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Acute Upper-Body and Lower-Body Neuromuscular Fatigue Effect on Baseball Pitchers' Velocity: A Pilot Study

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Abstract

Tremblay, M, Anderson Sirois, S, Verville, W, Auger, M, Abboud, J, and Descarreaux, M. Acute upper-body and lower-body neuromuscular fatigue effect on baseball pitchers' velocity: A pilot study. *J Strength Cond Res* 38(8): 1447–1452, 2024—The purpose of this pilot study was to explore the acute effect of upper-body and lower-body neuromuscular fatigue protocols on baseball pitchers' velocity. Sixteen baseball pitchers were recruited, and a crossover design was used to meet the study purpose. Pitchers were tested twice, 7 days apart, with their upper-body and lower-body explosiveness, pitching velocity, and muscle soreness perception of their throwing arm (forearm flexors, biceps, anterior deltoid, and upper trapezius muscles) assessed before and after an upper-body and lower-body neuromuscular fatigue protocol. Two-way analysis of variances and paired *t* tests ($p < 0.05$) were used to identify and compare prescores and postscores. Following both fatigue protocols, results revealed a significant decrease in time for pitching velocity ($p = 0.005$, $\eta p^2 = 0.462$), and increases in muscle soreness perception of the forearm flexors ($p = 0.005$, $\eta p^2 = 0.470$), anterior deltoid ($p = 0.045$, $\eta p^2 = 0.274$), and upper trapezius ($p = 0.023$, $\eta p^2 = 0.339$) muscles. Paired *t* test results showed a significant decrease in preneuromuscular and postneuromuscular fatigue protocol in the upper-body ($p < 0.01$) and lower-body ($p < 0.01$) explosiveness scores. These pilot study results show the impact of different exercise protocols on pitchers' explosiveness, velocity, and muscle soreness perception emphasizing the need for further investigation into the acute effect of exercise targeting the upper or lower-body on pitching performance, specifically at the pitcher's position.

Key Words: baseball pitching, muscle fatigue, performance, muscle soreness, explosiveness, motor control

Introduction

Neuromuscular fatigue is defined as any exercise-induced reduction in a muscle or muscle group capacity to produce power or strength (17). If not properly monitored, this phenomenon can significantly alter sports performance and potentially lead to negative outcomes in athletes such as an increased risk of musculoskeletal injuries (10,18). A better understanding of the neuromuscular fatigue phenomenon is critical to ensure repetition of athletes' peak performance.

In baseball, pitching is a repeated throwing skill involving maximum efforts being performed in both practice and game settings. Therefore, pitchers performance and workload are closely monitored by coaches and health specialists to avoid overuse or traumatic injuries (5). The different phases of the pitching motion involve the pitchers' lower limbs, upper limbs, and core muscles to execute the throwing action and produce velocity (4). In addition, previous studies have shown that multiple factors are associated with greater pitching velocity at the pitcher's position such as anthropometrics, kinematics, and kinetics factors as well as athletic abilities (15,19).

A recent systematic review by Birfer et al. (3) explored evidence regarding the manifestation of muscle fatigue in baseball pitching in an attempt to investigate the possible link between kinematics, performance, and injury. The results of original studies included in the review suggest that codependence exists between changes in upper and lower limbs and trunk kinematics and decreased pitching performance. Most studies included in the review investigated the impact of muscle fatigue occurring when pitch count increases. However, other parameters such as pitchers' external loads and internal loads associated with strength and conditioning-related training can potentially alter pitching performance and the neuromuscular function of baseball pitchers (9,16). External loads refer to the measurable work completed by pitchers in their training session independently of their internal psychological and physiological state, whereas the latter refer to the internal loads imposed on the pitchers by the training session (9).

For instance, the study by Freeston et al. (7) compared the throwing velocity, throwing accuracy, and throwing arm soreness perception before and after a throwing-specific and general running exercise in baseball players. The authors found that the players' throwing velocity, throwing accuracy, and throwing arm soreness were negatively affected by both throwing-specific and general running exercise and that throwing velocity was reduced to a similar degree after both types of exercise. Such results raise

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the following question: Does specific muscle fatigue, involving either the upper or lower limb muscles, affect baseball pitchers' pitching velocity similarly? To our knowledge, no study has examined the effect of specific acute upper and lower limbs' fatigue exercise in baseball pitchers.

Therefore, the purpose of this pilot study was to explore the acute effect of upper-body and lower-body neuromuscular fatigue protocols on baseball pitchers' velocity. We hypothesized that the upper-body and lower-body neuromuscular fatigue protocols would decrease pitching velocity and that the pitching velocity decrease would be greater for the upper-body neuromuscular fatigue protocol than for the lower-body neuromuscular fatigue protocol.

Methods

Experimental Approach to the Problem

To meet the purpose of this pilot study, a quasi-experimental crossover design including 2 experimental sessions was used to determine and compare the acute effects of upper-body and lower-body neuromuscular fatigue protocols on baseball pitchers' velocity. The experimental sessions were conducted 7 days apart to let the pitchers recover from the neuromuscular fatigue protocols. In both experimental sessions, both upper-body and lower-body neuromuscular fatigue protocols were performed. In order not to interfere with the program training schedule and pitchers' school schedule, the baseball program head coach assigned pitchers' equally to either the upper-body or lower-body fatigue protocol at the start of experimentation. Pitchers then switched to the other protocol during the second experimental session. Pitchers and their parents or guardian (if age younger than 18 years) were informed of the risks and benefits before providing their written informed consent to participate in the study. The Université du Québec à Trois-Rivières local ethics committee approved the study (no. CER-22-288-07.14).

Subjects

Sixteen male baseball pitchers (17.00 years ±0.82, range: 15–19) from the Académie de Baseball du Canada (Academy Baseball Canada) participated in this study. This academy consists of the best baseball players in the province of Quebec, Canada in the mentioned age group and plays its competitive season mostly between the end of April and the end of October each year. To be included in the study, pitchers must identify the pitching position as their primary playing position. Pitchers needed to be injury free and able to participate in the latest baseball-related activities of the baseball program. Pitchers who reported being injured in the past 6 months or who had pain before or while participating in the study were excluded.

Procedures

The experimental sessions took place in mid-April 2022 just before the start of the competitive season. Pitchers were required to attend the testing on 2 separate occasions, on the same day, a week apart (washout period). The testing was conducted in the beginning of the afternoon at the academy's training facility at the same time in both experiments. The academy's usual body warm-up and throwing routines were performed by pitchers before both experimental sessions. Pitchers were instructed to be ready to throw at full capacity before the beginning of the experimental sessions. Evaluators were kinesiology students or trained kinesiologists specialized in performance evaluation and kept their experimental assessments task through the end of the project. Figure 1 presents the schematic structure and testing order of assessments throughout the experimental sessions for both the upper-body and lower-body neuromuscular fatigue protocols.

Anthropometric Measurements. Pitchers' height and body mass were measured once on the first day of experimentation for both protocols. Height was evaluated with an SECA 213 mobile stadiometer placed against a flat wall. Pitchers were instructed to stand barefoot on this device, and their height was recorded to the nearest 0.1 cm (14). Pitchers' body mass was measured using a portable SECA 876 scale positioned on a solid surface. Pitchers were asked to step onto the scale without wearing shoes, and their body mass was recorded to the nearest 0.1 kg (14).

Upper-Body Explosiveness—Seated Medicine Ball Throw. Upper-body explosiveness assessment was measured before and after the upper-body neuromuscular fatigue protocol. The Ballistic Ball (MoveFactorX, MI) was used to assess the upper-body explosiveness with the peak velocity value measured in meters per second ($m{\cdot}s^{-1}$). The seated medicine ball throw protocol was used and performed as described in the study by Beckham et al. (19) investigating test-retest reliability using the Pearson's interclass coefficient (r) and coefficient of variation (CV) of the ballistic ball ($r = 0.94$–0.98; CV % = 4.2–6.8). Peak velocity score was shown to be correlated to pitching velocity in different youth age groups. Pitchers were allowed to perform 3 familiarization throws with corrections from evaluators if they were performed incorrectly. Three maximum capacity throws were assessed, and the mean value of peak velocity of the throws was used for statistical analysis.

Lower-Body Explosiveness—Countermovement Jump. Lower-body explosiveness assessment was measured before and after the lower-body neuromuscular fatigue protocol. To assess lower-body explosiveness, pitchers performed the countermovement vertical jump where the vertical jump height in centimeters (cm) was recorded. To assess the vertical jump height, the Optojump photoelectric cell instrument was used (Microgate, Bolzano, Italy). In their study, Glatthorn et al. (8) investigated the concurrent validity and reliability of the Optojump instrument when compared with the gold standard force plates and showed strong concurrent validity and reliability in assessing vertical jump performance (intraclass correlation coefficient [ICC]) [ICC = 0.998 (0.995–0.999)] 95% confidence interval and reliability [ICC = 0.984 (0.960–0.994); CV% = 2.8]. Pitchers were instructed to stand between the bars of the Optojump instrument with their hand on their hips, to jump as high as they could, and land on both feet in a static position. Pitchers performed 2 familiarization jumps. After recovery of the familiarization jumps, 3 jumps were recorded at full capacity. The mean value of jump height was used for statistical analysis.

Pitching Velocity Assessment. Pitching velocity was measured using the Rapsodo Pitching 2.0 system. This monocular camera-based system was positioned on the ground 4.72 meters in front of the home plate. Pitchers used a 141.75-gram regular baseball to assess their pitching velocity. Pitchers academy's usual warm-

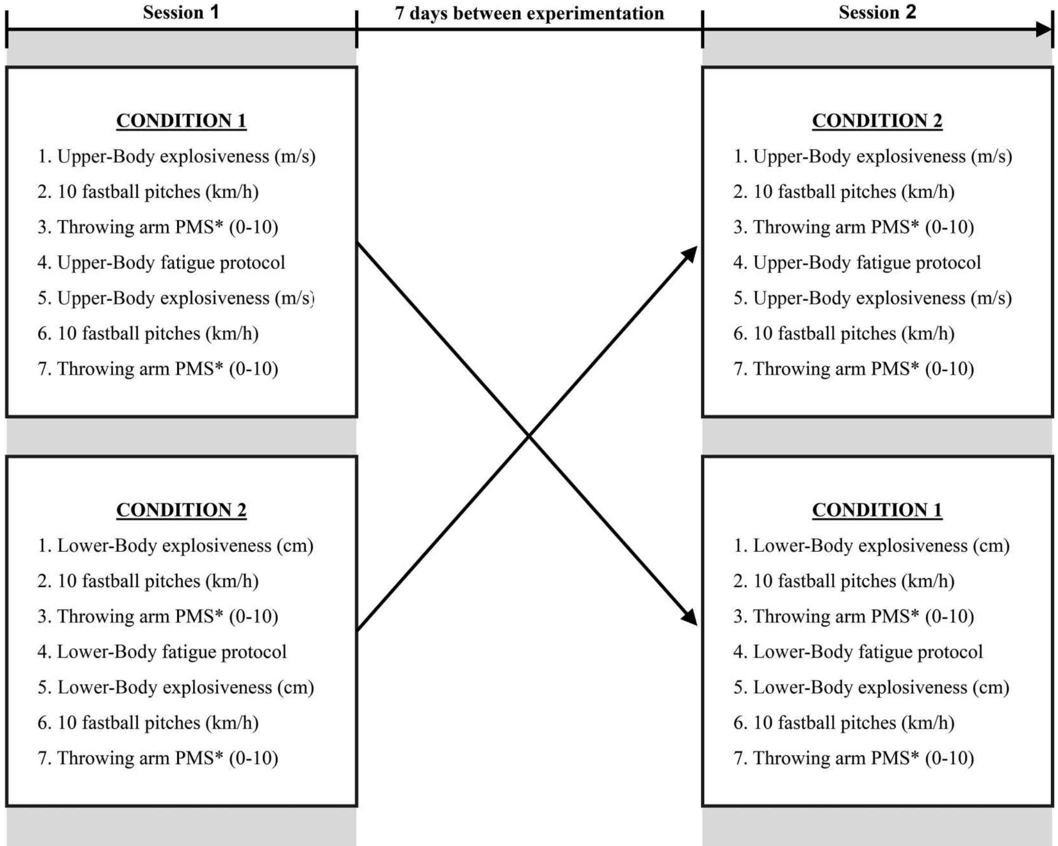

Figure 1. Schematic structure and testing order for both the upper-body and lower-body neuromuscular fatigue protocols.

up and throwing routines were realized before experimentation. The velocity of 10 fastball pitches at full capacity on the pitching mound in a windup position was recorded before and after the neuromuscular fatigue protocol. Pitchers threw to a catcher set in the center of the home plate and were asked to throw at the catcher's glove as accurately as possible as they would in a game to get batters out. The pitching mound was positioned to a standard 18.44 meters away from the home plate. The mean velocity of pitches in kilometers per hour was used for statistical analysis.

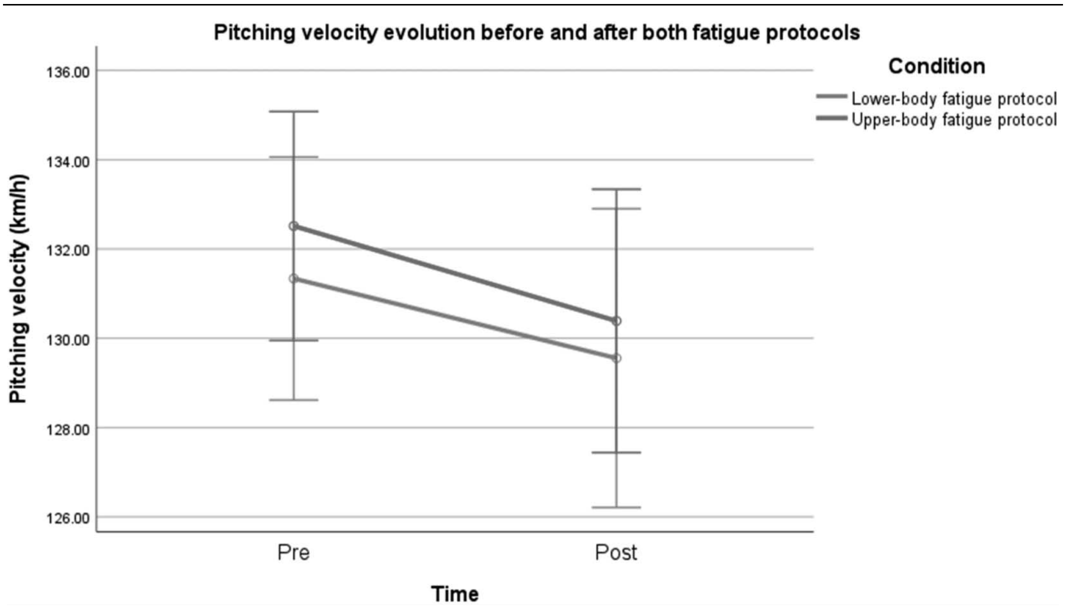

Figure 2. Pitching velocity evolution before and after both fatigue protocols.

Throwing Arm Muscle Soreness Perception. Throwing arm muscle soreness perception (PMS) was assessed using a numerical scale of 0–10 (12) for the following muscles: forearm flexors, biceps, anterior deltoid, and upper trapezius muscles of the pitchers' throwing arm. Measures were recorded after the first round of 10 pitches at full capacity before the neuromuscular fatigue protocol and after the second round of 10 pitches at full capacity. Pre-PMS and post-PMS scores in both protocols were used for statistical analysis.

Exercise Protocol

Upper-Body Neuromuscular Fatigue. The upper-body neuromuscular fatigue protocol consisted of rounds of push-ups to failure to induce upper-body neuromuscular fatigue in pitchers. The protocol was inspired by the Bauer et al. (2) study investigating the effects of fatigue on throwing performance in male adolescent handball players with a push-up protocol. The evaluators instructed the required push-up techniques to the pitchers. The instructions were based on the *American College of Sports Medicine* fitness assessment manual for push-up assessment (1). The first step of the protocol had the pitchers execute maximum push-ups with the correct techniques to failure counted by the evaluator. Pitchers had a 1-minute recovery period and then returned to a second round of push-ups to failure. If the second round of push-up scores was above 60% of the previous round's score, an additional round of push-ups was done after the 1-minute recovery period. If the score was below 60% of the previous round's score, the pitchers were considered "fatigued." After the last round of push-ups to failure, measurements of pitchers' upper-body explosiveness were immediately taken. Then, pitchers went immediately to the pitching mound where the second 10-fastball pitches' velocity was recorded.

Lower-Body Neuromuscular Fatigue. The lower-body neuromuscular fatigue protocol consisted of rounds of a 1-minute maximal repeated countermovement vertical jump to failure. The protocol was derived from the protocol used in the study by Lesinki et al. (13) investigating the effects of fatigue induced by the repetition of vertical jumps. The countermovement jump technique was similar to the one used to assess lower-body explosiveness. To ensure that pitchers went deep enough in each jump, a box jump was positioned with its lowest height placed in the vertical position. Pitchers had to squat and touch the box within each jump. A first round was realized, and the evaluators recorded the number of jumps. Pitchers had a 1-minute recovery period and then returned for a second round. If the second round of jumps was above 60% of the previous round's score, an additional round of jumps was done after the 1-minute recovery period. If the score was below 60% of the previous round's score, the pitchers were considered "fatigued." After the last round of jumps to failure, measurements of pitchers' lower-body explosiveness measures were immediately taken. Then, pitchers went immediately to the pitching mound where the second 10-fastball pitches' velocity was recorded.

Statistical Analyses

Descriptive data including mean ± *SD* were calculated. Normal distribution was assessed using the Shapiro-Wilk test and visual inspection. To meet the pilot study objectives and hypotheses, data were analyzed using 2-way repeated measures analysis of variance (ANOVA) (Fatigue condition × Time) to determine and compare before and after differences for pitching velocity in both neuromuscular fatigue conditions and PMS of the throwing arm muscles. Effect size was calculated using partial-eta squared (ηp^2). Paired *t* tests were performed to identify the before and after differences in upper-body and lower-body explosiveness assessment. The significance levels for all analyses were set to $p < 0.05$. Statistical computations were performed using IBM SPSS Statistics version 28.0.0 (Microsoft, Armonk, NY).

Results

Descriptive data and mean anthropometric measurements, upper-body and lower-body explosiveness, throwing arm PMS, and pitching velocity assessments are presented in Table 1. One pitcher did not perform the upper-body neuromuscular fatigue protocol because he was invited to a national prospect camp evaluation. One pitcher did not complete the lower-body neuromuscular fatigue protocol reporting significant muscle soreness on the second week of testing. One pitcher upper-body explosiveness data were incomplete because of instrumentation technical problems (MoveFactorX ballistic ball).

Results of the 2-way ANOVA for pitching velocity showed a significant main effect of time with a decrease in pitching velocity following both neuromuscular fatigue protocols ($F_{(1,13)} = 11.170$, $p = 0.005$, $\eta p^2 = 0.462$). No fatigue condition effect was found for both fatigue protocols ($F_{(1,13)} = 1.301$, $p = 0.275$, $\eta p^2 = 0.091$). No significant fatigue condition × time interaction was found for pitching velocity ($F_{(1,13)} = 0.108$, $p = 0.747$, $\eta p^2 = 0.008$). Figure 2 presents results of pitching velocity before and after for both neuromuscular fatigue protocols.

Results of the 2-way ANOVAs for the throwing arm PMS showed a significant main effect of time for both protocols with an increase in PMS for the forearm flexors ($F_{(1,13)} = 11.525$, $p = 0.005$, $\eta p^2 = 0.470$), anterior deltoid ($F_{(1,13)} = 4.904$, $p = 0.045$, $\eta p^2 = 0.274$), and upper trapezius ($F_{(1,13)} = 6.656$, $p = 0.023$, $\eta p^2 = 0.339$) muscles. No main effect of time was found for the biceps muscle in both protocols ($F_{(1,13)} = 3.721$, $p = 0.076$, $\eta p^2 = 0.223$). A fatigue condition effect was present for the upper trapezius muscle ($F_{(1,13)} = 4.839$, $p = 0.047$, $\eta p^2 = 0.271$) with PMS scores being higher for the lower-body fatigue condition than for the upper-body fatigue condition (pre: 0.87 ± 2.13; post: 3.07 ± 2.25 vs. pre: 2.20 ± 2.18; post: 2.80 ± 2.24). No fatigue condition × time interaction was found between protocols for PMS scores (forearm flexors: $F_{(1,13)} = 0.011$, $p = 0.917$, $\eta p^2 = 0.001$; biceps: $F_{(1,13)} = 2.273$, $p = 0.156$, $\eta p^2 = 0.149$; anterior deltoid: $F_{(1,13)} = 0.563$, $p = 0.466$, $\eta p^2 = 0.042$; upper trapezius: $F_{(1,13)} = 0.770$, $p = 0.396$, $\eta p^2 = 0.056$).

Results of paired *t* tests of pre and post neuromuscular fatigue upper-body explosiveness scores ($t_{(13)} = 4.95$, $p < 0.01$) and lower-body explosiveness scores ($t_{(14)} = 6.12$, $p < 0.01$) showed similar results with a significant decrease in explosiveness in both upper limb and lower limb power scores.

Discussion

The purpose of this pilot study was to explore the acute effect of upper-body and lower-body neuromuscular fatigue protocols on

Table 1

Descriptive data and mean of the anthropometric measurements, upper-body and lower-body explosiveness, throwing arm perceived muscle soreness, and pitching velocity assessments.*

Variables	Age (y)	Height (cm)	Body mass (kg)	UB-E Pre (m·s^{-1})	UB-E Post (m·s^{-1})	PV Pre (km·h^{-1}) UBP	PV Post (km·h^{-1}) UBP	LB-E Pre (cm)	LB-E Post (cm)	PV Pre (km·h^{-1}) LBP	PV Post (km·h^{-1}) LBP
N	16	16	16	14	14	15	15	15	15	15	15
Mean	17.00	185.90	91.26	5.91	5.35	132.80	130.69	40.03	30.96	131.35	129.74
SD	0.82	5.58	11.44	0.53	0.54	4.42	5.06	4.82	5.01	4.54	5.63

Throwing arm

Right-handed	*N* = 11	Left-handed	*N* = 5

Throwing arm PMS (0–10)

UBP	Forearm flexors	Biceps	Anterior deltoid	Upper trapezius
Pre	3.60 ± 1.35	4.07 ± 2.05	2.60 ± 2.38	2.20 ± 2.18
Post	4.60 ± 2.38	5.20 ± 2.51	3.40 ± 2.53	2.80 ± 2.24
LBP	**Forearm flexors**	**Biceps**	**Anterior deltoid**	**Upper trapezius**
Pre	3.60 ± 1.50	4.20 ± 2.01	3.07 ± 2.25	0.87 ± 2.13
Post	4.60 ± 1.64	4.60 ± 1.84	3.93 ± 2.58	3.07 ± 2.25

*LB-E = lower-body explosiveness; LBP = lower-body protocol; NF = neuromuscular fatigue; PMS = perceived muscle soreness; PV = pitching velocity; UB-E = upper-body explosiveness; UBP = upper-body protocol.

baseball pitchers' velocity. Our findings do not confirm our initial hypothesis, stating that the upper-body neuromuscular fatigue protocol would yield a greater decrease in pitching velocity than the lower-body neuromuscular fatigue protocol. In addition, both fatigue protocols showed a significant decrease in pitching velocity over time with large effect sizes.

The decline in pitching velocity was followed with a decrease in mean upper-body and lower-body explosiveness scores induced by both types of neuromuscular fatigue protocols. The results of this study highlighting a pitching velocity decline following the upper-body neuromuscular fatigue protocol are similar to those reported by Bauer et al. (2). Their results showed a decrease in throwing velocity among youth handball players of age 14–16 years following an upper-body neuromuscular fatigue protocol. Regarding lower-body explosiveness and motor performance decrease, Lesinski et al. (13) investigated the effects of fatigue induced with a similar repetitive vertical jumps fatigue protocol on jump performances and leg muscles activity in young male and female volleyball players. Although the study did not specifically compare lower-body neuromuscular fatigue protocol effect with a throwing task, the study results revealed a decrement in motor performance such as decrease in jump height and leg muscle activation. The results of both studies highlight the relevance of investigating fatigue-induced effect in the upper and lower limbs on baseball pitchers' velocity.

This pilot study is the first to compare the acute effect of an upper-body and lower-body neuromuscular fatigue protocol on pitching velocity in pitchers using a protocol that simulates the pitching task during competition (pitchers throwing from a pitching mound 18.44 meters away from a catcher). Freeston et al. used a similar study protocol but compared the effects of a throwing-specific and running protocol on markers of arm fatigue in baseball players without specifications about their playing position. Their results showed that mean and peak maximal throwing velocity decreased after both exercise protocols. In addition, they found that rating of general arm soreness increased significantly in players after the throwing protocol in comparison to the running exercise protocol.

In this pilot study, pitchers reported greater muscle soreness perception with large effect size over time in specific muscles for both fatigue protocols from baseline for the forearm flexors, anterior deltoid, and upper trapezius muscle. The upper trapezius PMS score was different between the 2 neuromuscular fatigue protocols. The push-up protocol further engaging the upper trapezius muscle compared with the repeated jumps protocol may explain this result. The functional role of this muscle is to assist retraction and stabilization of the scapula while pitching (11), and its activation is particularly high during the arm cocking phase and arm deceleration of the pitching motion (6). However, PMS scores did not change for 8 of the 15 pitchers following the lower-body fatigue condition making it hard to draw any strong conclusions. Further study with a larger sample should investigate the evolution of muscle soreness perception scores and pitching velocity in baseball pitchers to better understand their concomitant evolution.

Aside from the small sample size and preliminary nature of the results, other limitations of the current pilot study should be considered for a future study with a larger sample size. First, in order not to interfere with the athletes' training schedule, no randomization was done, and pitchers were assigned by the head coach to the fatigue protocols at the start of the experimentation. Second, pitchers were still in their preseason preparation. In-season testing would maybe have yielded different results, as pitchers would have been in peak physical condition and in-season form. Third, components of physical fitness selected for the neuromuscular fatigue task were different between fatigue protocols. Maximal push-ups assessment relates more to muscle endurance capacity and repeated vertical jumps more toward repeated muscle capacity to produce power. Fourth, the time between the neuromuscular fatigue protocols, upper-body and lower-body explosiveness, and the last round of pitching velocity assessment was not quantified. This limitation could have influenced the level of neuromuscular fatigue between subjects despite the fast transitions made between these assessments. To conclude, future investigations should examine the chronic effects of upper-body and lower-body neuromuscular fatigue protocol during repeated training block of upper-body and lower-body exercise such as delayed-onset muscle soreness on pitching performance.

Practical Applications

This pilot study compared both upper-body and lower-body neuromuscular fatigue condition on baseball pitchers' velocity. Preliminary results showed that pitchers' velocity and neuromuscular function decreased when exposed to a specific fatigue condition targeting either the upper or the lower limbs. These results suggest that practitioners working with pitchers should be aware that pitchers' neuromuscular function will be affected not only by pitching repetition but also after training-related exercises such as maximal push-ups or maximal jumps protocols. Such exercises may have negative consequences on pitching performance parameters such as pitching velocity. Altogether, these results suggest that strength and conditioning specialists should manage pitchers' training workload during upper-body and lower-body oriented training before pitchers need to perform pitches at full capacity and where pitching velocity achievement are important, for example, during showcase or recruiting events. It is important to mention that combined with a decrease in pitching velocity and neuromuscular function, pitchers' throwing arm muscle soreness increased as much after upper or lower-body fatigue condition, especially in the forearm and shoulder region. Therefore, a combination of neuromuscular function, subjective muscle soreness perception, and sport-specific performance assessment seems necessary to manage and monitor baseball pitchers' acute workload and performance.

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