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. A significant main effect of BLa clearance and recovery method across three innings pitched determined the most effective intervention. Post-hoc results confirmed that EMS and PR conditions outperformed the AR condition across all innings. The difference in clearance between AR with EMS was significant ($p = 0.0048$), closely followed by AR with PR ($p = 0.0328$), while PR with EMS was not significant ($p = 0.609$). These findings suggest that using EMS 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

1. 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 between age 8 and 18 report experiencing arm pain during their playing careers, but 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. A notable survey of 203 healthy youth players revealed that 46% felt pressured by coaches to continue competing despite experiencing arm discomfort and injuries (5). Most of these injuries are attributed to pitchers, who endure maximal stress on their upper limbs during the pitching motion (4,6). There is an urgent need to implement training and injury-prevention strategies to protect the health and prospects of young pitchers.

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. (7) 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 (8). Although preventing pitchers from playing various positions is impractical, supporting their recovery can decrease the likelihood of injury (7,8).

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 (9). As the game progresses, pitcher fatigue increases susceptibility to injury; needless to say, recovery becomes crucial to protect the arms of high school pitchers (10).

Research on pitcher recovery methods has traditionally focused on procedures performed between games, emphasizing the importance of prolonged recovery to minimize susceptibility to injury 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 (11). 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 buildup and maintaining muscular readiness (12).

1.1 Physiological Markers of Exertion

Blood lactate accumulation occurs in pitchers during high-intensity, repetitive motions. This buildup can adversely affect involved muscles and the surrounding circulatory system (13). 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 (14).

The initial impacts on motor control arise from the rapid accumulation of blood lactate in the muscles, which increases hydrogen ion concentrations (11,13,14). 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 (11). This decline may persist for multiple days if there is no intervention.

1.2 Recovery Methods

In a prior study conducted by Warren et al. (11), 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). 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 (15). Therefore, the efficacy of various between-inning recovery techniques may vary across different age groups.

AR is a method of recovery that focuses on bringing oxygen-rich blood into the muscle to increase the rate of hydrogen ion clearance in affected areas. Prior studies have found AR to be the most effective recovery method in decreasing fatigue and soreness. However, while effective in clearing BLa over the long term, AR increases heart rate and causes participants to exert physical force, which may impede short-term effectiveness (12).

PR is the most common between-inning recovery method among high school pitchers. It has consistently been an effective way of clearing BLa by naturally allowing oxygen-infused blood into the affected areas, which increases H^+ ion balance, leading to decreased pH levels.

EMS is a relatively new form of recovery, with few citations behind its success. However, studies such as Warren et al.'s (11) may prove its overall effectiveness in quick pitcher recovery. EMS uses electrical impulses that induce muscle contraction in local regions. In turn, localized blood flow increases, inhibiting the entry of large amounts of lactic acid (16).

1.3 Purpose

By prioritizing between-inning recovery strategies, we can create a comprehensive approach to athlete health that promotes performance and actively safeguards against injury. It is essential to recognize that every moment of rest during a game is an opportunity for pitcher recovery, and leveraging these moments effectively can be pivotal in extending their careers and ensuring their long-term well-being.

Due to increased injuries among high school pitchers, this experiment aimed to determine the most effective between-inning recovery method. Researchers in prior studies have hypothesized that EMS, followed closely by PR, is more effective in clearing BLa between innings than AR (11). Thus, the hypothesis of this study states that as pitchers progress through three innings of play, EMS should be the most effective between-inning recovery method.

2. 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 upon that of Warren et al.'s (11) study on the effectiveness of between-inning recovery methods in Division 2 collegiate athletes. These are the differences in methods used to study pitchers:

No free play was allowed meaning 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 decrease recovery intensity over the six-minute recovery period gradually. 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 prove viability for the study.

2.1 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. Parents and guardians signed consent forms approved by an Institutional Review Board. Parents/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.

2.2 Procedures:

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.

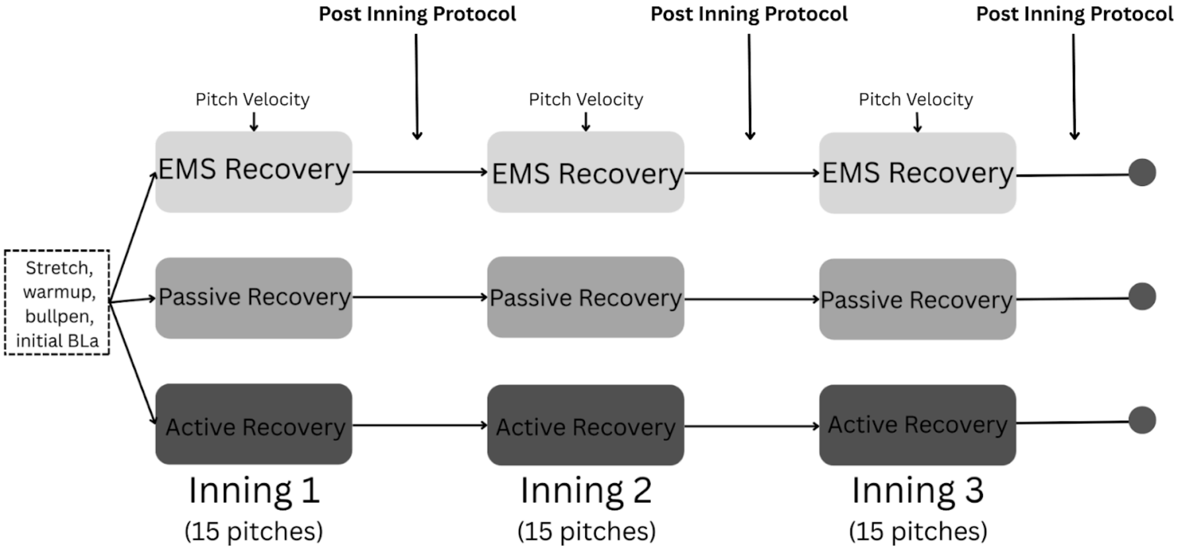

Figure 1: Overview of the study's procedure. Post-inning protocol is as follows: Pre-recovery BLa, Subjective Pitch intensity, 6 minutes of recovery, Post-recovery BLa, Subjective recovery rating

Pitcher 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 was 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 (Belifu, 2019).

All participating subjects and their parents/guardians attended the first day of testing, where they received instructions and demonstrations, were told about potential risks and benefits in the study, and respectfully signed assent and consent forms agreeing to participate. 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 same 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 (Triad Sports Group, 2018), 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 a spring high school baseball season.

3. Results

3.1 Intervention check

To ensure the integrity and validity of our main results, initial assessments were conducted to verify that the experimental conditions induced the intended level of fatigue and that participants’ subjective ratings aligned with objective measures. Without validity, the main results may be skewed due to inaccurate subjective ratings. To confirm that participants were fatigued from pitching across innings, the correlation between blood lactate and average velocity was calculated for each inning, with a consistent negative correlation coefficient (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 confirm that 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).

	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

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

3.2 Main Results

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)X3(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).

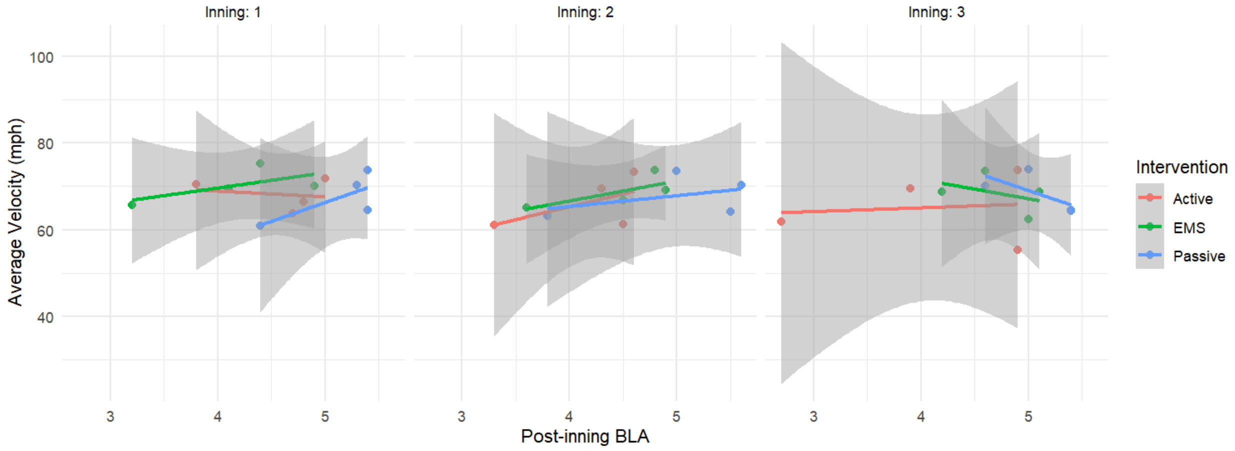

Figure 2: BLa-Velocity Relationship by Condition. This figure shows the Post-inning BLa-Velocity relationship by condition over three innings.

The relationship between blood lactate and recovery method across three innings was also 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 (F(2,12) = 0.11, p = 0.90). There was a statistically significant main effect of the recovery method on BLa (F(2,12) = 4.80, p = 0.021). Post hoc tests suggest this significance was driven by the AR condition outperforming the PR condition (p = 0.03), not the AR vs. EMS (p = 0.09) or EMS vs. PR (p = 1.00).

	Inning 1	Inning 2	Inning 3
PR vs EMS	0.0028 x 3 = 0.0084	0.0001 x 3 = 0.0003	<0.0001 x 3 = <0.0003
AR vs PR	0.0001 x 3 = 0.0003	<0.0001 x 3 = <0.0003	0.0308 x 3 = 0.0924
EMS vs PR	0.4151 x 3 = 1.000	0.2730 x 3 = 0.8190	0.0023 x 3 = 0.0069

Table 2: Bonferroni-Corrected Pairwise Comparisons for the BLa-recovery Method. EMS and PR, outperformed AR across all innings.

To analyze the congruence of the results with the hypothesis was the relationship between blood lactate clearance and the recovery intervention. The relationship between blood lactate clearance and recovery intervention across three innings was examined using a 3(recovery method)X3(innings) repeated measures ANOVA run in RStudio. There was a statistically significant main effect of inning (F(2,12) = 3.90, p = 0.08) and intervention (F(2,12) = 57.65, p = <0.01) on lactate clearance. Furthermore, there was an interaction effect between inning and intervention (F(4,36) = 6.07, p = 0.003). Post hoc assessments were completed using Bonferroni corrections to identify what relationships drove the interaction (Table 2), while controlling for multiple hypothesis testing. The EMS and passive conditions outperformed the active condition across all innings.

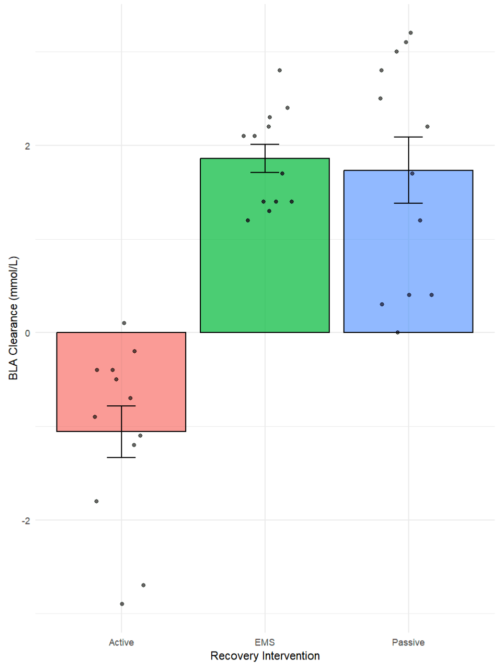

Figure 3: BLa Clearance by Recovery Intervention. Higher values reflect more effective recovery. EMS slightly outperforms PR, and AR significantly underperforms the other interventions.

4. Discussion and Conclusion

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 results support EMS promoting between-inning BLa reduction for high school pitchers. Statistical analyses using repeated-measures ANOVA and correlation coefficients revealed that EMS was the only recovery method to show a significant decrease in BLa across all three innings. Furthermore, PR, while marginally decreasing BLa, was less effective than EMS across both perceived and physiological measurements. In contrast, AR increased BLa by an average of 1.05 mmol/L per recovery period, demonstrating inferior efficacy compared to EMS and PR.

These findings 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 (12,18,19). 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). Wholistically, EMS was better for recovery than AR 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 (Table 1). This can 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 be helpful to blood filtration as well 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 (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 most significant decrease across three innings, beginning at 68.1 and decreasing 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 be a factor in the significant decrease in velocity. This can also be explained by the reduction of blood flow to glycogen stores (11, 12).

The results support the current literature on recovery methods and fatigue. The partially replicated study, Warren et al. (11), found similar results with EMS as the most effective method, for both clearing BLa and subjectively rated. Unlike the results, though, PR was much less effective at clearing BLa, yet still ranked second among recovery methods. Finally, AR was similarly ineffective between innings, increasing the BLa after each recovery period. 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.

4.2 Alternative explanations

Alternative explanations may explain why EMS was conceived as the most effective recovery form. 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 based solely on the biological processes that occurred, not on any other explanations.

4.3 Limitations and Future Directions

One major limitation of our study was its small sample size. Only four participants were tested, limiting the study's generalizability and statistical power. This may explain the statistically insignificant results, as an outlier in a small sample can affect them. 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.

Another limitation of this study was that, to control for 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.

AR was also not completed; thus, the full benefit of using the condition was not received. The pitchers were all 16 years old, which limits generalizability. In the future, studies should aim to include participants across ages to maximize generalizability to all high school pitchers. Participants were also all males, which limits the generalizability of the study as well.

Another limitation was that AR was not completed long enough; therefore, the full benefit of using the condition was not realised. One review using a culmination of 26 studies that performed AR finds that completing active recovery between 6-10 minutes is ideal for athlete recovery. However, six minutes of recovery was recommended after minimal exercise whereas up to ten minutes was recommended for higher intensity exercise (23). The six minute recovery period can be justified by the brief interval available to pitchers between innings. 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 at varying ages to maximize generalizability to all high school pitchers.

5. Conclusion

Based on the present study's findings, it is recommended that high school pitchers employ EMS between innings to maximize BLa clearance and potentially improve pitching performance. However, in cases where EMS is not available or affordable, pitchers should resort to PR between innings, as it is a simple and effective recovery method. With these findings, pitchers will hopefully minimize arm injuries and improve pitching performance by implementing EMS or PR as between inning recovery methods.

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