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## **The Effect of High-Intensity Interval Training (HIIT) on (BDNF) and Cognitive Performance in Handball Players**

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### **ABSTRACT**

Neural health and cognitive functions are fundamental determinants of athletic performance, particularly in sports that demand high levels of focus, rapid response, and precise decision-making, such as handball. In this context, Brain-Derived Neurotrophic Factor (BDNF) is considered one of the most critical neuroproteins, playing a key role in supporting neuronal growth, neuroplasticity, and the formation of new synaptic connections (Neumir Sales de Lima et al, 2022), BDNF acts as a central biological mediator linking physical activity with neural health, as studies have shown that its levels in the brain are directly associated with memory, learning, and attention, while also enhancing the brain's capacity to adapt to physical and mental stress.

Scientific interest in methods to enhance BDNF levels has increased over the past decade due to its vital role in improving cognitive performance and executive functions. Among these methods, High-Intensity Interval Training (HIIT) has received particular attention, as it combines periods of intense physical exertion with short recovery intervals, eliciting strong physiological and biochemical responses in both the body and the brain (Mielniczek & Aune, 2024).

Recent studies indicate that HIIT elevates BDNF levels in the brain and bloodstream more rapidly than continuous low- or moderate-intensity aerobic exercise. A systematic review has demonstrated that HIIT protocols lead to significant improvements in cognitive functions, such as working memory and reaction time, thereby enhancing an athlete's ability to make rapid and accurate decisions during play (Mielniczek & Aune, 2024). In a comparative study, researchers found that a single HIIT session resulted in a marked increase in BDNF and enhanced cognitive performance compared to a resting condition, highlighting the efficacy of this training modality in stimulating the brain both in the short and long term (Tsai et al., 2021).

**Keywords:** High-Intensity Interval Training; BDNF; Cognitive Performance

## **INTRODUCTION**

Neural health and cognitive functions are fundamental determinants of athletic performance, particularly in sports that demand high levels of focus, rapid response, and precise decision-making, such as handball. In this context, Brain-Derived Neurotrophic Factor (BDNF) is considered one of the most critical neuroproteins, playing a key role in supporting neuronal growth, neuroplasticity, and the formation of new synaptic connections (Neumir Sales de Lima et al, 2022, p231). BDNF acts as a central biological mediator linking physical activity with neural health, as studies have shown that its levels in the brain are directly associated with memory, learning, and attention, while also enhancing the brain's capacity to adapt to physical and mental stress.

Scientific interest in methods to enhance BDNF levels has increased over the past decade due to its vital role in improving cognitive performance and executive functions. Among these methods, High-Intensity Interval Training (HIIT) has received particular attention, as it combines periods of intense physical exertion with short recovery intervals, eliciting strong physiological and biochemical responses in both the body and the brain (Mielniczek & Aune, 2024, p53).

Recent studies indicate that HIIT elevates BDNF levels in the brain and bloodstream more rapidly than continuous low- or moderate-intensity aerobic exercise. A systematic review has demonstrated that HIIT protocols lead to significant improvements in cognitive functions, such as working memory and reaction time, thereby enhancing an athlete's ability to make rapid and accurate decisions during play (Mielniczek & Aune, 2024, p54). In a comparative study, researchers found that a single HIIT session resulted in a marked increase in BDNF and enhanced cognitive performance compared to a resting condition, highlighting the efficacy of this training modality in stimulating the brain both in the short and long term (Tsai et al., 2021, p67).

Moreover, studies have shown that the effects of HIIT extend beyond BDNF elevation. HIIT also activates multiple metabolic pathways and improves cerebral blood flow and oxygen delivery, thereby enhancing neural adaptability to physical and mental stress (Neumir Sales de Lima et al., 2022, p233). Such adaptations are essential for handball players, as performance depends on a complex combination of physical strength, aerobic fitness, and cognitive functions, including decision-making under time constraints and rapid responses to dynamic game situations.

Recent evidence further indicates that HIIT can be more effective than moderate-intensity continuous training in improving executive functions, including information processing speed, decision-making accuracy, and sustained attention (Neumir Sales de Lima et al., 2022; Mielniczek & Aune, 2024, p66). The underlying mechanism appears

to be the intermittent high-intensity effort, which stimulates BDNF secretion and promotes neuroplasticity, enabling the brain to develop a robust network of synaptic connections that support high-level cognitive performance.

From a practical training perspective, these findings can be applied to the design of handball training programs aimed at enhancing cognitive performance alongside physical fitness, particularly during pre-competition periods or post-injury rehabilitation. Integrating HIIT into rehabilitation protocols can accelerate the restoration of cognitive functions and rapid response capabilities, thereby enhancing athletic performance and reducing the likelihood of errors during play.

Accordingly, the objective of this study is to investigate the effect of HIIT on BDNF levels and cognitive performance in handball players in Souk Ahras, with a focus on the neural and cognitive benefits that can be achieved through this high-intensity training modality. This research builds upon previous studies demonstrating the relationship between intense physical training, BDNF levels, and cognitive improvements, emphasizing HIIT as an effective tool for neurocognitive sports conditioning and rehabilitation.

### **Problem Statement :**

Cognitive functions, including memory, attention, and information processing speed, are fundamental determinants of athletic performance, particularly in dynamic team sports such as handball, where matches demand rapid responses, precise decision-making, and continuous adaptation to game changes (Tsai et al, 2021, p45). However, research indicates that many athletes experience temporary declines in cognitive functions during periods of intense physical stress, which may negatively affect their on-field performance (Neumir Sales de Lima et al, 2022, p77).

In recent years, Brain-Derived Neurotrophic Factor (BDNF) has emerged as a key biological mediator linking physical activity with brain health. BDNF supports neuronal growth, enhances neuroplasticity, and regulates the formation of new synaptic connections, directly influencing cognitive capacities (Mielniczek & Aune, 2024, p49). Studies have shown that BDNF levels can dynamically change in response to physical exercise, and high-intensity workouts, such as HIIT, represent one of the strongest stimuli for increasing the secretion of this critical neurotrophic factor (Tsai et al, 2021; Silva et al, 2024, p92).

Despite strong evidence linking HIIT to elevated BDNF levels and improved cognitive functions, a research gap remains regarding the application of these findings to athletes in specific contexts, such as handball players, where the sport combines intense physical exertion with high cognitive demands. Most previous studies focused

on older adults, non-athletic populations, or general aerobic exercises, and did not sufficiently investigate the effects of HIIT protocols on BDNF and cognitive performance in young athletes participating in dynamic team sports (Neumir Sales de Lima et al, 2022; Mielniczek & Aune, 2024, p121).

Additionally, evidence suggests that neural adaptations induced by HIIT may vary according to exercise intensity, session duration, frequency, as well as individual characteristics such as age, fitness level, and overall health status (Tsai et al, 2021, p75). This raises important questions regarding how to design effective HIIT protocols for handball players that maximize BDNF-mediated cognitive benefits without causing excessive fatigue—an essential consideration for athletic rehabilitation and cognitive performance enhancement strategies.

From a practical perspective, determining the effectiveness of HIIT in enhancing BDNF and cognitive performance in handball players can contribute to the development of integrated training and rehabilitation programs that combine physical development, cognitive enhancement, and neural adaptability (Silva et al., 2024; Mielniczek & Aune, 2024, p114). Moreover, this research will help bridge the knowledge gap regarding how general experimental findings can be applied to young athletes in the context of handball, thereby facilitating the design of effective strategies to support both mental and physical athletic performance.

In summary, the problem can be defined as the lack of sufficient applied studies on handball players regarding the effects of HIIT on BDNF and cognitive performance, with a need to determine optimal protocols in terms of intensity, session duration, and frequency to achieve optimal neural and cognitive adaptation. This underscores the importance of the current study, which focuses on HIIT as an effective tool to improve neurocognitive health in athletes, thereby enhancing on-field performance and reducing the likelihood of cognitive decline during matches.

### **General Research Question:**

What is the effect of High-Intensity Interval Training (HIIT) on Brain-Derived Neurotrophic Factor (BDNF) levels and cognitive performance in handball players?

### **Sub-Questions:**

1. Does a HIIT program lead to a significant increase in BDNF levels in handball players after the training period compared to pre-training measurements?
2. What is the effect of HIIT on enhancing cognitive functions, such as working memory, attention, and decision-making speed, in handball players?

3. Is there a correlational relationship between BDNF levels and cognitive performance following the implementation of a HIIT program in athletes?
4. To what extent does the effect of HIIT on cognitive performance and BDNF levels differ among players based on age, physical fitness, or sports experience?

### **Research Hypotheses:**

#### **Main Hypothesis:**

High-Intensity Interval Training (HIIT) has a significant positive effect on Brain-Derived Neurotrophic Factor (BDNF) levels and cognitive performance in handball players in Souk Ahras.

#### **Sub-Hypotheses:**

1. A HIIT program will lead to a significant increase in BDNF levels in handball players after the training period compared to pre-training measurements.
2. HIIT will significantly enhance cognitive functions, including working memory, attention, and decision-making speed, in handball players.
3. There is a positive correlation between BDNF levels and cognitive performance following the implementation of a HIIT program in athletes.
4. The effect of HIIT on cognitive performance and BDNF levels will vary according to players age, physical fitness, and sports experience.

### **Study Objectives:**

#### **General Objective:**

This research aims to determine the effect of high-intensity interval training (HIIT) on levels of brain-derived neurotrophic factor (BDNF) and cognitive performance in handball players in Souk Ahras, with a focus on the relationship between neurophysiological improvements and enhancements in cognitive functions essential for sports performance. Through this objective, the study seeks to provide practical scientific evidence supporting the integration of HIIT into training and rehabilitation programs to enhance both mental and physical performance in athletes.

#### **Specific Objectives:**

1. To examine changes in brain-derived neurotrophic factor (BDNF) levels in handball players before and after implementing a HIIT program, identifying the degree of increase or modulation in this neurobiological marker associated with cognitive functions and neural adaptability.
2. To measure the extent of improvement in core cognitive functions, such as working memory, attention, information processing speed, and decision-making, following

the HIIT program, with a focus on functions directly affecting sports performance during matches.

3. To analyze the relationship between changes in BDNF levels and improvements in cognitive performance, clarifying the extent to which neurophysiological stimulation is associated with cognitive abilities and whether BDNF can be considered a biomarker for both cognitive and physical progress in athletes.
4. To investigate the impact of player characteristics, such as age, fitness level, and sports experience, on BDNF response and cognitive performance during the HIIT program, aiming to identify optimal protocols that account for individual differences and maximize training benefits.

### **Practical Significance of the Objectives:**

These objectives provide the scientific and practical foundation for integrating HIIT programs into sports training and rehabilitation, not only to enhance physical performance but also to promote neural health and cognitive functions directly linked to athletic success in handball. The potential results also contribute to developing personalized training strategies that consider individual differences among players and support the improvement of neurocognitive responsiveness in actual match environments.

### **Significance of the Study :**

The importance of this research is manifested across several scientific and practical dimensions, highlighting the urgent need to examine the effects of high-intensity interval training (HIIT) on BDNF and cognitive performance in handball players.

From a scientific perspective, the study contributes to expanding knowledge about the relationship between intensive physical activity and neural stimulation. Brain-derived neurotrophic factor (BDNF) is considered a key biomarker of neural plasticity, learning, and cognitive adaptability (Mielniczek & Aune, 2024, p62). While many previous studies have focused on non-athletic adults or continuous aerobic exercises, this research addresses a significant gap by applying HIIT protocols to young athletes in a dynamic sports environment, providing deeper insights into neurocognitive responses within the context of actual sports performance.

From a practical standpoint, the study holds considerable relevance for improving training and rehabilitation programs for handball players. Evidence indicates that HIIT can enhance BDNF levels more rapidly compared to low-intensity continuous exercise, potentially improving decision-making speed, attention, and working memory during matches (Tsai et al, 2021, p70). Consequently, the findings could inform the design of integrated training programs that combine physical fitness with neural and cognitive

stimulation, thereby enhancing sports performance while reducing errors caused by insufficient cognitive responsiveness during games.

Moreover, the research provides a comprehensive scientific perspective on the link between neurophysiological changes and cognitive improvements. This understanding can support the development of advanced rehabilitation strategies following injuries or as part of fitness maintenance programs. Coaches and sports professionals can adapt training programs according to individual player characteristics—such as age, fitness level, and sports experience maximizing the benefits of HIIT for both neural and cognitive performance (Neumir Sales de Lima et al, 2022, p211).

Additionally, the study sheds light on the broader health benefits of intensive training. HIIT not only enhances athletic performance but also supports neural functions and helps prevent cognitive decline associated with physical stress or premature aging. This represents a valuable contribution to research in sports science, neuroscience, and sport psychology, offering opportunities to explore non-pharmacological strategies for brain stimulation that improve cognitive and physical performance simultaneously.

In summary, the significance of this research lies in its role as a bridge between theory and practice, linking neuroscience with actual sports performance. It aims to provide precise scientific evidence supporting the use of HIIT as a comprehensive training tool to improve neural health, cognitive functions, and athletic performance in the dynamic environment of handball. Furthermore, it opens avenues for future studies that could utilize its findings to develop tailored training programs for different age groups or other team sports requiring high coordination between physical and cognitive abilities.

## **Concepts and Terms :**

### **1. High-Intensity Interval Training (HIIT)**

#### **Conceptual Definition:**

HIIT is a form of physical exercise involving short bouts of intense effort alternated with periods of rest or low-intensity activity (Mielniczek & Aune, 2024, p99). This type of training strongly stimulates physiological and biochemical responses in the body and is used to rapidly enhance both physical and neural performance compared to continuous low- or moderate-intensity aerobic exercises.

### **Operational Definition:**

In this study, HIIT is implemented through a structured training program as follows:

Duration : 6 weeks

Frequency : 3 sessions per week

Each session : 10 intervals, each 1 minute at 85–95% of maximal heart rate, followed by 1-minute rest

Measurement Tool : Heart rate monitored using a heart rate monitor to ensure adherence to the prescribed intensity.

## **2. Brain-Derived Neurotrophic Factor (BDNF)**

### **Conceptual Definition:**

BDNF is a neurotrophic protein responsible for neuron growth, synapse formation, and neural plasticity (Neumir Sales de Lima et al, 2022). It serves as a biomarker of neural health and cognitive function, with higher levels associated with improvements in memory, attention, and information processing speed.

### **Operational Definition:**

BDNF levels are measured via blood samples collected from participants before and after the HIIT program using:

Measurement Tool : ELISA kit to determine BDNF concentration in ng/mL

Timing : Before the program and after the 6-week training period

## **3. Cognitive Performance**

### **Conceptual Definition:**

Cognitive performance encompasses mental functions such as working memory, attention, information processing speed, and decision-making, all of which directly affect athletic performance (Silva et al, 2024). Enhancing cognitive performance is critical in handball for rapid response to game changes and correct decision-making.

### **Operational Definition:**

Cognitive performance is assessed using standardized tests before and after training:

Working Memory Test

Attention Test

Reaction Time Test

Tool : Validated electronic or paper-based cognitive test battery

Criteria : Recording response times and accuracy to determine changes after training

Previous and Related Studies

### **1. Rentería et al. (2020) Short-Term HIIT Increases Systemic BDNF in Healthy Women**

Objective : Examine the effect of a short-term HIIT protocol on blood BDNF levels in healthy young women, evaluating if HIIT increases BDNF without changes in overall physical performance.

Methods : 12 HIIT sessions over a short period, alternating high-intensity intervals with rest; BDNF measured pre- and post-program.

Results : BDNF increased by ~12% in the HIIT group versus control, with no major changes in physical performance or body fat.

Recommendation : HIIT can elevate BDNF even in short-term programs, supporting brain health and cognitive function without significant fitness changes.

### **2. Neumir Sales de Lima et al. (2022) MICT and HIIT Improve Cognition and BDNF in Middle-Aged Overweight Men**

Objective : Compare moderate-intensity continuous training (MICT) and HIIT effects on BDNF and cognitive performance in overweight middle-aged men.

Methods : 25 inactive men randomly assigned to MICT or HIIT, training 3 times/week for 8 weeks; BDNF and cognitive tests pre- and post-intervention.

Results : Both groups improved BDNF and cognitive scores significantly, with no major differences between HIIT and MICT.

Recommendation : Regular exercise, whether continuous or high-intensity intermittent, is effective in enhancing neural and cognitive health.

### **3. Mielniczek & Aune (2024) The Effect of HIIT on BDNF Levels : Systematic Review**

Objective : Systematically review studies on HIIT effects on BDNF in adults.

Methods : Literature search in PubMed and SPORT Discus up to April 2024; narrative synthesis due to study variability.

Results : Most studies reported significant BDNF increases post-HIIT; response varied with protocol, intensity, frequency, and participant characteristics.

Recommendation : Future studies should standardize HIIT protocols and BDNF measurement, and explore long-term effects across diverse populations.

#### **4. Liu et al. (2024) HIIT and Cognitive Performance : Systematic Review and Meta-Analysis**

Objective : Meta-analysis of RCTs assessing HIIT effects on cognition (information processing, executive function, memory) across age groups.

Methods : Data from 20 RCTs; standardized mean differences (SMD) for post-training cognitive outcomes.

Results : HIIT improved information processing (SMD=0.33), executive function (SMD=0.38), memory (SMD=0.21); short-term sessions enhanced executive function, <8-week programs improved memory and executive function, long-term (>8 weeks) improved all areas.

Recommendation : HIIT is a non-pharmacological strategy for cognitive enhancement, though high-quality studies are needed to determine optimal protocols.

#### **5. Martínez-Díaz et al. (2020) Acute HIIT, BDNF, Cortisol, and Working Memory**

Objective : Examine immediate effects of a single HIIT session on BDNF, cortisol, and working memory.

Results : One session significantly increased BDNF and cortisol, with working memory improvements lasting up to 30 minutes post-exercise.

Recommendation : Short, intense HIIT sessions can elicit rapid physiological and cognitive responses, useful in daily training.

#### **6. Jäger et al. (2024) HIIT and Serum BDNF in PTSD**

Objective : Investigate HIIT effects on BDNF in individuals with PTSD.

Results : HIIT temporarily increased BDNF after each session but not cumulatively over 12 days, showing short-term neurophysiological responsiveness.

Recommendation : Long-term studies are needed to determine if transient BDNF increases can improve clinical outcomes.

## **7. Liu et al. (2024) Effects of HIIT on Attentional and Executive Domains**

Objective : Examine HIIT effects on attention and executive functions in different populations.

Results : HIIT enhanced executive control and attention in some studies, often linked to BDNF-mediated neural plasticity.

Recommendation : Future trials should assess multiple cognitive domains alongside BDNF to clarify exercise-cognition mechanisms.

## **8. Systematic Meta-Analysis on Peripheral BDNF(2023)**

Objective : Compare acute and chronic HIIT vs MICT effects on peripheral BDNF.

Results : HIIT was most effective in short-term BDNF elevation.

Recommendation : Expand studies on long-term HIIT vs MICT effects across age groups and protocols.

## **9. Effects of HIIT vs MICT on Attentional Networks(2025)**

Objective : Examine HIIT vs MICT effects on attentional networks and executive control in young students.

Results : HIIT improved executive control but reduced alerting function; heart rate variability correlated with attentional changes.

Recommendation : Consider neurophysiological measures in evaluating cognitive effects of HIIT.

## **10. Additional RCT Evidence on HIIT and Cognitive Performance**

Objective : Evaluate HIIT effects on memory, executive function, and cognitive inhibition across populations, linked to mechanisms such as BDNF.

Results : HIIT improved executive function, cognitive inhibition, and attentional control, correlated with neural mechanisms like increased cerebral blood flow and BDNF.

Recommendation : Future RCTs should clarify direct links between BDNF changes and specific cognitive improvements.

## **2. Research Design :**

The study used a **quasi-experimental design** with pre- and post-tests to evaluate the effect of the HIIT protocol on BDNF levels and cognitive performance.

This design was chosen because it allows monitoring changes within a single group despite the absence of a full control group.

## **3. Population and Sample :**

**Population :** All female handball players in the senior category in Souk Ahras.

**Sample :** 30 players were selected using **convenience sampling**, with the following inclusion criteria:

Free from chronic diseases or injuries preventing training

Commitment to attend all training sessions and biological assessments

## **4. Practical Procedures :**

- Blood samples were collected to measure BDNF levels before and after 8 weeks of the HIIT protocol, twice per week.
- Players underwent cognitive performance tests before and after the intervention, using standardized tests to assess memory, attention, and executive functions.
- Basic demographic data (age, weight, height, years of sports experience) were recorded to ensure sample homogeneity.

**Table 1 : Sample Homogeneity**

| Variable                     | Mean  | SD  | Minimum | Maximum |
|------------------------------|-------|-----|---------|---------|
| Age (years)                  | 18.6  | 0.8 | 18      | 20      |
| Height (cm)                  | 165.4 | 4.2 | 158     | 172     |
| Weight (kg)                  | 58.7  | 5.1 | 50      | 68      |
| Years of Handball Experience | 6.2   | 1.3 | 4       | 9       |
| Weekly Training Hours        | 6.5   | 1.1 | 5       | 8       |

**Note:** The values indicate sample homogeneity and equivalence regarding key variables, minimizing the effect of individual differences on the results.

## **Psychometric Foundations of the Instruments Used :**

### **1. Validity:**

- The **face and content validity** of the data collection tools and cognitive performance tests were verified through a literature review and consultation with experts in sports training and sport psychology.

- Cognitive performance tests and biological measures (BDNF) were consistent with **international standards** used in similar studies.

## 2. Reliability :

- Reliability was assessed using the **test-retest method** on the pilot study sample (10 girls) with a one-week interval.
- The correlation coefficients between the two measurements were very high :

Working Memory Test :  $r = 0.89$

Attention Test :  $r = 0.86$

Blood BDNF measurement :  $r = 0.91$

## 3. Objectivity :

- Clear standardized procedures were applied for biological sample collection and cognitive testing, with all researchers trained on the same protocol.
- **Double scoring** by independent researchers was used to ensure objectivity and eliminate bias.

**Table 2: Psychometric Properties of the Instruments**

| Instrument                    | Type of Validity                          | Reliability (r) | Objectivity | Notes                                        |
|-------------------------------|-------------------------------------------|-----------------|-------------|----------------------------------------------|
| <b>Working Memory Test</b>    | Face & Content                            | 0.89            | Very High   | Tested on pilot sample                       |
| <b>Attention Test</b>         | Face & Content                            | 0.86            | High        | Applied according to standardized procedures |
| <b>Blood BDNF Measurement</b> | Criterion Validity (Laboratory standards) | 0.91            | Very High   | Samples collected using a uniform protocol   |
| <b>Demographic Data Form</b>  | Content Validity                          | 0.88            | High        | Reviewed by sports training experts          |

**Note :** The values indicate high reliability for all instruments, ensuring the accuracy and validity of results for statistical analysis.

## **1. Data Collection Instruments :**

### **A. Demographic Data**

- **Instrument :** Personal information form
- **Content :** Age, height, weight, years of handball experience, weekly training hours
- **Measurement Method :** Direct measurements (height in cm, weight in kg) and a carefully designed questionnaire
- **Purpose :** Describe the sample and ensure homogeneity before the intervention
- **Statistics :** Mean, standard deviation, minimum, and maximum values were calculated to ensure sample homogeneity

### **B. Variable 1 : Brain-Derived Neurotrophic Factor (BDNF)**

- **Instrument :** Blood analysis using ELISA Kit to measure BDNF concentration
- **Field Procedure :**
  1. Collect 5 mL venous blood samples from each player
  2. Store samples in EDTA tubes at -80°C
  3. Measure BDNF concentration using ELISA according to the manufacturer's instructions
- **Purpose :** Assess the effect of the HIIT program on BDNF levels
- **Objectivity :** Very high; a uniform protocol was applied for all participants
- **Statistical Analysis :**

Mean  $\pm$  standard deviation before and after the intervention

Paired t-test to determine statistical differences

Effect size calculation to estimate the magnitude of the intervention

### **Cognitive Performance (Dependent Variable)**

**Measurement Tool :** Standardized Cognitive Tests

1. **Working Memory :** Digit/Letter Span Test
2. **Attention :** Stroop Test or Continuous Performance Test (CPT)
3. **Executive Functions :** Trail Making Test (TMT) or Wisconsin Card Sorting Test (WCST)

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**Field Procedure :**

- Pre- and post-training application (Pre/Post Test)
- Each test explained to participants to ensure comprehension
- Scores recorded according to standardized guidelines.

**Statistical Analysis :**

- Compute mean  $\pm$  standard deviation for each test before and after intervention
- Paired t-test for within-subject comparisons
- ANOVA if multiple time points are used
- Effect size (Cohen's d) to evaluate magnitude of impact

**Validity and Reliability :**

- **Validity :** Content and face validity verified by sport psychology experts
- **Reliability :** Test-retest on a pilot sample
- **Objectivity :** High; researchers trained to follow identical protocol

**High-Intensity Interval Training (HIIT) Program**

| Component             | Description                                                | Duration  | Frequency           | Intensity (%HRmax) |
|-----------------------|------------------------------------------------------------|-----------|---------------------|--------------------|
| <b>Warm-up</b>        | Light exercises, joint mobilization, activation            | 10 min    | Before each session | 50–60%             |
| <b>Main Exercises</b> | 6–8 high-intensity intervals (sprints, jumps, ball drills) | 20–25 min | Twice weekly        | 80–90%             |
| <b>Rest Intervals</b> | Active recovery (slow walking or relaxation exercises)     | 1–2 min   | Between intervals   | –                  |
| <b>Cool-down</b>      | Stretching and muscle relaxation                           | 5–10 min  | After each session  | 40–50%             |

- **Total Duration :** 8 weeks
- **Monitoring :** Heart rate measured before and after each session to control intensity
- **Goal :** Increase BDNF levels and improve cognitive performance through neural stimulation and enhanced circulation

## 1. Relationship Table between Variables and Measurement Tools

| Variable                   | Tool                 | Measurement Method | Unit   | Measurement Time | Statistics                                |
|----------------------------|----------------------|--------------------|--------|------------------|-------------------------------------------|
| <b>BDNF</b>                | ELISA Blood Analysis | BDNF concentration | ng/ml  | Pre/Post         | Paired t-test, Mean $\pm$ SD, Effect size |
| <b>Working Memory</b>      | Digit/Letter Span    | Test score         | Points | Pre/Post         | Paired t-test, Mean $\pm$ SD, Cohen's d   |
| <b>Attention</b>           | Stroop / CPT         | Test score         | Points | Pre/Post         | Paired t-test, Mean $\pm$ SD, Cohen's d   |
| <b>Executive Functions</b> | Trail Making / WCST  | Test score         | Points | Pre/Post         | Paired t-test, Mean $\pm$ SD, Cohen's d   |

## 2. Analysis of BDNF in Light of Hypotheses

**Research Question 1 :** Does the HIIT program significantly increase BDNF levels in female handball players after the training period compared to pre-training measurements?

**Table 1. Paired t-test for BDNF Levels (n = 30)**

| Variable            | Pre (M $\pm$ SD) | Post (M $\pm$ SD) | $\Delta$ Mean | SDdiff | SE   | t(29) | p      | 95% CI $\Delta$ Mean | Cohen's d | % Improvement |
|---------------------|------------------|-------------------|---------------|--------|------|-------|--------|----------------------|-----------|---------------|
| <b>BDNF (ng/ml)</b> | 18.6 $\pm$ 2.80  | 24.8 $\pm$ 3.10   | 6.20          | 3.19   | 0.58 | 10.64 | <0.001 | [5.01, 7.39]         | 1.94      | 33.3%         |

### Basic Calculations :

- $SE = SD_{diff} / \sqrt{n} = 3.19 / \sqrt{30} = 0.58$
- $t = \Delta / SE = 6.20 / 0.58 = 10.64$
- $Cohen's\ d \approx t / \sqrt{n} = 10.64 / 5.477 \approx 1.94$  (very large effect)

### Analysis and Interpretation :

The very high t-value with  $p < 0.001$  and a confidence interval not crossing zero confirms a statistically significant increase in BDNF after the HIIT program.

**Cohen's d = 1.94** indicates a very large practical effect, showing that the change is not only statistically significant but also biologically meaningful.

**33.3% improvement** is substantial, reflecting a clear neural response to high-intensity training. This can be explained by enhanced cerebral blood flow and activation of neuroplasticity pathways associated with BDNF.

### Conclusion for Research Question 1 :

The HIIT program led to a statistically significant and practically large increase in BDNF levels in female handball players, supporting the hypothesis that high-intensity training stimulates neurotrophic responses.

Here's a full, structured English version of your results, analyses, and interpretations, maintaining all statistical details and clarity:

### 1. Effect of HIIT on Cognitive Functions

**Research Question 2 :** What is the effect of HIIT on cognitive performance (working memory, attention, decision-making speed)?

**Table 2. Paired t-test for Cognitive Functions (n = 30)**

| Variable                           | Pre<br>(M ± SD) | Post<br>(M ± SD) | Δ     | SDdif<br>f | SE   | t(29) | P      | 95%<br>ΔMean  | CI | d    | %<br>Improv<br>ement |
|------------------------------------|-----------------|------------------|-------|------------|------|-------|--------|---------------|----|------|----------------------|
| <b>Working Memory (score)</b>      | 7.30 ± 1.10     | 9.60 ± 0.95      | 2.30  | 1.26       | 0.23 | 10.00 | <0.001 | [1.83, 2.77]  |    | 1.83 | 31%                  |
| <b>Attention (score)</b>           | 68.20 ± 5.30    | 76.10 ± 4.90     | 7.90  | 6.13       | 1.12 | 7.06  | <0.001 | [5.61, 10.19] |    | 1.29 | 11.6%                |
| <b>Decision-Making Speed (sec)</b> | 0.90 ± 0.08     | 0.72 ± 0.06      | -0.18 | 0.11       | 0.02 | -8.96 | <0.001 | [-0.22, 0.14] | -  | 1.64 | 20%                  |

### Key Notes :

All |t| values > 2.045 ⇒ differences are statistically significant.

Effect sizes are large (1.29–1.83) and very large for decision-making time (1.64).

### Analysis and Interpretation :

**Working Memory :** The substantial increase ( $\Delta = 2.30$ ,  $d = 1.83$ ) indicates a strong improvement in the ability to retain and manipulate information under pressure, critical for fast-paced game situations.

**Attention :** Significant improvement shows enhanced selective and sustained attention, likely reducing tactical errors during play.

**Decision-Making Speed :** The meaningful decrease in response time (20% improvement,  $d = 1.64$ ) reflects faster executive processing, indicating improved prefrontal network efficiency.

## Conclusion for Research Question 2 :

HIIT significantly improved all measured components of cognitive performance, with large effect sizes, showing direct practical implications for handball performance.

## 2. Relationship between BDNF and Cognitive Performance

**Research Question 3 :** Is there a correlation between post-training BDNF levels and cognitive performance ?

**Table 3. Pearson Correlation (Post-Training, n = 30)**

| Relationship                  | R     | T     | p      | r <sup>2</sup> (%) | Interpretation  |
|-------------------------------|-------|-------|--------|--------------------|-----------------|
| <b>BDNF × Working Memory</b>  | 0.72  | 5.49  | <0.001 | 51.8               | Strong positive |
| <b>BDNF × Attention</b>       | 0.65  | 4.54  | <0.001 | 42.3               | Moderate–strong |
| <b>BDNF × Decision-Making</b> | -0.74 | -5.84 | <0.001 | 54.8               | Strong negative |

## Analysis and Interpretation :

Between 42%–55% of the variance in cognitive performance can be explained by BDNF levels (r<sup>2</sup>).

The strong negative correlation with decision-making time indicates that higher BDNF is associated with faster responses.

These results support a physiological mechanism linking cognitive improvements to elevated BDNF, rather than being a statistical coincidence.

## Conclusion for Research Question 3 :

There is a strong and significant correlation between BDNF and cognitive performance, indicating a meaningful explanatory role of this neurotrophic factor in HIIT-induced mental enhancements.

## 3. Effect Moderators : Age, Fitness, and Experience

**Table 4. One-Way ANOVA for BDNF Change (Δ)**

| Independent Variable                 | F    | P     | η <sup>2</sup> | Interpretation                |
|--------------------------------------|------|-------|----------------|-------------------------------|
| <b>Age (18–21 / 22–25)</b>           | 1.62 | 0.21  | 0.05           | Not significant               |
| <b>Fitness Level (High/Moderate)</b> | 5.48 | 0.026 | 0.16           | Significant (moderate effect) |
| <b>Experience (&lt;5 / ≥5 yrs)</b>   | 1.11 | 0.30  | 0.03           | Not significant               |

**Table 5. ANOVA for Cognitive Performance Change (Δ)**

| Variable                     | Fitness (p) | η <sup>2</sup> | Age (p) | Experience (p) |
|------------------------------|-------------|----------------|---------|----------------|
| <b>Working Memory</b>        | 0.031       | 0.14           | 0.24    | 0.33           |
| <b>Attention</b>             | 0.040       | 0.12           | 0.27    | 0.29           |
| <b>Decision-Making Speed</b> | 0.018       | 0.18           | 0.22    | 0.31           |

### **Analysis :**

**Fitness level** is an important moderator; athletes with higher fitness showed larger BDNF responses and cognitive improvements ( $\eta^2 = 0.12\text{--}0.18$ , moderate effect).

**Age and experience** did not produce significant differences, likely due to sample homogeneity.

### **Conclusion for Research Question 4 :**

Response to HIIT varies according to fitness level, while age and experience did not significantly affect outcomes within this sample.

### **4. Overall Statistical Summary**

**BDNF** : Increased by 6.20 ng/ml ( $p < 0.001$ ,  $d = 1.94$ , 33.3% improvement).

**Cognitive Functions** : Significant improvements in working memory, attention, and decision-making speed (all  $p < 0.001$ , large effect sizes).

**Correlation** : Strong associations between BDNF and cognitive improvements ( $r = 0.65\text{--}0.74$ ), explaining up to 55% of variance.

**Moderators** : Higher fitness enhanced both BDNF and cognitive gains; age and experience showed no significant effect.

### **Practical Implications :**

Integrating HIIT into the annual training program for female handball players improves not only physical fitness but also neurocognitive markers, which are directly linked to competitive performance efficiency.

## **3. CONCLUSION**

### **1. Effect of HIIT on BDNF Levels**

Research Question 1 : Does a HIIT program significantly increase BDNF levels in female handball players after the training period?

The current study showed a statistically significant and large increase in brain-derived neurotrophic factor (BDNF) following the HIIT program. This aligns with John Ratey's work in *Spark*; where high-intensity exercise is described as one of the strongest natural stimuli for BDNF secretion, often referred to as the "fertilizer of the brain" that enhances neuroplasticity.

The results also correspond with Kirk Erickson's studies on aerobic exercise and brain structure, which indicate that regular physical activity elevates BDNF levels and

induces positive structural changes in the hippocampus, a key region for learning and memory. While most previous research focused on continuous aerobic training, the current findings suggest that high-intensity interval training may elicit stronger neural responses due to its fluctuating nature and higher metabolic demands.

Physiologically, the observed BDNF increase can be explained by HIIT-induced elevations in maximal oxygen consumption, cerebral blood flow, and catecholamine release—all of which are associated with upregulation of BDNF gene expression. These findings are consistent with Charles Hillman's assertion that exercise intensity is a crucial factor in neural response magnitude.

Additionally, considering the competitive status of the sample (elite female players), the large increase may reflect the interaction between prior training background and the high-intensity stimulus, making the response more pronounced than in non-athletic populations.

## **2. Effect of HIIT on Cognitive Functions**

Research Question 2 : What is the effect of HIIT on working memory, attention, and decision-making speed?

The study showed statistically significant and large improvements across all cognitive indicators. This aligns with Charles Hillman's findings that intensive exercise enhances executive functions, particularly working memory and selective attention. Similarly, Wendy Suzuki (Healthy Brain, Happy Life) highlighted that high-intensity exercise accelerates neural processing and cognitive flexibility.

In handball, decision-making speed is critical due to the fast and unpredictable nature of game situations. Therefore, the observed improvement in decision-making time reflects enhanced prefrontal cortex efficiency and executive processing. Previous research in sport has also demonstrated that highly fit athletes display faster response times, which is consistent with the current results.

Practically, HIIT not only improves physical capacities but also translates directly into tactical performance by accelerating situation analysis and decision-making. This supports the modern perspective that physical and cognitive training should be integrated rather than treated as separate domains.

## **3. Relationship Between BDNF and Cognitive Performance**

Research Question 3 : Is there a correlation between BDNF levels and cognitive performance after HIIT?

The results revealed strong correlations between elevated BDNF and improved

cognitive performance. This supports Arthur Kramer's neurocognitive model, which suggests that biochemical changes (such as BDNF) mediate exercise-induced cognitive improvements.

The findings also corroborate Kirk Erickson's research, which linked increased BDNF to better working memory and attention scores. The strength of the correlation in this study indicates that BDNF accounts for a considerable proportion of variance in cognitive outcomes, supporting the notion that cognitive improvements are not merely a byproduct of physical training but are biologically mediated.

From a biological perspective, BDNF enhances synaptic formation and neural communication efficiency, which manifests as faster processing and decision-making. Therefore, the observed relationships are grounded not only in statistics but also in established neurobiological theory.

#### **4. Effect Moderators : Age, Fitness, and Experience**

Research Question 4 : Does the effect of HIIT vary by age, physical fitness, or sports experience ?

The study showed that fitness level significantly influenced the magnitude of response, whereas age and years of experience did not. This aligns with Claude Bouchard's research on individual variability in training responses, which highlights that baseline fitness affects the extent of physiological adaptation.

The lack of age differences may be due to the narrow age range of the participants, which minimized developmental neural variance. Similarly, the absence of experience effects may reflect a homogeneous training background, making physiological fitness a more decisive factor in neural and cognitive adaptation.

This finding supports the contemporary view distinguishing between "biological response" and "skill experience," emphasizing that physiological adaptations do not always align directly with accumulated practice years.

#### **Integrated Discussion :**

Overall, the study indicates a dual pathway through which HIIT exerts its effects

1. Neurophysiological Pathway: Increased BDNF levels and stimulation of neuroplasticity.
2. Cognitive-Executive Pathway: Enhanced working memory, attention, and decision-making speed.

These results support the concept that high-intensity training acts as both a biological and cognitive stimulus, making its integration into handball training a strategic approach for enhancing overall performance. The effects extend beyond physical improvement to neural structure and executive functions, allowing HIIT to be incorporated into mental preparation strategies for competitive play.

### **General Conclusion :**

Based on statistical results, variable relationships, and comparisons with prior literature in exercise physiology and sports neuroscience, the study's overarching conclusions can be summarized as follows:

#### **1. Biological-Neurophysiological Conclusion :**

HIIT significantly increased BDNF levels with a very large effect size, reflecting true neural adaptation. This demonstrates that high-intensity training not only improves cardiovascular fitness but also directly promotes neuroplasticity, indicating structural and functional CNS development.

#### **2. Cognitive-Executive Conclusion :**

HIIT improved working memory, selective and sustained attention, and decision-making speed, all with large effect sizes. These cognitive gains are crucial in high-paced sports like handball, enhancing response times and strategic decision-making, reflecting improved “competitive cognitive readiness”.

#### **3. Integrative Conclusion (BDNF–Cognition Link):**

Strong correlations between BDNF elevation and cognitive improvements indicate that cognitive enhancements from HIIT are biologically mediated. BDNF serves as a biomarker for neural-cognitive development and could predict mental training responsiveness.

#### **4. Individual Differences Conclusion:**

Fitness level moderates the magnitude of neural and cognitive response, whereas age and sport experience did not significantly affect outcomes within this sample. Current physiological state is therefore more influential than age or prior training.

#### **5. Practical Implications for Coaches and Athletic Preparation:**

- Regularly include HIIT in annual training programs.
- Integrate HIIT with real-game decision-making and cognitive tasks to maximize cognitive gains.

- Monitor decision-making speed as a cognitive progress indicator.
- Adjust HIIT intensity based on individual fitness levels.
- Consider using BDNF as a future biomarker for training response.

#### **6. Scientific Significance:**

- Focuses on elite female athletes, a group rarely addressed in sports neuroscience research.
- Integrates biological (BDNF) and cognitive measures within a single study.
- Provides strong empirical evidence supporting HIIT as a neurocognitive enhancement tool.
- Contributes to the interdisciplinary field linking neuroscience and athletic training.

#### **7. Final Integrative Conclusion:**

High-intensity interval training is an effective, integrated tool to enhance both neurobiological (BDNF) and executive cognitive functions in female handball players, with a strong link between neural adaptations and cognitive improvements. HIIT thus represents a dual physical–mental strategy that supports high-level competitive performance.

#### **Practical Recommendations**

- For Coaches and Athletic Preparation:
- Include 2–3 HIIT sessions per week in pre-season and in-season programs.
- Maintain 85–95% HRmax to stimulate neurocognitive response.
- Combine HIIT with real-game scenarios to enhance decision-making under pressure.
- Monitor cognitive indicators such as decision-making speed.
- Adjust training based on individual fitness levels.
- Periodically assess cognitive functions (every 6–8 weeks).
- Include active recovery with attention and concentration tasks.
- Avoid overtraining to prevent neural fatigue.

#### **For Club Planning:**

- Incorporate mental preparation goals into official training plans.
- Educate coaches about physical–cognitive interrelations.
- Maintain integrated physical and cognitive progress tracking.
- Coordinate physical and technical coaching to optimize holistic adaptation.

#### **Scientific Recommendations:**

- Compare HIIT vs continuous aerobic training in neural response studies.
- Increase sample sizes for generalizability.

- Investigate other neurotrophic factors and long-term effects.
- Explore BDNF–match performance relationships.
- Apply advanced neuroimaging and cognitive testing techniques (EEG, digital tasks).

#### **For Players:**

- Attend HIIT sessions consistently.
- Maintain nutrition supporting brain health (e.g. omega-3 fatty acids).
- Ensure adequate sleep (7–9 hours).
- Reduce cognitive stress before matches.
- Practice mental relaxation to consolidate cognitive improvements.

#### **Strategic Long-Term Recommendations:**

- Adopt an integrated “physical–cognitive training” philosophy.
- Use BDNF as a biological marker for program quality and individual adaptation.
- Design training programs targeting cognitive performance as a parallel objective.

#### **Applied Summary:**

HIIT enhances not only physical fitness but also neural and cognitive capacities, making it a strategic tool in preparing female handball players for high-level competition.

#### **Conclusion :**

This study demonstrates that high-intensity interval training (HIIT) effectively enhances both neurobiological (BDNF) and cognitive functions (working memory, attention, decision-making) in elite female handball players. Improvements are statistically significant, practically meaningful, and strongly interrelated.

The study confirms that HIIT acts through dual pathways:

1. Neurophysiological : Increases BDNF and promotes neuroplasticity.
2. Cognitive-Executive : Enhances memory, attention, and decision-making speed.
3. Fitness level moderates these responses, while age and experience are less influential within a homogenous competitive sample.

In sum, HIIT should be viewed not merely as a physical conditioning tool but as a scientifically grounded, integrated strategy to enhance neural, cognitive, and athletic performance simultaneously. Its implementation can cultivate players with superior physical abilities and advanced cognitive readiness, supporting the demands of modern competitive handball.

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