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► **To cite this version:**

Nicolas Olivier, Frederic Daussin. Relationships Between Isokinetic Shoulder Evaluation and Fitness Characteristics of Elite French Female Water-Polo Players. *Journal of Human Kinetics*, 2018, *Journal of human kinetics*, 64, pp.5-11. 10.1515/hukin-2017-0181 . hal-02378926

HAL Id: hal-02378926

<https://hal.univ-lille.fr/hal-02378926v1>

Submitted on 25 Nov 2019

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Relationships between isokinetic shoulder evaluation and fitness characteristics of elite French female water-polo players

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Acknowledgments:

None

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20 **Abstract**

21 Swimming and throwing are involved in water-polo player performance. These
22 movements have a common biomechanical basis in the use of the internal shoulder rotation and
23 adductor muscles. The aim of the study was to evaluate the relationship between shoulder
24 isokinetic evaluation and throwing velocity as well as swimming performance in female water-
25 polo players. Fifteen high level water-polo players completed two isokinetic shoulder
26 evaluations to determine peak torque of shoulder rotators of the dominant shoulder (concentric
27 and eccentric movements at an angular velocity of $60^{\circ}\cdot s^{-1}$ and concentric movements at an
28 angular velocity of $240^{\circ}\cdot s^{-1}$) and shoulder extensors of both arms (concentric movements at an
29 angular velocity of $60^{\circ}\cdot s^{-1}$ and $240^{\circ}\cdot s^{-1}$). Throwing velocity was measured using a radar gun
30 placed 5 m behind the goal post. Front crawl swimming velocity was determined at 25 m, 100 m
31 and 400 m distances. Concentric peak torque at $60^{\circ}\cdot s^{-1}$ and $240^{\circ}\cdot s^{-1}$ of internal rotators and
32 eccentric peak torque at $60^{\circ}\cdot s^{-1}$ of external rotators were predictors of throwing velocity. The
33 best model to explain the relationship between isokinetic evaluations and throwing velocity was
34 obtained with concentric IR peak torque at $60^{\circ}\cdot s^{-1}$ and eccentric ER peak torque at $60^{\circ}\cdot s^{-1}$ ($r^2 =$
35 0.52 , $p = 0.012$). Relative total work done and peak torque of shoulder extensors were predictors
36 of 25 m swimming velocity. Shoulder isokinetic evaluations correlate significantly with
37 swimming performance and throwing velocity of female water-polo players. The results may
38 help coaches to develop new strategies such as eccentric dry land training programs to increase
39 both shoulder external rotators strength and throwing velocity.

40 **Key words:** Internal rotators, External rotators, Swimming, Throwing velocity, Female athletes

41 **Introduction**

42 Water-polo is an intermittent and high-intensity team sport (Smith, 1998). The objective
43 of this discipline is to score more goals than the opposite team and success requires a
44 combination of technique, a high level of physical fitness and tactical skills (Botonis et al., 2016;
45 Ordóñez et al., 2016; Tucher et al., 2015). Consequently, the basic characteristics of elite water-
46 polo players are the ability to throw the ball with a high velocity and to swim at high speed
47 (Alcaraz et al., 2011; Martínez et al., 2015; Tan et al., 2009b; Vila et al., 2011; Zinner et al.,
48 2015).

49 Throwing is considered as one of the most important aspects of performance (Alcaraz et
50 al., 2011; Martínez et al., 2015). Accuracy and throwing speed are two crucial factors involved
51 in throwing efficacy (Alcaraz et al., 2011). The faster and more precise the throw, the more
52 difficult it is for the defense and goalkeeper to intercept the ball. 90% of throwing during a
53 water-polo game is overhead throwing (Bloomfield et al., 1990). Biomechanical analysis of
54 overhead throwing has revealed that the shoulder is medially rotated and horizontally adducted
55 by the anterior shoulder muscles (Feltner, 1986). When performing overhead activities such as
56 throwing in water-polo, the rotator muscles in the shoulder play a critical role in providing both
57 mobility and stability to the glenohumeral joint (Boettcher et al., 2010). However, throwing
58 velocity is multifactorial. In women, anthropometric characteristics such as the arm span or
59 forearm girth, and lower body power have been identified as predictors of throwing velocity
60 (Alcaraz et al., 2011; Martínez et al., 2015; McCluskey et al., 2010; Zinner et al., 2015).
61 Nevertheless, the influence of shoulder rotator performance on throwing velocity has never been
62 evaluated.

63 Analysis of women's water polo game revealed that water polo can be characterised as a
64 high intensity intermittent sport (Tan et al., 2009a). Players perform approximately 54 high
65 intensity activities per game, one every 38 s (Tan et al., 2009a). Elite players generally exhibit
66 sprinting and endurance swimming abilities (Tan et al., 2009b). During swimming, the shoulder
67 also moves into internal rotation, extension, and adduction at the glenohumeral joint during early
68 pull-through. Internal and adduction strength have been reported to be greater in swimmers
69 compared to the normal population (Batalha et al., 2013). However, the relationship between
70 shoulder internal rotators and/or extensors performance and swimming velocity has not been
71 evaluated. It would be of interest for coaches to choose adapted dry land strength training
72 strategies to increase strength in the shoulder muscle groups involved in the generation of forces
73 required for swimming.

74 Having considered that swimming and throwing have a common biomechanical basis in
75 the use of the shoulder internal rotation and adductor muscles, the aim of the study was to

76 evaluate the relationship between shoulder isokinetic variables and throwing velocity as well as
77 swimming performance in female water-polo players. It was hypothesized that 1) peak torque of
78 shoulder internal rotators would be a predictor of throwing velocity, and 2) peak torques of
79 shoulder internal rotators and abductors would be predictors of 25 m swimming performance.
80

81 **Methods**

82 ***Participants***

83 Fifteen female players of the French water-polo national team participated in this study
84 (mean \pm SD: 22 \pm 2 years; 68 \pm 9 kg; 1.72 \pm 0.08 m). The study was approved by the local Ethics
85 Board and the athletes were informed of the benefits and risks of the investigation prior to
86 signing an institutionally approved informed consent document to participate in the study. The
87 protocol was conducted according to the Declaration of Helsinki.
88

89 ***Study design***

90 Each player performed the following tests: (1) a throwing velocity test, (2) a 25 m
91 swimming trial, (3) a 100 m swimming trial, (4) a 400 m swimming trial, and (5) an isokinetic
92 evaluation. The players performed two tests per day separated by a minimum of 8 hr.
93

94 ***Assessment of throwing velocity***

95 Throwing velocity was measured using a radar gun (SR3600, Sports Radar Ltd,
96 Homosassa, USA), which operates using the Doppler effect. The radar was placed 5 m behind
97 the goal post. Players completed a standardized warm-up comprised of 5 min of light-moderate
98 swimming followed by 5 min of throwing with a progressive increase of intensity until maximal
99 intensity was reached. The players performed 6 shots from the 5 m penalty line. A 30 s rest
100 period elapsed between throws to minimize the effects of fatigue and reduce the risk of injury to
101 the participants. The best shot was selected for further analysis.
102

103 ***Assessment of swimming velocity***

104 After a standardized 10 min swimming warm-up, the players performed three tests of
105 swimming capacity: a 25 m, 100 m and 400 m trial in an indoor 25 m swimming pool on three
106 separate occasions. During the 100 m and 400 m trials, the players touched the wall after every
107 25 m lap. The time was recorded with a manual stopwatch (Casio, Japan) by three instructors
108 and the measurement begun when the legs left the wall and stopped when the hand touched the
109 wall. The mean value was selected for analysis. The start was given in water with a whistle blow.
110

111 *Assessment of isokinetic torque*

112 The measurements were performed using an isokinetic dynamometer (Con-Trex,
113 Medimex, Sainte Foy les Lyon, France). Isokinetic assessment was performed in the dominant
114 arm for internal rotators (IR) and external rotators (ER) of the shoulder joint with the players in
115 the supine position with the arm abducted at 90° in the frontal plane and the elbow flexed at 90°.
116 The range of motion was standardized between 50° of internal rotation and 70° of external
117 rotation as per Forthomme et al. (2013). Three conditions were tested: 1) 3 maximum concentric
118 movements at an angular velocity of 60°·s⁻¹, 2) 3 maximum concentric movements at an angular
119 velocity of 240°·s⁻¹, 3) 3 maximum eccentric movements of the external rotator at an angular
120 velocity of 60°·s⁻¹ with a passive movement of the internal rotator at an angular velocity of 60°·s⁻¹.
121 Isokinetic assessment was performed in both arms for shoulder extensors (EXT) with extended
122 elbows. The range of motion was standardized between 50° of extension and 70° of flexion. The
123 flexion was performed passively at an angular velocity of 60°·s⁻¹. Two conditions were tested: 1)
124 3 maximum concentric movements at an angular velocity of 60°·s⁻¹, 2) 20 maximum concentric
125 movements at an angular velocity of 240°·s⁻¹.

126 Isokinetic testing procedures enabled the measurement of absolute peak torque (PT; N·m)
127 and body mass relative to PT (N·m·kg⁻¹). The total work load was determined during the 20
128 repetition test and expressed relative to body mass (J·kg⁻¹). Agonist–antagonist ratios (ER/IR)
129 were calculated using the same speed and contraction mode for the agonist and antagonist
130 muscle groups (Forthomme et al., 2013). In addition to the usual “concentric” ratios, a mixed
131 ratio (combining ER PT in the eccentric mode at 60°·s⁻¹ and IR PT in the concentric mode at
132 240°·s⁻¹) was designed to more specifically approximate the relationship between shoulder
133 muscles during the throwing motion (Scoville et al., 1997).

134

135 *Statistical analysis*

136 Data are presented as means ± SD. Statistical analyses were performed using Sigma Stat for
137 Windows (version 3.0, SPSS Inc., Chicago, IL). After testing for normality and variance
138 homogeneity, the relationships between isokinetic variables and swimming speed as well as
139 throwing velocity were determined using Pearson correlation analysis. Variables significantly
140 associated with throwing velocity and swimming speed were entered into the regression model
141 as independent variables. Prior to calculating multiple regression models, the predictors (i.e.
142 isokinetic variables) were checked for multicollinearity by calculating the variance inflation
143 factor (VIF). The significance level was set at $p < 0.05$.

144

145 **Results**

146 The mean throwing velocity was $15.3 \pm 0.8 \text{ m}\cdot\text{s}^{-1}$. The mean swimming speeds were 1.76
147 $\pm 0.1 \text{ m}\cdot\text{s}^{-1}$ for the 25 m, $1.43 \pm 0.1 \text{ m}\cdot\text{s}^{-1}$ for the 100 m and $1.25 \pm 0.1 \text{ m}\cdot\text{s}^{-1}$ for the 400 m trial.
148 Table 1 summarizes the mean values of isokinetic evaluations. No difference was observed
149 between the dominant and non-dominant side during the shoulder extension evaluations.

150

151

INSERT TABLE 1 HERE

152

153 All variables significantly associated with throwing velocity in bivariate analysis were
154 entered into a multivariable regression model to determine the independent predictors of
155 throwing velocity (Table 2). Peak torque of IR at Con 60 and Con 240 were closely correlated
156 with each other in bivariate analysis and their concurrent inclusion in multiple regression
157 analysis resulted in a VIF >10 , indicating high multicollinearity. Accordingly, peak torques at
158 each speed were separately entered into the regression model. The best model was obtained with
159 concentric IR peak torque at $60^\circ\cdot\text{s}^{-1}$ and eccentric ER peak torque at $60^\circ\cdot\text{s}^{-1}$ ($r^2 = 0.52$, $p =$
160 0.012).

161

162

INSERT TABLE 2 HERE

163

164 All variables significantly associated with 25 m, 100 m and 400 m swimming velocity in
165 bivariate analysis were entered into a multivariable regression model to determine the
166 independent predictors of the different swimming velocities (Table 3). Relative total work ($\text{J}\cdot\text{kg}^{-1}$)
167 and EXT peak torque at $60^\circ\cdot\text{s}^{-1}$ remained the independent predictors of 25 m swimming
168 velocity when the variables were included in the regression model ($r^2 = 0.71$, $p = 0.001$). No
169 correlation was observed between the isokinetic variables and 100 m swimming velocity.
170 Relative total work ($\text{J}\cdot\text{kg}^{-1}$) remained the only independent predictor of 400 m swimming
171 velocity when the variables were included in the regression model ($r^2 = 0.27$, $p = 0.044$).

172

173

INSERT TABLE 3 HERE

174

175 **Discussion**

176 The aim of this study was to examine the relationship between isokinetic shoulder
177 evaluations and throwing velocity as well as swimming performance in female water-polo
178 players. Results revealed that concentric peak torque of internal rotators and eccentric peak
179 torque of external rotators were predictors of throwing velocity. Relative total work and peak

180 torque of shoulder extensors were good predictors of 25 m swimming velocity.

181

182 The effectiveness of the shot depends, in part, on throwing velocity. The mean value of
183 the maximal throwing velocity that was recorded in this study was $15.3 \pm 0.8 \text{ m}\cdot\text{s}^{-1}$. These values
184 were similar to those reported previously (range: 13.9 to $16.1 \text{ m}\cdot\text{s}^{-1}$) (McCluskey et al., 2010).

185 A number of variables have been tested to determine their influence on throwing
186 velocity. Previous studies showed that anthropometric characteristics influenced throwing
187 velocity in female water polo players (McCluskey et al., 2010; Platanou and Botonis, 2010;
188 Platanou and Varamenti, 2011). Specifically, body height, arm span and calf and upper arm
189 girths were associated with throwing velocity. Moreover, the influence of lower limb power is or
190 is not considered as a significant predictor of throwing velocity (Martínez et al., 2015;
191 McCluskey et al., 2010; Platanou and Botonis 2010; Platanou and Varamenti, 2011). In our
192 study, we focused on the shoulder torque influence on throwing velocity. Similarly to the study
193 of Platanou and Varamenti (2011), we found a correlation between internal rotators and throwing
194 velocity. This is consistent with the fact that muscular performance is an essential requirement to
195 achieve high throwing velocity (Pedegana et al., 1982) and that the production of the maximal
196 torque at the rotator muscles of the shoulder zone has a high correlation with throwing velocity
197 (Bloomfield et al., 1990).

198 In our study, we evaluated external rotators in the eccentric mode based on the fact that
199 during throwing, there is a complementary action of concentric and eccentric contractions.
200 During overarm throwing, there is an antagonist activity involved in deceleration following the
201 release of the ball (Hirashima et al., 2002). The eccentric contraction of external rotators plays a
202 key role and acts as a brake during the final deceleration of the upper limb, thereby limiting the
203 pronounced increase in distraction force (Sirota et al., 1997). Taken together the results suggest
204 that concentric peak torque of internal rotators and eccentric peak torque of external rotators
205 should be developed together to maximize the throwing velocity increase.

206 Several biochemical studies regarding competitive swimming have documented that
207 propulsive forces responsible for total body displacement are mainly produced by the upper
208 limbs, through arm adduction and shoulder internal rotation (Olivier et al., 2008; Yanai and Hay,
209 2000). A common criticism of isokinetic testing is the lack of agreement between the test and
210 performance speed. In our study, we chose a speed of $240^\circ\cdot\text{s}^{-1}$ which is similar to pull-through
211 phase duration reported previously (Bak and Magnusson, 1997). The present study evaluated
212 peak torques of both internal rotators and arm adductors. We did not find a relationship between
213 swimming velocity and peak torque of shoulder rotators. However, we observed that both
214 shoulder extensors peak torque and total work remained independent predictors of 25 m

215 swimming velocity, but not 100 m and 400 m swimming velocities. We could hypothesize that
216 the absence of the relationship between peak torque and 100 m and 400 m swimming velocities
217 could be explained by muscle fatigue that occurs during evaluations leading to lower muscle
218 peak torque. Accordingly, a previous study showed that muscle fatigue occurred during short
219 duration and high speed swims suggesting that muscle peak torque and muscle endurance were
220 distinct characteristics (Bassan et al., 2015). Future studies should evaluate if isokinetic muscle
221 endurance evaluations reflect endurance-swimming performance. All together, these results
222 suggest that maximal and short duration isokinetic evaluations only reflect swimming velocities
223 during short duration.

224 This study showed that isokinetic evaluations reflected throwing velocity as well as
225 swimming velocity in elite female water polo players. This has significant implication for
226 training practices and evaluations of this population. Firstly, for training strategies, it is
227 recommended to develop eccentric strength of shoulder external rotators to enhance throwing
228 velocity of the players. Moreover, coaches should use training programs to develop shoulder
229 adductor force in order to enhance sprint swimming performance. Secondly, the use of isokinetic
230 testing has significant implications for team selection, evaluation and training strategies.
231 Specifically, isokinetic evaluations may help coaches identify whether they should focus on
232 muscle strength development or throwing technique.

233 The present study had some limitations which require further discussion. The swimming
234 evaluations were performed with the front crawl with the head under the water technique.
235 Kinematic differences have been previously observed between different front crawl techniques
236 in young female players (Zamparo and Falco, 2010). However, no swimming velocity
237 differences were reported (De Jesus et al., 2012). Since we compared swimming velocity and
238 isokinetic evaluation, we hypothesized that the use of the front crawl with the head under the
239 water technique would reflect the performance with the use of the front crawl with the head
240 above the water technique. Another limitation was the 25 m distance which did not reflect
241 accurately the elite female water-polo sprint distance (Tan et al., 2009a). However, the
242 comparison of 15 m and 25 m sprint tests showed a high correlation level (Kontic et al., 2017).
243 We assumed that higher correlations with isokinetic variables would be observed in a 15 m
244 swimming test.

245

246 **Conclusions**

247 Isokinetic shoulder evaluations correlated significantly with swimming performance and
248 throwing velocity in female water-polo players. We observed that both concentric and eccentric

249 peak torques were influenced by throwing velocity. Future studies should examine the influence
250 of chronic training on shoulder rotators and throwing velocity.

251

252 **References**

253

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325

326

327

Tables

328 **Table 1:**
329 **Isokinetic performances of dominant and non-dominant shoulders**

Variables	Angular Velocity ($^{\circ}\cdot s^{-1}$)	D Side	ND Side
Peak Torque IR (N·m)	Con 60	37.3 ± 9.6	
	Con 240	31.9 ± 5.9	
Peak Torque ER (N·m)	Ecc 60	40.6 ± 10.3	
	Con 60	0.65 ± 0.11	
Ratio ER/IR	Con 240	0.66 ± 0.08	
	Ecc 60 / Con 240	1.27 ± 0.21	
Mixed ratio ER/IR			
Peak Torque EXT (N·m)	Con 60	72.5 ± 12	72.0 ± 9.5
Total work done ($J\cdot kg^{-1}$)	Con 240	29.8 ± 3.8	29.0 ± 3.6

330 *Values are presented as mean \pm SD. D Side, Dominant Side; ND Side, Non-dominant Side; Con*
331 *60 = $60^{\circ}\cdot s^{-1}$, concentric mode; Con 240 = $240^{\circ}\cdot s^{-1}$, concentric mode; Ecc 60 = $60^{\circ}\cdot s^{-1}$, eccentric*
332 *mode. ER, external rotators, IR, Internal rotators, EXT, shoulder extensors.*

333

334 **Table 2:**
335 **Correlations between throwing velocity and related variables in bivariate analysis**

	r	p
Peak Torque IR Con 60	0.692	0.004
Peak Torque IR Con 240	0.649	0.009
Peak Torque ER Ecc 60	0.681	0.005

336 *Con 60 = $60^{\circ}\cdot s^{-1}$, concentric mode; Con 240 = $240^{\circ}\cdot s^{-1}$, concentric mode; Ecc 60 = $60^{\circ}\cdot s^{-1}$,*
337 *eccentric mode. ER, external rotators, IR, Internal rotators.*

338

339

340

341 **Table 3:**342 **Correlations between swimming velocities and related variables in bivariate analysis**

	25 m		100 m		400 m	
	<i>r</i>	<i>p</i>	<i>r</i>	<i>p</i>	<i>r</i>	<i>p</i>
Peak Torque IR Con 60	-0.21	0.224	-0.15	0.291	0.04	0.443
Peak Torque IR Con 240	-0.41	0.063	-0.09	0.376	0.09	0.368
Peak Torque ER Con 60	-0.46	0.041	-0.38	0.077	-0.23	0.202
Peak Torque EXT (N·m) Con 60	-0.63	0.006	-0.34	0.109	-0.20	0.234
Total work done (J·kg ⁻¹) Con 240	-0.76	0.001	-0.29	0.140	-0.53	0.022

343 *Con 60 = 60°·s⁻¹, concentric mode; Con 240 = 240°·s⁻¹, concentric mode; Ecc 60 = 60°·s⁻¹,*344 *eccentric mode. ER, external rotators, IR, Internal rotators, EXT shoulder extensors.*

345