Regionally Interdependent Applications of Total Motion Release® and Active Rotational Shoulder Range of Motion in Overhead Athletes

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ABSTRACT

Healthy athletes commonly engage in pre-participation warm-up strategies designed to physiologically and mechanically prepare the body for training and competition. Alterations in rotational range of motion (ROM) of the dominant shoulder in overhead athletes, resulting in total rotation ROM loss, correlate with performance deficit, injury risk, and lost training time. Researchers have suggested that interventions using Total Motion Release® (TMR®) increase shoulder ROM more effectively than traditional warm-up methods. A randomized pre-test post-test trial was used to explore the effects of a regionally interdependent application of TMR® via a forward flexed trunk twist (FFTT) and seated straight leg raise (SLR) compared to a traditionally designed athletic warm-up on active shoulder internal rotation (IR) and external rotation (ER) in healthy overhead athletes measured with the *Clinometer©* smartphone application. Participants included twenty-two NCAA Division I, III, Club, and Secondary School senior student-athletes (9 javelin, 7 volleyball, 6 baseball; 13-females, 9-males; age= 19.3±1.1 years; height= 178±11.4 cm; weight= 76.4±11.2 kg), randomly assigned to TMR® (TMRG; n=11) and traditional warm-up (TWG; n=11) groups. The TMRG performed 3 sets of FFTT and SLR, each held for 20 seconds to the side of ease. The TWG completed a traditionally designed athletic warm-up including running, athletic drills, and dynamic and static stretching. The TMRG experienced significantly greater increases in dominant shoulder IR, non-dominant shoulder IR, and non-dominant shoulder ER (mean $_{change}$ =+9.5°, +7.5°, +4.7°), than the TWG (+1.7°, -6.7°, -4°) respectively. Intervention time to completion was also different between groups (TMRG = 7mins TWG = 25mins). This study indicates that an indirect TMR® application produces efficient meaningful changes in rotational active range of motion (AROM) of the shoulder in overhead athletes.

Key Phrases
Injury risk reduction, performance exercise, throwing athletes

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INTRODUCTION

Dynamic, forceful, and repetitive movement of the shoulder among overhead athletes may cause osseous and soft tissue adaptations as well as kinematic changes within the joint and surrounding musculature.[1-8] As a result, overhead athletes may present with increased external rotation (ER) and decreased internal rotation (IR) of the dominant shoulder.[1,3-7] Range of motion (ROM) adaptations, via the reduction of total rotational ROM, may elevate risk of shoulder injury, result in lost training and competition time, and raise the potential for decreases in performance via common injury patterns.[9,10]

Researchers suggest the goals of performance readiness be accomplished via the progressive sequencing of warm-up activities including low-intensity aerobic exercise, stretching, high load dynamic drills, and sports specific exercises.[11-13] It is recommended that this sequence elevate the heart rate, increase peripheral tissue temperature, address specific aims such as increasing ROM through static or dynamic stretching, and then incorporate specific skill based drills required by the training or competitive environment of the participant.[12,13] Interventions to improve shoulder ROM and increase performance readiness are employed by athletes regardless of ability and health status. These often include static stretches that have traditionally focused on local structures.[1,7,8,12,14] Though these types of interventions are regularly employed, improvements in shoulder IR are often found to be less than 5°.[14-16] While immediate increases in shoulder ROM have been found, static stretching has often not been found to produce lasting changes in ROM or increase performance in athletic populations.[12-16] Despite these findings, researchers have traditionally advocated that both healthy and at risk individuals engage in daily stretching programs, often as part of warm-up activities, in order to improve or maintain shoulder ROM.[4,12,14-17]

Focusing on specific tissues and localized areas of the body, while ignoring the complexity of the neuromuscular system, may reduce the efficacy of traditional warm-up protocols.[18-21] Instead, heeding the interconnected nature of the neuromuscular and fascial systems may be the key to producing meaningful injury prevention and performance enhancement strategies. Researchers have established that alterations in one region of the body affect not only local outcomes, such as positional changes in joints, tension dynamic changes across soft tissues, and alterations in stability,[22-24] mobility,[25-27] and motor control,[28,29] but invariably produce adjustments in other, interdependent, body regions.[26,27,30-32] The term regional interdependence (RI) is used to describe this phenomenon.[32] While the RI model is primarily concerned with musculoskeletal factors, it may also involve neurophysiological effects.[31,32] Therefore, neuromuscular adaptation is of particular interest when movement is the primary driver of intervention, as is the case during therapeutic exercise or warm-up programs prior to training or competition.

Total Motion Release® (TMR®), a movement based orthopedic intervention, utilizes RI, potentially via cross education,[22-25] neural coupling,[28] and the common core hypothesis,[29] as well as the fascial interconnectedness of the trunk and upper limbs,[33-35] to produce changes in ROM, pain, and dysfunction, through targeted pain-free movement.[30] The TMR® system is based on the theory that pain alters motor control, movement patterns adapt to dysfunction created by pain, and that the body seeks symmetry and will correct dysfunctional movement patterns in the absence of pain.[30] Participants using TMR® are asked to perform movements bilaterally and then self-rate to compare the motions on a scale of 0-100.[30] On this scale, 0 represents an absence of pain, dysfunction, or strength deficit, and equal quality and quantity of ROM. In contrast, a score of 100 represents extreme pain, complete dysfunction or unilateral strength deficit, or substantial loss of quality or quantity of ROM.[30] Once these self-determined ratings have been established, the motion with the highest rating (i.e., the most 'dysfunctional' movement or 'bad side') is addressed by performing the same motion to the side of ease (i.e., 'good side') through set and repetition schemes determined by the clinician or based on patient comfort.[30] The movement is completed so long as the motion is not bilaterally painful or dysfunctional, which would be a contraindication to use that movement within the TMR® system.[30] The use of TMR® may have benefits as a performance readiness and injury prevention strategy due to the proposed effects regarding increased ROM,[26,27] and may help patients/athletes achieve symmetry in paired movement patterns.[26]

Although TMR® research is scarce, its use has been found to quickly increase shoulder ROM in baseball players when using arm raise and trunk twisting motions.[26,27] However, TMR® as an

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intervention strategy, is often applied in a regionally interdependent fashion.[30] Therefore, further research is warranted to determine the effects of TMR® as an intervention for increasing shoulder ROM in overhead athletes. Specifically, it is necessary to assess if these positive changes in ROM are the result of direct application of TMR® movements at the upper extremity. Therefore, the purpose of this study was to explore the regionally interdependent effects of an indirect application of TMR® using forward flexed trunk twist (FFTT) and active straight leg raise (SLR) techniques on shoulder AROM compared to a traditional athletic warm-up among healthy overhead athletes.

PATIENTS

With the approval of a university Institutional Review Board, a non-blinded randomized control trial design was utilized to examine and compare the effects of an indirect TMR® intervention and a traditionally designed warm-up. All participants were informed of the risks and benefits of the investigation prior to signing informed consent documents and were aware that they could withdraw their participation at any time. A total of 22 student-athletes were recruited from NCAA Division I University volleyball and track and field teams, a NCAA Division I University Club Baseball team, a NCAA Division III track and field team, and secondary school baseball and volleyball teams. Gender and sport differences between groups are presented in the CONSORT flow chart (**Figure 1**).

Participants were included if they were between the age of 18 and 25, could complete all warm-up activities and ROM testing procedures, were a member of a Secondary School, Junior/Community College, NAIA, NCAA I, II, III, club baseball, baseball, volleyball, or track and field team, and had been competitive in their discipline for at least 3 years. Participants were excluded from this study if they had had any orthopedic surgery three months prior to data collection at the hip, knee, ankle, spine, shoulder, or elbow. Individuals with orthopedic injuries older than three months that remained symptomatic were also excluded. Participants were also excluded from this study if they were found to be unable to complete shoulder ROM testing or had painful motion with both left and right trunk rotation or left and right straight leg raise as these are contraindication within the TMR® system.[30] All participants were also able to complete a full traditionally designed athletic warm-up. If the participant was being advised by their medical or coaching staff not to take part in such activity, was unable to complete any portion of the traditional warm-up, or wished for their ROM or demographic information to not be utilized, withdrawal from participation was accepted. All volunteers met the pre-screened inclusion criteria with no participants dropping or being excluded once data collection had begun.

INTERVENTIONS

The study was conducted in a single session for each participant. All interventions were performed before any sport-specific or warm-up activities had occurred for the day. Randomization was accomplished by using a first generator by randomization.com, participants randomly assigned to either the TMR® group (TMRG; *n*=11) or the traditional warm-up group (TWG; *n*=11). A Certified Strength and Conditioning Specialist (CSCS) collected all measurements and data in their second year studying in a masters of science in athletic training program. All measurements and interventions were conducted indoors in athletic training facilities and gymnasiums. Pretest measurements

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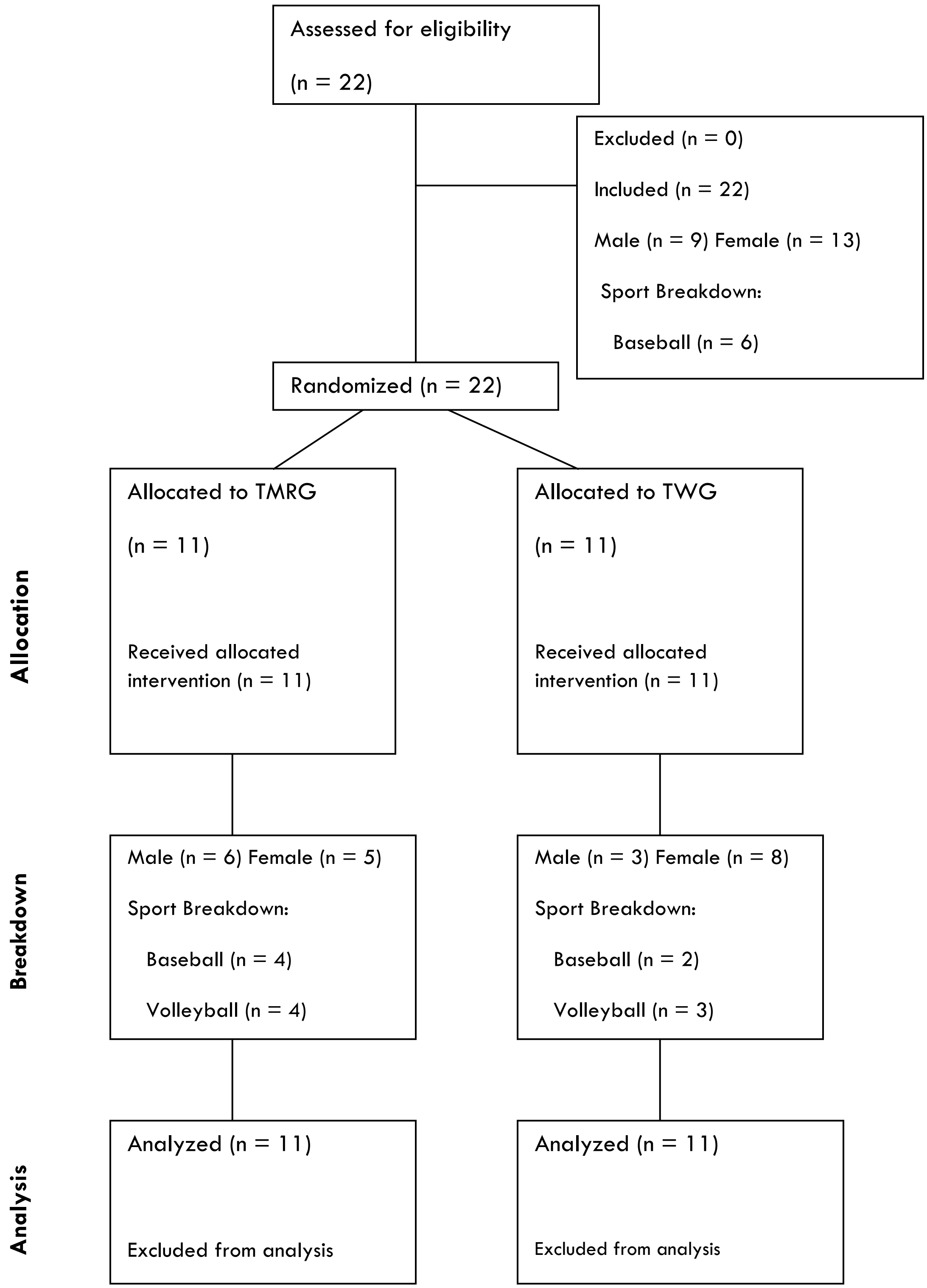
Figure 1. CONSORT diagram showing the breakdown of participants by intervention, gender, and sport.



of active shoulder IR and ER were measured on the dominant and non-dominant sides before performing either intervention. Following baseline AROM measurements, the participants in the TMRG performed one seated straight leg raise (SLR) (**Figure 2**) with each leg and one FFTT (**Figure 3**) with the arms across the chest placing the palmar surface of the hand at the anterior axilla, the hips slightly flexed as if performing a dead lift, and the torso at an angle which caused no discomfort in the lumbar region to each side. Hip angle, depth, and postural control were not controlled for as the TMR® system asks for the participant to reach their perceived end range requiring changes in joint angles during intervention.[30] The participant then determined which side or motion provided the most ROM, best quality of motion, was pain free, or free of restriction.[30]

Figure 2. Seated straight leg raise starting position and ending position.

Figure 3. Forward flexed trunk twist movement.

Total Motion Release® Group (TMRG Intervention)

Participants in the TMRG established a side of ease for both the seated TMR® SLR and FFTT through self-determination. After the easier side had been determined, participants performed the seated SLR (3 sets of 20-second static holds at end range) and the FFTT (3 sets of 20-second static holds) in the direction of the side of ease beginning with the most dysfunctional of the two patterns. After each set, there was a 30-second rest interval. Static holds of 20 seconds at end range were chosen to mitigate the fatigue associated with completing multiple high-volume repetition and set schemes as part of this intervention.[36] Participants in the TMRG were given instruction by a level 3 TMR™ trained investigator and were cued to 'sit back, rotate, and breathe' throughout the FFTT and 'to lift the foot up and breathe' during the SLR. Following the intervention, AROM measurements were reassessed. Each participant accomplished the TMRG intervention, including testing on the side of ease, in approximately 7 minutes.

Traditional Warm-Up Group (TWG Intervention)

Researchers suggest that a pre-training or pre-competition warm-up should include sequential phases designed with the specific goals of elevating the heart rate and increasing peripheral tissue temperature, addressing mobility and ROM through static or dynamic stretching, and incorporating specific skill based or sport specific drills.[11,13] The TWG in this study followed a protocol fashioned after these recommendations using static stretches shown in the literature to increase IR and decrease posterior capsular tightness at the shoulder.[14,15] Static stretching was done in the terminal phase, as increases in rotational ROM was the end goal of the TWG.[37] The TWG completed the warm-up protocol (**Table 1**) after baseline AROM measurements were assessed. Following the intervention, AROM measurements were reassessed. Each participant completed the TWG intervention in approximately 25 minutes. To complete the

Table 1. Traditional Warm-Up Protocol

Warm-up Exercise	Repetitions
Phase I	
Jog	3min at 25%
Phase II	
Walking Knee Hug	10m
Alternating Forward Lunge w/ Rotation	10m
Alternating Reverse Lunge w/ Rotation	10m
Alternating Walking Quadriceps Stretch	10m
Power Skips	10m
Alternating Lateral Lunges	10m
Walking dynamic forward overhead arm circles	10m
Walking dynamic reverse overhead arm circles	10m
Walking horizontal cross body arm swings	10m
Phase III	
Sprint (50%)	2 x 30m
Sprint (75%)	2 x 30m
Sprint (90%)	2 x 30m
Phase IV	
Alternating seated cross body stretch	3 x 30s each
Alternating seated upper trapezius stretch	3 x 30sec each
Alternating side lying sleeper stretch	3 x 30sec each

protocol, each participant in the TWG completed a 4-phase warm-up. Phase I consisted of a 3-minute steady state jog.[11] Phase II was comprised of a series of dynamic full body warm up drills with upper and lower extremity dynamic stretches, dynamic movements in all three planes of motion, and a focus on full range shoulder motion.[11,12] Phase II was completed in three continuous rounds with a 30-second rest interval. Phase III included two rounds of 30 meter runs at 50%, 75%, and 90% of perceived max intensity, each done with a 30-second rest interval.[11] Phase IV was comprised of 3 rounds of 30-second alternating static stretches for the shoulder done to produce a 30-second rest interval on the uninvolved side while the involved side was stretched.[11-14] Static stretches included a seated cross body stretch, a seated upper trapezius stretch, and a side lying sleeper stretch with the arm at 90 degrees of adduction, 90 degrees of shoulder flexion, and 90 degrees of elbow flexion.[14,15]

OUTCOMES MEASURES

Active shoulder IR and ER were measured using the *Clinometer*© digital smartphone application (Plaincode Software Solutions, Stephanskirchen, Germany) which is accurate to 0.1°. A smartphone was affixed to the participant's forearm just proximal to the wrist, utilizing an Ailkin Running Sports Armband for Droid Turbo™ Android Smartphone by Motorola© to make use of the *Clinometer*© digital application (**Figure 4**). Shin et al [38] demonstrated the *Clinometer*© app to have high intra-rater reliability when measuring active shoulder ER (ICC=0.98, 95% Confidence Interval [CI]=0.95-0.99 and IR (ICC=0.96, 95% CI=0.96-0.99) among evaluators. Significantly correlation with goniometer measurement have also been shown through Pearson Correlation Coefficient (PCC) evaluation for both active shoulder ER (PCC=.95) and IR (PCC=.92).[38] Inter-observer reliability was comparable to goniometry as well for both active ER (ICC= 0.87, 95% CI=0.79-0.92) and active IR (ICC=0.67, 95% CI=(0.43-0.82).[38]

Figure 4. Ailkin Running Sports Armband for Droid Turbo™ Android Smartphone by Motorola©

The examiner stood opposite the desired movement, near the head during active IR and at the torso during active ER to allow the examiner access to the functional use of the smartphone *Clinometer*©.[38] Each participant was asked which arm they primarily used during their competitive activity to determine dominance. For ER and IR measurements, the participant was instructed to lie supine on a table. An adjustable belt was placed across each participant's chest at the level of the sternoclavicular joint to limit trunk compensation into extension, rotation, or flexion during ROM testing (**Figure 5**).[39] Participants were positioned with the shoulder abducted to 90°, the elbow flexed to 90°, and the forearm supinated with support from the table along the proximal 50% of the humerus (**Figures 6** & **Figure 7**). Once positioned, the participant was instructed to either internally or externally rotate the arm, making sure to minimize excessive scapular and trunk motion by maintaining contact with the table at the humerus and posterior trunk. The measurement was recorded when the participant verbally confirmed reaching perceived end range.[38] All measurements occurred in the same order, beginning with dominant shoulder IR, dominant ER, non-dominant IR, and finally non-dominant ER.

Before completing this study, intra-rater reliability pilot testing was conducted using the *Clinometer*© application, armband, and chest strap. The examiner measured shoulder IR and ER five times with the smartphone application and averaged the values. The examiner placed the smartphone in the correct position for measurement and positioned the participants for proper measurement. Measurements were conducted on each participant (n=10) twice over a 5-day period. A two-way mixed effects model Intraclass Correlation (ICC) was used to assess intra-rater reliability for the investigating clinician responsible for data collection using the *Clinometer*© application. The standard error of the mean (SEM) values were calculated for shoulder IR and ER using the formula ($SEM = SD\sqrt{1- ICC}$). where SD is the standard deviation from the test.[40] Minimal Detectable Change (MDC) was calculated using the formula ($MDC=SEM\times 1.96\times \sqrt{2}$).[2, 22] The ICC, SEM and MDC values were excellent for both measurements, and comparable

Table 2. Intra-rater reliability for shoulder Internal & External Rotation using the *Clinometer* application (N = 10).

Active Range of Motion (AROM)	Intraclass Coefficient (ICC)	Standard Error Measurement Value (SEM)	Minimal Detectable Change Value (MDC)
Shoulder Internal Rotation	0.99	0.32	0.87
Shoulder External Rotation	0.96	0.80	2.22

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to previously research by Shin et al. for active ER (SEM=3.01, MDC=2) and active IR (SEM=1.86, MDC=3) (**Table 2**).[38,40,39]

Statistical Analysis

All data were analyzed using the Statistical Package SPSS version 21 (IBM Corp. Armonk, NY, USA). Normality was confirmed using the Shapiro-Wilk test. Levene's test for homogeneity of variances was non-significant for dominant IR (p=.504), non-dominant IR (p=.376), and non-dominant ER (p=.696). A one-way ANOVA was used to determine the difference between groups for change in shoulder IR and ER from pre-to post-intervention, to calculate effect size and observed power, and to assess group means comparisons. A priori α level of $p \leq .05$ was utilized for all statistical analyses. Effect size calculations were completed using partial Eta-squared. Partial eta squared values lower than 0.0099 were considered small, while 0.0588 was the benchmark for medium, and values greater than 0.1379 were considered large effect sizes.[42]

RESULTS

All of the 22 participants recruited for the study met inclusion criteria and completed the study in its entirety. Analyses of variables at baseline testing did not reveal any significant differences between groups in age (p=.349), weight (p=.188) (**Table 3**), pre-intervention dominant shoulder IR (**Table 4**), non-dominant shoulder IR (**Table 5**), pre-intervention dominant shoulder ER (**Table 4**), or non-dominant shoulder ER (**Table 5**). However, there was a significant difference between the mean height of participants in both groups (p=0.003) (**Table 3**). **Table 6** shows the differences in shoulder IR and ER pre-intervention. On average female participants had greater IR

Figure 5. Adjustable Belt Used to Stabilize Patient.

Figure 6. Internal Rotation Measurement Starting and Ending Position.

Figure 7. External Rotation Measurement Starting and Ending Position.

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Table 3. Descriptive Statistics

	Height (cm)	Age (years)	Weight (kg)
Participants	178±11.4	19.3±1.1	76.2±10.9
TMRG	184.7±10.4	19.5±1.3	79.3±10.8
TWG	171.6± 7.6	19±0.9	73.1±10.7

(TMRG) total motion release group, (TWG) traditional warm-up group

Table 4. Dominant Shoulder Range of Motion by Group

Active ROM	IR Pre	IR Post	ER Pre	ER Post
TMRG	96°±16.2°	106.4°±17.2°	117.7°±6.5°	120.1°±8.7°
TWG	101.8°±14.3°	103.5°±12.9°	114.5°±15.8°	117.1°±8.7°
p value	*p*=0.384	*p*=0.169	*p*=0.012	*p*=0.935

(IR) internal rotation, (ER) external rotation, (TMRG) total motion release group, (TWG) traditional warm-up group

Table 5. Non-Dominant Shoulder ROM by Group

Active ROM	IR Pre	IR Post	ER Pre	ER Post
TMRG	101.5°±16.1°	108°±14.7°	107.63°±13.2°	112.5°±12.4°
TWG	108.8°±9.5°	103°±11.9°	110.9°±10.4°	106.8°±13.2°
p value	*p*=0.068	*p*=0.176	*p*=0.773	*p* =0.824

(IR) internal rotation, (ER) external rotation, (TMRG) total motion release group, (TWG) traditional warm-up group

Table 6. Range of Motion Differences by Gender

Gender	DOM IR Pre	DOM ER Pre	NON DOM IR Pre	NON DOM ER Pre
Male	88.6°±16.09°	110.5°±9.26°	96.1°±14.45°	101.7°±10.91°
Female	105.7°±9.02°	119.4°±12.91°	111.6°±9.3°	115°±12.08°

(DOM) dominant shoulder, (NON DOM) non-dominant shoulder, (IR) internal rotation, (ER) external rotation

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and ER for both dominant and non-dominant shoulders.

Among the TMRG, a statistically significant increase in dominant shoulder IR ($F(1,21)=6.623$, $p=0.044$), non-dominant shoulder IR ($F(1,21)=20.52$, $p<0.001$), and non-dominant shoulder ER (($F(1,21)=9.108$, $p=$ 007) was observed after the intervention compared to the TWG (**Table 7**). A significant group difference was not observed for dominant shoulder ER ($F(1,21)<0.001$, $p=0.982$) and the variable did not meet the assumption for homogeneity of variance. The differences between groups represented a large effect size ($\eta^2 >0.138$) for the increases found in dominant shoulder IR, non-dominant shoulder ER, and non-dominant shoulder IR.[42]

DISCUSSION

While examining the effects of a regionally interdependent application of TMR® in healthy overhead athletes, members of the TMRG experienced significant increases in dominant shoulder IR when compared to participants who completed a traditional warm-up. The dominant shoulder IR and ER improvements found in the current study were not as large as those produced in previous TMR® shoulder ROM investigations.[26,27] However, in the current study, 9 out of the 11 members of the TMR® group experienced an increase in IR greater than 5° on the dominant shoulder without performing any upper extremity activity or warm-up. Interestingly, non-dominant shoulder IR and ER AROM increased significantly in the TMRG compared to the TWG, a result not identified in previous research utilizing TMR®.[26,27]

The improvements in dominant and non-dominant shoulder IR following the TMR® intervention used in this study exceeded shoulder ROM gains reported in much of the stretching literature, while the traditional warm-up protocol achieved similar ROM alterations cited in previous research.[14,16,26,27,43] Participants in the TWG of the current study experienced similar changes in dominant shoulder IR (mean=1.7°± 7°) to Laudner et al.[14] (3.1°), Oyama et al.[43] (3.8°), and Gamma et al.'s [26] findings (2.2°). In contrast, Gamma et al.'s [27] follow-up study found greater gains in the warm-up group (6.2°) than previous research, but this increase was still below the improvement experienced by the TMR® group for both dominant shoulder IR (mean=9.5°) and non-dominant shoulder IR (mean=7.5°) in the current study. The Faul's stretching routine,[16] which incorporates 3-7 second static stretches of shoulder flexion, extension, and ER, has produced gains in dominant shoulder ROM more similar to our TMR® findings. Sauers et al.[16] reported the Faul's stretching routine increased baseball players' ER by an average of 7.6° and IR 9.2°,

Table 7. Change in Shoulder Internal and External Rotation from Pre to Post-intervention Between Groups

Change from Baseline	TMRG	TWG	*p value*	Effect Size (η^2)	Observed Power
DOM IR	+9.5°±9.6°	+1.7° ± 7°	$p = .044$	$\eta^2 = .188$	.534
DOM ER	+ 2.5° ± 5.3°	+2.5° ± 11.9°	$p = .982$	$\eta^2 = .000$	.05
NON DOM IR	+7.5° ± 5.7°	-6.7° ± 9.7	$p < .001$	$\eta^2 = .468$	.99
NON DOM ER	+4.7° ± 6.2°	-4° ± 7.5°	$p = .007$	$\eta^2 = .313$	.819

(DOM) dominant shoulder, (NON DOM) non-dominant shoulder, (IR) internal rotation, (ER) external rotation, (TMRG) total motion release group, (TWG) traditional warm-up group but we do not know if this protocol results in ROM improvements in the non-dominant arm as was found with the application of TMR® in the current study. While non-dominant ER improvement was found, the result do not suggest that this application of TMR® will significantly increase dominant shoulder ER in overhead athletes. Methodological differences between studies may explain differences in the magnitude of ROM change when compared to previous research on TMR® and shoulder ROM.[26,27] While the length of time to complete the TMR® or traditional warm-up interventions was similar to previous research [26] (7 vs. 25 min), the application of TMR® was different.[26,27] In previous studies [26,27] examining the effect of TMR® on shoulder ROM, researchers combined a trunk twist motion with the arm raise, while the seated straight leg raise replaced the arm raise in the current study. It is possible that the use of the TMR® arm raise, even when performed on the non-dominant side, is more effective than the leg raise in producing changes in shoulder ROM. The arm raise may have either a contralateral or direct effect on shoulder motion and may be more effective than the SLR for increasing shoulder IR or ER due to the cross-education effect, or in the case of dominant side of ease, direct shoulder neuromuscular training paired with the indirect effects of the FFTT.

In addition to differences in TMR® application, other methodological differences were present in participant inclusion criteria. In the first Gamma et al.[26] study, participants presented with less baseline dominant IR (66°±12.06°) and dominant ER (82.4°±11.33°) than was found in the present study (baseline=96°±16.2°of IR and 117.7°±6.5° of ER). The current results could also be affected by gender and sport differences as the previous studies included only male baseball players,[26,27] while the current study included both male and female participants and participants who competed in a variety of overhead sports. It is important to note that our methods for shoulder IR and ER measurement did not call for the control of scapular motion via pinning of the scapula or visual inspection (i.e. stopping the measurement when the scapula begins to rotate and tilt anteriorly).[46-48] Measurement of this type accounts for scapulothoracic function and glenohumeral ROM providing a more integrated and performance driven active measure. Thus, shoulder complex ROM was measured in place of strict glenohumeral ROM. Researchers have compared passive ROM measurements with humeral head stabilization, scapular stabilization, visual inspection, and without stabilization and found that measurement without stabilization increased shoulder IR means by 8-30°.[46,47] As a result, when stabilization methods are accounted for, our IR measurements fall closer to normative values. Additionally, our study features 13 female participants while previous shoulder IR research has been largely conducted in male participant populations.[14,16,26,27,43,46] Multiple studies support our findings suggesting that females have greater IR and ER on average than males regardless of the measuring method (**Table 6**).[47,48] Furthermore, passive measurements of shoulder IR and ER ROM often produce values greater than active by approximately 4 degrees for males and females.[48] Despite the different methodology, the low MDC values for our measurement methods indicate that changes in ROM are unlikely due to measurement error.

Generalization of this study is limited due to the sample size (n=22) and use of collegiate and secondary school athletes. Additionally, neither the examiner nor the participants were blinded to the intervention or measurements. The investigating clinician, while trained in TMR®, was a relative novice using the intervention. A more experienced TMR® clinician may have achieved

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different alterations in ROM. Additionally, no follow-up measures were recorded, so it is unknown how long the ROM gains in either group remained. In spite of such limitations, the significant improvement in bilateral shoulder IR and non-dominant shoulder ER, and strong effect sizes, suggests the results of this study are clinically and practically meaningful. Thus, future research on TMR® is warranted. The time to completion differences between our intervention groups merits exploring interventions that are of a similar duration. Additionally, the duration of ROM improvement following TMR® intervention, along with assessing if multiple interventions produce more meaningful results, should be established. Further research efforts should also focus on single method interventions within the TMR® system and explore the TMR® intervention principle of addressing the side of ease versus the side of restriction. Finally, electromyographic study of activation patterns during trunk rotation may yield information regarding neuromuscular changes following TMR® intervention.

Considerations Regarding TMR® Mechanisms

Our findings, when compared with those in the current literature, [14,16,26,27,43] suggest that indirect RI interventions produce superior increases in ROM for overhead athletes bilaterally compared to a traditional direct methods, and require less time for completion. The findings, when combined with previous work, [26,27] support a hypothesis that increases in shoulder rotational ROM may be able to be driven by interventions directed at the core, which may be related to reducing ROM asymmetries of the trunk. The use of a trunk twist to improve shoulder ROM supports RI research linking the relationship between thoracic spine function and trunk stabilization to shoulder pain, mobility, and motor control.[5,31,32,49] Weakening of muscles that attach to the thoracolumbar fascia may have profound effects on the spine as the fascial structures provide for spinal integrity and mechanical function.[49] Loss of stiffness and mechanical function at the spine places greater stress upon the glenohumeral joint and rotator cuff in throwing athletes as the force needed to accelerate and decelerate the limb is initiated and increasingly dispersed through the glenohumeral joint during forceful overhead power production and deceleration.[49] Insufficient core stability also correlates with a higher incidence of scapular dyskinesis, which is a risk factor for shoulder injuries in volleyball players.[5]

The literature supports evidence of the importance of activation sequencing of the deep core musculature and trunk stabilization through the thoracic cage in counter rotation prior to movement at the upper extremity in overhead athletes.[5,26,27,32,49] Extremity function during forceful counter rotation, acceleration, and deceleration is dependent on the sequential and reciprocal relationship between core stiffness and rotatory control, providing a stable platform at the trunk.[5,18-21,32,49] The FFTT may have had a greater effect on ROM changes than the SLR in the TMRG due to the principle of proximal trunk stability predicating distal limb mobility. Neurological activity through the interconnected tissues of the posterior fascial chain and deep arm fascial chain during the FFTT also likely contributed to significant alterations in shoulder AROM.[33] Trunk twist motions can be performed in a variety of positions including seated, standing, and with the hips hinged or the trunk flexed when utilizing TMR®. Placing the spine in a position of angular shear force during the hip hinge portion of the FFTT utilized in this study forces the trunk to stabilize and protect the spine reflexively. As the trunk stabilizes the spine, a more rigid platform is created throughout the lumbopelvic and thoracolumbar regions, potentially resolving

ISSN Online 2577-8188

stability and motor control dysfunctions at the core, glenohumeral joint, and scapulothoracic articulation.[18-21]

When considering RI interventions like TMR® as neurophysiological processes, RI may be a combined function of three interrelated neuromotor principles: cross education,[22-25] neural coupling,[28] and the common core hypothesis.[29] Currently, it is understood that neuromuscular control and strength production relies on stimuli received and communicated throughout the whole body for optimal function during complex integrated movements.[22,23,28,29] Short term strength gains are due to increased neurological activity, not muscular hypertrophy, and are not dependent on local training effects in tissues.[22-28] Additionally, contralateral strength gains are due to increased motor neuron output rather than muscular fiber adaptations as ipsilateral motor neurons and branched spinal fibers project bilaterally.[22,25] Therefore, repeated or sustained contractions can induce adaptations in the untrained limb.[23,24,28] Such contralateral enhancement of motor control may serve as the fundamental basis of TMR®. Instead of reinforcing the painful, restricted, or dysfunctional movement, TMR® use may allow participants to adapt motor neurons of the spinal cord to the motor pattern perceived as non-threatening, which then 'spills over' to the other side of the body.[22]

CLINICAL APPLICATION

The use of TMR® in our study led to significant improvements in bilateral shoulder IR and non-dominant shoulder ER in overhead athletes. These findings are significant as IR deficit of the dominant shoulder is often associated with reduced performance and injury risk in overhead athletes. Based on the results of this study, the TMR® FFTT and SLR are more effective at immediately increasing bilateral shoulder IR, as well as non-dominant shoulder IR and ER, in overhead athletes than a traditionally designed athletic warm-up protocol. Several factors may contribute to a lack of increase in dominant shoulder ER. Commonly, adaptations in the dominant shoulder of overhead athletes include reductions in IR accompanied by increased ER.[6,44,45] Such paired adaptations in ROM of the shoulder in overhead athletes often contribute to asymmetries correlated with patterns of increased injury risk, performance deficit, and potentially to pathological circumstances such as Glenohumeral Internal Rotation Deficit (GIRD) in overhead athletes.[1-10,44,45] As such, it is plausible that increasing IR without paired increases in ER, moving ROM toward a state of symmetry, is a beneficial adaptation in healthy populations for injury prevention. For overhead athletes, this means that TMR® may potentially prepare the shoulder for throwing, spiking, and serving far better than static and dynamic stretching through rapid increase of shoulder IR through motor neuron adaptation, via increases in trunk stability, rotatory control, and RI alterations throughout the shoulder girdle.

The TMR® protocol was completed in less than one third of the time of the traditional warm-up indicating that the incorporation of the TMR® FFTT and SLR can increase shoulder AROM to a larger degree in a shorter amount of time than the common warm-up methods utilized in our TWG. Utilizing TMR® in place of traditional local stretching techniques, as part of a warm-up program, may result in decreased injury risk and increased performance in overhead athletes via increased AROM in crucial areas such as shoulder IR.

ISSN Online 2577-8188

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