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► To cite this version:

Cozette Maryne, Pierre-Marie Leprêtre, Weissland Thierry. Angular ranges as a reliable isokinetic method to assess shoulder rotator muscles. Medical Engineering & Physics, 2020, 84, pp.16-20. 10.1016/j.medengphy.2020.07.023 . hal-02919807

HAL Id: hal-02919807 https://hal.science/hal-02919807

Submitted on 22 Aug2022

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ABSTRACT

32	Objectives: Physiological and functional ratios of internal and external rotators are used to
33	assess the muscle balance of shoulder joint. Ratios are usually calculated from the peak torque
34	value (PT) of each muscle group, without taking into account the angular positions at which PT
35	are reached. The aim of our study was to propose an alternative and reliable method based on
36	sectorial analysis for isokinetic assessment of the shoulder muscle balance. Method: 22 men
37	(23.0±2.7y) participated in isokinetic tests of the muscle rotators in a seated position in scapular
38	plane, at 60°.s ⁻¹ , in concentric (CON) and eccentric (ECC) modes for both shoulders. Peak
39	torque (PT) and torque averaged per range of 10° (T) were calculated for internal and external
40	rotators. Physiological and functional ratios were calculated with classic peak approach (PT-
41	ratios) and new sectorial approach (T-ratios). Results: PT-ratios and T-ratios were different
42	(P<0.05). T-ratios were different between the angular ranges (P<0.05). The reliability was
43	variable as function of angular ranges. The majority of the T-ratios calculated over non-extreme
44	angular ranges were more reliable than PT-ratios (intraclass correlation coefficient=0.14-0.75;
45	coefficient of variation=7.0-28.5%). Conclusions: The angular range method showed a better
46	reliability than the peak torque method. Angular range method better reflects the functional
47	reality because it takes into account the muscular potential in its entirety of the range of
48	movement.
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51	Keywords : data accuracy, muscle balance, strength, sport, rehabilitation
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60 **INTRODUCTION**

The balance between internal (IR) and external (ER) rotator muscles has an important role in 61 mobility and in the stability of glenohumeral joint¹. The imbalance between IR and ER could be 62 responsible for a faulty centering of the humeral head². Tanaka et al. (2012)³ and Clément et al. 63 64 $(2017)^4$ showed that the range of instability was in the middle of the range of motion (ROM) rather than in maximum external rotation. The muscle strength balance is classically researched 65 66 by peak torque (PT) ratios of antagonist and agonist muscles in isokinetic standardized conditions⁵. The PT values are defined as the highest data point of the curve for torque output in 67 the ROM for each muscle group. However, the angular position at which PT is reached is not, 68 69 therefore, taken into account. It has been observed that agonist and antagonist muscles did not 70 attain their respective PT at the same angle^{6,7}. The torque analysis of rotator muscles generally 71 shows that PT values are reached at angles near to the limit of the ROM⁷. However, Brown et 72 al. $(1995)^8$ showed that imposed velocity is instable precisely at this angles near to the limit of 73 the ROM. These observations may explain the relative unreliability of the physiological 74 (antagonist-PT in concentric / agonist-PT in concentric) and functional (antagonist-PT in eccentric / agonist-PT in concentric) ratios of shoulder rotator muscles found by Edouard et al. 75 (2011, 2013)^{9,10}. Finally, the isokinetic PT method to calculate ratios did not appear to be 76 77 adapted to the shoulder muscle balance assessment according to Tanaka et al. (2012)³ and Clément et al. (2017)⁴. Indeed, the muscle balance must be assessed by angular sectors, in 78 particularly in range of instability that corresponds to the middle of ROM. 79

Together, these observations questioned the interest of physiological and functional ratios based on PT values in the dynamic exploration of shoulder muscles balance. From a dynamic perspective, it is therefore important to determine the muscular potential in its entirety. To that end, we here suggest an alternative and reliable method based on angular analysis for isokinetic assessment of shoulder rotator muscles strength balance.

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86 **METHODS**

Twenty-two male non-overhead trained collegiate athletes (23.0±2.7 years, 180.6±5.7 cm, 74.6±6.5 kg), voluntarily participated in the study, including ten subjects (22.8±2.0 years, 180.8±6.8 cm, 74.8±6.6 kg) who had also taken part in a reliability session. Each subject was familiarized with the experimental procedures before the study. All were free of upper extremity musculoskeletal injuries and did not present any contraindication to upper limb isokinetic testing. Before the experiments, the subjects were informed of the risks and stresses associated with the protocol and gave their written informed consent. The study was performed in accordance with the Ethical Standards in Sport and Exercise Research¹¹ and approved by the
national ethics committee of France (CERSTAPS 2015/07/07).

96 The muscular shoulder parameters of each subject were measured in seated position, the shoulder in scapular plane¹² on an isokinetic dynamometer (Cybex Norm[®], division of Lumex, 97 Inc., Ronkonkoma, New York, USA) in an air-conditioned room (Temperature: ~20.3°C, 98 Relative humidity: ~35.0% and Atmospheric pressure: ~762mmHg). The seat and handlebar 99 heights were set for each subject according to the Cybex isolated joint testing manual (Cybex/ 100 Isolated-Joint testing and Exercise. Ronkohoma, NY, USA: Cybex, 1983). After 10 minutes of 101 102 standardized warm-up on an arm ergometer (Cybex metabolic systems MET300[®], Ronkonkoma, New York, USA), and 3 minutes at rest, each subject performed two blocks in a 103 104 random order ; one block for the dominant shoulder (D) and another block for the non-dominant shoulder (ND). Each block consisted of 1 series of 3 repetitions at 60°.s⁻¹ in concentric 105 contraction, 2 minutes rest, and 1 series of 3 repetitions at 60° .s⁻¹ in eccentric contraction. One 106 repetition consisted in internal rotation (ranging from 0 to 110°) followed by external rotation 107 (ranging from 110 to 0°). The range of motion was 110° . The subjects of the test-retest 108 109 reliability study were tested with the same protocol at one-week interval. To minimize physical activity effects, the subjects were asked to avoid high-intensity exercise training one week 110 before and during the study. 111

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The torque (T) and peak torque (PT) values were measured for internal (IR) and external (ER) 113 114 rotators of dominant (D) and non-dominant (ND) shoulder in concentric (CON) and eccentric 115 (ECC) modalities without gravitational correction. All data were extracted and recorded with an acquisition unit (PowerLab 16/35 PL3516, ADInstruments[®], Bella Vista, NSW 2153, 116 Australia). The physiological ratios (ER/IR) measured exclusively in concentric modality, and 117 the functional ratios, i.e the torque value of ER measured in eccentric modality related to the 118 torque value of IR measured in concentric modality (ERecc/IRcon) and conversely 119 (IRecc/ERcon), were calculated. We distinguished the ratios calculated with the averaged torque 120 by the angular range of 10° as T-ratios (T_{ER/IR}; T_{ERecc/IRcon}; T_{IRecc/ERcon}) and the ratios calculated 121 with the peak torque as PT-ratios ($PT_{ER/IR}$; $PT_{ERecc/IRcon}$; $PT_{IRecc/ERcon}$). 122

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The isokinetic dynamometer software transfers the best PT value in a series of n repetitions, i.e for three repetitions, only the repetition associated with the highest PT was selected for IR and ER. To use the same method, we retained only the repetitions associated with PT of IR and ER. Data was acquired at a frequency of 100Hz at the angular velocity of 60.s⁻¹. The Torque data was averaged by angular range of 10°. To simplify the angular ranges reporting we used integers (i.e 10-19.9° was reported as 10-20°). Two extreme ranges (i.e 0-10° and 100-110°) were systematically excluded from analysis because they correspond to the delay time to
acceleration and deceleration phases, so they are not really at constant velocity. Data recorded
on these angular ranges are presented for illustrative purpose but our analysis focused on the
angular ranges from 10° to 100°. For sake of clarify, data were rounded to tenths.

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Descriptive statistics are expressed as means and standard deviation. The normal distribution 135 and homogeneity of variance were verified for each parameter (Shapiro-Wilk test). T-test was 136 137 used for comparing paired samples. We used ANOVA with repeated measures followed by 138 post-hoc analysis with Bonferroni t-test to compare the means for each angular range of 10°. 139 The coefficient of variation (CV) and the intraclass correlation coefficient (ICC) were calculated to test the absolute and relative reliability¹³. The tests were performed using the full version of 140 SPSS (IBM[®] SPSS[®] Statistics, Version 20.0.0, Chicago, USA). A significance level of P<0.05 141 142 was selected for all tests.

143

144 **RESULTS**

The PT and T values are reported in Table 1. Three observations were made on the reliability
indexes of the averaged torque by angular range (Fig. 1). Firstly, this approach exhibited better
reliability indexes of T-ratios compared to PT-ratios. Secondly, the reliability was better in
CON compared to ECC modality. Thirdly, the reliability of IR was better than ER.

ICC and CV were calculated for all ratios (Fig. 1). For both shoulders, functional and 149 physiological PT-ratios presented variable and unsatisfactory ICC (from 0.14 to 0.75) and CV 150 151 (from 7.0 to 28.5%) compared to T-ratios. Lower ICC and CV were found at the onset and the 152 end of ROM. Hence, for the majority of the angular ranges, the reliability indexes of T-ratios 153 were better than PT-ratios (Fig. 1). For the $T_{ER/IR}$ physiological ratio, the ICC scores were 0.33-0.85 (CV: 11.7-14.8%) and 0.14-0.84 (CV: 7.1-11.0%) for D and ND shoulders compared to 154 0.21 (CV: 12.7%) and 0.15 (CV: 16.8%) respectively for the PT_{ER/IR} ratio. For the functional 155 ratios, T_{ERecc/IRcon} ICC values were 0.18-0.79 (CV : 11.5-20.1%) and 0.03-0.79 (CV : 7.4-14.9%) 156 and ICC of T_{IRecc/ERcon} were 0.08-0.88 (CV : 12.2-32.2%) and 0.04-0.27 (CV : 19.0-36.3%) for D 157 and ND shoulders, respectively. 158

159 IR reached higher values of averaged torque between 20 to 40° , while averaged torque of ER 160 muscles reached their maximum between 60 to 90° (Fig. 2). All ratio values exhibited 161 significant changes with the angular range (P<0.05, Table 1). The maximal T_{ER/IR} and 162 T_{ERecc/IRcon} ratios occurred between 60 to 100° . In contrast, the higher values of T_{IRecc/ERcon} ratio 163 were found at angular ranges of 20-40°.

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166 **DISCUSSION**

167 The main purpose of this study was to propose an alternative method to explore shoulder rotator 168 muscles balance that was representative to the functional reality and reliable. Our main results 169 showed significant differences between the PT-ratio and the T-ratio for the three calculated 170 ratios (ER/IR; ERecc/IRcon; IRecc/ERcon), and significant differences between angular 171 ranges for T-ratios. Moreover, reliability was higher for the 10° steps angular approach 172 compared to ratios calculation based on the PT.

The physiological T_{ER/IR} ratio was lower in external rotation and tended to increase in internal 173 rotation. Indeed, the potential difference beetween agonist and antagonist muscles was less 174 important in internal rotation. This is explained by the length/tension relationship which 175 176 animates the rotator muscles: internal rotators were less effective when in slightly shortened position, and external rotators were more efficient in slightly stretched position. Cibulka et al. 177 178 (2014)¹⁴ showed that IR and ER muscles were weakest when placed in a position of shortest muscle length, i.e. at end-range of internal rotation for IR and at end-range of external rotation 179 180 for ER. For functional ratios, our results showed a better ability of the antagonists to counteract 181 the concentric action of the agonists at the end of the dynamic movement, i.e. at the end of the 182 internal rotation for the T_{ERecc/IRcon} and at the end of the external rotation for the T_{IRecc/ERcon} ratio. This eccentric control was more effective at the end of the dynamic movements of the throwing: 183 the cocking and the acceleration phases which are respectively associated with PT_{IRecc/ERcon} and 184 PT_{ERecc/IRcon} ratios¹⁵. 185

Ruas et al. (2014)¹⁶ studied the evolution of physiological and functional ratios of the shoulder 186 rotator muscles using the specific angular torque (AST) method. The AST method consists of 187 measuring the agonist and antagonist muscle torque and associated ratios at specific joint 188 189 angles¹⁷. They showed significant differences of the AST-ratio values between angles, and 190 between the PT_{ERecc/IRcon} ratio and the AST_{ERecc/IRcon} ratio. However there was no significant difference between the PT_{ER/IR} ratio and the AST_{ER/IR} ratio. The AST method allows to have 191 192 more information during the ROM, but corresponds to one data point at one angle. This method 193 applied to shoulder assessement has not been studied for reliability.

194The most widely used ratios in the literature (ER/IR and ERecc/IRcon) were more reliable by195using angular range method than PT method (Fig. 1). This is explained by smoothing since the196torques were averaged by angular ranges of 10°. Thus, at an acquisition frequency of 100 Hz

and the angular velocity of 60° .s⁻¹, the data is averaged with 20 points per angular range. This makes the averaged torque by angular range more constant and less variable than a raw and isolated value (PT). Moreover, the reliability of the T-ratios was better in the middle of the ROM, when the angular velocity was stabilised, i.e apart from the extreme ranges of the ROM which are non-isokinetic (phases of acceleration and deceleration)⁸. The reliability indexes could be improved by changing the test position. Hence, Forthomme et al. (2011)¹² showed better absolute reliability in supine position.

The results of our study support the proposed methodology, but there are certain aspects that 204 deserve discussion. The amplitude of angular ranges was set at 10° for two reasons. First, it is 205 206 the best compromise between precision and practicality. Indeed, the objective being to provide a 207 tool to the clinician, most of the measurements carried out have an accuracy to within 10°. Second, it allowed comparison of our results with the majority of previous sectorial studies¹⁷. 208 209 The seated position with shoulder in scapular plane was chosen because it is more physiological, safe, comfortable and allows the development of optimal torque⁹. However, it 210 would have been interesting to compare the two most used positions^{9,12} to assess their effect on 211 212 the T-ratios reliability: the seated position with the shoulder in scapular plane vs. the supine 213 position with shoulder in frontal plane. Finally, the absence of women in the sample represents a limit. Indeed Forthomme et al. (2013)¹⁸ showed significantly different PT-ratio values between 214 women and men. 215

In summary, isokinetic parameters evolved significantly during the ROM and the torque ratios were different of the ratios calculated with the peak torque. The physiological and functional ratios had a satisfactory reliability on the isokinetic angular ranges unlike the ratios usually used and associated to the peak torque. Thus, in view of these elements, the angular range method is a reliable method to determine dynamic stability during the ROM.

221

222 ACKNOWLEDGMENTS

223 The authors thank professor Charles Vincent for commenting an early draft of the manuscript.

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225 Conflicts of interest: None

- 226 Funding: Ministry of national education and research of France
- 227 Ethical Approval: National sport sciences ethics committee

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Captions

Figure 1. Relative (intraclass correlation coefficient; ICC) and absolute (coefficient of
variation; CV) reliability indexes of averaged torque by angular range of 10° and peak torque
(PT) for internal rotators (IR) in concentric (CON) and eccentric (ECC) modality (A), external
rotators (ER) in concentric (CON) and eccentric (ECC) modality (B) and physiological (ER/IR)
and functional (ERecc/IRcon; IRecc/ERcon) ratios (C) at 60°.s⁻¹ for dominant shoulder. Nonisokinetic ranges are highlighted in grey. \$ CV ≤ 15%.

Figure 2. Evolution of averaged torque per angular range of 10° (in N.m) and peak torque (PT)
production sector for internal rotators (IR) in concentric (CON) and eccentric (ECC) modality
(A), external rotators (ER) in concentric (CON) and eccentric (ECC) modality (B) and
associated angular range ratios (C,D) with PT-ratios values at 60°.s⁻¹ for dominant shoulder.
Non-isokinetic ranges are highlighted in grey. * Significant difference (P<0.05) between
averaged torque per angular range of 10° and PT-ratios.





physio	logical (E	R/IR) and fu	inctional	ratios (EF	kecc/IRco	n; IRecc/	ERcon). N	on-isokir	ietic range	es highligh	nted in gre	ey.			
	n=22				0-10°	10-20°	20-30°	30-40°	40-50°	50-60°	60-70 °	70-80°	80-90°	90-100°	100-110°
Corque (N.m)		CON	IR	53.79	29.39	47.19	49.53	50.51	50.27	49.05	46.92	44.87	42.81	39.70	24.53
				(9.99)	(6.76)	(9.92)	(10.13)	(9.66)	(9.40)	(9.01)	(8.46)	(7.89)	(7.53)	(7.59)	(7.15)
			ER	32.51	16.61	23.33	25.08	25.99	26.40	26.37	26.50	26.81	26.71	25.05	16.90
	D.			(5.45)	(4.96)	(4.86)	(5.36)	(5.37)	(5.58)	(5.83)	(6.06)	(6.42)	(6.39)	(6.38)	(3.78)
	D	ECC	ю	62.55	27.68	49.82	57.30	58.29	57.47	55.94	53.71	50.91	46.36	37.91	19.71
			IK	(9.48)	(16.73)	(11.15)	(9.57)	(9.44)	(8.73)	(8.27)	(7.60)	(6.85)	(6.03)	(5.87)	(5.78)
			ER	38.62	17.61	27.11	30.71	32.02	32.66	33.24	33.39	33.54	33.09	26.79	15.95
				(8.20)	(7.14)	(7.40)	(7.62)	(6.72)	(6.36)	(6.30)	(6.88)	(7.16)	(6.89)	(9.64)	(9.59)
		CON	IR	51.87	28.62	44.70	46.53	47.83	47.31	45.55	43.16	40.69	38.36	35.51	21.55
				(9.13)	(7.38)	(9.55)	(9.17)	(8.95)	(8.18)	(7.54)	(7.26)	(6.69)	(5.99)	(5.49)	(7.58)
			ER	27.46	13.56	19.95	21.45	22.10	22.25	22.34	22.26	22.61	23.15	21.98	14.36
	ND .			(3.71)	(4.36)	(5.11)	(5.28)	(5.27)	(4.68)	(4.33)	(3.96)	(3.69)	(3.68)	(3.56)	(3.49)
	ΝD	ECC	ID	56.98	27.21	46.69	51.36	52.09	51.63	50.00	47.25	43.36	38.69	31.01	17.40
			IIV	(9.85)	(15.21)	(14.26)	(10.69)	(9.50)	(8.35)	(7.36)	(6.17)	(5.40)	(5.43)	(6.05)	(6.34)
			ER	34.39	15.25	23.33	27.84	29.87	30.38	30.48	30.50	29.66	28.18	23.19	12.94
				(4.97)	(3.37)	(3.81)	(4.29)	(4.38)	(4.62)	(4.96)	(4.89)	(5.40)	(6.13)	(9.18)	(7.26)
Ratios		ER/I	ER/IR 0.61 (0.09)		0.59	0.51	0.52	0.52	0.53	0.54	0.57	0.60	0.62	0.63	0.76
					(0.22)	(0.12)	(0.10)	(0.09)	(0.09)	(0.09)	(0.09)	(0.09)	(0.10)	(0.13)	(0.38)
			Recc/IRcon 0.74		0.63	0.59	0.63	0.65	0.66	0.69	0.72	0.76	0.79	0.70	0.68
	D	EXECTINCOI		(0.16)	(0.28)	(0.19)	(0.17)	(0.14)	(0.13)	(0.12)	(0.13)	(0.15)	(0.17)	(0.27)	(0.41)
		IRecc/ERcon		1.95	1.82	2.22	2.36	2.31	2.24	2.19	2.10	1.98	1.81	1.61	1.25
				(0.27)	(1.21)	(0.62)	(0.53)	(0.48)	(0.43)	(0.43)	(0.41)	(0.40)	(0.40)	(0.48)	(0.53)
		ER/IR		0.54	0.51	0.46	0.47	0.47	0.48	0.50	0.52	0.56	0.61	0.64	0.82
				(0.08)	(0.23)	(0.14)	(0.11)	(0.10)	(0.09)	(0.09)	(0.09)	(0.10)	(0.12)	(0.15)	(0.58)
	ND	ERecc/IRcon		0.68	0.57	0.55	0.62	0.64	0.66	0.68	0.72	0.74	0.74	0.67	0.73
				(0.12)	(0.21)	(0.14)	(0.13)	(0.12)	(0.12)	(0.13)	(0.13)	(0.13)	(0.16)	(0.29)	(0.58)
		IRecc/ERcon		2.06	2.25	2.47	2.51	2.46	2.39	2.29	2.17	1.96	1.70	1.44	1.31
				(0.43)	(1.58)	(1.08)	(0.81)	(0.70)	(0.54)	(0.44)	(0.38)	(0.34)	(0.30)	(0.32)	(0.55)

Table 1 : Means (\pm SD) of Peak Torque (PT) and Averaged Torque par angular range of 10° (in N.m) during concentric (CON) and eccentric (ECC) at 60°.s-1 of internal (IR) and external (ER) shoulder rotation for dominant (D) and non-dominant shoulder (ND), associated physiological (ER/IR) and functional ratios (ERecc/IRcon; IRecc/ERcon). Non-isokinetic ranges highlighted in grey.