# Delayed onset muscle soreness (DOMS) recovery methods in high school relief pitchers: A small-scale experimental study

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**Abstract:**
The purpose of this study was to explore the efficacy of three high school baseball post-pitching recovery methods [Active Recovery (AR), passive recovery (PR), and cryotherapy (CT)] in preventing delayed onset muscle soreness (DOMS) for high school relief pitchers. To test the effectiveness, four key variables were used: 24-hour soreness, 48-hour soreness, perceived recovery rating (PRR), and velocity difference. This study hypothesized that AR would be the most effective recovery method against DOMS, consequently decreasing the likelihood of arm injuries. Six high school relief pitchers went through three testing days each, using every recovery method. Testing days consisted of dynamic warm-ups, throwing warm-ups, bullpen sessions, and two innings of 15 pitches each; velocity was recorded after each pitch. Following the completion of inning two, pitchers completed their respective recovery methods, and surveys for recovery/soreness ratings were completed. Repeated measures ANOVA tests suggested that AR was most effective, followed by PR and lastly CT. Simple paired t-tests were used to run post hoc tests on the independent variable, indicating significant differences between AR and other recovery methods. Across the four variables tested, AR has consistently yielded significantly lower p-values than other recovery interventions. PR also produced significant results compared with CT, demonstrating its potential effectiveness. These findings suggest using AR to prevent DOMS and minimize soreness in high school relievers and to improve pitching performance.

**Keywords**: Active Recovery, Delayed Onset Muscle Soreness (DOMS), Post-pitching Recovery Methods, High School Athletes, Relief Pitchers, Muscle Soreness Prevention

## Introduction

Pitchers have long been vital players in baseball, playing an important role in a team's victory (1). At the adolescent level, pitching and throwing velocities play a significant role in college recruitment and showcases. This velocity-driven mentality incentivizes high school pitchers to throw at higher intensities, increasing the likelihood of arm injuries (2). Although it is difficult to prevent pitchers from throwing at higher intensities, it is possible to control the recovery methods they use to reduce injury after pitching. Recovery methods have long been used by pitchers, particularly among professional and collegiate athletes. Studies that focus on the impact of blood flow on recovery show that the effectiveness of these methods directly correlates with the replenishment of oxygenated blood to affected areas. Specifically, blood flow is distributed to certain parts of the body to match their energy demands; enhancing this natural bodily process can also improve recovery (3). In baseball, as pitchers repeatedly repeat the throwing motion, blood flow is redirected to affected areas to replenish the depleted oxygen supply.

Soreness acts as a root cause for pitcher upper extremity injury caused by pitcher overuse through a cascade of events that follow (4). The most common form of soreness that baseball pitchers experience is delayed onset muscle soreness (DOMS), which is characterized by microscopic tears in muscle fibers, caused by repetitive high-intensity exercises that primarily target a single muscle or muscle group (5). DOMS was observed between the 24th and 48th hours after eccentric or unconventional exercise [study conducted from 0-96 hours], demonstrating a short, but intense, time window for deep soreness (5). This soreness period is critical in player performance as DOMS significantly reduces power and strength in pitchers, affecting their overall performance and increasing the likelihood of injury (4,6).

**Literature Review**

To understand this topic further, this paper will first explore the causes and significance of high school pitcher injuries. Through this, an understanding of the significant landscape of youth pitcher injuries will be established.

More than 50% of adolescents who play baseball have experienced shoulder or elbow injuries, likely due to repeated eccentric motions from heavy workload. An imbalance between a pitcher's workload and recovery causes tissue microtears in the muscles surrounding the arm (4). Accumulated damage from exponentiated microtrauma in muscle tissue causes pitchers to become highly susceptible to injuries, especially if the muscles are agitated; agitation mainly occurs by pitchers continue to pitch through soreness.

Agitation is common for relief pitchers, those who pitch often and for short bouts. Relief pitchers are at high risk for arm injuries due to their short but frequent outings as they are an incentive for pitchers to throw at higher intensities, which increases their likelihood of injury by placing frequent, high stress on muscles and tendons (7). At the high school level, the compounded effects of a short, high-intensity pitching performance to increase velocity make relief pitchers highly susceptible to arm injuries (2,7).

Relievers are more vulnerable to injury for more than just this reason. High school relief pitchers commonly play multiple positions on the field, as supported by a study showing that 97.6% of the study's total population [384 participants] attested to playing multiple other positions (8). The overuse of a pitcher's arm, caused by playing multiple positions, has a direct correlation with injury likelihood through an increase in soreness and fatigue through completing the repetitive, high-stress throwing motion (4,8). With this in mind, exploring the causes and potential preventive measures for injuries becomes pivotal.

Fatigue is defined in baseball as a state of decreased physical performance caused by inadequate rest and recovery (9). A study on the neuromuscular effects of fatigue on pitching determined that fatigue led to a greater muscle soreness, especially in the forearm [flexors] and the anterior deltoid, where many nerves were present (10). Pertinent to the model that predicts injury from an imbalance between workload and recovery, elevated levels of fatigue induce tissue microtrauma, and accumulated damage from these microtears causes pitcher injuries through agitation (4,11).

As signified in a study on between-inning recovery methods, one method to prevent fatigue and provide stamina is between-inning recovery, which keeps pitchers' arms warm for the following inning by removing blood lactate, a byproduct of fermentation in deoxygenated blood cells (11). Blood lactate buildup, or elevated blood lactate in concentrated areas, can cause increased arm soreness and fatigue, leading to impaired motor function, potentially affecting a pitcher's performance (9,11).

Pitchers face two main types of soreness that impact their performance and contribute to injuries. Short-term soreness, caused by blood lactate buildup, can impact a pitcher's performance in the current game but, if ignored, can lead to long-term effects (12). Long-term soreness, which usually lasts for 3-4 days after initial exercise, is caused by microscopic tears in muscle fiber from these short bouts, similar to the source of DOMS. Long-term soreness can also lead to effects that inhibit pitcher performance, but more importantly, significantly increase injury rates (12). Therefore, it becomes important to prevent injuries stemming from soreness in a particularly susceptible pitcher population.

Based on a study of the muscle timeline after strenuous exercise, pitchers are not given adequate recovery time between performances, thereby increasing their risk of injury due to DOMS (12,13). DOMS has been associated with inflammation and metabolic accumulation, stemming from microtears in skeletal muscle. During the period between performances, microscopic tears in the arm muscles from intense exercise begin to heal through an inflammatory process, leading to soreness (12,13,14). This soreness, a byproduct of the body's attempt to heal itself, lasts for 24-72 hours. In baseball, soreness peaks during a relief pitcher's next appearance, as relievers usually pitch on a one- to two-day cycle. High school athletes with physically immature bodies, less access to recovery resources, and little medical support struggle to combat this soreness, leaving them more susceptible to injury.

In a thorough review of DOMS's sources, it is commonly caused by the contraction of muscles, which occurs during pitching; regions of the shoulder, biceps, and elbow tendons are impacted (15). In an experiment on the effects of exercise intensity and volume on DOMS, the exhaustion level showed the greatest average decrease in pain threshold and the greatest increase in microtears in targeted muscles compared to submaximal and light-intensity exercise (16). Pitchers, as they perform the repetitive, high-intensity pitching motion, fall into the exhaustion category, which induces excess microtrauma in the arm muscles. Consequently, the intensity of DOMS is increased through the body's attempt to ameliorate the damage (14,16).

Throwing at high intensities while combating exhaustion and pain increases the likelihood of injury and decreases the intended velocity for high school pitchers. Therefore, recovery methods become crucial to combat the effects of DOMS and promote performance for relief pitchers at the high school level.

Muscle recovery is crucial to athletes' psychological and physical well-being. During a recovery period, the human body is given time to adapt to the exercise performed and to replenish muscle glycogen, which helps repair tissue damaged by high-intensity exercise (11,17). The most commonly used recovery techniques are neuromuscular electrical stimulation, cryotherapy, hydrotherapy, blood flow restriction, and cupping (18). Others, such as increased rest periods, are passive methods for helping younger athletes, with less equipment, recover effectively in an affordable and accessible manner (19). While both expensive and inexpensive recovery methods exist, their effectiveness varies with the player's physical maturity (18,19).

Relevant to this study, three recovery methods are commonly used by high school pitchers: active recovery (AR), passive recovery (PR), and cryotherapy (CT). These methods are easily accessible, mainly low-cost, and easy to complete, appealing to high school athletes. Scientifically, each has its rationale: AR replenishes oxygenated blood to affected regions through light running or movement, PR supports natural recovery, and CT uses ice therapy to limit inflammation and minimize pain (20). Ultimately, by determining the most effective recovery method that high school relief pitchers can use to prevent DOMS, the cascade of events that lead to injury following the soreness can be prevented.

### *Current gap and approach*

Today, the majority of baseball enthusiasts focus on preventing injuries among collegiate and professional pitchers. Conversely, many physicians worry about the health of adolescents who place significant stress on their growing bodies. This varying perspective is mainly due to baseball enthusiasts focusing on the present day rather than the sport's future, while health providers worry about the well-being of younger, immature athletes (2,21). The high-intensity theory posits that increased pitching intensity is directly correlated with an increased arm injury rate (2). However, it is virtually impossible to prevent high school pitchers from throwing at higher intensities, but it is possible to improve their recovery. Research on recovery methods for collegiate and professional pitchers is thorough, but little has been conducted on high school and adolescent athletes. Given the lack of a solution specifically targeted for high schoolers, a study analyzing recovery methods to combat DOMS would help minimize injuries from muscle soreness and potentially improve pitcher performance. This leads to the research question: *What is the relationship between recovery methods (AR, PR, CT) and the reduction of DOMS in High School X relief pitchers within 48 hours after pitching?*

Based on the current literature, negative effects of pitching are best countered by AR within 1-2 days (22). Furthermore, CT and PR have been shown to be more effective during shorter recovery periods [2-24 hours post-exercise] (18). Thus, the hypothesis of this study states that as pitchers are negatively affected by DOMS, AR is more likely to facilitate adequate recovery than PR and CT.

## Materials & Methods

### *Research design*

The purpose of this study was to explore the various recovery techniques used by pitchers to combat DOMS over a 48-hour period. A small-scale experimental research design was used to study the effectiveness of DOMS recovery methods. The experimental research design was chosen to align with the project goal: to assess the objective effectiveness of each dependent variable while controlling for various other variables. In a collegiate textbook on research planning and design, determine that the experimental method should be used to determine the effects of treatments through researcher-imposed specifications (23). In this study, quantitative measurements evaluated the impact of the three pitcher recovery interventions: AR, PR, and CT.

This study used multiple units of analysis to determine the effectiveness of recovery methods. Using the Likert scale, muscle soreness was measured in the upper extremity (1-10, 1 being no soreness to 10 being extreme soreness), and perceived effectiveness of the recovery method (1-10, 1 being no effect to 10 being extremely effective) 24 hours and 48 hours after pitching. Finally, velocity was measured in miles per hour using the Pocket Radar Smart Coach. A study on the effectiveness of Pocket Radar Smart Coach found its reliability to be r = 0.99 (24).

In this study, three recovery methods were used: AR, PR, and CT:

AR was defined as jogging 90 feet downhill on a nearly level slope six times immediately after pitching. After each run, participants would walk back to the top of the slope and repeat. Participants then continued on with their everyday activities until the next testing day. The rationale for running down a slope is that gravity takes most of the effort out of the method itself (25), while still flushing out lactate by bringing in oxygen-rich blood to affected areas.

PR was defined as the absence of a recovery method after pitching. Essentially, it is the control of this study. Participants finished pitching and continued with their everyday activities until the next testing day. There is minimal potential harm in using this recovery method, as the pitchers exert minimal physical movement.

CT was defined as applying two ‘Perfect Remedy’ ice packs to the long head of the throwing arm’s biceps (biceps brachii) and the throwing arm’s latissimus dorsi for 15 minutes immediately after pitching. These muscles are targeted in CT because they tend to get the most sore after pitching (5,10). To maximize effectiveness and minimize discomfort, kitchen towels were placed around the ice pack to prevent direct skin contact with the ice. One other potential risk is cold burn, which occurs when ice comes into direct contact with the skin for long periods; kitchen towels counter this, and it takes 20 or more minutes of direct ice contact for the cold burn effect to occur (26).

To maximize the study's effectiveness, participants were assigned to recovery methods in a randomized order. This way, the order had less of an effect on a participant's perceived effectiveness of the recovery method and their velocity. Random order was determined as follows: combinations of the three recovery methods were written on slips of paper and placed in a hat. The participants drew the paper on their first testing day, determining the order in which they would proceed.

On testing day, participants were first instructed to go through a set of dynamic warm-ups. To maintain consistency with game-like scenarios, participants were told to complete their own dynamics as they would before pitching in a game. Generally, warm-ups include stretching, throwing with weighted balls, and playing catch with a standard 5-oz baseball. After the dynamic warm-up was completed, participants were instructed to begin pitching in the bullpen (warm-up mound), where they spent time warming up their pitching motion until they were ready to begin testing. Participants then pitched two innings, each consisting of 15 pitches, with a 5-minute break between innings. This break was passive, meaning pitchers were instructed to minimize physical movement and sit in the dugout for the duration.

Throughout the inning, velocity, in miles per hour, was taken after every pitch and noted down on a velocity collection sheet. This data collection sheet, along with others, were kept confidential and only available to each participant and researcher. Furthermore, on testing day, pitchers were not throwing to a live catcher, instead into a BOWNET placed behind home plate. Following the conclusion of inning two, recovery methods were completed.

Between data collection days, participants completed a post-testing Google form, rating their perceived effectiveness and muscle soreness on a Likert scale. These were completed 24 and 48 hours after each testing day to measure muscle soreness and the perceived helpfulness of each recovery method over time. All of this data was noted and stored on data collection sheets, kept confidential.

***Sampling.*** Participants were High School X baseball pitchers who had at least one year of high school baseball experience. These participants were eligible for this study and provided parental consent and assent. The head coach of High School X baseball was emailed first to send out interest messages to their program. Contact information for potential participants was then emailed, and interested participants received supplementary emails detailing the study and forms. If participants qualified, testing dates were determined and testing began.

***Limitations:*** Sampling was conducted as such to limit potential bias. Having the coach ask participants ensured that they joined solely because of desire, not predisposed beliefs. This limited bias: participants did not know the researcher until they showed interest in the study, and thus joined without the intention of pleasing anyone. Another limitation was the small sample size, and that all students were High School X baseball players. While this cannot be countered, it was the reason for a small-scale experimental study and hindered the generalizability of the results.

While there may be biases in Likert-scale ratings due to predisposed beliefs and prior knowledge, participants were told throughout the study to provide the most honest rating possible. Furthermore, while writing the results section of the paper, intervention checks were conducted to mitigate bias, and objective measures such as velocity were used to confirm accurate ratings throughout the study.

***Ethical considerations:*** In no way, shape, or form were any participants pressured into participating in this study. Furthermore, full confidentiality was maintained: no names, personal information, or study results were shared with anyone but the participants themselves. Monikers such as 'Player A' were used to differentiate between players, and all information was kept behind a password-protected personal device. More information is provided in the letter of intent. Moreover, participants were already used to throwing in-game scenarios, thus there is minimal potential for injury. All precautions were taken to minimize injuries for participants and they were warned of all potential risks prior to beginning the study. Participants could opt out of the study at any time, without any punishment or harm.

**Results**

The purpose of the study was to explore the most effective recovery method to be used against DOMS for high school relief pitchers. A repeated-measures ANOVA test on the results of six participants, along with paired t-tests (post-hoc) for statistically significant data, was completed to determine the relationships between tested variables; these tests were run using R-code in Statistics Kingdom.

The analysis began by selecting variables to identify relationships and assess the effectiveness of each recovery method. After careful consideration, four measurements were used to determine effectiveness: 24-hour soreness, 48-hour soreness, perceived recovery rating, and velocity differences (Table 1). From here, the repeated-measures ANOVA was used because it has proven effectiveness for determining relationships among three or more conditions or points in time within the same subjects. After running each initial repeated measures ANOVA, if a significant value was produced, a paired t-test or post-hoc test was used to compare the relationship between two variables. Post-hoc tests were used to reduce the risk of Type 1 errors in the analysis and to show one-on-one relationships (Leedy & Ormrod, 2015); these values were Bonferroni-corrected using a built-in feature in Statistics Kingdom to strengthen the relationships. Finally, the strength of each recovery method was determined.

| | 24 Hour Soreness | 48 Hour Soreness | PRR | Avg. Velocity Difference |
|---|---|---|---|---|
| AR | 2.5 | 1.667 | 9 | 2.15 |

| | | | | |
|---|---|---|---|---|
| PR | 5.667 | 2.167 | 5 | -0.05 |
| CT | 8.5 | 5.167 | 1.833 | -2.10 |

***Table 1.*** Average values for recovery methods across four dependent variables were tested. Means values for 24-hour soreness, 48-hour soreness, perceived recovery rating (PRR), and average velocity difference (mph).

***Relationship between recovery methods for 24-hour soreness***

The relationship between recovery methods and 24-hour soreness was analyzed using a repeated-measures ANOVA in Statistics Kingdom. There was a statistically significant main effect of intervention on 24-hour soreness ($F(2,10) = 103.51$, $p < 0.001$). Consequently, post hoc paired t-tests were conducted to examine relationships among variables, revealing significant results across recovery methods (Figure 1).

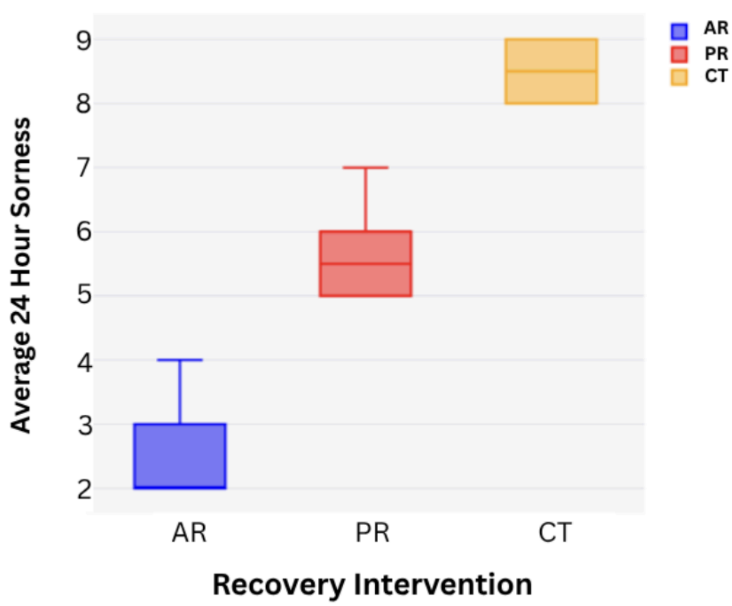


***Figure 1.*** Average 24-hour soreness over three innings by recovery intervention. Higher values reflect lower overall recovery. Each value is statistically significant from the others, shown by the lack of error bar interference.

Results of the paired t-test indicated that there was a significant difference between AR ($M = 2.5$, $SD = 0.8$) and PR ($M = 5.7$, $SD = 0.8$), $t(5) = 6.6$, $p = 0.001$. There was also a significant large difference between CT ($M = 8.5$, $SD = 0.5$) and PR ($M = 5.7$, $SD = 0.8$), $t(5) =$

9.2, p < 0.001. Finally, there was a significant difference between AR (M = 2.5, SD = 0.8) and CT (M = 8.5, SD = 0.5), t(5) = 13.4, p < 0.001.

***Relationship between recovery methods for 48-hour soreness***

A repeated-measures ANOVA in Statistics Kingdom was used to analyze the relationship between recovery methods and 48-hour soreness. There was a statistically significant main effect of intervention on 48-hour soreness (F(2,10) = 24.38, p < 0.001). Given the significance, post hoc paired t-tests were conducted to examine relationships among variables, revealing significant results across recovery methods (Figure 2).

Results of the paired t-test indicated that there was a significantly large difference between AR (M = 1.2, SD = 0.4) and PR (M = 2.2, SD = 1.2), t(5) = 2.2, p = 0.076. There was also a significant large difference between CT (M = 5.2, SD = 1.2) and PR (M = 2.2, SD = 1.2), t(5) = 3.9, p = 0.012. There was a significant large difference between AR (M = 1.2, SD = 0.4) and CT (M = 5.2, SD = 1.2), t(5) = 7.7, p < 0.001.

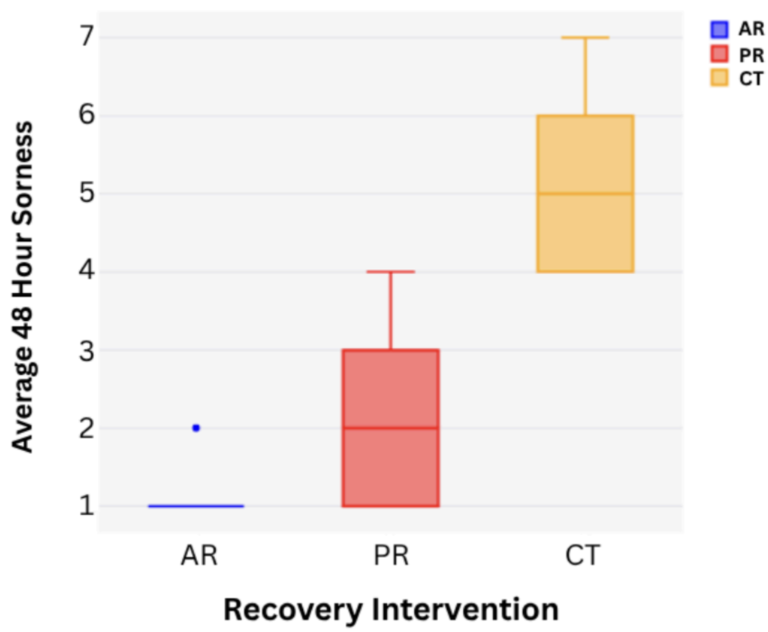


***Figure 2.*** Average 48 hour soreness over three innings by recovery intervention. Higher values reflect lower overall recovery. Each value is statistically significant relative to the others, except for PR and CT, as indicated by the overlapping error bars.

***Relationship between recovery methods for perceived recovery rating***

The relationship between recovery methods and perceived recovery ratings was analyzed using a repeated-measures ANOVA in Statistics Kingdom. There was a statistically significant main effect of intervention on perceived recovery rating (F(2,10) = 65.09, p < 0.001). Post hoc paired t-tests examined the relationships among variables and found significant results across recovery methods.

Results of the paired t-test indicated a significant difference between AR (M = 9, SD = 0.9) and PR (M = 5, SD = 1.3), t(5) = 5.5, p = 0.003. There was also a significant large difference between CT (M = 1.8, SD = 0.8) and PR (M = 5, SD = 1.3), t(5) = 5.3, p = 0.003. Lastly, there was a significant large difference between AR (M = 9, SD = 0.9) and CT (M = 1.8, SD = 0.8), t(5) = 13.2, p < 0.001.

***Relationship between recovery methods for velocity differences***

The relationship between recovery methods and velocity differences was analyzed using a repeated-measures ANOVA in Statistics Kingdom. There was a statistically significant main effect of intervention on velocity difference (F(1.01, 3.02) = 36.38, p < 0.009). Post hoc paired t-tests revealed significant relationships among variables and across recovery methods (Figure 3).

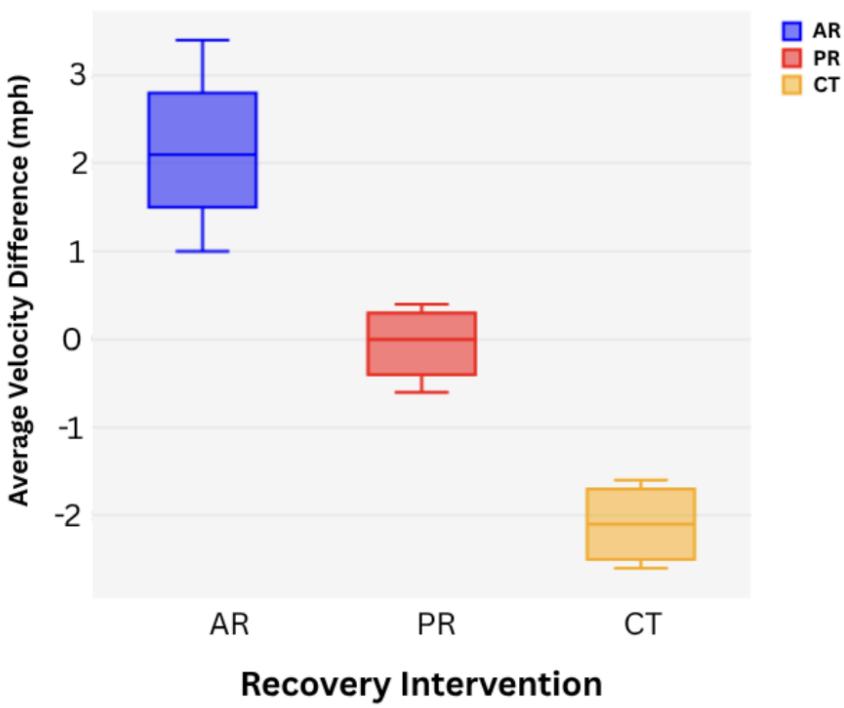


***Figure 3.*** Average velocity difference over three innings by recovery intervention. Higher values reflect higher overall recovery. Each value is statistically significant from each other, shown by the lack of error bar interference.

Results of the paired t-test indicated that there was a significant difference between AR (M = 2.1, SD = 1) and PR (M = -0.05, SD = 0.4), t(5) = 3.5, p = 0.038. There was also a significant large difference between CT (M = -2.1, SD = 0.5) and PR (M = -0.05, SD = 0.4), t(5) = 41, p < 0.001. Finally, there was a significant large difference between AR (M = 2.1, SD = 1) and CT (M = -2.1, SD = 0.5), t(5) = 7.1, p = 0.006.

## Discussion

The purpose of this study was to explore the effectiveness of three recovery methods to be used by high school relief pitchers to prevent DOMS from disrupting pitching performance between games. Overall, the results support using AR between games to decrease the likelihood of injury and improve pitcher performance by reducing DOMS after repeated high-intensity exercise. Statistical analyses using repeated-measures ANOVA and post hoc tests showed that AR significantly outperformed PR and CT across the 24- and 48-hour testing intervals and for velocity differences. Subjective ratings on the perceived effectiveness of each recovery method also supported the usage of AR. AR's superiority may be explained by its ability to induce rapid muscle recovery by bringing oxygenated blood into regions of low blood pH and oxygen (11). By bringing oxygenated blood to affected regions, the body speeds up recovery, accelerating the repair of damaged muscle fibers and reducing inflammation (22). Therefore, by using AR as a recovery technique, pitchers alleviate DOMS, thereby improving recovery and increasing the likelihood of better performance.

The relationship between 24-hour soreness and recovery helps support the superiority of AR. The ANOVA, which was statistically significant, showed a correlation between the use of specific recovery techniques and perception of soreness after 24 hours. Furthermore, to assess the effectiveness of relationships among the independent variables, post hoc paired t-tests were run, indicating significant differences between AR and CT ($p<0.001$) and between AR and PR ($p = 0.001$). This may be explained by the use of AR to speed up bodily processes, resulting in a shorter time than with PR or CT. PR, while significantly more effective than AR in reducing 24-hour soreness ($p<0.001$), differed from AR. The rationale behind PR is to allow the natural bodily processes, such as protein synthesis and the inflammatory response to effectively recover damaged tissue (22). Because the body is only given 24 hours to recover, there is a stark contrast between the effects of AR and PR. Research suggests that the body takes at least 48 hours to show signs of effective recovery without external intervention (11). For high school relievers pitching in back-to-back games, the results support the use of AR to maximize recovery.

However, at the 48-hour mark, the post hoc results show a weaker correlation between recovery method and soreness. CT remained inferior to both AR ($p<0.001$) and PR ($p = 0.012$), however the difference between AR and PR was not statistically significant ($p = 0.076$). Scientifically, research shows that the body's natural processes for reducing soreness, specifically DOMS, are most effective around the 48-hour mark (13). DOMS peaks between 24 and 48 hours after high-intensity exercise is complete; however, in adolescents, who usually have a quicker recovery due to increased growth hormone and cellular metabolism (19), DOMS may peak at 36 hours, which may explain the decrease in soreness across recovery methods. Nevertheless, one potential limitation may explain the overly significant results produced through the analysis. The lack of participants may have contributed to an underpowered analysis that produced highly significant results, including multiple p-values below 0.001. It can be assumed that if this study had included more participants, the p-values would have been closer to 0.01. Furthermore, a formal power analysis was not completed for this study, limiting the generalizability of the results. A smaller sample size justifies the significance of the data by reducing the likelihood of bias. Despite these limitations, the results indicate that at 48 hours after testing, AR is objectively superior at reducing DOMS.

The ineffectiveness of CT can be explained from various perspectives. From a biological perspective, CT, while reducing inflammation in affected regions after pitching, does not naturally increase blood flow but rather inhibits it (20). The minimal recovery observed with CT may be explained by this phenomenon. From a psychological perspective, CT was perceived as the most ineffective recovery technique by the participants through their perceived recovery rating. The significance between PR and CT ($p = 0.003$) and AR and CT ($p < 0.001$) shows the negative perception of recovery participants, determined that they were feeling. Another potential explanation for CT's dislike may originate from prior perceptions of using ice therapy. Ice therapy, unlike other common relief mechanisms such as electromuscular stimulation, is minimally used at the high school level for between-game recovery. Therefore, pitchers may have entered the study with a predisposition to CT, which could have influenced the results. Nonetheless, the present results were most likely driven by biological processes rather than other factors.

A limitation that may have contributed to the diminished CT results was the potential ineffectiveness of the technology used to mimic ice therapy. Wrapable ice packs and kitchen towels were used instead of a formal cryotherapy machine due to economic constraints; cryotherapy machines cost thousands of dollars, which is difficult for most high school baseball teams to afford. Therefore, to most closely mimic what high school pitchers could use for post-game recovery, this form of ice therapy was used, which may have inhibited the maximum effects. Using a formal CT machine may offer many more benefits and provide more effective recovery than the ice therapy used in this study. This limitation may explain the CT results and the perceived ineffectiveness of ice therapy.

The variability in velocity differences across recovery methods seems to be directly correlated with the soreness at 48 hours. Velocity differences between AR and PR are statistically significant ($p = 0.038$), as are those between PR and CT ($p = 0.001$); differences between AR and CT are also significant ($p = 0.006$). In line with the results of soreness and even perceived recovery, the differences in velocity support the superiority of AR in alleviating the effects of DOMS, followed by PR and CT. The feeling of recovery and the decrease in soreness may be directly correlated with velocity variability, further supporting prior research findings (9).

## Conclusions & Future Directions

Based on this study's findings, it is recommended that high school relief pitchers use AR to enhance recovery, reduce the likelihood of DOMS, and improve pitching performance. In the case that pitchers are unable to perform AR, they should resort to using PR due to its simplicity and proven effectiveness in alleviating soreness and preventing DOMS.

Though these findings are merely exploratory, given the small sample size, it may provide insight for future research that is done in this field. Future researchers should consider increasing sample sizes to maximize generalizability and reduce statistical errors and inconsistencies. In addition, researchers should aim to test pitchers across various adolescent ages to widen the relevance of the findings, while still maintaining focus on a specified population. By completing this, researchers may effectively prove the efficacy of these recovery methods and support the findings of this study.

Finally, future research should consider conducting these tests in game scenarios. Factors such as adrenaline and the psychological need to perform well can potentially affect perceptions of soreness and the effectiveness of recovery methods. Not only would testing in a real game provide more accurate results, but mimicking the setting may actually help pitcher performance on testing day. These potential directions for future research raise questions to the effectiveness of other recovery methods that could be tested to prevent DOMS, and even other forms of soreness. Nevertheless, further work in this area may improve the recovery techniques used by high school pitchers and prevent pitching-induced injuries to a population that is significantly vulnerable.

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