



3-2017

## Effectiveness of a Home-Based Eccentric-Exercise Program on the Torque-Angle Relationship of the Shoulder External Rotators: A Pilot Study

Timothy L. Uhl  
*University of Kentucky, tluhl2@uky.edu*

Thomas Rice  
*Louisiana Tech University*

Brianna M. Papotto  
*University of Kentucky, brianna.papotto@uky.edu*

Timothy A. Butterfield  
*University of Kentucky, tim.butterfield@uky.edu*

Follow this and additional works at: [https://uknowledge.uky.edu/rehabsci\\_facpub](https://uknowledge.uky.edu/rehabsci_facpub)

 Part of the [Rehabilitation and Therapy Commons](#)

[Right click to open a feedback form in a new tab to let us know how this document benefits you.](#)

---

### Repository Citation

Uhl, Timothy L.; Rice, Thomas; Papotto, Brianna M.; and Butterfield, Timothy A., "Effectiveness of a Home-Based Eccentric-Exercise Program on the Torque-Angle Relationship of the Shoulder External Rotators: A Pilot Study" (2017). *Physical Therapy Faculty Publications*. 66.  
[https://uknowledge.uky.edu/rehabsci\\_facpub/66](https://uknowledge.uky.edu/rehabsci_facpub/66)

This Article is brought to you for free and open access by the Physical Therapy at UKnowledge. It has been accepted for inclusion in Physical Therapy Faculty Publications by an authorized administrator of UKnowledge. For more information, please contact [UKnowledge@lsv.uky.edu](mailto:UKnowledge@lsv.uky.edu).

---

## Effectiveness of a Home-Based Eccentric-Exercise Program on the Torque-Angle Relationship of the Shoulder External Rotators: A Pilot Study

Digital Object Identifier (DOI)

<https://doi.org/10.1123/jsr.2017-0020>

### Notes/Citation Information

Published in *Journal of Sport Rehabilitation*, v. 26, issue 2, p. 141-150.

© 2017 Human Kinetics, Inc.

The copyright holder has granted the permission for posting the article here.

The document available for download is the authors' post-peer-review final draft of the article.

# Effectiveness of a Home-based Eccentric Exercise Program on the Torque-Angle Relationship of the Shoulder External Rotators: A Pilot Study

Timothy L. Uhl<sup>1,2</sup> Thomas Rice<sup>3</sup> Brianna Papotto<sup>1</sup> Timothy A. Butterfield<sup>1,2,4</sup>

1. Department of Rehabilitation Sciences, Division of Athletic Training, University of Kentucky
2. Center for Muscle Biology, University of Kentucky, Lexington, KY
3. Department of Athletics, Louisiana Tech University, Ruston, LA
4. Department of Physiology, University of Kentucky, Lexington, KY

## **Corresponding author.**

Timothy A Butterfield, PhD ATC

Department of Rehabilitations Sciences

University of Kentucky

Lexington, KY 40536-0200

859-218-0840

tim.butterfield@uky.edu

1 **ABSTRACT**

2

3 Context: The role of the rotator cuff is to provide dynamic stability to the glenohumeral  
4 joint. Human and animal studies have identified sarcomereogenesis as an outcome of  
5 eccentric training indicated by more torque generation with the muscle in a lengthen  
6 position.

7 Objective: We hypothesize that a home-based eccentric exercise program can increase  
8 the shoulder external rotators eccentric strength at terminal internal rotation.

9 Design: Prospective case series.

10 Setting: Clinical laboratory and home exercising.

11 Participants: 10 healthy subjects (age=30 ±10 years)

12 Intervention: All participants performed two eccentric exercises targeting the posterior  
13 shoulder for 6 weeks using a home based intervention program using side-lying external  
14 rotation and horizontal abduction.

15 Main Outcome Measures: Dynamic eccentric shoulder strength measured at 60°/sec  
16 through a 100° arc divided into four equal 25° arcs (ER 50-25°, ER 25-0°, IR 0-25°, IR  
17 25-50°) to measure angular impulse to represent the work performed. Additionally,  
18 isometric shoulder external rotation was measured at 5 points throughout the arc of  
19 motion (45° IR, 30° IR, 15° IR, 0°, and 15° ER). Comparison of isometric and dynamic  
20 strength from pre to post testing was evaluated with a repeated measure ANOVA using  
21 time and arc or positions as within factors.

22 Results: The isometric force measures revealed no significant differences between the  
23 five positions (P = 0.56, Table 1). The dynamic eccentric data analysis revealed a  
24 significant difference between arcs (P = 0.02). The arc of Internal Rotation 25-50°  
25 percent change score was found to be significantly greater than the arc of Internal  
26 Rotation 0-25° (P = 0.007).

27

28 Conclusion: Following eccentric training the only arc of motion that had a positive  
29 improvement in the capacity to absorb eccentric loads was the arc of motion that  
30 represented eccentric contractions at the longest muscle length.

31 **INTRODUCTION**

32

33           The innate function of skeletal muscle is determined by its cell structure (fiber  
34 morphology) and how these cells are arranged (muscle architecture). Fortunately, the  
35 plasticity of skeletal muscle permits modifications to morphology and architecture when  
36 the fibers are subjected to altered biochemical and mechanical stress during exercise-  
37 induced loss of homeostasis.<sup>1</sup> The subsequent architectural and structural adaptations  
38 attenuate these stresses, thereby modifying fiber and muscle function.<sup>2,3</sup> For example,  
39 chronic training-induced fiber type transitions reduce the biochemical stresses produced  
40 by cell metabolism,<sup>4</sup> whereas fiber specific hypertrophy attenuates mechanical  
41 stresses.<sup>5</sup> Arguably, the most clinically recognizable exercise-induced adaptation in  
42 skeletal muscle is hypertrophy, or the cumulative effect of increased muscle fiber size.  
43 At the cellular level, muscle fibers can increase their size through mechanisms of  
44 myofibrillogenesis and / or sarcomerogenesis.

45           Myofibrillogenesis is muscle fiber hypertrophy in the axial direction and increases  
46 the cross sectional area of the fiber, because sarcomeres are added in parallel.  
47 Sarcomeres are force producing elements, and the forces produced by them are additive  
48 in parallel. Therefore, increases in muscle cross sectional area is a good predictor of  
49 peak isometric force<sup>6</sup> which is easily tested in the clinic and used as an objective criteria  
50 for return to play following injury.<sup>7</sup> Muscle fiber activation and the production of internal  
51 forces are essential stimuli to optimize exercise-induced myofibrillogenesis.<sup>8-10</sup>  
52 However, if a muscle fiber is also subjected to an external load that results in positive  
53 strain or stretch of the fiber, hypertrophy will also occur in the longitudinal direction,  
54 increasing fiber length due to sarcomerogenesis.<sup>11, 12</sup>

55           Sarcomereogenesis, or the addition of sarcomeres in series within a muscle  
56 fiber, has been studied extensively with *in-vitro*<sup>13, 14</sup>, *in-situ*<sup>15, 16</sup> and *in-vivo*<sup>12, 17-23</sup>  
57 models. Although immobilizing a muscle in a lengthened position results in an increase

58 in serial sarcomere number<sup>21, 22, 24, 25</sup> this addition is reversed if the stimulus is removed.  
59 Subsequently, the lack of tension sensing in the sarcomeres returns the serial  
60 sarcomere number to pre-stretch numbers within weeks, and demonstrates the plasticity  
61 of sarcomere number and its relationship to joint angle, and muscle tension.

62 Serial sarcomere number within individual fibers demonstrates a high correlation  
63 to joint angle<sup>26</sup>, and signifies a mechanical advantage produced through the gain of  
64 sarcomeres in series. Increased serial sarcomere number would be of benefit in a static  
65 contraction, improving the muscle function by shifting the force-length relationship to the  
66 right, producing peak isometric force at a longer muscle length, or greater torque at a  
67 greater joint angle. During a dynamic contraction, this would reduce sarcomere strain for  
68 a given joint angle during eccentric contractions<sup>3, 12</sup>. Further adaptations to function  
69 would be manifested as increases in contractile velocity<sup>27</sup>, muscle power<sup>28</sup>, and  
70 extensibility<sup>11</sup>. Clinically, this functional adaptation in serial sarcomere number may also  
71 prevent injury when the muscle consistently works eccentrically at longer lengths<sup>11, 22, 29</sup>.  
72 These dynamic adaptations have been demonstrated in animal models using freely  
73 walking rats<sup>20, 23, 30</sup> and controlled eccentric exercise protocols in rabbits<sup>12, 15, 31</sup>.

74 The adaptation of sarcomere addition in series following chronic eccentric  
75 exercise supports a previously proposed mechanism whereby sarcomere length is  
76 optimized for the muscle length at which force exerted on the tendon is the greatest<sup>32</sup>.  
77 Therefore this adaptation in serial sarcomere number has clinical implications as a  
78 potential injury preventing mechanism, due to the shift of the force-length (torque-joint  
79 angle) relationship to produce greater force (torque) at longer muscle lengths<sup>11</sup>.  
80 Although sarcomere numbers have not been counted in human subjects following  
81 eccentric exercise training, recent studies have demonstrated indirect evidence of  
82 sarcomerogenesis in human subjects, including adaptations in muscle function<sup>33, 34</sup> and  
83 morphology<sup>35, 36</sup> focused primarily on thigh<sup>35-39</sup> and brachial<sup>34, 35</sup> muscles. To date,

84 there are no data available as to the effectiveness of an eccentrically biased training  
85 protocol on the function of the external rotators of the glenohumeral joint. Because these  
86 muscles are integral to the deceleration of the humerus during throwing <sup>40</sup>, training  
87 protocols that produce a rightward shift of the torque – joint angle relationship may prove  
88 beneficial. Therefore, the purpose of this study was examine the effectiveness of a six  
89 week home-based eccentric exercise program to enhance isometric and eccentric  
90 external rotation strength in lengthened positions.

91

## 92 **METHODS**

93

94

### 95 **Setting and Participants**

96

97

98 Ten participants volunteered for this study from a sample of convenience at a  
99 university setting. (Age:  $30 \pm 10$  years, Height:  $164 \pm 10$  cm, Mass:  $79 \pm 18$  kg). Subjects were  
100 excluded from participation if they reported a history of shoulder or neck pathology,  
101 previous shoulder or neck surgery, or shoulder or neck pain within the last 6 months. All  
102 healthy subjects not excluded and willing to participate read and signed a University of  
103 Kentucky Institutional Institutional Review Board approved informed consent prior to  
104 participation in the study.

105 Subjects filled out the Penn Shoulder Score before testing to evaluate level of  
106 shoulder function prior to participating. The Penn shoulder score ranges from 0-100 with  
107 100 representing highest level of function. The score has been found to be a reliable and  
108 valid measure of shoulder function<sup>41</sup>. The Penn shoulder score averaged 97 with a range  
109 (85 – 100) indicating that current participants demonstrated near normal function at the  
110 onset of the study. All testing was completed at the Musculoskeletal Laboratory at the  
111 University of Kentucky with a single unblinded investigator performing all testing.



112

### 113 **Study Design**

114

115           This prospective case series investigation was designed to investigate the  
116 effectiveness of home-based eccentric exercises for the posterior shoulder to improve  
117 external rotation strength and improve ability of the posterior shoulder to absorb dynamic  
118 internal rotation forces. Three days of familiarization with 1 week of rest between testing  
119 episodes was used to establish baseline values and evaluate reliability of testing  
120 procedures. A six-week exercise intervention incorporating 2 exercises was carried out  
121 by all participants. The same testing procedures were repeated after the program to  
122 evaluate changes from the intervention. Participants were asked to not start a new  
123 exercise program during the study however they could continue to perform their normal  
124 exercise and activities of daily living during the study. The independent variable is time  
125 identified as pre-exercise and post-exercise tests. There are 2 dependent variables  
126 (isometric torque at 5 angles and dynamic eccentric shoulder external rotation angular  
127 impulse) that were measured at every time point.

128

### 129 **Isometric and Isokinetic Testing Procedures**

130

131           Prior to shoulder testing all participants completed 3 shoulder stretches (cross  
132 body, sleeper stretch, corner wall shoulder stretch) for 2 sets of 30 seconds each.  
133 Participants then warmed up with two active range of motion exercises with no load  
134 consisting of side-lying external rotation and side-lying horizontal shoulder abduction and  
135 adduction. Each exercise was performed for approximately one minute. The same  
136 warm-up occurred prior to each day of testing.

137           Next, shoulder strength testing was performed using an isokinetic dynamometer  
138 (Cybex Norm, Ronkonkoma, NY) as previously reported.<sup>42</sup> Participants were seated  
139 with their dominant shoulder in 60 degrees of abduction and 30 degrees of horizontal

140 adduction. This was defined as the scapular plane in the Cybex Norm user's manual.  
141 Both positions were confirmed using a hand held goniometer on all subjects. Isometric  
142 testing was always performed first, isometric shoulder external rotation strength was  
143 determined from the average of two trials taken at five test positions (45° IR, 30° IR, 15°  
144 IR, 0°, and 15° ER). The order of the test position was randomly assigned using a  
145 random number generator with Microsoft Excel on each testing day in order to minimize  
146 length change biases related to the length-dependent and time-dependent properties of  
147 muscle.<sup>43, 44</sup>

148 In each test position, subjects performed one sub-maximal practice repetition for  
149 3 seconds, rested for 20 seconds and then performed two maximal repetitions for 3-  
150 seconds with a 60 second rest between each effort as previously established.<sup>33</sup>  
151 Standardized verbal encouragement was given during isometric strength testing for  
152 maximal repetitions to attempt to maximize the subject's effort and strength potential.<sup>45</sup>  
153 Peak torque was recorded for both isometric contractions at every angle and averaged  
154 to represent angle specific torque. The excellent reliability of these testing procedures  
155 between days (ICC  $\geq$  0.85) has been previously reported.<sup>42</sup>

156 Following the collection of isometric torque data, dynamic eccentric shoulder  
157 external rotation torque data were collected, while maintaining the shoulder in the same  
158 test position and through a 100° arc of motion from 50° of external rotation to 50° of  
159 internal rotation. The continuous passive motion (CPM) mode was used with the Humac  
160 software (Computer Sports Medicine Inc, Stoughton, MA) on the Cybex Norm with an  
161 internal rotation velocity set at 60°/second. From the start position of 50° external  
162 rotation, the subject was instructed to maximally contract into external rotation to initiate  
163 internal rotation. The subject was instructed to maximally resist internal rotation through  
164 the entire range of motion in order to evaluate dynamic eccentric external rotation torque  
165 production. The subject was asked to relax his/her arm as the isokinetic dynamometer

166 passively returned the arm into external rotation starting position at 15°/second. This  
167 process removed all concentric activity during testing. Participants were given three  
168 minutes to rest following the familiarization phase and then performed six maximal  
169 efforts in a row, with 7 seconds of recovery during the passive return to 50° of external  
170 rotation between trials. Standardized verbal encouragement was given during eccentric  
171 testing. The middle four trials were averaged together to determine angular impulse later  
172 used for data reduction and statistical analyses. A total of 3 baseline-testing sessions,  
173 one week apart, were collected before initiating the home exercise eccentric program to  
174 reduce the effect of motor learning during a novel task.<sup>46, 47</sup> Post-intervention testing  
175 occurred at 6 weeks after the start of the home exercise program, and consisted of the  
176 same procedures described above. The reliability of the dynamic eccentric shoulder  
177 external rotation strength as determined by angular impulse is excellent (ICC ≥ 0.97) as  
178 previously reported.<sup>42</sup>

179  
180  
181

### **Exercise Procedures**

182         The home-based exercise program consisted of 2 eccentrically-biased exercises  
183 consisting of side-lying horizontal adduction and side-lying external rotation. This  
184 exercise protocol is modified from Blackburn et al., shown to be an excellent position to  
185 activate the posterior shoulder musculature<sup>48</sup>. Participants were all given the same  
186 exercise instructions for performing two sets of each exercise with 15 repetitions per set,  
187 4 times a week. In order to focus on the eccentric component of the exercise and  
188 minimize the concentric portion, specific instructions were provided and initially  
189 performed with investigator supervision. To bias the exercises for eccentric contractions,  
190 subjects removed the weight from their own hand at the end of the eccentric contraction  
191 phase, and rotated to a supine position to allow gravity to externally rotate the humerus

192 back to the starting position to minimize concentric activity. They then placed the weight  
193 back in the hand of the experimental side, and rotated back to side laying for the next  
194 repetition. All participants had to demonstrate proper form with both eccentric exercise  
195 maneuvers. Form was deemed proper when subjects could effectively eliminate  
196 concentric contractions from both exercises regimens, and perform eccentric  
197 contractions through the full range of motion at the correct speed as per the instructions  
198 (Appendix). To support the clinical instruction, detailed written methods and pictures  
199 were given to participants to take home (Appendix). All eccentric exercises were  
200 performed at a slow pace of eight seconds for lowering the weight to emphasize the  
201 eccentric load to the posterior rotator cuff. Participants returned weekly to progress their  
202 resistance loads and assure proper exercise form.

203 Starting resistance for the eccentric exercise was determined from the highest  
204 dynamic eccentric shoulder external rotation average peak torque generated on one of  
205 the 3 baseline testing days. Average peak torque (Nm) was divided by the length of the  
206 subject's forearm (m) to estimate the force (N), which was then converted to pounds and  
207 multiplied by 0.2 to determine the weight used for the first week of training. Subjects  
208 were progressed on a weekly basis using a linear progression of increasing loads while  
209 repetitions were held constant. After the first week, the initial load was increased 20%  
210 and then subsequently increased by 25% weekly for the next 5 training weeks. Subjects  
211 were given a log to track their weight, sets, and repetitions that was returned at the end  
212 of the study. Additionally, a modified Borg perceived exertion scale was used to record  
213 level of difficulty when performing exercise. The scale ranged from 0-10 with 10  
214 representing maximal effort during an exercise. This allowed the researchers to monitor  
215 exercise progress so that resistance loads could match perceived exertion during  
216 exercise.

217

## 218 **Data Reduction and Statistical Analysis**

219

220

221 The two isometric trials for each day of testing were averaged together to  
222 represent external rotation torque at each shoulder angle. The post-exercise test data  
223 were subtracted from the pre-exercise test data for each subject to determine the  
224 change score. Shapiro-Wilk test for normality revealed that the isometric data were not  
225 normally distributed. Non-Parametric analysis was carried out using Friedman test to  
226 determine if change scores differed across the five positions (IR 45°, IR 30°, IR 15°,  
227 Neutral, ER 15°) for isometric data with alpha level set at  $P \leq 0.05$ . Wilcoxon Signed  
228 Rank Test was used to compare individual differences between positions if appropriate,  
229 with alpha level corrected for ten comparisons ( $P \leq 0.005$ ).

229

230 Raw data from each dynamic eccentric testing day for each subject were  
231 extracted from the Cybex. The raw data provided time, speed, angle and torque at a rate  
232 of 100Hz. These data were imported into an excel (Microsoft, Redwood CA) template to  
233 calculate angular impulse. Angular impulse was calculated using the trapezoidal  
234 equation for area  $\{\Sigma(1/2 [\theta \text{ at point A} + \text{torque at point B}] \cdot .01)\}$  for entire trial. The four  
235 middle efforts of the 6 trials were averaged together. The average total angular impulse  
236 was further divided into 4 equal 25° arcs of motion to clearly represent work production  
237 through the range of motion. The post-exercise test data were subtracted from the pre-  
238 exercise test data for each subject to determine the change score. Shapiro-Wilk test for  
239 normality revealed that the dynamic eccentric data were not normally distributed. Non-  
240 Parametric analysis was carried out using Friedman test to determine if change scores  
241 differed across the four arcs (ER 50-25°, ER 25-0°, IR 0-25°, IR 25-50°) for dynamic  
242 eccentric data with alpha level set at  $P \leq 0.05$ . Wilcoxon Signed Rank Test was used to  
243 compare individual differences between arcs if appropriate, with alpha level corrected for  
244 six comparisons ( $P \leq 0.0083$ ).

244

## 245 **RESULTS**

246

247

248

249

250

251

252

253

254

255

256

The isometric data analysis is presented using median values and inter-quartile ranges as non-parametric analysis was performed which revealed no significant differences between the five positions ( $P = 0.56$ , Table 1). The dynamic eccentric data analysis revealed a significant difference between arcs ( $P = 0.02$ , Figure 1). Correcting for multiple comparisons between the four arcs, there was only one pairwise comparison to reach significant difference. The arc of Internal Rotation 25-50° percent change score was found to be significantly greater than the arc of Internal Rotation 0-25° ( $P = 0.007$ , Table 2). Following eccentric training the only arc of motion that had a positive improvement in the capacity to absorb eccentric loads was the arc of motion that represented eccentric contractions at the longest muscle length.

257

## **DISCUSSION**

258

259

260

261

262

263

264

265

266

267

268

269

Although Fridén was the first to propose sarcomerogenesis as a beneficial, functional adaptation to eccentric exercise in 1984,<sup>49</sup> direct mechanistic evidence of increased serial sarcomere number following chronic training with eccentrically biased contractions has only been demonstrated in animal models to date. By training rats to walk on a treadmill, Lynn and Morgan were the first to show an exercise-specific adaptation in serial sarcomere number in the vastus intermedius muscle.<sup>30</sup> Although fiber strains were not directly measured, it was reasonably assumed that the quadriceps operated eccentrically during daily bouts of downhill walking, and eccentric training was associated with a significant increase in fiber length and serial sarcomere number, and therefore greater force at longer lengths.<sup>20, 30</sup> By directly measuring fiber dynamics, Butterfield et al. associated positive active fiber strains to subsequent serial sarcomere

270 number increases of ~10% in the vastus intermedius after 10 days of eccentrically-  
271 biased exercise.<sup>23</sup> Subsequently it was shown that higher positive fiber strains during  
272 eccentric exercise resulted in greater serial sarcomere number adaptations, and this  
273 could be accomplished by exercising the muscle through excursions involving long  
274 muscle lengths near or at terminal ranges of motion.<sup>50 12</sup>

275 Serial sarcomere number measurements, and therefore direct measurements of  
276 sarcomerogenesis, are impractical, if not impossible in human subjects. Therefore,  
277 architectural and functional measures previously associated with sarcomerogenesis in  
278 animal models are used as indirect measures of a beneficial adaptation to eccentric  
279 exercise in humans, including a rightward shift in the muscle's torque-joint angle  
280 relationship,<sup>34, 37</sup> adaptations in muscle architecture such as longer muscle fibers,<sup>35, 36, 51</sup>  
281 and/or increased fiber pennation angles.<sup>52</sup>

282 In this study, by training the posterior shoulder muscles eccentrically, we were  
283 interested to see if changes in both isometric and dynamic eccentric strength of the  
284 shoulder external rotators would increase the ability of the posterior shoulder  
285 musculature to absorb eccentric loads at the end range of the eccentric motion. We  
286 found that our eccentrically biased training program for the posterior shoulder muscles  
287 did not have an effect on their isometric torque-joint angle relationship. Although a  
288 rightward shift following repeated bouts of eccentric exercise training has been  
289 associated with serial sarcomerogenesis in human muscle,<sup>37</sup> there is evidence that  
290 sarcomere number adaptations can also occur without a significant shift in this  
291 relationship. Chen et al., found a direct association between training load and torque-  
292 angle shift following eccentric exercise training in human subjects.<sup>34</sup> In their study, only  
293 subjects that performed eccentric exercises at 100% of maximal voluntary contraction  
294 exhibited a rightward shift of the torque-angle curve on the biceps brachii, despite  
295 additional groups that trained submaximally exhibiting other beneficial training

296 adaptations such as the repeated bout effect, or resistance to subsequent eccentric  
297 exercise-induced injury.<sup>34</sup>

298         It is therefore possible that our training program was not long enough or the  
299 resistive load may not have been adequate to facilitate a measureable muscular  
300 adaption in isometric torque. This is supported, in part, by the aforementioned eccentric  
301 training studies in rabbits, whereby higher evoked forces during eight weeks of eccentric  
302 training resulted in greater rightward shift of the torque-angle curves.<sup>12, 50</sup> In addition,  
303 the lack of a shift in the isometric torque-angle relationship may be associated with the  
304 methodology in calculating the angle of isometric peak torque production.<sup>53</sup> By  
305 necessity, the isometric torque measures in our study herein are discreet data points,  
306 measured at every 15° of glenohumeral rotation. Therefore, it is possible that changes  
307 in isometric peak torque may have occurred between two discreet measurements.  
308 Lastly, the torque-angle relationship is a measurement that is sensitive to several  
309 factors, and easily altered by factors such as reduced effort, fatigue, alterations in series  
310 compliance, and/or changes in muscle / tendon stiffness.<sup>53</sup>

311         Therefore, we also measured the dynamic eccentric torque-angle relationship as  
312 a more robust indicator of the muscle's capacity for energy absorption.<sup>54, 55</sup> The  
313 mechanism of force production during an eccentric contraction differs significantly from  
314 the traditional mechanism of cross-bridge produced force during isometric and  
315 concentric contractions.<sup>56-60</sup> Therefore, forces produced eccentrically are independent of  
316 fiber type<sup>61</sup> and although fiber transitions can modify the muscle's contractile velocity,  
317 power, and rate of force development during concentric contractions, their influence on  
318 force is essentially eliminated during isometric contractions, when the velocity is zero.<sup>62</sup>  
319 However, exercise-induced alterations in the elastic elements of the muscle and/or  
320 tendon can modify force production.<sup>63, 64</sup> Elastic energy storage is an essential  
321 component of the shoulder musculature for throwing activities<sup>65</sup> and stiffening of the



322 parallel elastic component of the muscle by itself or in conjunction with  
323 sarcomerogenesis could explain our results. The increase in angular impulse at the  
324 longest muscle length is a significant adaptation to eccentrically biased exercise. It can  
325 be produced by increasing the length of the muscle fibers<sup>20</sup>, is indicative of serial  
326 sarcomere number increases<sup>11, 12</sup>, and it increases the amount of energy that the  
327 external rotators can absorb while actively lengthening,<sup>3, 66</sup> and reduces the potential for  
328 eccentric exercise-induced strain damage and injury.<sup>11, 20, 29, 33, 34, 36, 37, 39, 51, 52, 54</sup>

329 It is well documented that the posterior shoulder needs to act eccentrically to  
330 decelerate the arm during the termination of a baseball pitch, tennis serve or similar  
331 movement.<sup>67-70</sup> We believe the ability to effectively activate the posterior shoulder  
332 musculature eccentrically through the full range of motion is critical for avoiding injuries  
333 in the shoulder, specifically for overhead throwing athletes. Although our subjects  
334 performed the testing and exercise procedures with the shoulder in a different position  
335 compared to that of a throwing motion, we propose that the functional adaptations  
336 measured in this study are translatable. The posterior shoulder musculature must  
337 decelerate the shoulder during both the deceleration phase and the follow-through  
338 phase of pitching, as the loads are dissipated. Fleisig et al., calculated a significant  
339 internal rotation torque at the shoulder that was still evident at terminal internal rotation.<sup>69</sup>  
340 At the time of ball release, Werner et al., calculated high distraction forces that were  
341 dissipated over course of the following 200ms<sup>71, 72</sup>, as the shoulder continues to  
342 internally rotate to approximately 0° of glenohumeral rotation.<sup>73</sup>

343

#### 344 **Limitations**

345 We used two different positions for exercising and testing the muscles of the  
346 posterior shoulder. It is reasonable to expect that exercise-induced adaptations in  
347 skeletal muscle to be specific function; i.e. contraction type and muscle length.

348 Therefore, it is possible that the exact magnitude of the adaptations were not measured  
349 due to the different position of testing. However, we did find an improved eccentric  
350 impulse at long muscle lengths for the posterior shoulder musculature in a shoulder  
351 position (and muscle position), which indicates the robustness of the adaptation at the  
352 tissue level. Future studies will utilize a laboratory setting to test and measure in  
353 identical positions.

354 It is possible that adaptations in motor unit recruitment occurred in our subjects  
355 over the course of the study. However, the lack of a significant training effect in the  
356 isometric torque data in conjunction with the systematic improvement in eccentric torque  
357 production in only the terminal arc of motion makes this less likely. In addition, muscle  
358 morphological and functional adaptations to eccentric loading are evident earlier  
359 compared to adaptations from isometric and concentric training, which supports fiber  
360 adaptation following a short, eccentrically-biased, four week training program.<sup>74</sup> In future  
361 studies measuring eccentric exercise-induced adaptations in our laboratory, we will  
362 include longer exercise durations and higher intensities, incorporate methods to assess  
363 muscle activation such as EMG, and measure rate of torque development and muscle  
364 stiffness to further separate viable mechanisms underlying the functional adaptations in  
365 skeletal muscle.

366

## 367 **Conclusion**

368 In this pilot study, we have shown for the first time that an eccentrically-biased  
369 home exercise program can improve the energy absorption capacity of the posterior  
370 shoulder muscles by increasing the eccentric torque production at terminal internal  
371 rotation. The exercises performed in this study can be translated easily for clinical use  
372 by overhead athletes. While these exercises do not approach the velocity seen in  
373 overhead sports, they could be good options for training program for overhead athletes

374 or during rehabilitation to facilitate eccentric strengthening of the posterior shoulder  
375 musculature. The two posterior shoulder eccentric exercises used during this six week  
376 intervention appear to support the concept of specific adaptation to imposed demand  
377 principle and increases the ability to absorb forces with the muscle in a lengthened  
378 position.

379

380 **Table 1.** Isometric Change scores

	Median Change Score	Interquartile Range
External Rotation 15°	4.79	(-5.6 – 11.4%)
Neutral 0°	1.18	(-5.1 – 21.6%)
Internal Rotation 15°	7.75	(-10.4 – 26.5%)
Internal Rotation 30°	-1.91	(-2.9 – 17.8%)
Internal Rotation 45°	1.64	(-1.2 – 17.4%)

381 (-) indicates that the isometric strength decreased from baseline value

382

383

384

385 **Table 2.** Dynamic Eccentric Percent Change Scores compared to the longest position of

386 Internal Rotation arc 25-50°

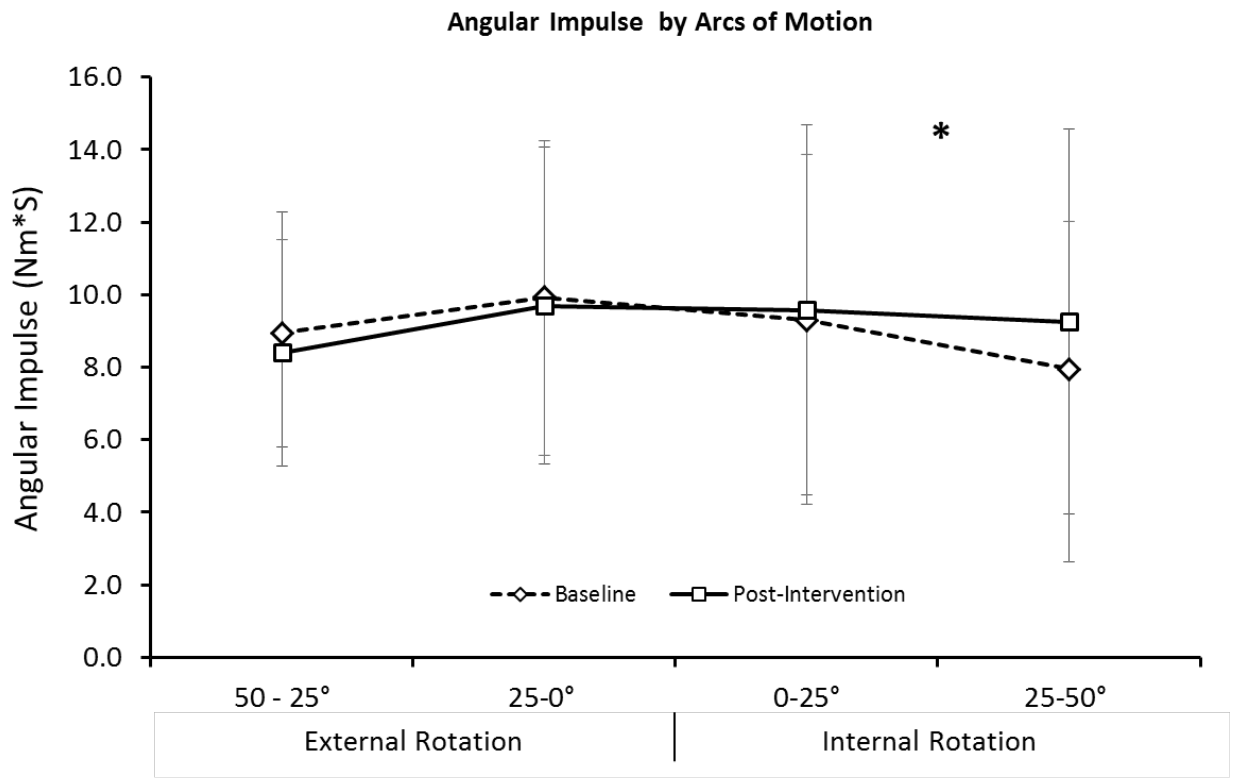
	Short		Long	
	External	External	Internal	Internal
	Rotation	Rotation	Rotation	Rotation
	50-25°	25-0°	0-25°	25-50°
Median Change Scores	-3.4	-3.0	+0.4	+9.5
Interquartile Range	(-21.8 – 12.7)	(-14.1 – 7.9)	(-8.9 – 12.9)	(2.2 – 31.0)
Significance	P = 0.059	P = 0.017	P = 0.007*	
Compared to Long IR 25-50°				

387 \* Indicates that change scores is significantly different from Internal Rotation 25-50°

388 (-) indicates that the angular impulse decreased from baseline value

389

390 Figure 1



391

392 **Figure captions**  
393

394 **Figure 1.** Mean eccentric angular impulse for the posterior shoulder muscles on day 1  
395 (open triangles) and following and eccentrically biased training program (open squares)  
396 for four arcs of motion. Eccentric contractions began with the posterior shoulder muscles  
397 at their shortest length (50° of external rotation) and the muscles were lengthened during  
398 contraction to their longest lengths (50° internal rotation). Following eccentrically biased  
399 training, the area under the eccentric torque-angle curve (angular impulse) was  
400 significantly greater (\*) for the arc of motion that represented the longest muscle lengths  
401 (25-50° internal rotation).

402  
403

## References

404

- 405 **1.** Vanrenterghem J, Nedergaard NJ, Robinson MA, Drust B. Training Load  
406 Monitoring in Team Sports: A Novel Framework Separating Physiological and  
407 Biomechanical Load-Adaptation Pathways. *Sports Med.* 2017.
- 408 **2.** Clarkson PM, Nosaka K, Braun B. Muscle function after exercise-induced muscle  
409 damage and rapid adaptation. *Med Sci Sports Exerc.* 1992;24(5):512-520.
- 410 **3.** Butterfield TA. Eccentric exercise in vivo: strain-induced muscle damage and  
411 adaptation in a stable system. *Exerc Sport Sci Rev.* 2010;38(2):51-60.
- 412 **4.** Simoneau JA, Lortie G, Boulay MR, Marcotte M, Thibault MC, Bouchard C.  
413 Human skeletal muscle fiber type alteration with high-intensity intermittent  
414 training. *Eur J Appl Physiol Occup Physiol.* 1985;54(3):250-253.
- 415 **5.** Fry AC. The role of resistance exercise intensity on muscle fibre adaptations.  
416 *Sports Med.* 2004;34(10):663-679.
- 417 **6.** Blazevich AJ, Gill ND, Zhou S. Intra- and intermuscular variation in human  
418 quadriceps femoris architecture assessed in vivo. *J Anat.* 2006;209(3):289-310.
- 419 **7.** Petersen W, Taheri P, Forkel P, Zantop T. Return to play following ACL  
420 reconstruction: a systematic review about strength deficits. *Arch Orthop Trauma*  
421 *Surg.* 2014;134(10):1417-1428.
- 422 **8.** Fluck M, Waxham MN, Hamilton MT, Booth FW. Skeletal muscle Ca(2+)-  
423 independent kinase activity increases during either hypertrophy or running. *J Appl*  
424 *Physiol (1985).* 2000;88(1):352-358.
- 425 **9.** Nader GA, McLoughlin TJ, Esser KA. mTOR function in skeletal muscle  
426 hypertrophy: increased ribosomal RNA via cell cycle regulators. *Am J Physiol*  
427 *Cell Physiol.* 2005;289(6):C1457-1465.
- 428 **10.** Esser K. Regulation of mTOR signaling in skeletal muscle hypertrophy. *J*  
429 *Musculoskelet Neuronal Interact.* 2008;8(4):338-339.
- 430 **11.** Proske U, Morgan DL. Muscle damage from eccentric exercise: mechanism,  
431 mechanical signs, adaptation and clinical applications. *J Physiol.* 2001;537(Pt  
432 2):333-345.
- 433 **12.** Butterfield TA, Herzog W. The magnitude of muscle strain does not influence  
434 serial sarcomere number adaptations following eccentric exercise. *Pflugers Arch.*  
435 2006;451(5):688-700.
- 436 **13.** De Deyne PG. Formation of sarcomeres in developing myotubes: role of  
437 mechanical stretch and contractile activation. *Am J Physiol Cell Physiol.*  
438 2000;279(6):C1801-1811.
- 439 **14.** Hofmann WW. Mechanisms of muscular hypertrophy. *J Neurol Sci.* 1980;45(2-  
440 3):205-216.
- 441 **15.** Koh TJ, Herzog W. Eccentric training does not increase sarcomere number in  
442 rabbit dorsiflexor muscles. *J Biomech.* 1998;31(5):499-501.
- 443 **16.** Koh TJ, Herzog W. Excursion is important in regulating sarcomere number in the  
444 growing rabbit tibialis anterior. *J Physiol.* 1998;508 ( Pt 1):267-280.
- 445 **17.** Burkholder TJ. Age does not influence muscle fiber length adaptation to increased  
446 excursion. *J Appl Physiol (1985).* 2001;91(6):2466-2470.



- 447 **18.** Burkholder TJ, Lieber RL. Sarcomere number adaptation after retinaculum  
448 transection in adult mice. *J Exp Biol.* 1998;201(Pt 3):309-316.
- 449 **19.** Williams PE, Goldspink G. Longitudinal growth of striated muscle fibres. *J Cell*  
450 *Sci.* 1971;9(3):751-767.
- 451 **20.** Lynn R, Talbot JA, Morgan DL. Differences in rat skeletal muscles after incline  
452 and decline running. *J Appl Physiol (1985).* 1998;85(1):98-104.
- 453 **21.** Tabary JC, Tabary C, Tardieu C, Tardieu G, Goldspink G. Physiological and  
454 structural changes in the cat's soleus muscle due to immobilization at different  
455 lengths by plaster casts. *J Physiol.* 1972;224(1):231-244.
- 456 **22.** Tabary JC, Tardieu C, Tabary C, Lombard M, Gagnard L, Tardieu G. [Neural  
457 regulation and adaptation of the number of sarcomeres of the muscle fiber to the  
458 length imposed upon it]. *J Physiol (Paris).* 1972;65:Suppl 1:168A.
- 459 **23.** Butterfield TA, Leonard TR, Herzog W. Differential serial sarcomere number  
460 adaptations in knee extensor muscles of rats is contraction type dependent. *J Appl*  
461 *Physiol (1985).* 2005;99(4):1352-1358.
- 462 **24.** Tardieu C, Tabary JC, Gagnard L, Lombard M, Tabary C, Tardieu G. [Change in  
463 the number of sarcomeres and in isometric tetanic tension after immobilization of  
464 the cat anterior tibialis muscle at different lengths]. *J Physiol (Paris).*  
465 1974;68(2):205-218.
- 466 **25.** Williams PE, Goldspink G. The effect of immobilization on the longitudinal  
467 growth of striated muscle fibres. *J Anat.* 1973;116(Pt 1):45-55.
- 468 **26.** Tabary JC, Tardieu C, Tardieu G, Tabary C, Gagnard L. Functional adaptation of  
469 sarcomere number of normal cat muscle. *J Physiol (Paris).* 1976;72(3):277-291.
- 470 **27.** Woledge RC, Curtin NA, Homsher E. Energetic aspects of muscle contraction.  
471 *Monogr Physiol Soc.* 1985;41:1-357.
- 472 **28.** Goldspink G. Malleability of the motor system: a comparative approach. *J Exp*  
473 *Biol.* 1985;115:375-391.
- 474 **29.** Friden J. Changes in human skeletal muscle induced by long-term eccentric  
475 exercise. *Cell Tissue Res.* 1984;236(2):365-372.
- 476 **30.** Lynn R, Morgan DL. Decline running produces more sarcomeres in rat vastus  
477 intermedius muscle fibers than does incline running. *J Appl Physiol (1985).*  
478 1994;77(3):1439-1444.
- 479 **31.** Butterfield TA, Best TM. Stretch-activated ion channel blockade attenuates  
480 adaptations to eccentric exercise. *Med Sci Sports Exerc.* 2009;41(2):351-356.
- 481 **32.** Herring SW, Grimm AF, Grimm BR. Regulation of sarcomere number in skeletal  
482 muscle: a comparison of hypotheses. *Muscle Nerve.* 1984;7(2):161-173.
- 483 **33.** Philippou A, Bogdanis GC, Nevill AM, Maridaki M. Changes in the angle-force  
484 curve of human elbow flexors following eccentric and isometric exercise. *Eur J*  
485 *Appl Physiol.* 2004;93(1-2):237-244.
- 486 **34.** Chen TC, Nosaka K, Sacco P. Intensity of eccentric exercise, shift of optimum  
487 angle, and the magnitude of repeated-bout effect. *J Appl Physiol (1985).*  
488 2007;102(3):992-999.
- 489 **35.** Lau WY, Blazevich AJ, Newton MJ, Wu SS, Nosaka K. Reduced muscle  
490 lengthening during eccentric contractions as a mechanism underpinning the  
491 repeated-bout effect. *Am J Physiol Regul Integr Comp Physiol.*  
492 2015;308(10):R879-886.

- 493 **36.** Potier TG, Alexander CM, Seynnes OR. Effects of eccentric strength training on  
494 biceps femoris muscle architecture and knee joint range of movement. *Eur J Appl*  
495 *Physiol.* 2009;105(6):939-944.
- 496 **37.** Brockett CL, Morgan DL, Proske U. Human hamstring muscles adapt to eccentric  
497 exercise by changing optimum length. *Med Sci Sports Exerc.* 2001;33(5):783-790.
- 498 **38.** Brughelli M, Nosaka K, Cronin J. Application of eccentric exercise on an  
499 Australian Rules football player with recurrent hamstring injuries. *Phys Ther*  
500 *Sport.* 2009;10(2):75-80.
- 501 **39.** McHugh MP, Tetro DT. Changes in the relationship between joint angle and  
502 torque production associated with the repeated bout effect. *J Sports Sci.*  
503 2003;21(11):927-932.
- 504 **40.** Kibler WB, Kuhn JE, Wilk K, et al. The disabled throwing shoulder: spectrum of  
505 pathology-10-year update. *Arthroscopy.* 2013;29(1):141-161 e126.
- 506 **41.** Leggin BG, Michener LA, Shaffer MA, Brenneman SK, Iannotti JP, Williams  
507 GR, Jr. The Penn shoulder score: reliability and validity. *J Orthop Sports Phys*  
508 *Ther.* 2006;36(3):138-151.
- 509 **42.** Papotto BM, Rice T, Malone T, Butterfield T, Uhl TL. Reliability of Isometric  
510 and Eccentric Isokinetic Shoulder External Rotation. *J Sport Rehabil.*  
511 2016;Technical Report.
- 512 **43.** Maganaris CN, Baltzopoulos V, Sargeant AJ. Repeated contractions alter the  
513 geometry of human skeletal muscle. *J Appl Physiol (1985).* 2002;93(6):2089-  
514 2094.
- 515 **44.** Rassier DE. The effects of length on fatigue and twitch potentiation in human  
516 skeletal muscle. *Clin Physiol.* 2000;20(6):474-482.
- 517 **45.** McNair PJ. Verbal encouragement of voluntary muscle action: reply to  
518 commentary by Roger Eston. *Br J Sports Med.* 1996;30(4):365.
- 519 **46.** Lagasse PP, Katch FI, Katch VL, Roy MA. Reliability and validity of the  
520 Omnitron hydraulic resistance exercise and testing device. *Int J Sports Med.*  
521 1989;10(6):455-459.
- 522 **47.** Mayer F, Horstmann T, Kranenberg U, Rocker K, Dickhuth HH. Reproducibility  
523 of isokinetic peak torque and angle at peak torque in the shoulder joint. *Int J*  
524 *Sports Med.* 1994;15 Suppl 1:S26-31.
- 525 **48.** Blackburn TA, MacLeod WD, White B, Wofford L. EMG analysis of posterior  
526 rotator cuff exercises. *Journal of Athletic Training.* 1990;25:5.
- 527 **49.** Friden J, Seger J, Sjostrom M, Ekblom B. Adaptive response in human skeletal  
528 muscle subjected to prolonged eccentric training. *Int J Sports Med.*  
529 1983;4(3):177-183.
- 530 **50.** Butterfield TA, Herzog W. Effect of altering starting length and activation timing  
531 of muscle on fiber strain and muscle damage. *J Appl Physiol (1985).*  
532 2006;100(5):1489-1498.
- 533 **51.** Baroni BM, Geremia JM, Rodrigues R, De Azevedo Franke R, Karamanidis K,  
534 Vaz MA. Muscle architecture adaptations to knee extensor eccentric training:  
535 rectus femoris vs. vastus lateralis. *Muscle Nerve.* 2013;48(4):498-506.
- 536 **52.** Blazeovich AJ, Cannavan D, Coleman DR, Horne S. Influence of concentric and  
537 eccentric resistance training on architectural adaptation in human quadriceps  
538 muscles. *J Appl Physiol (1985).* 2007;103(5):1565-1575.




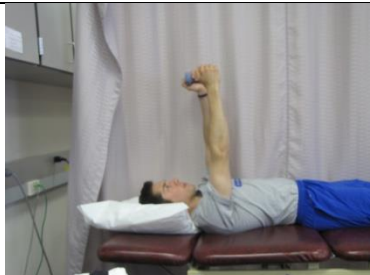





- 539 **53.** Butterfield TA, Herzog W. Is the force-length relationship a useful indicator of  
540 contractile element damage following eccentric exercise? *J Biomech.*  
541 2005;38(9):1932-1937.
- 542 **54.** Lindstedt SL, LaStayo PC, Reich TE. When active muscles lengthen: properties  
543 and consequences of eccentric contractions. *News Physiol Sci.* 2001;16:256-261.
- 544 **55.** Kaminski TW, Wabbersen CV, Murphy RM. Concentric versus enhanced  
545 eccentric hamstring strength training: clinical implications. *J Athl Train.*  
546 1998;33(3):216-221.
- 547 **56.** Herzog W. The role of titin in eccentric muscle contraction. *J Exp Biol.*  
548 2014;217(Pt 16):2825-2833.
- 549 **57.** Herzog W. Mechanisms of enhanced force production in lengthening (eccentric)  
550 muscle contractions. *J Appl Physiol (1985).* 2014;116(11):1407-1417.
- 551 **58.** Herzog W, Leonard T, Joumaa V, DuVall M, Panchangam A. The three filament  
552 model of skeletal muscle stability and force production. *Mol Cell Biomech.*  
553 2012;9(3):175-191.
- 554 **59.** Hoppeler H, Herzog W. Eccentric exercise: many questions unanswered. *J Appl*  
555 *Physiol (1985).* 2014;116(11):1405-1406.
- 556 **60.** Schappacher-Tilp G, Leonard T, Desch G, Herzog W. A novel three-filament  
557 model of force generation in eccentric contraction of skeletal muscles. *PLoS One.*  
558 2015;10(3):e0117634.
- 559 **61.** Hortobagyi T, Zheng D, Weidner M, Lambert NJ, Westbrook S, Houmard JA.  
560 The influence of aging on muscle strength and muscle fiber characteristics with  
561 special reference to eccentric strength. *J Gerontol A Biol Sci Med Sci.*  
562 1995;50(6):B399-406.
- 563 **62.** Komi PV. Training of muscle strength and power: interaction of neuromotoric,  
564 hypertrophic, and mechanical factors. *Int J Sports Med.* 1986;7 Suppl 1:10-15.
- 565 **63.** Magnusson SP, Narici MV, Maganaris CN, Kjaer M. Human tendon behaviour  
566 and adaptation, in vivo. *J Physiol.* 2008;586(1):71-81.
- 567 **64.** Urlando A, Hawkins D. Achilles tendon adaptation during strength training in  
568 young adults. *Med Sci Sports Exerc.* 2007;39(7):1147-1152.
- 569 **65.** Roach NT, Venkadesan M, Rainbow MJ, Lieberman DE. Elastic energy storage  
570 in the shoulder and the evolution of high-speed throwing in Homo. *Nature.*  
571 2013;498(7455):483-486.
- 572 **66.** Garrett WE, Jr., Safran MR, Seaber AV, Glisson RR, Ribbeck BM.  
573 Biomechanical comparison of stimulated and nonstimulated skeletal muscle  
574 pulled to failure. *Am J Sports Med.* 1987;15(5):448-454.
- 575 **67.** Ellenbecker TS, Davies GJ, Rowinski MJ. Concentric versus eccentric isokinetic  
576 strengthening of the rotator cuff. Objective data versus functional test. *Am J*  
577 *Sports Med.* 1988;16(1):64-69.
- 578 **68.** Escamilla RF, Andrews JR. Shoulder muscle recruitment patterns and related  
579 biomechanics during upper extremity sports. *Sports Med.* 2009;39(7):569-590.
- 580 **69.** Fleisig GS, Andrews JR, Dillman CJ, Escamilla RF. Kinetics of baseball pitching  
581 with implications about injury mechanisms. *Am J Sports Med.* 1995;23(2):233-  
582 239.
- 583 **70.** Jobe FW, Tibone JE, Perry J, Moynes D. An EMG analysis of the shoulder in  
584 throwing and pitching. A preliminary report. *Am J Sports Med.* 1983;11(1):3-5.

- 585 **71.** Werner SL, Guido JA, Delude NA, Stewart GW, Greenfield JH, Meister K.  
586 Throwing arm dominance in collegiate baseball pitching: a biomechanical study.  
587 *Am J Sports Med.* 2010;38(8):1606-1610.
- 588 **72.** Werner SL, Suri M, Guido JA, Jr., Meister K, Jones DG. Relationships between  
589 ball velocity and throwing mechanics in collegiate baseball pitchers. *J Shoulder*  
590 *Elbow Surg.* 2008;17(6):905-908.
- 591 **73.** Dillman CJ, Fleisig GS, Andrews JR. Biomechanics of pitching with emphasis  
592 upon shoulder kinematics. *J Orthop Sports Phys Ther.* 1993;18(2):402-408.
- 593 **74.** Douglas J, Pearson S, Ross A, McGuigan M. Eccentric Exercise: Physiological  
594 Characteristics and Acute Responses. *Sports Med.* 2016.  
595

## Appendix

### Side-lying Eccentric Horizontal Adduction

- 1) Lie on your back near the edge of a firm surface; preferably the floor or a firm mattress. (Figure 1)
- 2) Extend the non-exercising arm straight up in the air while holding the weight. (Figure 2)
- 3) Extend your exercising arm straight up in the air, transfer the weight to the opposite (exercising) hand and drop your non-exercising hand to your side. (Figures 3-5)
- 4) Roll on to your non-exercising side keeping the weight still extended straight up in the air. (Figure 6)
- 5) Now, using an 8 count, slowly lower the weight, keeping your thumb pointing towards the ceiling, your arm straight, and your arm in-line with your mouth. (Figures 7-8)
- 6) Let the weight lower as far as the surface will permit, hanging off if possible (Figure 8)
- 7) Once the weight has been fully lowered, roll on to your back (Figure 9) and assume the starting position. (Figure 1) Repeat the steps for 2 sets of 15 repetitions.

		
Figure 1	Figure 2	Figure 3
		
Figure 4	Figure 5	Figure 6
		
Figure 7	Figure 8	Figure 9

### Side-Lying Eccentric External Rotation

- 1) Lie on your side on a firm surface, with a rolled up towel or bolster placed under your arm, with the weight held by your non-exercising arm as shown. (Figure 1)
- 2) Roll onto your back and bring the weight up to your exercising arm, making sure to keep the towel under your arm. (Figure 2)
- 3) Roll back on to your side, your arm should rotate up towards the ceiling. (Figure 3)
- 4) Slowly lower the weight towards the surface, keeping the elbow bent at a right angle. (Figures 4-6)
- 5) Once you have gone through your available range of motion, drop the weight to the surface. (Figure 7)
- 6) With the non-exercising arm, pick up the weight. (Figure 8) and position your arm back in the starting position to repeat the exercise for the given number of repetitions. (Figures 9, 1)

