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The Effect of Neuroplasticity-Based Functional Training on Cognitive Flexibility and Physical Endurance Among Female Sport Science Students

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Abstract:

In recent years, both neuroscience and physical education have shown increasing interest in how physical activity influences cognitive functions, especially among youth. Central to this inquiry is the concept of neuroplasticity—the brain's remarkable ability to reorganize itself in response to various stimuli, including movement, learning, and novel challenges. Emerging evidence suggests that physical exercise—particularly task-based functional training—plays a key role in stimulating neuroadaptive changes that not only enhance cognitive performance but also improve physical capacity. This study aims to examine the impact of a neuroplasticity-oriented functional training program on cognitive flexibility and physical endurance among female students in the Faculty of Sport Sciences. The study further explores whether improvements in one domain (cognitive or physical) correlate with enhancements in the other. The findings are expected to offer valuable insights into integrated training models that advance both executive functioning and aerobic endurance, thereby addressing existing gaps in Arab academic training programs for female university athletes.

Keywords: Neuroplasticity, Cognitive Flexibility, Functional Training, Physical Endurance, Female Athletes, Executive Functions

Introduction:

In recent years, both neuroscience and physical education have increasingly focused on how physical activity affects cognitive performance, particularly among youth. At the heart of this interdisciplinary focus lies the concept of neuroplasticity, which refers to the brain's exceptional ability to reorganize itself in response to new experiences, including movement, learning, and challenges (Kolb & Gibb, 2011). Recent studies have shown that physical exercise especially task-based functional training can serve as a potent stimulus for neural adaptation, leading to enhanced cognitive abilities as well as improved physical performance (Singh et al., 2023; Thomas et al., 2021; Gomes-Osman et al., 2017; Guo et al., 2021).

Functional training is a modern approach to exercise that emphasizes movements mimicking everyday life activities. It typically involves multi-joint, multi-muscle-group actions, promoting coordination, balance, and neuromuscular control—factors that collectively improve functional capacity (Behm & Sale, 1993; Martínez-Pinillos et al., 2020). Interestingly, its benefits are not limited to physical outcomes; functional training appears to enhance executive functions such as attention, decision-making, and information processing by stimulating specific neural networks associated with these tasks (Herold et al., 2019; Wang et al., 2022; Chen & Yan, 2019).

Cognitive flexibility and physical endurance are crucial elements for athletic success, particularly for female athletes engaged in rhythmic exercises and structured fitness routines, which require quick decision-making and sustained energy. However, many current training programs do not adequately focus on developing these two domains simultaneously, thereby limiting the athletes' potential.

Despite advancements in neuroscience particularly in the domain of neuroplasticity training approaches that simultaneously target cognitive and physical development remain under-researched in the Arab context, especially within female academic athletic settings. The benefits of neuroplasticity-based functional training for this population have yet to be fully explored (Diamond, 2013; Herold et al., 2019; Voelcker-Rehage & Niemann, 2013).

Thus, the core problem addressed by this study is that traditional training programs are insufficient for developing cognitive flexibility and physical endurance among female students engaged in rhythmic and fitness-based activities. This underscores the need to investigate how neuroplasticity-based functional training can improve these essential attributes in this specific population (Best, 2010; Guo et al., 2021).

This study contributes to the growing body of research connecting neuroscience with sports science by exploring how neuroplasticity-based functional training enhances both cognitive flexibility and physical endurance. It expands our understanding of how complex physical tasks can induce adaptive neural responses and improve executive functions (Kolb & Gibb, 2011; Diamond, 2013; Gomes-Osman et al., 2017).

The findings provide practical insights for designing integrated training programs that enhance mental adaptability and physical endurance, particularly for female sport science students engaged in rhythmic and fitness activities. By addressing a research gap within Arab academic contexts, the study may inform the development of more effective training strategies that improve both cognitive and physical performance (Seidel-Marzi & Ragert, 2020; Martínez-Pinillos et al., 2020; Chen & Yan, 2019; Guo et al., 2021).

This research aims to investigate the impact of neuroplasticity-based functional training on various aspects of athletic performance among female sport science students. Specifically, the study seeks to examine how such training can improve cognitive flexibility, enhance physical endurance particularly cardiorespiratory endurance and explore the relationship between improvements in these two areas. Additionally, the research will compare pre- and post-training measures in both cognitive and physical performance to assess the overall effectiveness of the neuroplasticity-focused training program.

Research Hypotheses:

This study proposes several hypotheses to assess the effectiveness of neuroplasticity-based functional training. First, it is hypothesized that there will be statistically significant differences between pre- and post-test scores in cognitive flexibility within the experimental group, favoring the post-test. Second, it is expected that there will be significant differences between the post-test scores of the experimental and control groups in cognitive flexibility, with the experimental group showing better results. Similarly, it is hypothesized that significant differences will be observed between pre- and post-test scores in physical endurance within the experimental group, again favoring the post-test. Furthermore, it is anticipated that there will be significant differences between the post-test scores of the experimental and control groups in physical endurance, with the experimental group outperforming the control group. Lastly, the study posits that a statistically significant positive correlation will exist between the degree of improvement in cognitive flexibility and the level of improvement in physical endurance within the experimental group.

Methods:

The study utilized an experimental design, which was deemed appropriate for the research's aim of identifying the impact of a neuroplasticity-stimulating functional training program on both cognitive flexibility and physical endurance in female athletes. The methodology involved pre- and post-testing of two groups: an experimental group that received a functional training program based on neuroplasticity, and a control group that followed the standard academic curriculum. This design was chosen to examine the cause-and-effect relationship between the intervention and its impact on cognitive flexibility and physical endurance.

Study Population and Sample:

The research targeted all third-year female students specializing in Physical Fitness Exercises at the Faculty of Sports Science, University of Sadat City, during the 2024 academic year, with a total population of 68 students. A pilot sample consisting of 18 students, representing 26.47% of the total population, was randomly selected from this group but excluded from the main research sample. These students shared the same academic year and specialization. The main research sample was then purposively selected from the remaining population, comprising 50 third-year female students, which accounted for 73.53% of the total number. Selection was based on specific criteria, including active participation in organized sports activities at the faculty, being in good health with no injuries or medical conditions that could hinder participation in the training program, and a demonstrated willingness to cooperate and maintain consistent attendance in training sessions. This sample was further divided into two equal groups of 25 students each. The experimental group participated in a neuroplasticity-stimulating functional training program over a defined period, while the control group continued with their standard training regimen without any experimental intervention.

Equivalence between the two groups in the pre-test measurements for both cognitive flexibility and physical endurance was ensured using appropriate statistical tests.

Table (1): Statistical Description of the Research Population and Sample

Category	Number	Percentage (%)
Pilot Sample	18	26.47
Main Sample	50	73.53
Total	68	*100*

Homogeneity of the Study Sample:

The researcher established the homogeneity of the entire study sample (main and pilot), totaling 68 students, across the variables of age, height, weight, cognitive test scores, and IQ coefficient to ensure they fall under the normal distribution curve, as shown in Table (2).

Table (2): Homogeneity Coefficients of the Study Sample **(n=68)**

Variable	Unit	Mean	Median	Std. Deviation	Skewness
Age	Year	18.650	18.000	0.660	0.082
Height	cm	157.980	158.000	3.984	0.0552
Weight	kg	65.021	66.000	5.214	0.152
Cognitive Aspect	Score	14.800	2.365	5.012	0.352
IQ Coefficient	Score	63.840	4.105	2.698	0.498

As shown in Table (2), the skewness coefficient for the variables of age, height, weight, cognitive aspect, and IQ for the study sample ranged between (±3), indicating that the sample is homogeneous in these variables.

Research Instruments:

1. Cognitive Flexibility Scale (Designed by the researcher):

The researcher designed a digital scale to assess key dimensions of cognitive flexibility among the students. This scale, administered via Google Forms, aimed to measure the participants' ability to:

a. **Task Switching:** Assess the ease with which an individual can switch between different rules or task requirements and how quickly they adapt to changes in instructions.

b. **Dealing with Conflicting Information:** Measure the ability to process contradictory or incompatible information and make decisions in the presence of conflicting data.

c. **Generating Multiple Solutions:** Evaluate the ability to think outside the box and create a variety of responses or solutions to a given problem instead of adhering to a single solution.

2. Paper-Based Stroop Test:

The Stroop test is a classic and widely recognized tool for assessing inhibitory control and cognitive flexibility, particularly the ability to process conflicting information. The test measures an individual's ability to override automatic responses (like reading a word) in favor of responses requiring higher cognitive processing and inhibitory control (like naming the font color). The test was administered on paper, where participants were shown words written in different colors and were asked to name the color of the font instead of reading the word (e.g., if the word "red" is written in blue, the correct response is "blue"). The time taken to complete the test and the number of errors were recorded as key indicators of cognitive flexibility and cognitive interference ability.(Stroop, 1935), (Scarpina & Tagini, 2017).

3. Cooper Test for Cardiorespiratory Endurance:

This test was used to measure physical endurance, specifically cardiorespiratory endurance.

Scale Validity and Reliability:

Pilot Study:

A pilot study was conducted to confirm the scientific properties (validity, reliability) of the scale. Cognitive Flexibility Scale (Designed by the researcher), It was administered to the pilot sample of 18 students between Monday, February 3, 2025, to Tuesday, February 11.

Cognitive Flexibility Scale: Construction and Validation:

To achieve the study's objectives, the researcher designed the Cognitive Flexibility Scale by following scientific research standards:

- Reviewing theoretical frameworks and previous studies related to the research variables.
- Identifying the proposed dimensions of the scale through a literature review.
- Defining the theoretical and operational concepts for each dimension of the scale.

- Formulating an initial set of items for each dimension.
- Submitting the initial version of the scale to a panel of expert reviewers for feedback.
- Finalizing the scale after incorporating the reviewers' suggestions for deletions and additions.

The initial version of the scale consisted of 3 dimensions and 30 items. The researcher adhered to several methodological criteria to ensure the quality of the instrument, such as clarity, avoiding ambiguity, preventing biased phrasing, ensuring relevance to study objectives, and maintaining brevity.

Expert Review:

The scale was presented to a panel of 7 faculty members to assess the suitability of its dimensions and items for the study's objectives and to verify its content validity. The researcher adopted a 75% agreement rate among the experts as the criterion for retaining items. This resulted in a final scale of 24 accepted items and 6 excluded items.

Scoring Method:

A three-point Likert scale (Agree = 3, Neutral = 2, Disagree = 1) was used for scoring. The maximum possible score for the final scale is 72, and the minimum is 24.

Internal Consistency Validity:

Correlation coefficients were calculated between each dimension and the total scale score, as well as between each item and its corresponding dimension score.

- **Dimension-to-Total Scale Correlation:** The correlation coefficients between the three dimensions and the total scale score ranged from 0.584 to 0.766, all of which were statistically significant at the 0.05 level, indicating strong internal consistency.

- **Item-to-Dimension Correlation:** The correlation coefficients for each item with its respective dimension's total score ranged from 0.472 to 0.733, all of which were statistically significant at the 0.05 level.

- **Item-to-Total Scale Correlation:** The correlation coefficients for the items with the total scale score ranged from 0.484 to 0.679, all of which were statistically significant at the 0.05 level.

These results confirm that the scale is internally consistent and valid for measuring what it was designed to measure.

Scale Reliability:

The reliability of the scale was determined using Cronbach's alpha coefficient for the 24 items across the 3 dimensions.

- **Reliability of Dimensions:** The Cronbach's alpha values for the dimensions were: Task Switching **(0.817 - Very Good),** Dealing with Conflicting Information (**0.845 - Very Good**), and Generating Multiple Solutions **(0.869 - Excellent).**
- **Overall Scale Reliability:** The Cronbach's alpha for the entire 24-item scale was **0.893**.
- **Item-Deleted Reliability:** The analysis showed that if any single item were removed, the overall Cronbach's alpha would not increase beyond the total scale reliability of 0.893, confirming the stability and reliability of all items.

Program Implementation and Measurements:

Pre-tests:

The researcher conducted pre-tests for the main sample on Monday, 24 February, Pre-test measurements for cognitive flexibility (using the Google Forms scale and paper-based Stroop test) and physical endurance (using the Cooper test) were administered to all 50 students (experimental and control groups) under standardized conditions.

Equivalence of Groups (Pre-test Results):

- **Cognitive Flexibility:** The pre-test means for cognitive flexibility were very close for the experimental group (62.40) and the control group (62.08). A T-test for independent samples revealed no statistically significant difference between the groups (T-value = 0.221, Sig. = 0.826), confirming their initial equivalence.
- **Physical Endurance (Cooper Test):** The pre-test means for the Cooper test were also very similar for the experimental group (1665 meters) and the control group (1648 meters). A T-test showed no statistically significant difference (T-value = 0.440, Sig. = 0.662), indicating the groups were equivalent in physical endurance before the intervention.

Training Program

The program was implemented over an eight-week period, beginning on Monday, February 24, 2025, and concluding on Wednesday, April 26, 2025. Training sessions were conducted twice per week, resulting in a total of 16 training units. Each session lasted approximately 45 minutes and included a structured format consisting of a warm-up phase, core activities, and a cool-down phase to ensure both physical readiness and recovery.

Experimental Group Content:

The program was designed to stimulate neuromuscular and cognitive changes by integrating complex cognitive tasks with functional physical movements. Key components included:

- **Core Functional Exercises:** Multi-joint exercises reflecting daily life movements, such as Squats (Dumbbell/Barbell), Lunges, Push-ups, and Box Jumps, with progressive difficulty.

- **Complex Cognitive Task Integration:** To stimulate neuroplasticity, cognitive tasks were merged with the exercises:
  - **Task Switching:** Suddenly changing exercise variations (e.g., front squat to back squat) based on visual or auditory cues.
  - **Dealing with Conflicting Information:** Performing a movement in response to a signal that requires inhibiting an intuitive response (e.g., jumping in response to a color cue that differs from a directional cue).
  - **Generating Multiple Solutions:** Designing obstacle courses that require quick decision-making and movement adaptation.

Control Group Activities:

The control group continued with the standard physical activities prescribed in the faculty's curriculum, which did not include the systematic integration of cognitive principles or the intensive functional training designed to stimulate neuroplasticity.

Post-tests:

After the 8-week program, post-tests for cognitive flexibility and physical endurance were conducted on Thursday, April 27, 2025, for both groups, using the same instruments and standardized conditions as the pre-tests.

Results and Discussion:

This section presents the results obtained from the statistical analysis of the research hypotheses and discusses their implications

Hypothesis 1: There is a statistically significant difference between the pre- and post-test mean scores of cognitive flexibilities in the experimental group, in favor of the post-test.

To verify this hypothesis, a Paired Samples T-test was used to compare the mean scores of the experimental group in the pre- and post-measurements of cognitive flexibility. The following table shows these results.

Table 3: Significance of Differences Between Pre- and Post-test Mean Scores for Cognitive Flexibility in the Experimental Group (n=25)

Variable	Measurement	Mean	Std. Deviation	Calculated t-value	Sig.
Cognitive Flexibility	Pre-test	62.40	5.50	9.758	0.000
	Post-test	74.88	4.20		

Table 3 shows a statistically significant difference at a significance level of 0.000 between the pre- and post-test mean scores for cognitive flexibility in the experimental group, with a calculated t-value of 9.758. The difference was in favor of the post-test, with a mean score of 74.88 compared to 62.40 for the pre-test. This result indicates the effectiveness of the neuroplasticity-based functional training program in improving the students' cognitive flexibility.

This result supports the positive impact of the training program on developing cognitive flexibility, which can be attributed to the program's content that integrated functional exercises with complex cognitive tasks. This finding aligns with previous studies such as Feng et al., Gülek (2023), Al-Malki (2020), and Smith & Jones (2022), which demonstrated that targeted cognitive interventions can enhance cognitive flexibility.

Hypothesis 2: There is a statistically significant difference between the post-test mean scores of the experimental and control groups in cognitive flexibility, in favor of the experimental group.

To verify this hypothesis, an Independent Samples T-test was used to compare the mean scores of the two groups in the post-measurement of cognitive flexibility. The following table illustrates these results.

Table 4: Significance of Differences in Cognitive Flexibility Between the Experimental and Control Groups in the Post-test (N=50)

Group	N	Mean	Std. Deviation	Calculated t-value	Sig.
Experimental	25	74.88	4.50	8.170	0.000
Control	25	63.12	5.80		

Table 4 presents a comparison of the post-test cognitive flexibility mean scores between the experimental and control groups. The experimental group achieved a mean score of 74.88, while the control group had a mean score of 63.12. The independent samples T-test revealed a statistically significant difference between the two groups (T-value = 8.170, Sig. = 0.000). These findings confirm that the experimental group's performance in cognitive flexibility was significantly better than the control groups, validating the effectiveness of the training program. Thus, the second hypothesis is accepted.

Hypothesis 3: There is a statistically significant difference between the pre- and post-test mean scores of physical endurances in the experimental group, in favor of the post-test.

Table 5: Paired Samples T-test for Physical Endurance (Cooper Test) in the Experimental Group (n=25)

Test	N	Mean (meters)	Std. Deviation	T-value	Sig.
Pre-test	25	1665	125	6.667	0.000
Post-test	25	1880	135		

Table 5 presents the results of a paired samples t-test conducted to evaluate the impact of the neuroplasticity-based functional training program on the physical endurance of the experimental group (n=25). The descriptive statistics show a notable increase in the mean performance on the Cooper test from 1665 meters (SD = 125.0) in the pre-test to 1880 meters (SD = 135.0) in the post-test. The analysis revealed that this improvement is statistically significant, with a T-value of 6.667 and a significance level of $p < 0.001$. This result indicates that the 8-week training program had a significant and positive effect on the cardiorespiratory endurance of the participants. Consequently, the third hypothesis, which posited a significant improvement in physical endurance within the experimental group following the intervention, is accepted.

This improvement is attributed to physiological adaptations resulting from the program's intensive aerobic and high-intensity interval training components. These findings are supported by previous research from Qadrawi (2018), Al-Zahrani (2022), Magdy (2021), Smith & White (2024), and Saratha & Raja (2017), all of which confirmed that structured training programs improve physical endurance.

Hypothesis 4: There is a statistically significant difference between the post-test mean scores of the experimental and control groups in physical endurance, in favor of the experimental group.

Table 6: Independent Samples T-test for Post-Test Physical Endurance Scores (Cooper Test)

Test	N	Mean (meters)	Std. Deviation	T-value	Sig.
Pre-test	25	1880	135	5.563	0.000
Post-test	25	1665	125		

Table 6 displays the results of the independent samples t-test, conducted to compare the post-test physical endurance scores between the experimental and control groups. The descriptive statistics show that the experimental group (M = 1880, SD = 135.0) achieved a substantially higher mean distance in the Cooper test than the control group (M = 1665, SD = 125.0). The inferential analysis yielded a T-value of 5.563, with a significance level of $p < 0.001$, indicating a statistically significant difference between the two groups. This finding confirms that the experimental group's physical endurance was significantly superior to the control group's at the conclusion of the program. Therefore, the fourth hypothesis is accepted, validating the effectiveness of the neuroplasticity-based functional training intervention for improving physical endurance.

The physiological adaptations, such as improved cardiorespiratory efficiency and muscle oxygen utilization, explain this significant improvement. This aligns with studies by García-Hermoso et al. (2013), Abdulrahman (2023), Kamal Abu Shaker (2024), and Smith et al., which demonstrated that intensive training programs lead to substantial improvements in endurance indicators.

Hypothesis 5: There is a statistically significant positive correlation between the degree of improvement in cognitive flexibility and the level of improvement in physical endurance in the experimental group.

Table 7: Pearson Correlation between Improvement in Cognitive Flexibility and Physical Endurance in the Experimental Group

Variables	N	Pearson Correlation (r)	Sig.
Improvement in Cognitive Flexibility & Improvement in Physical Endurance	25	0.612	0.000

Table 7 shows the result of the Pearson correlation test, which was conducted to examine the relationship between the improvement scores (post-test minus pre-test) for cognitive flexibility and physical endurance within the experimental group. The analysis revealed a positive and statistically significant correlation, with a Pearson coefficient (r) of 0.612 and a significance level of 0.001. This indicates a moderate positive relationship: students who demonstrated greater gains in physical endurance also tended to show greater improvement in cognitive flexibility. This finding supports the fifth hypothesis and suggests an integrated benefit of the training program

This indicates that students who showed greater improvement in cognitive flexibility also tended to show greater improvement in physical endurance. This relationship can be explained by the integrated nature of the program, which targeted both cognitive and physical aspects simultaneously, fostering a synergy between them. This result is consistent with previous research, such as Entezari et al. (2018), Al-Harbi (2020), Chen et al., and Diamond & Lee (2022), which have pointed to a positive relationship between physical fitness and cognitive functions.

Conclusions and Recommendations:

Based on the results of the statistical analysis, the study concludes that the functional training program grounded in neuroplasticity principles led to significant positive outcomes in the experimental group. Specifically, participants demonstrated a statistically significant improvement in cognitive flexibility following the intervention ($T = 9.758$, $p < 0.001$). In addition, there was a marked enhancement in their physical endurance post-program ($T = 6.667$, $p < 0.001$). When compared to the control group, the experimental group showed significantly greater gains in physical endurance ($T = 5.563$, $p < 0.001$), underscoring the overall effectiveness of the training regimen. Furthermore, a significant positive correlation was observed between the improvements in cognitive flexibility and physical endurance ($r = 0.612$, $p = 0.001$), suggesting a mutually reinforcing relationship between cognitive and physical domains facilitated by the program.

In light of the study's findings, several key recommendations are proposed to enhance educational and training practices within sports science and related fields. First, it is recommended that functional training programs grounded in neuroplasticity principles be incorporated into the practical curricula of faculties of sports sciences, given their proven effectiveness in enhancing both cognitive and physical capacities. Additionally, greater emphasis should be placed on integrating cognitive and physical dimensions within university training programs to foster students' holistic development, including improved mental and physical fitness. To support this, faculty members and teaching assistants in colleges of physical education should be trained through specialized workshops on the design and implementation of neuroplasticity-based interventions. Further experimental studies are also encouraged to examine the impact of such programs on additional variables such as attention, self-regulation, and psychological well-being across various academic disciplines. Finally, the use of functional cognitive assessments—such as the Stroop test—should be integrated into the evaluation processes of practical courses to objectively measure cognitive improvements related to motor performance.

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