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The Effect of Affect Arousal on the Consolidation of Motor Memory in Adolescents: Investigating the Role of Rest Intervals

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A B S T R A C T

Objective: The purpose of this study was to investigate the effect of affect arousal on the consolidation of motor memory in adolescents: investigating the role of rest intervals.

Methods and Materials: The research employed a semi-experimental, applied design. The statistical population included semi-skilled male adolescent basketball players from clubs in Kurdistan province. A total of sixty participants, aged 14 to 16, were purposively selected based on inclusion criteria and randomly assigned to one of five groups: control, immediate positive Affect arousal, immediate negative Affect arousal, delayed positive Affect arousal, and delayed negative Affect arousal. Participants in each group performed 100 basketball free throws, with two-minute rest intervals after every twenty throws. Immediately following their final practice session, participants in the Affect arousal groups were shown a ten-minute film clip designed to evoke either positive or negative Affects. The Affect arousal stimuli were administered immediately or after a delay, according to the group assignment. Subsequently, participants completed a memory recall test, with ten free throws performed at two intervals: fifteen minutes and forty-eight hours' post-acquisition.

Findings: The results of a repeated measures analysis of variance indicated that the mean scores in the fifth practice block were significantly higher than those in the first practice block (p=0.001). A significant interaction effect was observed between evaluation time (fifteen minutes and forty-eight hours' post-acquisition) and group type (p=0.042). In the immediate Affect arousal groups (both positive and negative), participants scored higher on the memory recall test fifteen minutes' post-acquisition compared to forty-eight hours' post-acquisition. In contrast, in the delayed Affect arousal groups (both positive and negative), participants performed better in the memory recall test forty-eight hours' post-acquisition compared to fifteen minutes' post-acquisition.

Conclusion: The long-term effects of positive and negative Affect arousal increase over time, and the effects of positive and negative Affects decrease in individual performance after fifteen minutes.

Keywords: *Off-line Practice, Positive Affect, Negative Affect, Adolescents*

1. Introduction

Memory constitutes one of the core cognitive systems through which humans acquire, stabilize, and later retrieve information and skills, enabling adaptation to complex environmental demands. Contemporary theoretical frameworks define memory not as a static storage unit, but as a dynamic, multi-stage process involving encoding, consolidation, reconsolidation, and retrieval, each of which is sensitive to contextual, physiological, and emotional influences (Zlotnik & Vansintjan, 2019). Within this broad system, motor memory occupies a distinct yet highly consequential domain, as it underlies the acquisition and long-term retention of motor skills ranging from simple actions to complex sport-specific techniques. Motor memory supports the transformation of repeated movements into stable motor representations through practice, rest, and neuroplastic reorganization, allowing skills to persist beyond the immediate training context (Kim & Wright, 2021; Stee & Peigneux, 2023). Understanding the factors that enhance or disrupt motor memory consolidation is therefore of critical importance for developmental psychology, neuroscience, education, rehabilitation, and sport sciences.

Motor memory consolidation refers to the time-dependent processes through which newly acquired motor skills are stabilized and strengthened after practice has ceased. Empirical evidence indicates that consolidation unfolds both during wakeful rest and during sleep, with offline gains often emerging hours or even days after training (Mednick et al., 2003; Walker et al., 2003). These offline processes are not merely passive, but involve active neural reactivation and reorganization within motor and associative brain networks, leading to qualitative changes in performance without additional physical practice (Rasch et al., 2007; Stee & Peigneux, 2023). Importantly, consolidation is not uniform across individuals or contexts, and its efficiency can be modulated by task characteristics, practice structure, rest intervals, sleep quality, and neurochemical states (Kim & Wright, 2021; Tomlin et al., 2024). Among the most influential modulators of consolidation are affective and arousal-related states experienced before, during, or after learning.

Affect arousal has long been recognized as a powerful determinant of memory formation and persistence. Foundational research demonstrated that emotionally arousing experiences are remembered more vividly and retained longer than neutral events, a phenomenon consistently observed across laboratory and real-world contexts (Cahill et al., 1996; McGaugh, 2005). Neurobiological models attribute this enhancement to interactions between affect-responsive systems—most notably the amygdala—and memory-related structures such as the hippocampus and neocortex (McEwen & Sapolsky, 1995; McGaugh, 2018). Affect arousal activates the hypothalamic–pituitary–adrenal axis, leading to the release of stress hormones and neuromodulators that influence synaptic plasticity and consolidation processes (Baker & Kim, 2002; McEwen & Sapolsky, 1995). These mechanisms suggest that affect does not merely accompany learning but actively shapes how memories are stabilized over time.

Empirical research on affect and memory has consistently shown that both positive and negative affective states can modulate memory outcomes, although the direction and magnitude of these effects depend on timing, intensity, and cognitive demands. Studies on verbal and episodic memory indicate that affectively charged stimuli are encoded more deeply and retrieved more vividly than neutral material (Kensinger & Corkin, 2003; Kensinger & Ford, 2020). Affect arousal induced after learning, even from semantically unrelated sources, has been shown to enhance consolidation, supporting the notion that arousal operates at a systems level rather than through content-specific associations (Judde & Rickard, 2010; Nielson et al., 2005). However, not all memory components benefit equally; while item memory is often enhanced, source memory and reality monitoring may show weaker or inconsistent effects (Wang & Bukuan, 2015; Wang & Sun, 2017). These findings highlight the complexity of affect–memory interactions and underscore the importance of temporal dynamics.

Timing has emerged as a critical variable in determining whether affect arousal facilitates or impairs memory consolidation. Experimental evidence suggests that affective stimulation delivered immediately or shortly after learning can strengthen consolidation, whereas delayed arousal may produce diminished or qualitatively different effects (Judde & Rickard, 2010; Wang & Bukuan, 2015). Some studies indicate that negative affect elicited within minutes after learning enhances consolidation more reliably than affect induced after longer delays, suggesting a sensitive temporal window during which consolidation processes are particularly susceptible to modulation (Wang & Bukuan, 2015). Conversely, other research demonstrates that delayed affective arousal can still exert long-term effects, especially when consolidation unfolds over extended intervals involving sleep and offline processing (McGaugh, 2018; Stee & Peigneux, 2023). These findings collectively point to

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a nuanced interaction between affect, time, and memory systems.

Beyond declarative memory, affective modulation of cognitive performance extends to working memory, cognitive control, and executive processes. Positive and negative affect have been shown to differentially influence attentional allocation, cognitive flexibility, and resource management, with consequences for learning efficiency (Gray, 2001; Storbeck, 2012). Anxiety and heightened negative affect can impose cognitive costs under certain conditions, particularly in tasks requiring high executive control or working memory capacity (Vytal et al., 2013). Nevertheless, under moderate levels of arousal, negative affect may enhance vigilance and memory selectivity, contributing to stronger consolidation for salient information (Cornelisse et al., 2011). These findings suggest that affect arousal is neither uniformly beneficial nor detrimental, but context-dependent.

Despite the extensive literature on affect and declarative memory, considerably less attention has been devoted to the role of affect arousal in motor memory consolidation. Motor skills differ fundamentally from verbal or episodic memories in their reliance on sensorimotor representations, procedural learning mechanisms, and distributed neural networks involving motor cortex, basal ganglia, cerebellum, and associative regions (Kim et al., 2024; Yun et al., 2025). While studies have shown that practice structure, task difficulty, and sleep strongly influence motor consolidation (Mednick et al., 2003; Walker et al., 2003), the extent to which affective states interact with these processes remains underexplored. Given that motor learning frequently occurs in emotionally charged environments—such as competitive sports, rehabilitation settings, and educational contexts—this gap represents a significant limitation in the existing literature.

Emerging evidence suggests that affect and motor learning are closely intertwined. Positive affect has been associated with improved motor performance, greater engagement, and enhanced adaptability, particularly in skill acquisition and transfer tasks (Bolte et al., 2003; Tomlin et al., 2024). Conversely, excessive anxiety or negative affect may disrupt motor coordination and learning efficiency, although moderate arousal can sometimes facilitate performance depending on task demands (Tremblay et al., 2014; Vytal et al., 2013). Neurophysiological studies indicate that affective states can influence motor cortical excitability and plasticity, thereby shaping consolidation trajectories (Kim et al., 2024; Tremblay et al., 2014). These findings provide a compelling rationale for systematically examining affect arousal as a modulator of motor memory.

The developmental context further amplifies the importance of this inquiry. Adolescence is characterized by ongoing maturation of neural circuits involved in emotion regulation, executive control, and motor coordination, rendering memory systems particularly sensitive to affective influences during this period (Kensinger & Ford, 2020; McEwen & Sapolsky, 1995). At the same time, adolescents frequently engage in structured motor learning through sports and physical education, where affective experiences such as excitement, stress, success, and failure are common. Research on children and adolescents with typical and atypical development demonstrates that motor interventions can influence not only motor outcomes but also cognitive and emotional functioning (Xie et al., 2024; Xing & Wu, 2025). However, the specific role of affect arousal timing in adolescent motor memory consolidation has not been adequately addressed.

Recent applied studies in physical activity and sport contexts underscore the potential practical significance of this line of research. Training programs that incorporate emotionally engaging elements have been shown to improve motor skill acquisition, self-control, and memory in diverse populations, including children with visual impairments and neurodevelopmental conditions (Suhartini et al., 2024; Xie et al., 2024). Similarly, sport-specific training in adolescents has demonstrated that structured practice and affectively rich environments can support motor development and performance (Stoica & Barbu, 2025). Yet, these studies often focus on immediate performance outcomes rather than long-term consolidation, leaving open the question of how affect arousal during or after practice influences memory stability over time.

Another critical factor interacting with affect arousal is the structure of practice and rest intervals. The spacing of practice blocks and the duration of rest periods have been shown to shape consolidation by allowing neural reactivation and reducing interference (Stee & Peigneux, 2023; Walker et al., 2003). Rest intervals may provide a temporal window during which affective states exert differential effects on consolidation processes, particularly when combined with sleep-dependent mechanisms (Mednick et al., 2003; Zhang et al., 2008). Understanding how affect arousal interacts with rest intervals is therefore essential for optimizing training protocols in sport and rehabilitation settings.

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Taken together, the existing literature indicates that affect arousal, timing, and practice structure are individually important determinants of memory consolidation, yet their combined influence on motor memory—especially in adolescents—remains insufficiently understood. Most prior studies have focused on declarative memory or adult populations, have examined affect in isolation from practice structure, or have failed to distinguish between immediate and delayed affective modulation. Addressing these gaps is necessary to develop a more comprehensive model of motor memory consolidation that integrates emotional, temporal, and behavioral dimensions.

Accordingly, the aim of the present study was to investigate the effects of positive and negative affect arousal, administered at different post-practice intervals, on the consolidation of motor memory in adolescent athletes.

2. Methods and Materials

2.1. *Study Design and Participants*

The present study was conducted as a semi-experimental field research, utilizing a pretest-posttest design, training sessions, and memory recall tests with both control and experimental groups. The statistical population of the research included semi-skilled teenage male basketball players in the clubs of Kurdistan province. The inclusion criteria for the study were teenagers aged between 14 to 16 years, right-handedness, semi-skilled in basketball, no sleep problems, normal or corrected-to-normal vision, no use of drugs, alcohol, or caffeine, and no high levels of stress, anxiety, depression, or excitement.

2.2. *Measures*

Edinburgh Handedness Inventory: The Edinburgh Handedness Questionnaire consists of four parts, which examine hand superiority, foot superiority, ear superiority, and eye superiority, respectively. The hand dominance section consists of ten questions that assess lateralization by asking the individual or their caregivers about which hand (right, left, or both) they use while performing ten tasks.

Pittsburgh Sleep Quality Index: This questionnaire was developed in 1989 by Dr. Boyce and his colleagues at the Psychiatric Institute of Pittsburgh. It is scored on a four-point Likert scale from zero to three. The questionnaire was used to assess the quality of sleep and exclude adolescents with inadequate quality and quantity.

Depression, Anxiety and Stress Scales: This questionnaire was utilized to screen out individuals with depression, anxiety, and stress. The Depression, Anxiety, and Stress Questionnaire comprises 21 items that pertain to symptoms of negative Affects (depression, anxiety, and stress). The depression subscale includes items that gauge feelings of unhappiness, lack of self-confidence, hopelessness, worthlessness, disinterest in activities, lack of enjoyment in life, and lack of energy and vitality. The anxiety subscale includes items aimed at evaluating physiological arousal, fears, situational anxiety, and the stress subscale includes items such as difficulty in achieving calmness, nervous tension, irritability, and restlessness. Each of the depression, anxiety, and stress subscales consists of 7 questions, and the final score for each is calculated by adding up the scores of the questions associated with it. Each question is rated from 0 (not applicable to me at all) to 3 (completely applicable to me). The alpha coefficient for these factors was 0.97 and 0.95.

PANAS Positive and Negative Affect Questionnaire: The PANAS Positive and Negative Affect Questionnaire was utilized to assess levels of positive and negative Affects before and after the Affect arousal session. This questionnaire consists of twenty questions, with ten questions measuring positive Affects and ten questions measuring negative Affects. A higher score indicates a greater level of excitement, while a lower score indicates a lower level of excitement (Nielson et al., 2005; Wang & Sun, 2017).

Sony laptop VAIO Z131X-0211 i5 8 256, placed on the ground at a standard distance of 4.60 meters from the basketball backboard (free throw line). A Molten leather ball was used for the basketball free throw test to evaluate performance during the acquisition stages. Recall tests were conducted at intervals of 15 minutes and 48 hours after use.

2.3. *Intervention*

After selecting participants as a sample based on the inclusion criteria, they were randomly assigned to five groups. The participants then went through the training phase, which consisted of two parts: general training and specific training. All groups performed 100 free throws in five blocks of 20 attempts, with a 2-minute rest interval between each block. The first group (control group) performed five blocks of 20 attempts without receiving any positive or negative Affect arousal. The second and third groups, who experienced positive Affect arousal, were shown video clips of successful throws by professional athletes, positive photos of basketball players on the court, and recorded applause from spectators immediately and half an hour after the last block of the acquisition phase. This lasted for ten minutes. For the subjects of the fourth and fifth groups, who experienced negative Affect arousal, violent and injury movie clips from the playground, negative photos of injuries and fights among basketball players, and recordings of stressed and tense voices from the audience were presented immediately and half an hour after the last block of the acquisition phase. This also lasted for ten minutes. A questionnaire was used to assess the level of state trait anxiety, as well as the Affects and mood of each experimental group before the acquisition session and after the induced Affect arousal (Wang & Sun, 2017). If the type of Affect arousal does not affect the level of excitement and mood of the subject, the subject will be excluded from the exercise. After 15 minutes and 48 hours, participants performed a recall test by shooting 10 basketball free throws without Affect arousal.

2.4. Data Analysis

The Shapiro-Wilk test was used to determine the normality of data distribution. For the statistical analysis of the data from the composite analysis of variance design (type of positive Affect arousal) 2 × (type of negative Affect arousal) 2 × 5 (five blocks of acquisition) with repeated measures and mixed variance analysis with repeated measures (type of positive Affect arousal) 2 × (type of negative Affect arousal) × 2 (recall test with an interval of 48 hours and the last block of acquisition) and independent t-test, one-way analysis of variance, and Bonferroni's post hoc test were used.

3. Findings and Results

The results of the Shapiro-Wilk test to check the normality of the data distribution showed that the data distribution in the first (p=0.65), second (p=0.98), third (p=0.63), fourth (p=0.74) groups and the fifth (p=0.68) is normal. The results of Leven's test showed that the performance of the groups in the pre-test has homogeneity of variance (p=0.88). The results of the one-way analysis of variance test to compare the basketball free throw performance of five groups in the first training block showed that there is no significant difference between the average performance of the subjects of the five groups in the first training block ($F (4, 55) = 0.097$ and $P = 0.96$).

To investigate the effect of training efforts on the consolidation of motor memory in the acquisition phase (first and fifth blocks of acquisition) in the control groups, immediate positive Affect arousal, positive Affect arousal after 30 minutes, immediate negative Affect arousal and negative Affect arousal after 30 minutes from factorial variance analysis. A 5 (group) × 2 (training block) design with repeated measures was used.

The findings showed that the main effect of the group (control, immediate positive Affect arousal, positive Affect arousal after 30 minutes, immediate negative Affect arousal and negative Affect arousal after 30 minutes) is not significant ($F (4,55) =0.722$, $P=0.58$, $\eta 2=0.05$). The main effect of evaluation time (first and fifth blocks of acquisition) is significant ($F (1,55) =20.999$, $P=0.001$, $\eta 2=0.276$). Bonferroni's post hoc test in the comparison of evaluation steps showed that the average evaluation score in the fifth practice block (Mean=36.000) is higher than the first block (Mean=32.867). The interaction effect of evaluation time (first and fifth blocks) in the group (control, immediate positive Affect arousal, positive Affect arousal after 30 minutes, negative Affect arousal and negative Affect arousal after 30 minutes) is not significant ($F (4,55) = 1/088$, $P=0.371$, $\eta 2=0.073$). The findings presented in Figure 1 showed that the average performance of the control group and experimental groups improved in the fifth training block compared to the first training block.

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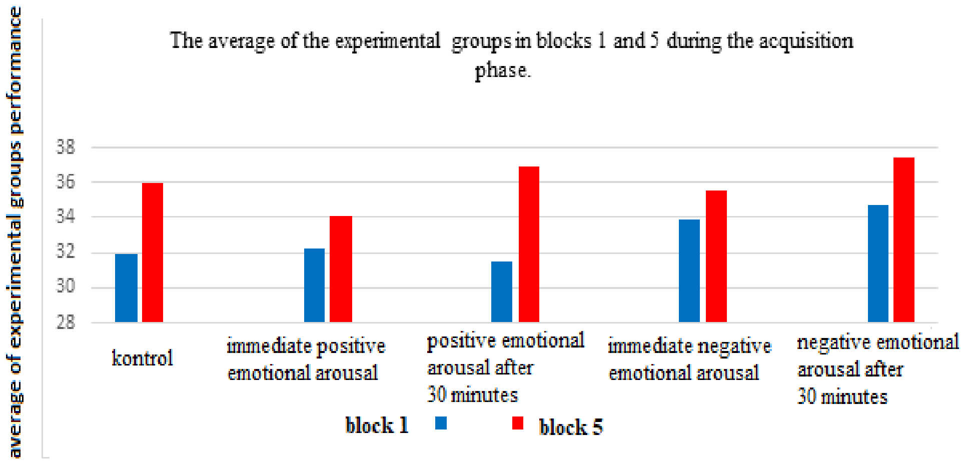
Figure 1

Average of performance of experimental groups of control, immediate positive Affect arousal, positive Affect arousal after 30 minutes, negative Affect arousal and negative Affect arousal after 30 minutes in the first and fifth blocks of training in the acquisition phase.



The results of 5 (group) × 2 (evaluation stages) mixed factor variance analysis with repeated measures to compare the performance of control groups, immediate positive Affect arousal, positive Affect arousal after 30 minutes, immediate negative Affect arousal and negative Affect arousal after 30 minutes in the evaluation stages. Recall after 15 minutes and recall after 48 hours showed that the main effect of the group (control, immediate positive Affect arousal, positive Affect arousal after 30 minutes, immediate negative Affect arousal and negative Affect arousal after 30 minutes) was not significant in any of the groups ($F(4,55) = 0.281$, $P=0.889$, $\eta^2=0.02$). The main effect of evaluation stages (recall stage after 15 minutes, recall after 48 hours) is not significant ($F(1,55) = 0.115$, $P=0.736$, $\eta^2=0.003$).

The interactive effect of evaluation stages (recall stage after 15 minutes, recall after 48 hours) is significant in groups (control, immediate positive Affect arousal, positive Affect arousal after 30 minutes, immediate negative Affect arousal and negative Affect arousal after 30 minutes). ($F(4,55) = 2.662$, $P = 0.042$, $\eta^2 = 0.162$). A paired t-test was used to compare the effect of positive and negative Affect arousal on motor memory consolidation in the recall stage after 15 minutes and recall after 48 hours in each of the groups (Table 1).

Table 1

Comparison of the effects of positive and negative Affect arousal on the consolidation of motor memory in the recall test after 48 hours and recall after 15 minutes in each of the groups

Statistics		M	t	df	p
Control Group	Recall after 15 minutes	37.25	0.631	11	0.541
	Recall after 48 hours	37.75			
Immediate positive Affect arousal group	Recall after 15 minutes	40/41	1.25	11	0.237
	Recall after 48 hours	36/75			
Positive Affect arousal group after 30 minutes	Recall after 15 minutes	36/75	1.046	11	0.318
	Recall after 48 hours	36/25			
Immediate negative Affect arousal group	Recall after 15 minutes	38/08	0.928	11	0.374
	Recall after 48 hours	39/16			
Negative Affect arousal group after 30 minutes	Recall after 15 minutes	37/33	2.53	11	0.028
	Recall after 48 hours	34/83			

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The findings presented in Table 1 showed that the pairwise differences in the evaluation stages are significant for the group of creating negative Affect arousal after 30 minutes (p=0.028). The comparison of averages showed that the subjects of this group have better memory consolidation in performing the recall test after 48 hours than the recall test stage after 15 minutes. Other pairwise comparisons in each of the experimental groups were not significant in the two recall tests (p>0.05).

The findings of one-way analysis of variance to compare the average scores of the groups in each of the steps of recalling after 15 minutes and recalling after 48 hours are presented in Table 2.

Table 2

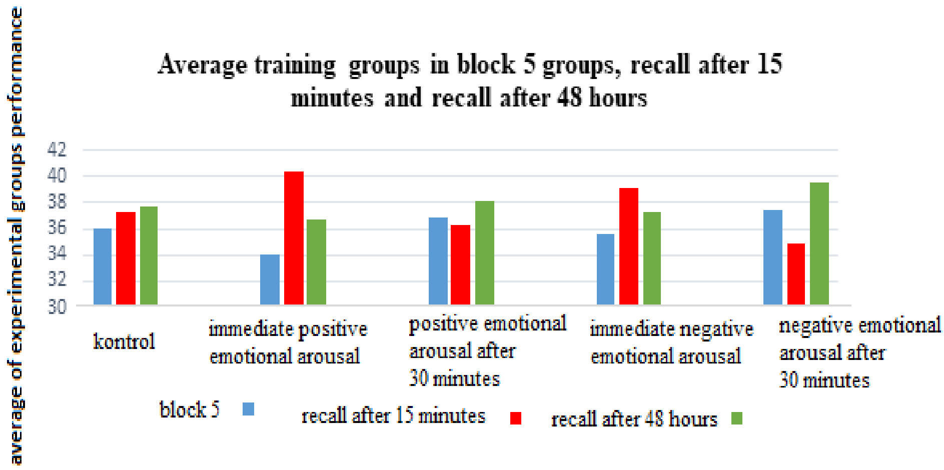
Comparison of the average effects of positive and negative Affect arousal on the consolidation of motor memory in the recall test after 48 hours and recall after 15 minutes

Statistics		SS	df	MS	F	P
The difference between the groups in the recall test after 15 minutes	between groups	239.833	4	59.958	0.150	0.021
	Within Groups	1046.750	55	19.032		
Group differences in recall test after 48 hours	betwee groups	51.100	4	12.775	3/315	0.866
	Within Groups	2227/083	55	40/492		

The results of one-way analysis of variance showed that there is no significant difference between the performance of the groups in the performance of the recall test after 48 hours (p=0.886), but there is a significant difference in the performance of the recall test after 15 minutes (p=0.021). The results of the Bonferroni post hoc test showed that there is a significant difference between the average performance of the positive Affect arousal group after 15 minutes and the negative Affect arousal group after 30 minutes (p=0.028). Other pairwise differences were not significant. The comparison of means showed that the immediate positive Affect arousal group (Mean=40.41) had the best performance and the negative Affect arousal group after 30 minutes (Mean=34.83) had the weakest performance.

Figure 2

Average performance of control groups, immediate positive Affect arousal, positive Affect arousal after 30 minutes, immediate negative Affect arousal and negative Affect arousal after 30 minutes in block 5, recall after 15 minutes and recall after 48 hours.



In Figure 2, the comparison of the average scores in the experimental groups showed that the average scores in the groups (positive and negative Affect arousal after 30 minutes) increased in the phase of the recall test after 48 hours. The average in the recall test after 48 hours in the group of creating positive Affect arousal after 30 minutes and creating negative Affect arousal after 30 minutes was higher than other groups and it shows that with the passage

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of time the effect of negative and positive Affect arousal in the test memories increase. The comparison of the average scores in other test groups showed that the average scores in the recall test after 48 hours decreased compared to the recall test after 15 minutes, and this indicates that with the passage of time, the effect of negative and positive Affect arousal after 15 minutes' decreases in the individual.

4. Discussion

The present study examined the effects of positive and negative affect arousal, administered at different post-practice intervals, on the consolidation of motor memory in adolescent basketball players. The findings demonstrated that although all groups showed performance improvements across acquisition blocks, the interaction between affect arousal timing and recall interval played a decisive role in motor memory consolidation. Specifically, immediate affect arousal (both positive and negative) was associated with superior short-term recall, whereas delayed affect arousal—particularly delayed negative affect—was linked to enhanced long-term retention assessed 48 hours after acquisition. These results underscore the importance of temporal dynamics in affect–memory interactions and provide novel evidence for the role of affect arousal in motor memory consolidation during adolescence.

The significant improvement observed across practice blocks in all groups confirms the effectiveness of repetitive practice and rest intervals in motor skill acquisition. This finding aligns with well-established models of motor learning, which posit that repeated execution combined with structured rest facilitates encoding and early stabilization of motor representations (Stee & Peigneux, 2023; Walker et al., 2003). The absence of group differences during acquisition further suggests that affect arousal did not interfere with initial learning, supporting the view that its primary influence emerges during post-practice consolidation rather than online performance. This distinction is consistent with evidence showing that consolidation processes unfold offline and are particularly sensitive to post-learning neurochemical and affective states (McGaugh, 2018; Mednick et al., 2003).

One of the central findings of this study was the superiority of immediate affect arousal in enhancing short-term motor memory recall. Participants exposed to positive or negative affect immediately after practice demonstrated better performance in the 15-minute recall test compared to delayed recall. This result aligns with research indicating that affect arousal shortly after learning strengthens consolidation by modulating amygdala–hippocampal interactions and facilitating synaptic plasticity during a sensitive post-encoding window (McGaugh, 2005; Wang & Bukuan, 2015). Immediate affect arousal may amplify neural reactivation of recently encoded motor representations, thereby increasing their resistance to rapid decay. Similar effects have been reported in declarative memory studies, where post-learning affective stimulation enhanced retention even when the affective content was unrelated to the learning material (Judde & Rickard, 2010; Nielson et al., 2005).

Interestingly, the present findings indicate that the benefits of immediate affect arousal were more pronounced for short-term recall than for long-term retention. This pattern suggests that while immediate arousal may boost early consolidation, its effects may diminish over time unless reinforced by additional consolidation processes such as sleep. This interpretation is consistent with evidence that affect-induced enhancements can be transient unless supported by offline reprocessing during sleep or extended rest intervals (Rasch et al., 2007; Stee & Peigneux, 2023). It also aligns with studies showing that affect arousal preferentially enhances item-level memory rather than durable source or procedural representations (Wang & Sun, 2017).

In contrast, delayed affect arousal—particularly delayed negative affect—was associated with superior long-term motor memory consolidation assessed after 48 hours. Participants in the delayed negative affect group showed improved recall at 48 hours compared to 15 minutes, indicating that affect arousal delivered after a temporal delay can selectively enhance long-term retention. This finding is highly consistent with research demonstrating that negative affect elicited several minutes after learning can strengthen consolidation processes that unfold over extended intervals (McGaugh, 2018; Wang & Bukuan, 2015). Delayed affect arousal may interact with slower neurobiological mechanisms, such as stress-hormone-mediated modulation of synaptic plasticity, leading to more durable motor memory traces.

The particular effectiveness of delayed negative affect in enhancing long-term consolidation may reflect the heightened salience and attentional capture associated with negative emotional states. Negative affect has been shown to narrow attentional focus and prioritize memory for task-relevant information, which can be advantageous for consolidation under certain conditions (Gray, 2001;

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Storbeck, 2012). Moreover, psychosocial stress and moderate anxiety have been associated with enhanced memory formation, especially when they occur outside the immediate encoding phase (Cornelisse et al., 2011). In the context of motor learning, delayed negative affect may facilitate deeper offline processing of motor representations, leading to improved retention over time.

The developmental characteristics of adolescence may further explain the observed sensitivity to affect arousal timing. Adolescence is marked by ongoing maturation of neural circuits involved in emotion regulation, reward processing, and motor control, rendering memory systems particularly responsive to affective modulation (Kensinger & Ford, 2020; McEwen & Sapolsky, 1995). The interaction between affect arousal and consolidation processes may therefore be amplified during this period, especially in emotionally salient contexts such as sport training. This interpretation is consistent with applied research demonstrating that emotionally engaging motor interventions can enhance memory and performance in children and adolescents (Suhartini et al., 2024; Xie et al., 2024).

The present findings also resonate with evidence from motor learning and rehabilitation studies emphasizing the importance of post-practice conditions. Research on motor skill transfer and adaptability indicates that brief reactivation or contextual modulation after practice can significantly influence consolidation outcomes (Tomlin et al., 2024; Yun et al., 2025). Similarly, studies in physical training contexts suggest that emotionally rich or challenging environments can shape motor development and long-term skill retention (Stoica & Barbu, 2025). By demonstrating that affect arousal timing differentially influences short- and long-term motor memory, the current study extends these findings and highlights affect as a critical yet underexplored variable in motor learning research.

Sleep-related consolidation processes likely played an important role in the observed long-term effects. The superior 48-hour recall in delayed affect arousal groups coincided with at least one full sleep cycle between acquisition and testing. Extensive evidence indicates that sleep facilitates the reactivation and integration of motor memories, leading to performance gains without additional practice (Mednick et al., 2003; Walker et al., 2003). Affect arousal experienced after learning may tag motor memories for prioritized reprocessing during sleep, thereby enhancing their stability and accessibility at delayed recall (Rasch et al., 2007; Stee & Peigneux, 2023). This mechanism provides a plausible explanation for the delayed emergence of affect-related benefits observed in the present study.

Notably, the absence of significant group differences in overall recall performance suggests that affect arousal does not uniformly enhance motor memory but operates through interaction effects with time and consolidation stage. This nuanced pattern aligns with contemporary models emphasizing that affect can both facilitate and impair cognitive performance depending on task demands, timing, and arousal intensity (Tremblay et al., 2014; Vytal et al., 2013). The present results therefore contribute to a more differentiated understanding of affect–memory relationships by demonstrating that the same affective manipulation can yield distinct outcomes at different consolidation stages.

5. Conclusion

In summary, the findings of this study provide robust evidence that affect arousal modulates motor memory consolidation in adolescents in a time-dependent manner. Immediate affect arousal enhances short-term recall, whereas delayed affect arousal—particularly negative affect—supports long-term retention. These results integrate and extend prior research on affective modulation of memory (Cahill et al., 1996; McGaugh, 2018) by demonstrating their relevance for motor memory and highlighting the critical role of temporal dynamics. By situating affect within the broader framework of offline consolidation, rest intervals, and developmental sensitivity, the present study advances theoretical and applied perspectives on motor learning.

6. Limitations & Suggestions

Despite its contributions, this study has several limitations that should be acknowledged. First, the sample consisted exclusively of male adolescent basketball players, which limits the generalizability of the findings to females, non-athletes, or individuals from other age groups. Second, affect arousal was induced using audiovisual stimuli, and individual differences in emotional responsiveness may have influenced the strength of the manipulation. Third, physiological indicators of arousal were not measured, restricting conclusions about underlying neurobiological mechanisms. Finally, the study focused on a single motor task, and the results may not extend to other types of motor skills with different cognitive or coordinative demands.

Future studies should examine the effects of affect arousal on motor memory consolidation across diverse

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populations, including females, younger children, adults, and clinical groups. Incorporating physiological and neuroimaging measures would help clarify the neural mechanisms underlying affect-related modulation of motor consolidation. Researchers should also explore a wider range of motor tasks and affect induction methods to determine the boundary conditions of these effects. Additionally, longitudinal designs could assess how repeated exposure to affective modulation during training influences long-term skill development and transfer.

From an applied perspective, the findings suggest that coaches, educators, and practitioners can strategically manipulate affective states after practice to enhance motor memory retention. Introducing emotionally engaging or motivational elements immediately after training may support short-term performance, while carefully timed affective challenges could promote long-term retention. Training programs for adolescents should therefore consider not only practice structure and rest intervals but also the emotional context surrounding learning to optimize skill consolidation and performance outcomes.

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Declaration of Interest

The authors of this article declared no conflict of interest.

Ethical Considerations

The study protocol adhered to the principles outlined in the Helsinki Declaration, which provides guidelines for ethical research involving human participants.

Transparency of Data

In accordance with the principles of transparency and open research, we declare that all data and materials used in this study are available upon request.

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Authors' Contributions

All authors equally contributed to this article.

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