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1 **Isokinetic torque imbalances of shoulder of the french women's**
2 **national water polo team**

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15
16 **Keywords:** Isokinetic ratio, Eccentric contraction, shoulder

25 **ABSTRACT**

26 **Objective :** Evaluate the shoulder isokinetic strength of high-level female water polo players.

27 **Methods :** Two groups were compared: a control group of noncompetitive females (n=10),
28 and members of the the french women's national water polo (n=18). Isokinetic measurements
29 focused on the shoulder internal rotators (IR) and external rotators (ER), the evaluations were
30 realized at $60^{\circ}\cdot s^{-1}$ and $240^{\circ}\cdot s^{-1}$ in the concentric mode and at $60^{\circ}\cdot s^{-1}$ in the eccentric mode.
31 Agonist–antagonist ratios (ER/IR) were calculated using the same speed and contraction
32 mode for the agonist and antagonist muscle groups and the mixed ratio, combining peak
33 torque (PT; N·m) of the ER in the eccentric mode at $60^{\circ}\cdot s^{-1}$ and PT of the IR in the concentric
34 mode at $240^{\circ}\cdot s^{-1}$, was calculated.

35 **Results :** In concentric contraction, the PT of IR of the polo-players was stronger than
36 controls ($p<0.05$). In eccentric contraction the PT of ER were greater in water-polo players
37 ($p<0.05$). For the water-polo players, a difference between both sides was observed when
38 comparing the PT at $60^{\circ}\cdot s^{-1}$ ($p<0.05$). No significant difference was found through the
39 agonist–antagonist ratios between the dominant and the nondominant shoulders in both
40 groups. Some players exhibit an altered mixed ratio.

41
42 **Conclusion :** Intensive engagement in playing water polo will lead to an asymmetry in terms
43 of force, with a dominance of the internal rotors of the dominant shoulder that could be
44 detrimental and leads to shoulder soreness.

45

46 Table 1: Mean physical characteristics of control and water-polo players

47 Table 2 : Isokinetic performance of D and ND shoulders corresponding to the whole
48 population of the study.

49 Table 3: Isokinetic ratios for of water polo players and control group for the both shoulders

50 Table 4 : morphostatic results for water-polo players

51

52

53 **INTRODUCTION**

54

55 Water-polo is an intermittent and high-intensity team sport that requires a combination
56 of technical, high physical fitness and tactical skills [1]. This activity presents asymmetric
57 aspects, particularly during the passing and throwing motions [1]. Repetition of these dynamic
58 motions and swimming result in a cumulative micro-trauma leading to shoulder soreness [2].
59 Shoulder soreness is the most common musculoskeletal complaint for water-polo players [3].
60 The relative increase in dominant shoulder external rotation observed in water-polo players
61 suggests that levels of shoulder soreness would be a result of throwing actions rather than
62 swimming which did not require high level of force of external rotators [4]. Moreover, the
63 shoulder soreness is classically associated with impingement syndrome and increased
64 shoulder mobility as a result of imbalances in rotator cuff muscles [5]. The shoulder injury
65 prevention is a relevant challenge for trainer and need to be taken in account to enhance their
66 team performance. Therefore, evaluation of shoulder muscle strength is of interest to prevent
67 injury.

68

69 Measurement of isokinetic torque production remains the method of choice to assess
70 peak muscle performance [6, 7, 8, 9, 10]. Quantitative establishment of the balance between
71 the forces in rotator cuff muscles requires investigation of agonist/antagonist ratios [5].
72 Previous studies reported that water-polo players have greater internal than external rotation
73 strength [11]. Female water-polo players experienced higher rates of shoulder injury than
74 male players [12]. To our knowledge, isokinetics shoulder performance has not been
75 investigated in high-level female players. It should be of interest to determine in muscle
76 imbalance will be involved in this process.

77

78 In sports where overarm throwing plays an important role, isokinetic evaluations
79 revealed a imbalance in muscle strength of the shoulder [9, 13, 14]. During throwing, there is
80 a complementary action of concentric and eccentric contractions. The concentric action of
81 internal rotators determines mainly the throwing velocity. The eccentric contraction of
82 external rotators plays a key role and act as a brake during the final deceleration of the upper
83 limb, thereby limiting the pronounced increase in distraction force [15]. The use of a mixed
84 ratio (eccentric peak torque of external rotators divided by concentric peak torque of internal
85 rotators) is therefore advocated [16]. Upon comparing various high-level sporting populations
86 and control subjects, Forthomme et al. [17] observed a decreased mixed ratio (ER ecc/IR
87 conc) for the individuals engaged in the throwing activities (volleyball, javelin, badminton,
88 tennis) relative to control group. This altered ratio is the result of an increase in the peak
89 torque performances of the IR in concentric mode without an increase of the ER in eccentric
90 mode [18]. The lower limit of the mixed ratio among the control or non-participating
91 individuals (who define the “normal” context) was set arbitrarily at 1.11 in previous studies
92 that focus on throwing activities [19, 20, 21].

93

94 The aim of this study was to determine if there is an imbalance in muscle strength of
95 the shoulder in high-level female water polo players. These various findings will allow
96 elucidation of the impact of high-level engagement in women water-polo on the
97 musculoskeletal system.

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102

103 **MATERIALS AND METHODS**

104

105 **Study design**

106 Two groups were evaluated: a control group of noncompetitive females (n=10), and
107 members of the the french women's national water polo team (n=18). Control subjects did not
108 practice throwing activities and were matched for age (+/- 4 years), height (+/-5 cm) and
109 weight (+/-4 kg). The evaluations were performed at the end of the first part of the season
110 which should reflect training adaptations. The evaluations were always carried out in the
111 morning, under identical conditions. The first evaluation consisted in morphostatic bilateral
112 assessments (for the water polo players) and the second evaluation consist in isokinetic
113 shoulder strength assessments. All the subjects provided signed informed consent prior to
114 their participation. The protocol was conducted according to the Declaration of Helsinki.

115

116 **Population**

117 Subjects characteristics were presented in table 1. All water-polo players were
118 considered to be elite and highly trained at the time of testing (training duration >15h per
119 week). Control subjects trained less than four hours of physical activity per week. All were
120 right-hand dominant. None had a history of upper extremity injury, nor were they involved in
121 regular upper arm activities.

122 -- Insert Table 1 here --

123

124 **Isokinetic assessment**

125 Isokinetic evaluations were performed using a CON-TREX dynamometer (CMV AG,
126 Regensdorf, swiss). After a warm-up with an elastic band and arm cranking, subjects were
127 familiarized with the test using 10 submaximal concentric repetitions at $120^{\circ}\cdot s^{-1}$ and three

128 submaximal preliminary repetitions before each test speed data collection. Shoulders on both
129 sides (dominant [D] and nondominant [ND]) of the subjects were assessed. The test was
130 standardized to evaluate the right shoulder first. Measurements focused on the shoulder
131 internal rotators (IR) and external rotators (ER). Subjects were placed in a supine position,
132 with the arm abducted at 90° in the frontal plane and the elbow flexed at 90° [22]. To
133 maximize the stability, the thorax and the elbow of the subject were strapped. The range of
134 motion was standardized at between 50° of internal rotation and 70° of external rotation. The
135 isokinetic speeds selected were 60°·s⁻¹ (three repetitions of testing) and 240°·s⁻¹ (twenty
136 repetitions of testing) in the concentric mode and 60°·s⁻¹ (four repetitions of testing) in the
137 eccentric mode. Successive testing velocities were separated by 90 seconds of rest. The
138 isokinetic testing procedure enabled the measurement of absolute peak torque (PT; N·m) and
139 total work (joules). Agonist–antagonist ratios (ER/IR) were calculated using the same speed
140 and contraction mode for the agonist and antagonist muscle groups. A mixed ratio (combining
141 ER PT in the eccentric mode at 60°·s⁻¹ and IR PT in the concentric mode at 240°·s⁻¹) was also
142 calculated [19]. The subjects were instructed and encouraged to reach the highest possible
143 force level during these tasks but they did not receive any visual feedback .

144

145

146 **Morphostatic bilateral assessments.**

147

148 *Internal and external passive glenohumeral rotations*

149 Goniometric range-of-motion measurements of internal and external rotation of the
150 dominant and the nondominant glenohumeral joint were made by the same physical therapist.
151 Each subject was positioned supine on a table with the scapula stabilized, the humerus
152 abducted to 90°, and the glenohumeral joint in neutral rotation. We then passively rotated the

153 forearm of the subject to maximal external and internal rotation positions. The sides of a
154 goniometer were placed along the ulnar border and perpendicular to the floor. The authors
155 recorded maximal internal rotation when a firm end point was reached at the glenohumeral
156 joint, just before the scapula protracted or the shoulder rotated up and off the table. External
157 rotation measurement was recorded when a firm end point was reached, just before the back
158 arched [23].

159

160 *Scapular static position on the thorax*

161 The subject stood, with arms at their side in resting condition. The examiner measured
162 the distance (cm) between the spine of the scapula proximal border and the corresponding
163 spinous process [24].

164

165 *Forward presenting shoulder*

166 The player was supine, with arms at their side, palms facing downward. A
167 measurement was taken to quantify the distance (cm) between the posterior edge of the
168 acromion and the table [25].

169

170

171 **Statistical Analysis**

172 All data are presented as means \pm SD. The Shapiro–Wilk normality test was used to check the
173 normal distribution of the data. A Student unpaired *t* test was used to identify differences
174 between the control group and the water-polo players. The paired Student *t* was used to
175 identify the significant differences between D and ND shoulders for the water-polo players
176 group. All statistical analyses were carried out with the SPSS statistical package (version10,
177 Chicago, IL) and $p < 0.05$ was used as the accepted level of significance.

178 **RESULTS**

179

180 **Isokinetic assessment**

181 The comparison of isokinetic parameters of both groups are presented in table 2. In
182 concentric contraction, the IR peak torque was stronger in water-polo players at velocities of
183 $60^{\circ}\cdot s^{-1}$ and $240^{\circ}\cdot s^{-1}$ compared to control group (respectively +50% and +39% for D side and
184 +46% and +30% for ND side). The control group displayed a lower total work over the
185 exercises realized at $240^{\circ}\cdot s^{-1}$ than the water-polo players ($P<0.05$). For the water-polo
186 players, there was a difference between D and ND sides when comparing the PT developed
187 by the IR at $60^{\circ}\cdot s^{-1}$ ($P<0.05$). No difference between both groups and sides was observed for
188 concentric contraction of ER at $60^{\circ}\cdot s^{-1}$ and $240^{\circ}\cdot s^{-1}$.

189 In excentric contraction, no difference was observed between both groups and sides
190 for IR. The peak torque of ER was greater in water-polo players by 44% for D side and 38%
191 for ND side ($p<0.05$).

192 No difference was found through the agonist–antagonist ratios between the D and the
193 ND shoulders and the two groups (table 3). However, 16% of water-polo players presented a
194 mixed ratio below 1.11 (range: 0.93 – 1.07) whereas no subject have ratio below 1.11 in the
195 control group.

196

197 **Morphostatic measurements :**

198 The morphostatic measurements realized in water-polo players have shown a change
199 in the glenohumeral joint movement (table 4). External passive glenohumeral rotation of the
200 D shoulder was greater compared to the ND side ($P<0.05$). No significant difference was
201 observed when we compared the other measures (IR glenohumeral mobility, spine of
202 scapula/spinous process, forward presenting shoulder).

203

204

205 **DISCUSSION**

206

207 The results showed that intensive engagement in playing water polo will lead to an
208 asymmetry in terms of force, with a dominance of the internal rotators of the dominant
209 shoulder. The isokinetic performances of the water polo-players was stronger than controls.
210 No difference was found through the agonist–antagonist ratios between the D and the ND
211 shoulders and the two groups.

212

213 **Peak torque measurements**

214 Measurement of isokinetic torque production remains the preferred technique to assess
215 peak muscle strength and to calculate the balance between agonist and antagonist groups [9].
216 Of all the positions described for shoulder muscle assessment of athletes in the cocking phase
217 of throwing, the dorsal decubitus position with a shoulder adduction of 90° is considered to be
218 the most suitable, while a seated position with 45° of shoulder adduction in the plane of the
219 scapula (known as the modified Davies position) is thought to be the most relevant when it
220 comes to pathologies [22]. Moreover, the position used in our study was associated with
221 higher reproductibility and reliability for internal and external rotators [22].

222

223 Although isokinetic protocols are increasingly standardized (posture, saved settings,
224 repetitions), the question concerning the speed of execution does not seem to have reached
225 consensus yet. However, we believe that in the context of expertise, it is essential to take this
226 element into account. An unsuited speed to the physical abilities of the subjects could lead to
227 wrong conclusions. In our study, 3 subjects from the control group did not reach the faster
228 speed (i.e. 240°·s⁻¹) and were excluded from the protocol. Faster is the velocity, smaller is the
229 isokinetic phase. According to Osternig [26], for speeds of 300°·s⁻¹, the working phase at a

230 constant speed does not exceed 55% of the range of motion (leg extension motion). This
231 makes the interpretation of the results obtained during high-speed tests very random. We
232 believe that beyond $240^{\circ}\cdot\text{s}^{-1}$ with sedentary subjects, the part of the curve that is truly
233 isokinetic is not large enough for the test carried out to be significant. Speeds close to $180^{\circ}\cdot\text{s}^{-1}$
234 are probably best suited for the evaluation of the shoulder joint.

235

236 The main difference between water-polo players and control subjects is that the
237 dominant shoulder of water-polo players is stronger than the non dominant shoulder. This
238 imbalance had already been observed in previous studies [23, 24, 27]. This imbalance has
239 been observed in men swimmers but not in women suggesting that the swimming practice per
240 se favorise the imbalance of shoulder strength [23]. The muscular performance of our female
241 players is close to those recorded in women who participate in throwing sports [21].
242 Therefore, it seems that imbalance observed in our study is the result of the the practice of
243 high-level swimming and is probably accentuated by the throwing of repetitions.

244

245 **Agonist/antagonist ratios**

246 Quantitative establishment of the balance of the force between muscles with opposing
247 actions requires investigation of the agonist/antagonist ratios [6]. Our results revealed a
248 significant difference in the muscle performances between the two shoulders of our players
249 whereas no difference were observed for the different ratios. Investigation of
250 agonist/antagonist ratios is typically of the concentric contraction alone. The ratio observed in
251 our study were in accordance with previous studies [9, 21]. However, use of the shoulder
252 involves concentric as well as eccentric movements. A mixed ratio imbalance, reflecting
253 weakness of the ER, would constitute the main risk factor for shoulder tendon pain [28].
254 Change in the agonist/antagonist balance with athletes is manifested particularly in the mixed

255 ratio, with values that are consistently lower than the limit defined for healthy subjects [19].
256 The increase in the concentric force of the IR therefore does not appear to be proportionately
257 compensated for by the braking action of the ER. Regarding the mixed ratios, some of the
258 players exhibit lower ratio (ratio lower than 1.11) compared to the other players. Such a profile
259 could prove to be detrimental in terms of tendon lesions of this joint. Specific muscle training
260 performed each week with gym equipment could be a reason for this. Most of the exercises
261 used during gym session aim to develop IR peak torque and eccentric contraction exercises
262 of ER was never used. Moreover, the exercises are performed at high intensity levels that
263 promote peak force production by the internal rotators, the performance speeds are slow and
264 close to those used for the isokinetic evaluation (60°/s). An imbalance of force between
265 antagonist muscles triggers an abnormal excursion of the humeral head in the glenoid cavity,
266 which can lead to impingement or instability [29]. More typical for purely concentric ratios,
267 most studies have confirmed the relative weakness of the ER relative to the IR [5, 8, 10, 28].
268 This has proven to be detrimental to functioning of the shoulder area: the external rotators play
269 an essential role at the end of the cocking phase since, by keeping the humeral head in the
270 glenoid cavity, they limit tensioning of the inferior glenohumeral ligament [30]. At the
271 biomechanical level, the integration of eccentric contraction of the ER in the establishment of
272 the agonist/antagonist relationship seems obvious. Eccentric engagement of the posterior
273 muscle girdle ensures a protective role upon throwing: the braking action limits the anterior
274 translation of the humeral head upon powerful concentric contraction of the IR.

275

276 **Morphostatic assessments**

277 The clinical examination showed a significant change in IR glenohumeral mobility:
278 $124.1 \pm 8.9^\circ$ for the dominant shoulder (D) vs. $114.3 \pm 7.5^\circ$ for the non dominant side (ND,
279 $p < 0.05$). In keeping with the literature [31, 32], we observed an increased range of external

280 rotation and a decreased range of internal rotation [33]. This change could be explained by the
281 repetitive nature of the throws, since with this action the external rotators convert their
282 concentric contraction for the cocking phase into an eccentric control during the final stages
283 of arm deceleration. This hypermobility is not a problem in itself, but it can become one when
284 muscle fatigue sets in. At the end of training, for example, the shoulder may be engaged
285 without the humeral head necessarily being centered [34]. It is at this stage that a player can
286 injure their periarticular structures, thereby triggering a painful condition. As for the other
287 tests, our measurements did not reveal any differences between the shoulders. The results of
288 these clinical tests must be interpreted with caution since some studies have raised the
289 possibility that there is no connection between the results of these evaluations and the pain or
290 the severity of the injury. Conversely, the isokinetic data underscores that there are substantial
291 differences between the two shoulders.

292

293 **Practical applications**

294

295 Wilk et al. 2002 [35] and Kibler 2003 [29] suggest to use concentric and eccentric ER
296 strengthening exercises at the conclusion of a preventative and curative athlete's shoulder
297 treatment to compensate for the weakness of the posterior girdle. They emphasize that an
298 adequate compensatory strengthening of the antagonists (ER) does not seem to be detrimental
299 to on-field performance [10]. We believe that preventive strengthening of the ER for
300 concentric and eccentric contraction modes, while keeping the IR in shape, would avoid an
301 agonist/antagonist imbalance, without harming the overall competitive performance. We
302 suggest to use analytic movements to strengthen ER. A specific work outside of the water
303 should be used because the water did not offer solid support to better control the movement.

304 Studies pertaining to rebalancing of the ratios, the development of performance and the extent
305 of shoulder injury should be considered.

306

307 **Conclusion**

308 Intensive engagement in playing water polo will lead to an asymmetry in terms of force, with
309 a dominance of the internal rotators of the dominant shoulder. The players also present greater
310 peak torque force of external rotator compared to control subjects when assessed during
311 eccentric contraction. Some players present low mixed ratio that could be detrimental in terms
312 the susceptibility toward shoulder tendon lesions.

313

314 **Disclosure of interest**

315 The authors declare that they have no competing interest.

316

317

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Table 1: Mean physical characteristics of control and water-polo players

	Control (n=10)	Water-polo players (n=18)
Age (years)	22 ± 2	22 ± 3
Height (cm)	167 ± 10	172 ± 8
Weight (kg)	62 ± 5	67 ± 10
Dominant hand		
right	10	18
left	0	0

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Values are presented as mean ± SD. No difference was observed between the groups.

Table 2 : Isokinetic performance of D and ND shoulders corresponding to the whole population of the study.

Motion	Control (n=10)		Water-polo players (n=18)	
	D Side	ND Side	D Side	ND Side
peak torque				
IR CON 60 (N·m)	24.9 ±4.7 †	23.5 ±4.6 †	37.3 ±9.6	34.4 ±8.5*
ER CON 60 (N·m)	18.1 ±2.7	18.7 ±2.1	23.6 ±9.5	24.4 ±5.1
IR CON 240	22.9 ±2.1 †	23.2 ±1.9 †	31.9 ±5.9	30.2 ±6.1
ER CON 240	17.8 ±1.6	18.8 ±1.4	20.9 ±3.4	21.3 ±4.1
IR ECC 60	27.4 ±2.4	26.8 ±2.1	29.9 ±7.2	29.5 ±7.2
ER ECC 60	28.1 ±1.9 †	29.1 ±1.2 †	40.6 ±10.3	40.1 ±9.4
Total work (J)				
IR CON 240	572.2 ±57.7 †	545.4 ±63.5 †	1033.9 ±200.4	981.4 ±210.1
ER CON 240	463.8 ±35.9 †	428.6 ±46.5 †	636.9 ±124.4	645.1 ±141.1

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Values are presented as mean ± SD.

ER, External Rotators, IR, Internal Rotators; Con 60 = 60°·s⁻¹, concentric mode; Con 240 = 240°·s⁻¹, concentric mode; Ecc 60 = 60°·s⁻¹, eccentric mode; † p<0.05 between the control and water-polo players. * p<0.05 between the D and ND shoulders.

459 **Table 3 : Isokinetic ratios of water polo players and control group for the both shoulders**
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Motion	Control (n=10)		Water-polo players (n=18)	
	D Side	ND Side	D Side	ND Side
<i>ER / IR concentric ratios</i>				
Angular velocity of 60° /s	0.73 ±0.16	0.79 ±0.14	0.63 ±0.11	0.70 ±0.12
Angular velocity of 240° /s	0.77 ±0.07	0.81 ±0.08	0.66 ±0.09	0.71 ±0.12
<i>Mixed ratio</i>				
ER ecc 60°/s / IR con 240°/s	1.23 ±0.06	1.26 ±0.09	1.27 ±0.21	1.32 ±0.23
Mixed ratio <1.11 (%)	0	0	16	0

462 Values are presented as mean ± SD. Con, concentric mode; Ecc, eccentric mode; ER, External Rotators, IR,
 463 Internal Rotators. Conc 60°·s⁻¹ = 60°·s⁻¹, concentric mode; Conc 240°·s⁻¹ = 240°·s⁻¹, concentric mode; Ecc 60
 464 = 60°·s⁻¹, eccentric mode. No difference was observed between the groups.
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470 **Table 4 : morphostatic results for water-polo players**
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	Dominant shoulder	Non dominant shoulder
IR glenohumeral mobility (°)	55.5 ±12.8	57.8 ±13.2
ER glenohumeral mobility (°)	124.1 ±8.9	114.3 ±7.5*
Spine of scapula/spinous process (cm)	7.5 ±2.1	7.1 ±1.8
Forward presenting shoulder (cm)	6.6 ±0.9	6.7 ±0.8

472 Values are presented as mean ± SD. IR, internal rotators. ER, external rotators. * p<0.05 between the D and ND
 473 shoulders.
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