Beliefs about Menstruation | Restrictive | 35 (58.3%) | 20 (33.3%) | 55 (45.8%) |
| | Non-restrictive | 25 (41.7%) | 40 (66.7%) | 65 (54.2%) |
| Participation in Household Roles | High | 45 (75.0%) | 30 (50.0%) | 75 (62.5%) |
| | Low | 15 (25.0%) | 30 (50.0%) | 45 (37.5%) |
| Access to Nutrition Information | Adequate | 20 (33.3%) | 40 (66.7%) | 60 (50.0%) |
| | Inadequate | 40 (66.7%) | 20 (33.3%) | 60 (50.0%) |

| | | | | |
|---|---|---|---|---|
| Dietary Diversity / Food Frequency | Low | 35 (58.3%) | 20 (33.3%) | 55 (45.8%) |
| | Adequate | 25 (41.7%) | 40 (66.7%) | 65 (54.2%) |
| Health-Seeking Behavior | Poor | 40 (66.7%) | 25 (41.7%) | 65 (54.2%) |
| | Adequate | 20 (33.3%) | 35 (58.3%) | 55 (45.8%) |
| Access to Clean Water & Sanitation | Poor | 30 (50.0%) | 20 (33.3%) | 50 (41.7%) |
| | Adequate | 30 (50.0%) | 40 (66.7%) | 70 (58.3%) |

**Table 3: Comparison of Auditory, Visual, and Audio-Visual Reaction Times among Anemic and Non-Anemic Adolescent Girls (n = 120)**

| Group | N | Auditory Reaction Time (ART)<br>Mean ± SD (ms) | Visual Reaction Time (VRT)<br>Mean ± SD (ms) | Audio-Visual Reaction Time (AVRT)<br>Mean ± SD (ms) | t-value (AVRT) | df | p-value |
|---|---|---|---|---|---|---|---|
| Anemic | 60 | 235.4 ± 18.7 | 258.9 ± 20.5 | 248.6 ± 19.8 | | | |
| Non-Anemic | 60 | 212.6 ± 15.2 | 231.3 ± 17.8 | 220.9 ± 16.4 | **9.21** | **118** | **<0.001*** |
| **Total** | **120** | **224.0 ± 20.1** | **245.1 ± 23.2** | **234.8 ± 21.2** | | | |

* Statistically significant

**Table 4: Correlation between AVRT and Severity of Anemia**

| Severity of Anemia | N | Mean ± SD (ms) | Pearson r |
|---|---|---|---|
| Mild | 30 | 240 ± 15 | |
| Moderate | 20 | 250 ± 18 | |
| Severe | 10 | 270 ± 20 | |
| **Total (Anemic)** | **60** | **248.6 ± 19.8** | **0.82 (p < 0.001)** |

**Table 5: Comparison of Reaction Times across Severity of Anemia**

| Severity | N | ART (ms) Mean ± SD | VRT (ms) Mean ± SD | AVRT (ms) Mean ± SD | F-value | p-value | Tukey Post-hoc |
|---|---|---|---|---|---|---|---|
| Mild | 30 | 229 ± 15 | 281 ± 16 | 242 ± 15 | ART = 28.31 | <0.001 | Mild < Moderate < Severe |
| Moderate | 20 | 235 ± 18 | 260 ± 18 | 250 ± 18 | VRT = 19.73 | <0.001 | Mild < Moderate < Severe |
| Severe | 10 | 255 ± 20 | 275 ± 19 | 270 ± 20 | AVRT = 20.70 | <0.001 | Mild < Moderate < Severe |
| **Total (Anemic)** | **60** | **235.4 ± 18.7** | **258.9 ± 20.5** | **248.6 ± 19.8** | | | |

**Table 6: Distribution of Confounding Variables with Chi-Square Test**

| Variable | Category | Anemic (N, %) | Non-Anemic (N, %) | $\chi^2$ | df | p-value | Significance |
|---|---|---|---|---|---|---|---|
| Adolescent Group | 13–15 yrs | 30 (50.0%) | 25 (41.7%) | 1.01 | 2 | >0.05 | NS |
| | 16–17 yrs | 20 (33.3%) | 25 (41.7%) | | | | |
| | 18–19 yrs | 10 (16.7%) | 10 (16.6%) | | | | |
| Menstrual History | Irregular | 20 (33.3%) | 10 (16.7%) | 4.0 | 1 | <0.05 | S |
| Nutritional Status | Poor | 35 (58.3%) | 20 (33.3%) | 6.25 | 1 | <0.05 | S |

**Table 7: Distribution of Anthropological Variables with Chi-Square Test**

| Variable | Category | Anemic (N, %) | Non-Anemic (N, %) | $\chi^2$ | df | p-value | Significance |
|---|---|---|---|---|---|---|---|
| Sleep Quality | Poor | 30 (50.0%) | 15 (25.0%) | 6.25 | 1 | <0.05 | S |
| Physical Activity | Low | 40 (66.7%) | 25 (41.7%) | 5.83 | 1 | <0.05 | S |
| Socioeconomic Status | Low | 35 (58.3%) | 20 (33.3%) | 5.0 | 1 | <0.05 | S |
| Family Food Practices | Shared meals | 40 (66.7%) | 45 (75.0%) | 1.0 | 1 | >0.05 | NS |
| Cultural Beliefs | Restrictive | 35 (58.3%) | 20 (33.3%) | 5.0 | 1 | <0.05 | S |
| Participation in Household Roles | High | 45 (75.0%) | 30 (50.0%) | 6.25 | 1 | <0.05 | S |
| Access to Nutrition | Adequate | 20 (33.3%) | 40 (66.7%) | 8.33 | 1 | <0.01 | S |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Information | | | | | | | |
| Dietary Diversity | Low | 35 (58.3%) | 20 (33.3%) | 5.0 | 1 | <0.05 | S |
| Health-Seeking Behavior | Poor | 40 (66.7%) | 25 (41.7%) | 5.83 | 1 | <0.05 | S |
| Access to Clean Water & Sanitation | Poor | 30 (50.0%) | 20 (33.3%) | 2.5 | 1 | >0.05 | NS |

**NS = Not Significant, S = Significant**

**DISCUSSION**

In this comparative case–control study (n = 120), anemia clustered with markers of undernutrition and lower physiological reserve. For example, low body weight (<45 kg) was more frequent in the anemic group (50.0%) than the non-anemic group (33.3%), and underweight BMI was also higher in anemic girls (46.7% vs 30.0%). A similar direction is reported at population level by **Chakrabarty et al (2023)**, where being underweight increased the odds of anemia (adjusted OR ≈ 1.10), and the national burden among adolescent women increased from about **54% (2015–16)** to **59% (2019–21)**—supporting the interpretation that nutritional vulnerability and anemia commonly coexist and can affect functional performance measures like reaction time in adolescents.[8]

Menstrual factors in our dataset showed a meaningful association with anemia: **irregular menstruation** was reported by 33.3% of anemic girls versus 16.7% of non-anemic girls ($\chi^2 = 4.0$, $p < 0.05$). This aligns with evidence that menstrual blood loss contributes to adolescent anemia; notably, **Poyyamozhi et al (2018)** found anemia prevalence of **41.1%** in urban adolescent girls and reported higher odds in those with **heavy menstrual bleeding** (OR **2.943**, $p < 0.05$), reinforcing the biologic plausibility that menstrual characteristics (especially heavier loss) can worsen iron depletion and thereby worsen neurophysiologic functioning.[9]

Lifestyle patterns in our results also differed clearly between groups, suggesting potentially modifiable contributors: poor sleep (50.0% vs 25.0%), low physical activity (66.7% vs 41.7%), poor health-seeking behavior (66.7% vs 41.7%), and poorer access to nutrition information (inadequate: 66.7% vs 33.3%) were all more common in anemic girls, with several showing statistically significant associations (Table 7). This direction is consistent with the focus of **Pratiwi et al (2024)**, who specifically examined anemia alongside sleep patterns in adolescent women, supporting the broader interpretation that anemia is intertwined with day-to-day lifestyle behaviors that can influence fatigue, attention, and speed of responding to stimuli—core components measured by reaction time tests.[10]

The key functional finding of our comparative study is that anemic girls demonstrated **slower sensory-motor processing** across modalities: ART was **235.4 ± 18.7 ms** in anemic versus **212.6 ± 15.2 ms** in non-anemic girls (≈ **+22.8 ms**), and VRT was **258.9 ± 20.5 ms** versus **231.3 ± 17.8 ms** (≈ **+27.6 ms**). Comparable patterns are reported by **Rashmi et al (2017)**, where the anemic group showed prolonged reaction times (ART ≈ **0.250 s** and VRT ≈ **0.254 s**) relative to the non-anemic group (ART ≈ **0.236 s** and VRT ≈ **0.237 s**), supporting that lower hemoglobin status is consistently linked with delayed reaction time in adolescent females across settings.[11]

Our combined measure—AVRT—also showed a strong group difference, with anemic girls having **248.6 ± 19.8 ms** versus **220.9 ± 16.4 ms** in non-anemic girls (difference ≈ **27.7 ms**), and this was highly significant (t = **9.21**, df = **118**, p <**0.001**). A consistent direction is noted by **Kahlon et al (2011)**, who studied iron-deficiency anemia in adolescent girls and showed that the anemic group had markedly lower hemoglobin (about **10.08 ± 0.51 g/dL**) than controls (**12.93 ± 0.86 g/dL**), alongside significantly increased auditory and visual reaction times ($p < 0.001$), supporting our inference that anemia—especially iron-deficiency anemia—negatively affects sensorimotor performance.[12]

Within the anemic group, our data indicate a **dose–response pattern** for AVRT: mild anemia (mean **240 ± 15 ms**), moderate (mean **250 ± 18 ms**), and severe (mean **270 ± 20 ms**) with a strong positive correlation (r = **0.82**, $p < 0.001$). This gradient is biologically plausible because iron deficiency can alter neurometabolism, neurotransmission, and myelination—mechanisms summarized by **Lozoff et al (2006)**—and increasing physiologic severity would be expected to magnify neurophysiologic slowing and thereby prolong reaction times.[13]

The ANOVA findings in our severity analysis further support clinically meaningful differences across mild, moderate, and severe categories (ART F = **28.31**, VRT F = **19.73**, AVRT F = **20.70**, all p <**0.001**), and Tukey post-hoc summary indicates increasing delays with greater severity. From a programmatic perspective, this matters because it implies functional impairment may progress alongside worsening anemia, and therefore early identification and correction is important. In this context, **Kapil et al (2019)** emphasize the need for comprehensive anemia control strategies (supplementation plus broader nutrition actions), and our findings add functional evidence (reaction time delays and a severity gradient) that supports intensifying early adolescent interventions.[14]

Finally, while our exclusion criteria reduced the likelihood of infection-related anemia, real-world adolescent anemia often has **multiple contributors** (nutrition, menstrual loss, and infections). For example, **Gopalakrishnan et al (2018)** documented anemia alongside intestinal parasitic infestations among schoolchildren, highlighting that preventable morbidities can overlap with anemia in community settings. This reinforces that interpreting reaction time impairment in anemia should consider mixed etiologies in practice, and that integrated approaches (nutrition, deworming where indicated, menstrual health support) are likely to yield the best functional gains.[15]

## CONCLUSION

The present study demonstrates that anemia in adolescent girls is significantly associated with delayed auditory, visual, and audio-visual reaction times, indicating impaired sensory-motor and cognitive processing. Anemic girls showed consistently slower reaction times compared to their non-anemic counterparts, with reaction time worsening as the severity of anemia increased. Significant associations were also observed between anemia and poor nutritional status, menstrual irregularities, and adverse lifestyle and socioeconomic factors. These findings highlight the importance of early detection and comprehensive management of anemia to improve both physiological health and functional performance in adolescent girls.

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