Original Research Article

Evaluating Active, Passive, and Electromuscular Recovery Methods on Pitching Performance and Fatigue in High School Athletes

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ABSTRACT

The purpose of this study was to explore the efficacy of three between-inning recovery methods [Active recovery (AR), passive recovery (PR), and electromuscular stimulation (EMS)] among high school pitchers. Four indicators were used to evaluate effectiveness: blood lactate (BLa) clearance, average pitcher velocity, perceived pitch intensity, and a subjective recovery rating. The study hypothesized that as pitchers progress through three innings of play, EMS is the most effective method for between-inning recovery. Four high school pitchers, aged 16, underwent three testing days, each separated by four days of rest. Testing days consisted of warm-ups, bullpen sessions, three innings pitched (15 per inning), and a post-inning protocol that included 6 minutes of recovery, measurements of blood lactate, and subjective effort ratings. Statistical analyses identified a significant main effect of recovery method on BLa clearance ($p<0.001$) and an interaction between recovery method and inning ($p = 0.003$). Simple planned, Bonferroni corrected comparisons suggest that EMS and PR conditions outperformed the AR condition across all innings. The simple planned Bonferroni corrected comparisons indicate the average per-inning difference in BLa clearance between AR with EMS and between AR with PR was significant, while PR with EMS was not significant. These findings suggest that using EMS or PR between innings optimizes BLa clearance, which may improve pitching performance and reduce the risk of arm injury in high school pitchers.

Keywords: Between-inning recovery; Blood lactate clearance; Pitcher fatigue; High school pitchers; Electromuscular stimulation; Active recovery; Passive recovery

INTRODUCTION

Pitchers have long been recognized to significantly influence baseball match outcomes (1). At the collegiate and professional levels, pitchers face the dual challenges of safeguarding their arms throughout the lengthy season while maintaining peak performance (2). The youth baseball landscape in the United States has evolved dramatically in the past few decades, with nearly 4 million youth athletes participating, and approximately 500,000 continuing their baseball journey beyond Little League into high school (3). Alarmingly, research indicates that 74% of youth players aged 8 to 18 report experiencing arm pain during their playing careers, yet only 23% acknowledge sustaining a significant injury (4). This discrepancy highlights a concerning trend: many players enter seasons with a heightened risk of arm injuries, particularly in the context of modern youth baseball practices. To prevent such injuries, pitchers use recovery methods to mitigate the adverse effects of repetitive, high-intensity motion.

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Research on pitcher recovery methods has traditionally focused on procedures performed between games, emphasizing the importance of prolonged recovery to minimize injury risk and maintain arm health (4). However, a crucial aspect demands attention: between-inning recovery methods. This often-overlooked factor can significantly contribute to arm injuries in pitchers (5). Understanding the significance of between-inning recovery is vital for protecting athletes from injury. The primary goal is to keep a pitcher's arm 'warm' during the game, which fosters optimal performance and minimizes the risk of strain. This process plays a critical role in clearing lactic acid (BLa) buildup and maintaining muscular readiness (6).

In a prior study conducted by Warren *et al*. (5), between-inning recovery was found to reduce injury and enhance pitcher performance significantly. Three recovery techniques were evaluated to identify the most effective method for between-inning recovery: electromuscular stimulation (EMS), active recovery (AR), and passive recovery (PR). By using measurements such as BLa after each inning and recovery period, average velocities, and subjective ratings, the effectiveness of each method was determined. The results indicated that EMS was the most effective method for lactate clearance between innings. However, it is essential to note that this study was conducted on NCAA Division II collegiate baseball pitchers, whose game-day routines differ significantly from those of high school athletes. Moreover, collegiate athletes typically exhibit greater physical maturation than high school athletes, who are often still undergoing somatic development (7). Therefore, the efficacy of various between-inning recovery techniques may vary across different age groups. Due to increased injuries among high school pitchers, this experiment aimed to determine the most effective between-inning recovery method.

AR is a rehabilitation method that promotes oxygen-rich blood flow to muscles, thereby facilitating the clearance of hydrogen ions in fatigued areas. In previous studies, AR has been identified as one of the most effective techniques for reducing post-exercise fatigue and soreness. However, while AR enhances BLa clearance over time, it also elevates heart rate and requires physical exertion, which may in turn limit its short-term effectiveness (6). In contrast, PR remains the most common between-inning recovery method among high school pitchers. Specifically, it effectively promotes the natural circulation of oxygenated blood, helping to restore the hydrogen ion balance and reduce muscle acidity. As a result, PR contributes to improved short-term recovery efficiency without additional exertion. Meanwhile, EMS is a newer recovery technique with limited empirical support. Nevertheless, studies such as Warren *et al*. have demonstrated its potential for accelerating recovery in pitchers (5). EMS applies localized electrical impulses to induce muscle contractions, which in turn increase regional blood flow and help prevent excessive lactic acid accumulation (8).

Taken together, prior research has suggested that EMS, followed closely by PR, may be more effective than AR in clearing BLa between innings (5). Therefore, this study hypothesizes that as pitchers progress through three innings of play, EMS will prove to be the most effective between-inning recovery method.

LITERATURE REVIEW

As youth pitchers progress to higher levels of baseball, the intensity of competition increases, requiring pitchers to adapt to the rapidly evolving game. A study by Zaremski *et al*. (9) found that the heightened intensity aimed at increasing throwing velocity is the leading cause of arm-related pitching injuries among high school players. While controlling the intensity of a pitcher's throws is challenging, managing the recovery methods used after a game may help reduce the risk of arm injury.

Another study involving a random sample of more than 350 high school pitchers revealed that 97% played at least one additional position besides pitcher. Those who played multiple positions exhibited a 2.9 times greater chance of injury than pitchers who focused solely on pitching (10). Although preventing pitchers from playing various positions is impractical, supporting their recovery can decrease the likelihood of injury (9, 10).

A notable survey of 203 healthy youth players revealed that 46% felt pressured by coaches to continue competing despite experiencing arm discomfort and injuries (11). Most of these injuries are attributed to pitchers, who endure maximal stress on their upper limbs during the pitching motion (4, 12). There is an urgent need to implement training and injury-prevention strategies to protect the health and prospects of young pitchers.

A high school baseball game lasts 7 innings, with the potential for a "mercy rule" to take effect after the third inning if one team already outscores the other by 10 or more runs, ending the game early. At the high school level, the most common maximum pitch count among 48 states (excluding Montana and Wyoming) for starting pitchers was 110 pitches, as found in a study

conducted by Manzi *et al*. Furthermore, only 4 days of rest were required for pitchers throwing the maximum number of pitches (13). As the game progresses, pitcher fatigue increases susceptibility to injury; needless to say, recovery becomes crucial to protect the arms of high school pitchers (14).

As BLa buildup can adversely affect involved muscles and the surrounding circulatory system (15) it becomes important to study this in high school athletes. BLa accumulation occurs in pitchers during high-intensity, repetitive motions. Recent studies have clarified that blood lactate does not directly induce muscle soreness and fatigue, contradicting prior hypotheses. However, it significantly impacts a critical component of pitching: motor control. Motor control is defined as the central nervous system's capacity to coordinate movement effectively with bodily function. Impairments in motor control can reduce power, strength, and fluidity, all vital attributes for a pitcher (16).

The initial impacts on motor control arise from the rapid accumulation of blood lactate in the muscles, which increases hydrogen ion concentrations (5, 15, 16). This rise in hydrogen ion concentration results in a decrease in pH within the muscle tissue, ultimately leading to impaired motor control. As lactate levels escalate, pitchers may experience a decline in both velocity and power due to this pH-related impairment in their arm muscles (5). This decline may persist for multiple days if there is no intervention.

METHODS AND MATERIALS

This experiment was a repeated-measures study evaluating the influence of BLa on high school pitcher performance and velocity. Institutional review board approval was obtained before the study began. The methodology of this study is based on Warren *et al*.'s (5) study on the effectiveness of between-inning recovery methods in Division 2 collegiate athletes. However, this study's methodology differs from Warren *et al*.'s (5) study. No free play was allowed; pitchers threw 15 pitches per inning in a controlled scenario against no batters and without a catcher. Furthermore, heart rate was not tracked during AR to gradually decrease recovery intensity over the six-minute recovery period. Instead, pitchers were told to maintain 60% of a sprint pace and progressively decrease it by 10% every two minutes. Finally, this study tracked initial BLa after warmups to support intervention checks and to demonstrate the study's viability.

Participants

The study involved four starting high school pitchers with a mean age of 16 years (SD ±0), an average weight of 77.90 kg (SD ±4.56), and a mean height of 180.34 cm (SD ±3.11). All participants underwent a physical examination by a licensed medical professional before the study. They were informed about the potential risks, benefits, and expectations of participation. Complete instructions and demonstrations of the study process were provided to both participants and their parents/guardians. Participants read and signed assent forms. All participating subjects and their parents/guardians attended the first day of testing, where they received instructions and demonstrations, and were told about potential risks and benefits in the study. Parents and guardians signed consent forms approved by an Institutional Review Board. Parents and guardians also granted permission for the testing to proceed without their supervision. Participants had the right to withdraw from the study at any time and were under no pressure to meet performance standards.

Experimental Procedures & Outcome Measures

Testing was completed during the pitcher's first three innings, using the same recovery method for each inning. Thus, to complete the study, three testing days were required, where participants used one recovery method per testing day. Three variables were measured to determine the maximum effectiveness of each recovery technique. The difference in BLa (in millimoles [mmol]) levels was taken as a biological measurement. Average velocity (in miles per hour [mph]) was measured as a physiological assessment, and a psychological evaluation was completed via a subjective rating scale in which pitchers rated their perceived pitching and recovery. To maintain uniformity, testing was conducted between 4 and 6 pm to mimic high school game times. Subjects were requested to follow regular dietary and hydration routines as they would during the season.

Average velocity was calculated immediately after each inning, while the pitcher was performing the assigned recovery technique. Velocity was measured using Pocket Radar Smart Coach (Pocket Radar, Inc., 2018); in a study done by Belmonted and Sanchez-Pay (17), Pocket Radar's reliability was $r = 0.99$.

LactoSpark Lactate Meter (Sensa Core Medical Instrumentation) was used to measure BLa. Blood was collected using a lancet finger prick on the non-pitching hand. This was taken once before the pitching as a baseline, immediately after each inning pitched,

and promptly after the end of each recovery period. A six-minute recovery (AR, PR, EMS) began after BLa was collected and pitcher intensity was determined on a scale of (0-9); 0 for throwing with no intensity and 9 with maximal intensity, following the end of an inning. This same process was completed for three innings while using the same recovery method each inning. Each pitcher was exposed to a different recovery method across the three days of testing, for three innings each. After BLa was measured, pitchers were asked to rate their recovery on a scale (0-9) on their perceived effectiveness of the recovery method; 0 for feeling no recovery and 9 for full recovery.

Study Design

The format of the testing days was structured to mimic a real game as closely as possible. Pitchers would first participate in a warm-up that included stretching, throwing, and plyometrics, before beginning to warm up in the bullpen with a catcher. Pitchers were told to closely follow their regular game-day routine to better simulate pitching in a real game. Pitchers were placed on a 5-day pitching rotation, similar to a high school rotation, and after each testing day, were asked to follow their regular 4-day recovery routine as directed by their coach during the season. Pitchers were also requested to follow regular dietary and hydration routines as they would during the season. To most precisely match game scenarios, pitchers were evaluated between 4 and 6 pm, the most common high school game times; testing was completed at the exact times every testing day. Testing was completed on a dirt field, with grass infield and outfield. Pitchers warmed up on the side of the field and in the outfield before moving to the bullpen to warm up their pitching motion. During testing, pitchers threw off a dirt mound into a BOWNET, which was placed just behind home plate. Standard conventions were present with pitchers throwing from 60'6", measured from the mound to the very end of home plate. Testing took place outdoors in warm weather, similar to conditions during the spring high school baseball season (Figure 1).

After testing was complete, pitchers used three different recovery methods: AR, PR, and EMS. During AR, pitchers were instructed to jog for 6 minutes, starting at 60% of max speed and gradually decreasing by 10% every 2 minutes to bring heart rate into a "pitchable" range. During PR, Pitchers sat in a dugout with minimal physical activity for 6 minutes. During EMS, pitchers used the machine inside of a dugout, in four locations on their arms: biceps brachii, triceps brachii, and the anterior/posterior deltoid. Intensity began at 9 Hz and decreased by 1 Hz every 2 minutes for 6 total minutes. The EMS unit used for this study was the Belifu Dual Channel Tens EMS Unit.

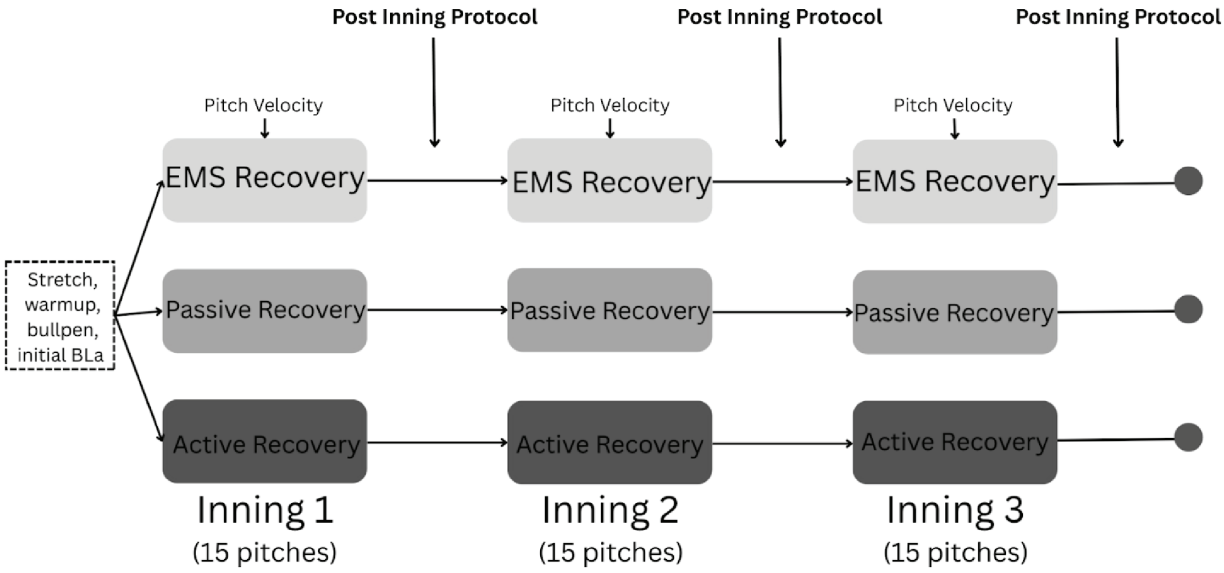

Figure 1. *Overview of the study's procedure. Post-inning protocol is as follows: Pre-recovery BLa, Subjective Pitch intensity, 6 minutes of recovery, Post-recovery BLa, Subjective recovery rating.*

RESULTS

Intervention check

To support the integrity and validity of the main results, initial assessments were conducted to examine whether the experimental conditions were associated with the intended level of fatigue and whether participants' subjective ratings were consistent with objective measures. Without validity, the main results may be skewed due to inaccurate subjective ratings. To assess whether participants exhibited signs consistent with fatigue across innings, the correlation between blood lactate and average velocity was calculated for each inning, with a consistently negative correlation coefficient observed (Inning 1: r = -0.012, p = 0.979; Inning 2: r = -0.084, p = 0.845; Inning 3: r = -0.295, p = 0.477). To assess whether participants correctly reported perceived intensity, the correlation between average velocity and perceived intensity was calculated for each inning, with a consistent positive correlation coefficient. (Inning 1: r = 0.345, p = 0.401; Inning 2: r = 0.423, p = 0.297; Inning 3: r = 0.290, p = 0.485). Table 1 shows the average performance across innings for participants during data collection, as measured by average velocity, subjective recovery rating, and perceived intensity.

Study Findings

The study's main results were examined to determine the effectiveness of each recovery method. The relationship between average velocity and recovery method across three innings was analyzed using a 3(recovery method) X 3(innings) repeated-measures ANOVA run in RStudio. There was no statistically significant main effect of inning on velocity ($F(2, 12) = 4.35$, $p = 0.07$). There was no statistically significant main effect of recovery method on velocity ($F(2,12) = 3.05$, $p = 0.07$). There was no interaction between these main effects ($F(4, 36) = 0.64$, $p = 0.64$) (Figure 2).

Blood lactate clearance was calculated by subtracting the post-recovery BLa from the pre-recovery BLa, where positive values indicate improved recovery (i.e. lower lactate levels). The relationships between inning, recovery intervention, and BLa clearance, was examined using a 3(recovery method) X 3(innings) repeated-measures ANOVA run in RStudio. There was no statistically significant main effect of inning on BLa

Table 1. Average Performance Across Participants During Data Collection. Mean values for average velocity (mph), subjective recovery rating (SRR), and perceived intensity.

	Avg. Velocity In. 1	Avg. Velocity In. 2	Avg. Velocity In. 3	SRR	Intensity In. 1	Intensity In. 2	Intensity In. 3
PR	67.4	67.8	68.3	5.67	8	8.25	8.25
EMS	70.2	68.7	68.4	7.5	8.5	7	6.75
AR	68.1	66.3	65.1	4.5	8	7.75	6.75

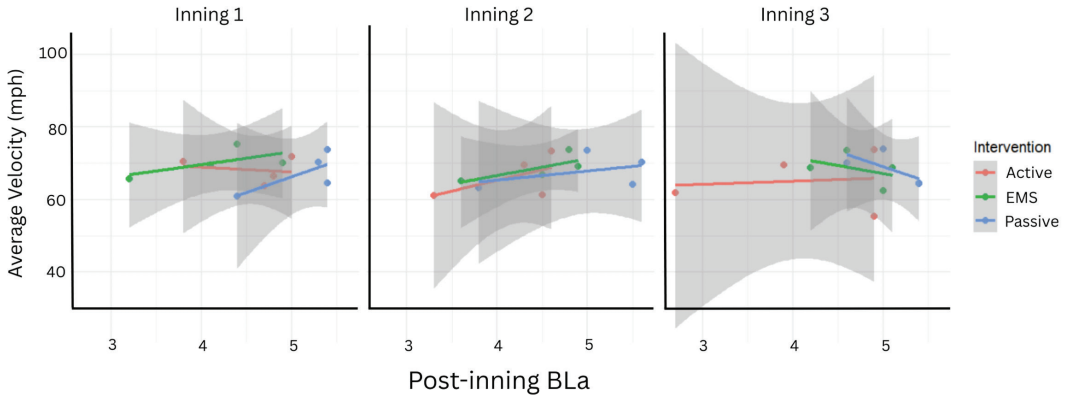

Figure 2. *BLa-Velocity Relationship by Condition. This figure shows the post-inning BLa-Velocity relationship by condition over three innings.*

clearance (F(2,12) = 3.897, p = 0.082). However, the main effect of recovery intervention on BLa clearance was statistically significant (F (2,12) = 57.652, p <0.001). An interaction between inning and recovery method was also found to be statistically significant (F(4, 36) = 6.072, p = 0.003). Table 2 presents the simple planned comparisons, corrected with a Bonferroni correction, between recovery intervention and inning to identify which relationships drive the interaction effect. Mean blood lactate clearance across recovery interventions is shown in Figure 3.

Table 2. Bonferroni-Corrected Pairwise Comparisons for the BLa-recovery Method.

	Inning 1	Inning 2	Inning 3
AR vs EMS	0.003	0.0001	<0.001
AR vs PR	0.0001	<0.001	0.031
EMS vs PR	0.415	0.273	0.002

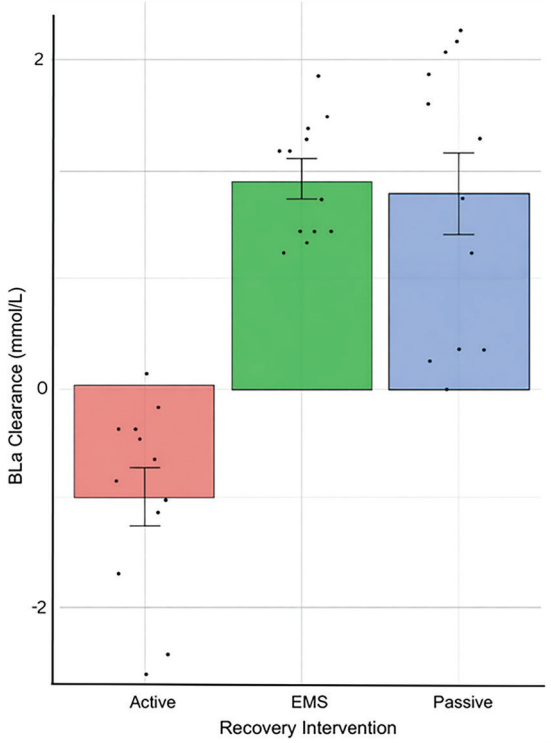

Figure 3. *Average BLa Clearance Across All Innings by Recovery Intervention. Higher values reflect more effective recovery. EMS significantly outperformed AR (p<0.001) and PR significantly outperformed AR (p<0.001). There was no statistical difference between EMS and PR (p = 1.000).*

DISCUSSION

Interpretation of Main Findings

The purpose of this study was to explore the differences between-inning recovery techniques used by high schoolers and their effects on pitcher performance. Overall, the exploratory results support EMS or PR promoting between-inning BLa reduction for high school pitchers. Statistical analyses using repeated-measures ANOVA and correlation coefficients revealed that EMS and PR were the only recovery methods to show a significant decrease in BLa across all three innings. In contrast, AR increased BLa by an average of 1.05 mmol/L per recovery period, likely demonstrating inferior efficacy compared to EMS and PR.

Current high school pitchers primarily use passive recovery, occasionally active recovery, and only rarely EMS. PR has the lowest barrier for engagement, making it the most popular and accessible amongst high school pitchers. Found in Table 1, PR showed an increase in velocity between innings 1 and 2, from a mean of 67.3 mph to 67.7 mph. PR also maintained intensity across three innings, beginning at a mean of 8 and ending at 8.25. This may be explained by the lack of fatigue induced by the recovery method, since PR allows the body to undergo unassisted recovery processes as it usually would. By resynthesizing phosphocreatine stores to generate ATP rather than using glycogen stores to support muscle recovery, PR helps short-term recovery (22). PR may also be helpful for blood filtration because of its non-exhaustive nature (22).

Surprisingly, the mean velocity for EMS decreased each inning from 1-3, from 70.2 to 68.4 mph. This could be explained by the pitch intensity for each inning, which began at a mean of 8.5 and decreased to 6.75 by the third inning, as shown in Table 1. The use of EMS, a new machine to all participants, may explain the decrease in intensity. After using the EMS machine, the new feeling may have caused pitchers to throw at a lower intensity.

The mean velocity for AR showed the largest decrease across three innings, from 68.1 to 65.1 by the third inning. This may be explained by the reduction in intensity, especially between the first and second innings, when the velocity dropped 2 miles per hour, and the intensity dropped an average of 1.5. One probable explanation is that the physical activity required during AR led to fatigue and exhaustion, thereby reducing the pitcher's maximal power output (18). While AR may be effective for long-term recovery, short-term fatigue may contribute to the significant decrease in velocity. This

can also be explained by the reduction of blood flow to glycogen stores (5, 6).

Comparison with Prior Studies

The preliminary findings of this study are consistent with preexisting research that shows the effectiveness of EMS (18). AR, while used as a recovery method for pitchers, appears ineffective between innings because of its short-term recovery period, which actually increases blood lactate after running (6,18,19): insufficient ATP and oxygen cause lactate to accumulate in muscles. Lactate levels will naturally decrease when ATP is generated through PR and oxygen is replenished. EMS, while little literature supports its effectiveness, has decreased due to concentrated, increased blood circulation in specific regions along the arm. Increased blood flow brings oxygen into localized areas along with the natural generation of ATP, flushing out BLa at higher rates than PR (20, 21, 22). Spencer *et al*.'s (18) study on active versus passive recovery in repeated-sprint cycles found similar results: both AR and PR showed recovery, but AR showed a significant decrease in maximal power output. Wholistically, EMS and PR were more effective for recovery than AR.

The results reflect the current literature on recovery methods and fatigue. The partially replicated study, Warren *et al*. (5), found similar results with EMS as the most effective method, for both clearing BLa and subjectively rated. Unlike our results, though, PR was much less effective at clearing BLa, and was recommended as a secondary recovery method if EMS was not available. Finally, AR was similarly ineffective between innings, increasing the BLa after each recovery period.

Alternative explanations

Alternative explanations may explain why EMS was conceived as the most effective recovery form, as shown by the subjective recovery rating in Table 1. EMS earned the highest score on the subjective scale from 1-10, followed by PR and AR, demonstrating its perceived effectiveness by pitchers. A placebo effect may have occurred where pitchers had preconceived notions about the effectiveness of each recovery method. Since the EMS machine is physical equipment supporting muscle recovery, participants may have perceived its effectiveness as greater. Conversely, participants may have believed that AR would be ineffective for muscle recovery due to the physical exertion required during recovery.

Another possible explanation for the decreased velocity in AR is that, for two of the four participants, it was the last form of recovery tested. Pitchers may have experienced long-term arm fatigue, leading to a decrease in velocity (22). However, because intensity was measured and found to be the lowest for active recovery, this may not be the case. Nevertheless, regardless of any alternative explanations, the present results were most likely driven by the biological processes that occurred, rather than any other factors.

Limitations and Future Directions

As this study focused on recovery relationships among adolescents, it was conservatively designed as an exploratory study with a small sample. A formal power analysis was not conducted for this study, limiting the interpretability and generalizability of the findings. This may explain the statistically insignificant results, as the small sample size increased data variability. Having a small sample size may also justify the significance of the data, as lower chances of disparity may yield near-perfect results. In the future, researchers should use more participants to compose stronger conclusions on the effectiveness of recovery methods.

Although the main effect of inning on blood lactate (BLa) clearance did not reach statistical significance ($p = 0.082$), the result was approaching the conventional threshold for significance. While some would argue it would be inappropriate to explore interactions due to the lack of the main effect, given the physiological expectation of progressive fatigue across multiple innings of high-intensity pitching, a core rationale for the study's three-inning, the repeated-measures design, and the highly significant interaction effect between inning and recovery method ($p = 0.003$), interpreting the interaction was deemed appropriate.

To control pitch count and environmental factors, pitchers were not placed in a game-like scenario. This was done to maintain consistent results among participants, as the number of pitches thrown per inning can influence intensity and velocity. Future studies should consider using a controlled game-like setting to maintain consistency while preventing pitchers from altering their normal routines.

Another limitation was that the AR was not completed long enough; therefore, the full benefit of the condition was not realized. One review, combining 26 studies that examined AR, finds that active recovery lasting 6-10 minutes is ideal for athlete recovery. However, six minutes of recovery was recommended after minimal

exercise, whereas up to 10 minutes was recommended for higher-intensity exercise (23). The brief interval between innings can justify the six-minute recovery period. The pitchers were all 16 years old, which lacks variation despite differences in height and weight; this decreases generalizability. In the future, studies should aim to include participants of all ages to maximize generalizability to all high school pitchers.

CONCLUSION

Based on the present study's findings, it is recommended that high school pitchers employ EMS or PR between innings to maximize BLa clearance and potentially improve pitching performance. When EMS is unavailable or unaffordable, pitchers should resort to PR between innings, as it is a simple and effective recovery method. While these findings are highly preliminary, given the small sample size, it may still give insight to pitching recovery methods for adolescents. By adopting either EMS or PR as a recovery method between innings, adolescent pitchers may be able to use these findings to minimize arm injuries and enhance pitching performance.

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CONFLICT OF INTEREST

The author declares that there are no conflicts of interest related to this work.

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