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THE EFFECTS OF CONTRALATERAL BASEBALL THROWING PRACTICE ON DOMINANT ARM THROWING PERFORMANCE: A PILOT STUDY

Raad H. Gheith[1], Matthew H. Sharp[1], Dallen A. Reber[1], Matthew W. Stefan[1], Salvatore LoDuca[2], Ryan P. Lowery[1], and Jacob M. Wilson[1]

[1] The Applied Science & Performance Institute, Research Department; Tampa, FL, USA, 33607
[2] Robosport Technologies, LLC, Whitestone, NY, USA, 11357

**Corresponding author: rgheith@theaspi.com*

ABSTRACT

Baseball throwing is typically performed with one dominant arm, and after years of throwing, the skills becomes autonomous and improvement is slowed. Incorporating training of the non-dominant arm could induce a cross-education effect and assist in improving the dominant throwing arm. Therefore, the purpose of this study was to determine the effect of contralateral (CL) throwing practice on dominant arm throwing accuracy and other parameters in experienced baseball players. Sixteen in-season male baseball players were randomly assigned to either contralateral (CL) or control (CON) following a pre-test of 30 dominant throws to a standard catch net. Both groups participated in a baseball specific practice schedule whereas only the CL group underwent additional throwing practice. The additional throwing practice sessions consisted of 30 non-dominant arm throws from a randomized location to a standard catch net, twice a week for 4 weeks. Following the 4 weeks of training, participants were post-tested to determine the effects of the contralateral throwing program. Throwing accuracy percentage, throwing velocity, Accuracy:Velocity ratio (Acc:Velo), and other non-throwing specific parameters were collected in the dominant limb to determine the effect of the contralateral throwing program. A significant group by time interaction was detected for throwing accuracy ($p = 0.032$) favoring a significant improvement in the CL group (CL: +16%, ES = 0.76, $p<0.001$; CON: +4%, ES = 0.25, $p = 0.472$). Likewise, a significant group by time interaction was detected for Acc:Velo ($p = 0.045$) favoring a significant improvement in the CL group (CL: +17%, ES = 0.80, $p = 0.002$; CON: 4%, ES = 0.21, $p = 0.673$). No significant differences for throwing velocity or non-throwing specific parameters were detected ($p > 0.05$). Contralateral throwing practice improved accuracy and Acc:Velo ratio in the CL group. Use of a contralateral training can be used to improve performance in a well-learned, complex, open skill such as baseball throwing drills.

Keywords: Motor learning, contralateral training, baseball, accuracy, velocity

INTRODUCTION

Motor learning is the relatively permanent increase in the capacity to express skill as a result of practice or experience (1,2). Research indicates that learning occurs in at least three stages (1). The first is known as the cognitive verbal stage in which learning is rapid and cognitive challenges and cortical output are at their greatest. These are followed by the associative and autonomous stages. During the associative stage, the learner has formed an internal representation of how to perform a given skill and refines it via auditory, and visual feedback. Learning is moderate during this phase as is cognitive effort. During the autonomous stage, cognitive effort and cortical output are at their lowest while the skill becomes automatic and learning is asymptotic or plateaued.

In throwing sports (i.e. baseball, football, softball), throwing is typically done with one dominant arm. After years of practice this skill reaches an autonomous stage where velocity and accuracy improvements are slowed (1). However, due to the lack of practice, the untrained non-dominant arm has room for substantial progress as it is in the cognitive verbal (early) stage of learning. Non-dominant arm training, hereafter referred to as contralateral training (CL), induces a cross-education effect from a rapidly improving non-dominant arm, may be a potential solution to elevate skill in the dominant arm. The cross-education of strength and skill learning was first discovered in 1894 by Scripture et al.(3), who found that muscular strength and task steadiness (skill) could be improved in the contralateral limb following unilateral training. Cross-education of strength refers to the strength gain that is transferred to the contralateral limb following a unilateral training program in the ipsilateral limb. An extensive meta-analysis demonstrated an 18% average increase in strength (4) via cross-education training. Indeed, extensive research has been done in strength training using very controlled unilateral movements. However, the improvement of motor skills is an important clinical aspect that has been widely overlooked in contralateral training literature (4). Recent research (5) has demonstrated that training in the contralateral arm reduced variability of force in the ipsilateral arm indicating an increase in skill. To date, however, the literature lacks research in more complex and open skills such as the throwing that occurs in baseball.

Indirect research demonstrates that baseball players who bat opposite of their dominant throwing arm (e.g. left-handed hitter, right-handed thrower) demonstrate greater baseball performance than those who bat and throw on the same side (6). These data indicate that contralateral training may offer a performance advantage in baseball. Moreover, our recent data demonstrated that the combination of randomized contralateral batting practice can improve performance in the dominant baseball batting swing (7). However, the cross-education effect in well-trained baseball players who have plateaued, or reached the autonomous stage in throwing accuracy, has yet to be examined. While looking to determine the impact of cross-education on well-trained baseball players, the use of randomized practice should benefit training as it has been shown in baseball hitting to improve performance and learning (7,8), but has yet to be investigated in baseball specific throwing.

There are numerous variables that relate to throwing that can determine one's performance or assist in injury prevention. Such variables can include velocity, accuracy, shoulder range of motion, grip strength, and rotational strength of the shoulder (9–11). Decreases in velocity, range of motion, or different areas of strength could be a sign of fatigue and a precursor to injury. There are difficulties maintaining strength due to lean mass loss (12) and discrepancies in range of motion of the shoulder (13) over the course of a competitive baseball season.The ability to maintain peak performance over your opponent by the end of a season while they deal with fatigue can provide a competitive advantage. Additionally, with limited availability to train during a season, particularly in high school athletes due to their in-season training/practice regulations (14), players could benefit from improving their velocity, accuracy, and other non-throwing specific parameters without using their dominant arm more than necessary.

Investigating the ratio of accuracy to velocity over time can assist a player's performance as the ability to maintain one's accuracy while increasing velocity, or vice versa, can be difficult as one of the variables is commonly sacrificed for improvement in the other (Speed-Accuracy Tradeoff) (2). Ballistic skills, such as baseball throwing, require maximum amounts of force to be applied in a rapid, sequential manner and if an athlete attempts to alter their skill in any form, sacrifices in speed or accuracy can occur (15). Freeston et al. (16) found decreases in accuracy as well-trained baseball players progressed from throwing 10 balls at 80% maximum velocity to 100% of maximum velocity to a 7-cm target placed 20m away. The authors concluded that there was speed-accuracy trade off at 100% of maximum velocity, but not at 80%. Therefore, an athlete who can avoid the speed-accuracy trade off can maintain a competitive advantage.

The primary purpose of this study was to examine the effects of contralateral throwing practice on throwing specific and non-throwing specific parameters in the dominant limb during a season in well-trained baseball players. Non-dominant arm throwing practice was only used as a training intervention during the duration of the study. We hypothesized that contralateral throwing would improve accuracy and improve non-throwing specific parameters, albeit to a lesser extent.

METHODS

Participants

A total of 16 healthy high school baseball players with at least 6 years' experience of organized baseball play comprised the participant pool. All players in the study were recruited from the same high school baseball team and thus following the same baseball practice schedule (i.e. 4 baseball specific practice sessions and 2 competitive games per week). The participant pool consisted of an equal number of pitchers and position players (n=8 pitchers, n=8 position players). The participants needed to be free of musculoskeletal injuries within the previous six months at the start of the study. All participants were asked on their handedness and confirmed to be right-handed following observation during familiarization sessions. Eligibility was determined during screening prior to enrollment. Prior to the commencement of the study, written informed consent was obtained from the participants and their parent(s) or legal guardian(s). The procedures carried out in this study were approved by an Institutional Review Board (IntegReview, Austin, TX; Protocol #051902) and in agreement with the Declaration of Helsinki. Baseline descriptive statistics are provided in Table 1.

Table 1. Baseline Descriptive Statistics.

Variable	CL	CON
Age (years)	16.6 (0.3)	15.6 (0.4)
Height (cm)	177.2 (1.4)	182.8 (2.1)
Weight (kg)	75.0 (6.6)	78.3 (9.3)
Baseball Experience (years)	8.9 (0.3)	7.9 (0.4)

Data are expressed as mean (SEM). CL: Contralateral, CON:Control

Familiarization & Participant Randomization

The week prior to baseline testing, participants underwent two familiarization sessions separated by 48 hours to mimic the protocol's rest period between throwing sessions. The purpose of the familiarization session was to acquaint participants with study procedures. In both familiarization sessions participants were informed of the study timeline, scoring system (Figure 4) and layout of the throwing training session (Figure 2). Thereafter, participants completed a walkthrough demonstrating the training protocol and testing procedures for throwing performance, hand grip and shoulder dynamometry detailed below. At the end of the second familiarization session and following a dynamic warm-up, subjects completed three maximum intent throws from flat ground into a catch net and velocity of each throw was collected with a radar gun (Stalker ATS II, Stalker Sport; Richardson, TX, USA) behind the catch net. The three throws were averaged, and participants were quartile ranked based on the average maximum velocity. Participants within each quartile were randomly assigned to either the control (CON) or CL group using a random number generator (random.org).

Throwing Practice Protocol (4-week Training Period)

All participants continued their regular team practice schedules during the study. However, the CL group also included 30 non-dominant arm throws performed 2 non-consecutive days (separated by 48 hours) per week for 4 weeks, totaling 240 non-dominant arm throws (60 per week). For each training session, participants stood with their backs against the target (catch net), retrieved a baseball from the ground placed at one of three randomized locations; turned, stepped, and threw toward a catch net. The sequential order of randomized ball retrieval was predetermined by research personnel, which differed every throwing session and was blinded to participants. For each throwing session, participants completed ten throws from each of three randomized ball locations. The catch net remained in a stagnant location for all training sessions. Participants were instructed to release the ball behind a throwing line marked 15.25 m from the catch net. The catch net (PitchersPocket9, BetterBaseball; Marietta, GA, USA) measured 91.4 cm wide, 106.7 cm tall, and 121.9 cm diagonal including a cushioned frame. Within the frame of the catch net were 9 catch pockets measuring approximately 25.4 cm wide by 30.5 cm in height. Participants were instructed to aim for the center most catch pocket ("target") for every throw (Figure 1). After each throw, participants reset with their back to the catch net and repeated the procedure for 30 throws. An illustration of the training procedure is provided in Figure 2.

Figure 1. Illustration of the Catch Net.

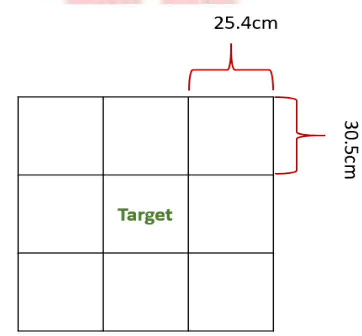
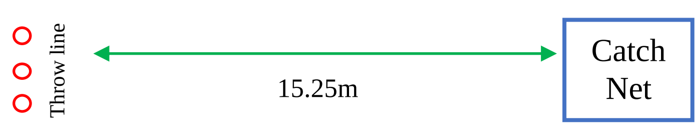


Figure 2. Illustration of Training Procedure.



Pre- and Post-Throwing Performance

To assess throwing performance objectives, the authors created a standardized throwing performance assessment in which all participants performed at pre- and post-testing. The test included 30 throws in total that were all completed with the dominant arm. Participants stood with their backs against the target (catch net), retrieved a baseball from the ground at a non-randomized location; turned, stepped, and threw toward the catch net. Participants were instructed to release the ball behind a throwing line marked 15.25 m from the catch net and aim for the center most catch pocket for each throw. The location of the catch net and baseball remained constant for pre- and post-testing for each of the 30 throws (Figure 3). All throws were scored according the to the following: center pocket = 5 points, surrounding pockets = 3 points, foam padding = 1 point, miss/other = 0 points (Figure 4). A radar gun was placed behind the catch net to collect velocity of each throw. This was used for the measurements of throwing velocity and accuracy-to-velocity ratio (Acc:Velo).

Figure 3. Illustration of Pre- and Post-Testing Procedure.

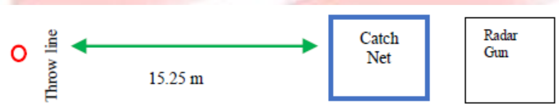
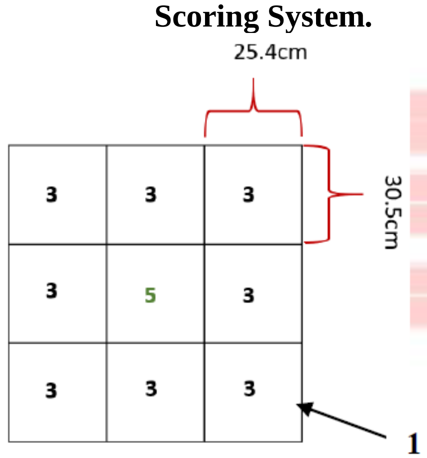


Figure 4. Illustration of the Catch Net Scoring System.



Hand Grip Strength

Maximal hand grip strength was assessed in the dominant hand via hand grip dynamometry (Trailite, Digital Hand-Dynamometer, Germany). Participants were asked to stand with the dynamometer in hand with the arm parallel to the body without squeezing the arm against the body. The width of the handle was adjusted to the size of the hand such that the middle phalanx rested on the inner handle. Participants were allowed to perform one practice trial. Thereafter, participants underwent three testing trials separated by 1-minute rest. The best result of the three testing trials was recorded in kilograms and used for analysis. Participants were asked to exert maximal effort and strong verbal encouragement was used for the testing trials. Hand grip strength was assessed at pre- and post-testing.

Shoulder Isometric Dynamometry

Maximal voluntary isometric contraction (MVIC) of internal and external shoulder rotation was assessed on the dominant arm using a dynamometer (Biodex System 3, Biodex Medical System; Shirley , NY, USA). Prior to testing, the dynamometer was calibrated to the manufacturer's guidelines. Internal and external range of motion values were collected upon calibration prior to testing to assess range of motion limits. Participants were seated at the respect to the dynamometer with the shoulder in 90° of abduction, the elbow in 90° of flexion, and the forearm/wrist pronated. Stabilization belts were fastened across the trunk, pelvis, and thigh to prevent movement compensation. The testing protocol consisted of 3 sets of 3 repetitions of MVIC of internal and external shoulder rotation in an alternating fashion separated by 60 seconds rest (i.e. internal rotation, 60s rest, external rotation, 60s rest, etc.). Each maximal isometric contraction lasted 5 seconds. Strong verbal encouragement was used during the testing bout. The data recorded for analysis was the highest peak torque achieved in the 3 sets. Shoulder dynamometry testing occurred at pre- and post-testing.

Statistical Analysis

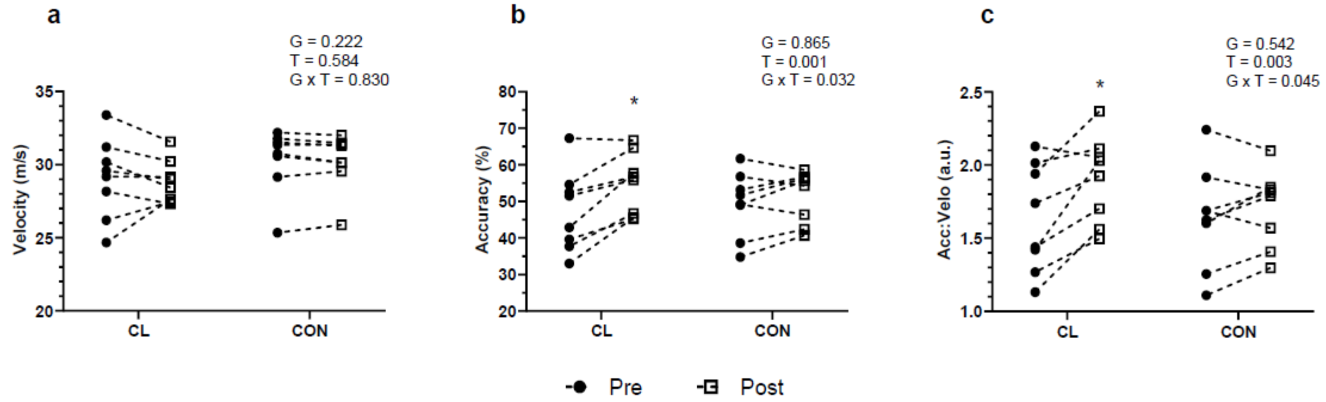
Prior to performing inferential statistics, normality and variance was assured with Shapiro Wilk tests and Levene's test, respectively. Afterwards, an unpaired, two-tailed *t*-test was used to assess differences between groups at Pre. A mixed model was performed on dependent variables assuming group (CL and CON) and time (Pre and Post) as fixed factors with participants as a random factor. Whenever a significant F-value was obtained, a post-hoc test with Bonferroni's adjustment was performed for multiple comparison purposes. Additionally, we included 95% confidence intervals (95% CI) for significant results, and individual delta change values (Post-Pre) are provided for throwing specific parameters. Finally, within-group effect size (ES) was calculated using Cohen's *d* for significant results as [($mean_2$ – $mean_1$)/pooled standard deviation] (17). Ranges for ES analysis were set at <0.2 (trivial), 0.2–0.6 (small), 0.6–1.2 (moderate), 1.2–2 (high), and >2 (very high) (18). All statistical analysis was performed using GraphPad Prism (Version: Prism 8, San Diego, CA, USA). The alpha level was set at $p \leq 0.05$. Data are reported as mean ± standard error of the mean (SEM).

RESULTS

Throwing Parameters

No significant differences between groups were detected at Pre for any dependent variable analyzed in the study (p > 0.05). There were no statistically significant changes detected for throwing velocity (G x T: F = 0.05, p = 0.83; Figure 5a). Table 2 displays individual values for throwing velocity. A significant group by time interaction was indicated for throwing accuracy (F = 5.70, p = 0.03; Figure 5b). Post hoc testing showed that there were no significant differences between groups at Pre (p = 0.98) or Post (p = 0.89); however, only the CL group demonstrated a significant increase from Pre to Post (CL: mean diff = 7.5, 95% CI = 3.4 to 11.6, +16%, ES = 0.76, p < 0.001; CON: mean diff = 2.0, 95% CI = -2.1 to 6.1, +4%, ES = 0.25, p = 0.47). Individual values for throwing accuracy results are reported in Table 3. A significant group by time interaction was detected for Acc:Velo ratio (F = 4.84, p = 0.04; Figure 5c). No between-group differences were detected at Pre (p = 0.99) or Post (p = 0.46); however, the CL group demonstrated a significant increase from Pre to Post whereas CON did not (CL: mean diff = 0.271, 95% CI = 0.105 to 0.437, +17%, ES = 0.80, p = 0.002; CON: mean diff = 0.066, 95% CI = -0.100 to 0.232, 4%, ES = 0.21, p = 0.67). This variable is quantified as (Accuracy % / Velocity in meters per second) and expressed in arbitrary units.

Figure 5. Pre and Post Throwing Velocity (a), Accuracy (a), and Accuracy to Velocity Ratio (c) per Group.



* = significantly different from Pre ($p<0.05$). CL= Contralateral, CON = Control.

Table 2. Individual Throwing Velocity Results $(m \cdot s^{-1})$.

	CL				CON		
Participant	Pre	Post	Δ	Participant	Pre	Post	Δ
1	29.6	29.0	-0.6	9	30.8	30.1	-0.7
2	31.2	30.2	-1.0	10	31.3	31.4	-0.1
3	33.4	31.6	-1.8	11	25.4	25.8	0.4
4	26.2	27.5	1.3	12	31.8	31.5	-0.3
5	28.2	27.3	-0.9	13	30.6	30.1	-0.5
6	29.2	29.2	0.0	14	32.2	32.0	-0.2
7	24.7	27.6	3.0	15	31.5	31.3	-0.2
8	30.2	28.4	-1.8	16	29.2	29.6	0.4
Mean	29.1	28.8	-0.3		30.3	30.2	-0.1
SEM	1.0	0.5	0.6		0.8	0.7	0.1
95% CL of Mean	26.8, 31.4	27.6, 30.1	-1.6, 1.1		28.5, 32.2	28.6, 31.9	-0.4, 0.2

CL = Contralateral, CON = Control.

Table 3. Individual Throwing Accuracy Values (%).

	CL				**CON**		
Participant	**Pre**	**Post**	**Δ**	Participant	**Pre**	**Post**	**Δ**
1	51.5	55.9	4.4	9	38.6	42.4	3.8
2	39.6	45.2	5.6	10	34.8	40.7	5.9
3	67.3	66.7	-0.6	11	56.8	54.3	-2.5
4	37.7	46.7	9.0	12	51.7	56.3	4.6
5	54.6	64.7	10.1	13	49.7	55.7	6.7
6	33.0	45.5	12.5	14	61.7	58.6	-3.1
7	52.5	56.7	4.2	15	53.2	56.7	3.5
8	42.9	57.7	14.8	16	49.2	46.4	-2.8
Mean	47.4	54.9	7.5		49.4	51.4	2.0
SEM	4.0	3.0	1.8		3.2	2.5	1.5
95% CL of Mean	38.1, 56.7	47.8, 61.9	3.3, 11.7		41.9, 56.8	45.5, 57.3	-1.43, 5.5

CL = Contralateral, CON = Control.

Non-Throwing Specific Parameters

There were no significant differences in maximum grip strength (G x T: $F = 1.85$, $p = 0.19$). No significant differences were detected in either group for internal rotation peak torque (G x T: $F = 1.93$, $p = 0.19$), external rotation peak torque (G x T: $F = 0.48$, $p = 0.50$), internal range of motion (G x T: $F = 2.44$, $p = 0.14$), or external range of motion (G x T: $F = 0.71$, $p = 0.41$). Results for non-throwing specific parameters are presented in Table 4.

Table 4. Non-Throwing Specific Parameters.

Variable	CL	CON
Grip Strength (kg)		
Pre	49.3 (2.8)	45.1 (2.8)
Post	50.4 (2.9)	43.4 (2.6)
Int. Shoulder Rot. Peak Torque (N·m)		
Pre	51.4 (5.6)	46.1 (3.9)
Post	50.8 (4.3)	47.0 (4.5)
Ext. Shoulder Rot. Peak Torque (N·m)		
Pre	30.3 (2.0)	26.3 (1.9)
Post	30.2 (2.0)	24.8 (2.0)
Int. Shoulder Rot. ROM (°)		
Pre	42.9 (3.6)	44.0 (3.5)
Post	41.1 (3.2)	46.5 (3.8)
Ext Shoulder Rot. ROM (°)		
Pre	98.1 (5.6)	103.3 (6.5)
Post	98.2 (5.2)	101.4 (6.8)

Data are expressed as mean (SEM). Ext = external, Int = internal, Rot = rotation; CL = Contralateral, CON = Control

DISCUSSION

The primary purpose of this study was to examine the effects of contralateral throwing practice with the non-dominant limb on accuracy, the Acc:Velo ratio, and non-throwing specific parameters in the dominant limb during a competitive baseball season in well-trained baseball players. We hypothesized that contralateral throwing would improve accuracy in the dominant arm. We also hypothesized improvement in non-throwing specific parameters, albeit, to a lesser extent. The hypothesis was partially supported in that throwing accuracy increased by 16% and the Acc:Velo ratio by 17% in the CL group, but there were no improvements in non-throwing specific parameters.

The overwhelming majority of research in cross-education literature has taken place in general strength parameters. A meta-analysis of research demonstrated an 18% average increase in strength in the non-trained arm when exercising in a contralateral manner (4). However, the improvement of motor skills is an important clinical aspect that has been widely overlooked in contralateral training literature. Our research, in which the dominant arm was the “non-trained" arm, was the first that we are aware of that investigated the cross-education effects of a highly complex sports specific skill such as baseball throwing. We found strong agreement with strength literature demonstrating a 16% increase in throwing accuracy in an otherwise asymptotic group of athletes as demonstrated in the CL group (4,19). The lack of improvement in throwing accuracy by the CON group supports that these athletes were well-trained in baseball throwing as they demonstrated a plateau in throwing performance, placing them in the autonomous stage of learning. It is in this stage where theoretical cortical activation is at its lowest and performance improvements are minimal (1).

We posited that underlying measurable physiological parameters, such as improved torque and range of motion and/or general strength, might underlie changes in performance. However, this generalized hypothesis was not supported. While we did not examine other explanations, scientists have proposed two major frameworks to explain cross-education effects (19). The first include "cross-activation models." These models are centered on the observation that contralateral movements result in bilateral increases in corticospinal excitability (19). The associated speculation is that such generalized activity, when present during contralateral practice, leads to concurrent adaptations in neural circuits that project to the untrained arm; thus, improving throwing accuracy in the current study. Alternatively, "bilateral access" models entail that motor programs formed during contralateral practice may subsequently be utilized on the other limb—that is, by the motor program that constitutes the control centers for movements of *both* limbs (20). Considering that cortical activity is greatest during the cognitive verbal phase of learning, it is possible that greater activation improved performance in throwing accuracy. However, to date, this is speculative in our throwing experiment and remains to be studied.

In baseball throwing activities, it has been well described and demonstrated that accuracy is greater at lower velocities (16). In the current study, we observed an improvement in accuracy without a sacrifice in velocity following contralateral throwing practice. This was indicated by an improvement in the ratio of accuracy to velocity (Figure 5a). Indeed, since the time of Fitts (see Kovacs et al., 2008 for explanation) it has been known that there is a strong inverse relationship between velocity and accuracy. Researchers believe that a hallmark of throwing expertise is the ability to sustain high velocities while demonstrating greater than average or excellent improvements in accuracy (21). While we are uncertain of why this ratio improved, previous research in strength literature has shown a decrease in force variation that transferred from contralateral training to the untrained limb (4). Future research will need to investigate if this underlies the changes seen in this study.

One reason to potentially account for the lack of changes in non-throwing specific parameters, such as range of motion and grip strength, is task specificity in training. The primary focus of the training utilized in this study was throwing accuracy; therefore, we would expect improvements in throwing accuracy but not velocity or non-throwing specific parameters. Hubbard and colleagues stated that increases in learning are task specific as learning is maximal in the task that is being trained (22). If the training regimen focused on improving velocity over the 4 weeks, then we would expect to see velocity and, potentially, strength improvements as training effects are confined to the practiced task (23). Including a strength training protocol and maximal intent throws to enforce strength and velocity in addition to accuracy training could be a solution to improving all aspects of baseball throwing. However, future research will need to investigate the impact of contralateral strength and accuracy training on complex and open skills such as baseball throwing.

The authors acknowledge that the current study was carried out with a small sample size (n=16), which limit the ability to generalize the results from a small, homogenous sample. However, a noteworthy counterpoint is that this investigation utilized players from the same high school team. This ensured that all participants were similar in their baseball specific skills and participated in the same baseball specific practice schedule outside of the laboratory (i.e. 4 practice sessions and 2 competitive games per week). This inherently controls baseball throwing-specific practice volume. Theoretically, the amount of sport specific experience (competitive years played) is relatively even among high school athletes given the homogeneity of their biological ages. However, this does not guarantee that the cumulative practice volume of a sport specific skill is equal because some athletes are limited to one varsity sport throughout a school year, whereas other athletes may play two or more sports, and regional climate can impact practice time. Thus, these are potential confounding variables that limit the generalization of our findings across different geographical regions. Additionally, a common critique to studies with small sample sizes is the lack of statistical power. It is plausible that the trade-off of small sample sizes and low statistical power is worth the potential for gaining sport meaningful outcomes in sport specific skills (i.e., throwing) in well-trained athletes. To date, there is a lack of literature investigating contralateral training on throwing parameters in athletic populations. This void prevented the authors from utilizing an effect size-based power analysis to estimate a sample size. Previous research investigating the impact of contextual interference in sport specific activities in volleyball (24,25), badminton (26), and golf (27) have been afforded larger sample sizes due to the inclusion of general, novice populations. However, studies investigating contextual interference in well-trained, sport specific populations such as tennis (28) and baseball (8) use smaller sample sizes similar to the current study (tennis *n*=8 per group; baseball *n*=10 per group). The aforementioned studies found that contextual interference in well-trained athletes significantly improved serving performance and number of solid hits in tennis and baseball, respectively, which indicate congruency in the reported findings of the current study.

Conclusions

In conclusion, we demonstrate for the first time that contralateral throwing practice of the non-dominant arm in well-trained baseball players significantly improves throwing accuracy and the Acc:Velo ratio of the dominant throwing arm. These findings are important as skilled athletes become asymptotic in their performances as their training age increases. Contralateral training, even in fairly advanced athletes, may provide a viable solution to this eminent problem.

List of Abbreviations

Acc:Velo: accuracy to velocity ratio; ANOVA: analysis of variance; CL: contralateral; CON: control; DOM: dominant; ES: effect size; Int: Internal; Ext: External; $m \cdot s^{-1}$: meters per second; MVIC: maximal voluntary isometric contraction; N·m: Newton-meters; kg: kilograms; ND: non-dominant; Rot: rotation; SEM: standard error of the mean.

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