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rotator cuff injury: a biomechanical and
kinematic analysis

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Mestrado em Fisioterapia

Opção Terapia Manual

Dezembro de 2016

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Dissertação submetida à Escola Superior de Saúde do Porto para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Fisioterapia – Opção Terapia Manual, realizada sob a orientação científica da Doutora Andrea Ribeiro, Doutorada em Ciências da Motricidade-Especialidade Fisioterapia.

Dezembro de 2016

Shoulder drop arm test in subjects with rotator cuff injury: a biomechanical and kinematic analysis

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Abstract

Background: Impingement syndrome is often reported in literature and clinical practice although its meaning has varied along time and is ambiguous. Rotator cuff tears can be the final step of impingement syndrome conditions, and can be investigated with clinical tests, one of which is drop arm test (DAT). **Aims:** The aim of this study was to verify the correlation between rotator cuff gravity of lesion, pain, function and the kinematic characteristics of DAT such as the arch of movement and smoothness (SPARC measure). **Methods:** Twenty subjects with rotator cuff pathology performed DAT bilaterally and kinematic data were caught with a motion capture system. Information on ultrasound gravity of lesion, function (DASH scale) and pain were previously collected. Kinematic variables and smoothness were then calculated. **Results:** No statistically significant differences were found between smoothness in the two shoulders (median SPARC rating -9.7305 for the painful shoulder and -10.1569 for the healthy shoulder; $Z=-1.12$, $p= 0,263$). In our sample subjects tended to move in a similar way between the two limbs in terms of smoothness, arch of movement and velocity. Pain and function were not correlated to the other variables. **Conclusion:** The asymptomatic arm moved faster than the painful one, even though DAT requires to slowly lower the arm to side. Conversely, subjects with more disability tended to move the painful arm faster. Affected and unaffected limbs had similar smoothness. Furthermore, the level of gravity of the lesion did not seem to play a role in determining the performance during the test and pain was not correlated with any other variable. A relation between the level of smoothness, the arch of movement and velocity in the painful and uninvolved limb was found suggesting that subjects tended to move in a uniform way between the two sides.

Key words: drop arm test, smoothness, kinematic analysis

1 Introduction

1.1 Impingement syndrome: an umbrella term

Shoulder pain is a common reason for consultation in physiotherapist practice. It affects a considerable number of subjects and this population appears to be heterogeneous ranging from elderly people to athletes (Koester, George, & Kuhn, 2005). Subacromial impingement syndrome is among the most reported painful conditions of the shoulder in clinical practice and in literature (van der Windt, Koes, de Jong, & Bouter, 1995).

Historically, it was described as a painful syndrome of the gleno-humeral joint that occurs when the structures in the subacromial space (rotator cuff, biceps tendon long head and subacromial bursa) become compressed and inflamed under the coraco-acromial ligament (Bigliani & Levine, 1997). Typical signs and symptoms were described such as pain with overhead activities, a ‘painful arc’, pain through specific manoeuvres such as shoulder elevation with internal rotation, or possibly signs of impaired rotator cuff function (Bigliani & Levine, 1997). According to the level of evolution of the disease, three stages of impingement were identified: subacromial bursitis, partial-thickness and full-thickness rotator cuff tears (van der Windt et al., 1995).

However, since Neer first described “subacromial impingement” as a clinical entity (Neer, 1972), the meaning of this term has changed and has been associated to a wide range of different painful conditions of the shoulder. The discovery of a new mechanical impingement phenomenon called “internal impingement” turned the diagnostic category of this syndrome increasingly complicated (Garofalo et al., 2010): it was described as the result of an impact between rotator cuff and joint capsule on the glenoid, rotator cuff and glenoid rim itself or between the glenoid and humerus, frequently found in asymptomatic shoulders (Garofalo et al., 2010; Tagg, Campbell, & McNally, 2013). Finally, a third category called coracoid impingement, in which the subscapularis tendon makes contact with the coracoid, has also been identified (Braman, Zhao, Lawrence, Harrison, & Ludewig, 2014).

As to etiology, another classification in functional and structural impingement has been proposed. Structural impingement consists of a reduction of the subacromial space due to bony growth or soft-tissue inflammation, while functional impingement is

reconducted to superior migration of the humeral head caused by weakness and/or muscle imbalance. Due to this lack in the dynamic control of movement that characterizes it, this second category is often reported as functional instability of the gleno-humeral joint (Phil Page, 2011). The shoulder complex indeed relies on muscles to provide dynamic stability during its large range of mobility, and if this muscular balance is not guaranteed changes in arthrokinematics and movement impairments can occur and ultimately cause structural damage. Structural and functional impingement are therefore not supposed to be intended as two separated situations as one can lead to the other and vice versa, and it is also possible that some subacromial impingement conditions result from a combination of factors belonging to both of these two categories (Ludewig & Braman, 2011; Phillip Page, Frank, & Lardner, 2010).

Nowadays it has become evident that “impingement syndrome” is not an isolated condition that can be easily diagnosed with clinical tests or most successfully treated surgically (Braman et al., 2014; Braun, Bularczyk, Heintsch, & Hanchard, 2013). It is rather likely to be a complex of conditions involving a combination of intrinsic and extrinsic factors. Researchers using the diagnostic label of “shoulder impingement” are probably not studying homogenous patient groups and it is not possible to determine consistent etiologic factors or recommend specific treatment interventions for these subjects. For these reasons consensus is growing to the need of clearly distinguish “mechanical impingement” resulting in compression or frictional shear that causes soft tissue abrasion from the diagnostic label of “shoulder impingement syndrome”, and some authors recently proposed that this clinical diagnostic term may be eliminated as it is no more informative, having become too broad to effectively direct treatment (Braman et al., 2014). “Anterior shoulder pain” has been proposed by the same authors as an alternative term because although it is not a helpful diagnostic label in directing treatment, at least this option does not do the harm that a label of “impingement syndrome” can do if it results in an unnecessary or unsuccessful surgery (Vitale, Arons, Hurwitz, Ahmad, & Levine, 2010).

Nevertheless, despite the lack of consensus on terminology, scientific publications are still using the term impingement syndrome with considerable frequency (Papadonikolakis, McKenna, Warne, Martin, & Matsen, 2011) when describing groups of patients affected by shoulder pain, clinical assessment or treatment. Due to the multifactorial nature of this syndrome and to the ambiguity of the term, we do not have definitive clinical tests that clearly isolate the presence of shoulder impingement (Braman et al., 2014). However, various pain inducers (Neer, Hawkins, Yocum) and rotator cuff strength tests (empty can,

lift-off, drop arm test and others) have been described, especially in association between each other, to suggest the possible presence of impingement and to determine the individual integrity of the various components of the rotator cuff (Alqunae, Galvin, & Fahey, 2012; Bak et al., 2010; Cadogan, Laslett, Hing, McNair, & Williams, 2011; Hermans et al., 2013b; Moen, de Vos, Ellenbecker, & Weir, 2010; van Kampen et al., 2014). As previously stated indeed, one of the consequences of repetitive shoulder impingement mechanism, can affect rotator cuff tendons, through an evolution that starting from tendinosis can lead to partial or complete ruptures.

1.2 From shoulder impingement to rotator cuff injury

Rotator cuff lesions are the most common tendon injuries in the adult population, affecting at least 10 % of people over 60 years of age in the United States alone (Eljabu, Klinger, & von Knoch, 2015).

The importance of the rotator cuff functioning can be fully understood looking at the anatomy of the shoulder, which is the most mobile and less constrained joint in the human body. The rotator cuff muscle activity balances translational (destabilizing) forces with compressive (stabilizing) forces to maintain glenohumeral joint stability throughout its arc of motion (Gomberawalla & Sekiya, 2014). When the active and passive restraints of the rotator cuff are lost, the shoulder may therefore become unstable. On the other hand, incidence of asymptomatic tears increases with age and many now consider this to be part of the normal ageing process (Baring, Emery, & Reilly, 2007), as reported by an often cited 2006 systematic review that showed how in an unselected cadaveric population the incidence of both partial and full thickness rotator cuff tears was 30.24% (Reilly, Macleod, Macfarlane, Windley, & Emery, 2006).

As to pathogenesis, various hypotheses have been proposed. In the 1930s Ernest Codman, a shoulder surgeon from Boston, introduced the theory that the cause of rotator cuff disease was an intrinsic degeneration of the tendon (Codman, 1937). Later on, consensus grew towards the idea that external factors, such as mechanical compression of the tendons of the cuff, which is one of the consequences of shoulder impingement, were the main component in the etiology of rotator cuff tears. Morphological changes of the structures surrounding the supraspinatus outlet leading to stenosis were thought to

compress the cuff underneath the acromion. This led with high frequency to patients undergoing surgical resection of the acromion, that in the long term did not reveal to be better than conservative physiotherapy treatment (Braman et al., 2014). Currently consensus has returned to Codman's original theory supporting a combination of repetitive micro-trauma and age-related degeneration (Baring et al., 2007).

It has been stated that nowadays one of the great challenges in shoulder surgery is to balance the detection of symptomatic tears of the rotator cuff at an early stage and not to overtreat asymptomatic tears (Bak et al., 2010). For diagnostic purposes, clinicians tend to rely heavily on imaging data from magnetic resonance and ultrasound, nevertheless a careful history and structured physical examination can often establish the diagnosis of rotator cuff tear (Jain, Wilcox, Katz, & Higgins, 2013). Most frequently used clinical tests for the rotator cuff include Jobe, Yocum, empty can, lift off, belly press, and drop arm test (Beaudreuil et al., 2009; Jain et al., 2013) and seem to be useful especially in association between each other (Alqunae et al., 2012; Bak et al., 2010; Cadogan et al., 2011; Hermans et al., 2013b; Moen et al., 2010; van Kampen et al., 2014).

Due to the strictly connected nature of the two broad categories of shoulder impingement and rotator cuff injuries, and also, as previously mentioned, because of the ambiguous definition of the first term, similar tests are included in the diagnosis of the two conditions. One of these is the drop arm test.

1.3 Drop arm test

The drop arm test (DAT) is commonly used in clinical practice and is often reported in literature regarding shoulder pathology, especially associated to other tests, as a component of the clinical assessment of patients with shoulder complaints related to the rotator cuff. Although its origins are not clear it is commonly ascribed to Codman in the first decades of the XXth century (Codman, 1937).

This test has been used to detect rotator cuff tears, particularly of the supraspinatus (Malanga & Nadler, 2006) and normally the execution is described as follows: the examiner passively abducts the arm of the subject at 90° of abduction and then asks the subject to slowly lower the limb without "dropping" it (Magee, 2014; Malanga & Nadler, 2006; Ostor, Richards, Prevost, Hazleman, & Speed, 2004; Çalış et al., 2000). The test is

considered to be positive if the patient is unable to slowly return the arm to side or has severe pain when attempting to do so.

Nevertheless different versions of DAT are found in literature, revealing heterogeneity in the way this test is performed and intended by different clinicians (Magee, 2014; Malanga & Nadler, 2006) (Cadogan et al., 2011; Hermans et al., 2013a; Murrell & Walton, 2001; Nanda, Gupta, Kanapathipillai, Liow, & Rangan, 2008; Park, Yokota, Gill, El Rassi, & McFarland, 2005b; Çalış et al., 2000). Some differences indeed exist both regarding the modality of execution of this test and as to what DAT is supposed to assess. A recent review and meta-analysis (Alqunae et al., 2012) which aimed to examine the accuracy of clinical tests for the diagnosis of shoulder impingement included four studies presenting DAT. In the description of the modality of execution provided in the review, the arm is actively fully elevated by the subject instead of passively abducted at 90° as previously stated (Magee, 2014; Malanga & Nadler, 2006), even though the authors of the review do not give information about existing variations in the execution of this test among the studies included. In addition we noted that in one out the four studies included (Hertel, Ballmer, Lambert, & Gerber, 1996) DAT is surprisingly not present at all, and what is described is the drop sign for the infraspinatus. DAT should not be confounded with drop sign, that investigates the infraspinatus and is defined as follows: the patient is seated, the elbow is passively flexed to 90°, and the examiner holds the shoulder at 90° elevation (in the scapular plane), near maximal external rotation. The patient is then asked to maintain the external rotation in elevation as the examiner releases the wrist but maintains support of the limb at the elbow. The sign is considered positive when a lag or angular drop occurs (Hertel et al., 1996). Unfortunately some authors referring to DAT call it "drop arm sign" (Alqunae et al., 2012); (Park, Yokota, Gill, El Rassi, & McFarland, 2005a) increasing the confusion in terminology. Finally, taking into consideration another study that analyzed the inter-examiner reliability of DAT, the reported criteria for a positive result was the inability to hold the arm at 90° or a sudden drop of the arm when a downwards pressure was applied (Cadogan et al., 2011).

There are also some variations in the literature regarding what exactly this test is supposed to evaluate. Some authors (Nanda et al., 2008; Çalış et al., 2000) describe DAT as useful to diagnose subacromial impact. For others, DAT is a diagnostic test for a complete tear of supraspinatus (Cadogan et al., 2011; Hermans et al., 2013a; Murrell & Walton, 2001; Park et al., 2005b). Finally the authors of a 2012 review (Alqunae et al., 2012) describe it as a test that examines the integrity of infraspinatus, but as already

mentioned incoherent information was found in this paper because the only one of the four studied included in the review that reported a test for infraspinatus (Hertel et al., 1996) actually described the drop sign and not DAT (and should have not logically been included in the review) while the others stated that it can diagnose impingement (Nanda et al., 2008) or supraspinatus tears (Murrell & Walton, 2001; Park et al., 2005a).

A possible explication for the lack of uniformity around DAT is connected to the multifactorial origin and complex manifestation that characterizes the impingement syndrome that for some authors this test is supposed to investigate. As previously mentioned, there is no consensus indeed around what exactly impingement syndrome is, as its definition has widely varied along time, in addition to the fact that several sub-categories of shoulder impingement have been identified. Despite these differences, DAT is still widely used and considered to be useful, especially in association to other tests in the assessment of the shoulder. (Çalış et al., 2000) examined the diagnostic value of some tests for differential diagnosis of impingement syndrome, subacromial injection was performed as a reference standard test. Marked relief of pain and almost total improvement in the shoulder range of motion after the injection suggested that DAT was able to discriminate impingement from other shoulder pathologies. Also an already cited meta-analysis (Alqunae et al., 2012) aimed to determine the diagnostic accuracy of clinical tests to detect impingement. All studies included in this systematic review presented surgery diagnosis as a reference standard and findings had to include the presence of an enlarged or fibrotic-appearing bursa (stage 1 of impingement) as well as partial or full rotator cuff tear (for stage 2 and 3 respectively). All the tests included in the study (Neer, Hawkins-Kennedy, Empty can, Lift off, DAT) were identified as having useful diagnostic value. The DAT was found to have higher specificity than sensibility, indicating that when the clinical test is positive impingement is more likely to be present. Several studies which investigated the validity of DAT to detect rotator cuff tears found that DAT has low sensitivity but high to very high specificity for diagnosis of a full thickness tear of supraspinatus (van Kampen et al., 2014), the same findings were reported by (Bak et al., 2010), that in addition observed that after a subacromial lidocaine injection the sensitivity dropped while the specificity improved further.

As already mentioned, orthopedic clinical tests for shoulder are mainly used in combination with each other. A recent review (Hegedus, Cook, Lewis, Wright, & Park, 2015) aimed to select the best quality published test clusters for diagnosing different pathologies of the shoulder. Only four clusters were presented by the authors, one of these

was introduced by (Park et al., 2005a) to detect full thickness rotator cuff tears, and consists of a combination of a positive DAT along with age >60, positive painful arc test and positive infraspinatus test . Similarly, the results of a systematic review (Hughes, Taylor, & Green, 2008) highlighted that suspicion of a rotator cuff tear may be heightened by a positive palpation, combined Hawkins, painful arc, infraspinatus test, Napoleon test, lift-off test, belly-press test, or DAT.

An interesting topic that to our knowledge has never been taken into consideration in literature is to study the kinematic characteristics of this test. Firstly because much interest is growing in the direction of highlighting the loss in control of movement more than the presence of structural alterations in the musculoskeletal system as a key to interpret musculoskeletal conditions (Comerford & Mottram, 2001; Phillip Page et al., 2010; Sahrman, 2002). Secondly because this test requires an action (slowly lowering the arm) which can be adequately described in terms of quality of movement. In other tests for the rotator cuff (Jobe, palm up, belly press, Hawkins, Yocum, Neer) the positivity of the test itself is depending on the presence of pain or the impossibility to perform a certain movement or to maintain a given position.

The interpretation of DAT can be possibly conceived in a different way allowing the clinician to assess not only the possibility or impossibility to slowly lower the arm but also to assess how the patient performs the movement, is the movement smooth?

1.4 Importance of studying movement smoothness

A good representation of healthy and well trained motor behavior are smooth movements, which we perceive as such when they happen in a continuous way, without interruptions (Krylow & Rymer, 1997). Lack of smoothness is instead found when movement is characterized by intermittencies that can be caused by poor motor planning or execution due to neurological impairments, lack of familiarity with the task or the environment, and/or injury to the musculoskeletal system (Sivakumar Balasubramanian, Melendez-Calderon, Roby-Brami, & Burdet, 2015).

In scientific literature, especially targeting neurological conditions, the concept of smoothness has been used several times as a parameter to assess the quality of movement, for example to study the evolution of a pathology or improvements after therapies (Hussain

et al., 2015; Merlo et al., 2013; Montes et al., 2014; Postacchini et al., 2015). Nevertheless, there is not uniformity in the way of measuring smoothness, as many systems are found in literature like calculating the number of peaks, root mean square jerk, dimensionless jerk, spectral arc-length, speed arc-length and others (S. Balasubramanian, Melendez-Calderon, & Burdet, 2012). Recently a new measure of smoothness was introduced by (Sivakumar Balasubramanian et al., 2015), the SPARC, Spectral Arc Length modified , updating the SAL previously proposed by the same author (S. Balasubramanian et al., 2012). SPARC measure, based on calculating the arc length of the movement speed profile's normalized Fourier magnitude spectrum, seems to be more valid, sensitive and reliable than any other smoothness measure. Anyway, for any measure one chooses, it has to be clear that smoothness is task-dependent so in order to assess one subject's motor control focusing on fluidity of movement it is advisable to compare activities of the same kind, i.e., in terms of smoothness, with similar levels of intermittency.

As previously stated, the interpretation of DAT test can be focused on the quality of movement, that is, in terms of smoothness, the assessment of intermittency of movement. If smoothness is an intuitive concept, that any clinician is probably used to observe, a quantitative and systematic assessment of the fluency of movement in DAT would be a step forward in understating the role of this test. It is therefore interesting to study the kinematic quantitative properties of DAT using a system of motion capture, in presence of symptoms or not. In addition it is important to estimate the fluidity of movement required in this test and to study how this smoothness changes between injured and healthy members.

The objectives of this study were:

- **verify the correlation between the presence of rotator cuff injury, lesion severity, function level and kinematic characteristics of DAT such as the arc of movement and velocity, obtained with a system of motion capture, taking into consideration both the injured and the healthy limb;**
- **study the level of smoothness in this test using the best measure of smoothness proposed in recent literature, and verify the correlation between smoothness and the other variables.**

2 Methods

2.1 Participants

Twenty subjects diagnosed with shoulder pain and rotator cuff pathology were recruited for this study as a sample of convenience. Diagnosis was supported by ultrasound on the affected shoulder. Background data regarding injury level are reported in Table IV. Testing procedures took place between April and August 2014 in the Laboratory of Biomechanics *Labiomep* at the University of Porto, Portugal.

Subjects aged from 39 to 74 years old (mean age 57.5). The inclusion criteria were: suffering from shoulder pain for more than 6 months, having received a diagnosis of pathology of the rotator cuff and recent ultrasound of the affected arm available (no more than 12 months). As exclusion criteria we defined neurological conditions. Information on level of pain and function were collected by sub administration of two self-report questionnaires, respectively the VAS, Visual Analogic Scale (Collins, Moore, & McQuay, 1997) and the DASH, Disabilities of the Arm, Shoulder and Hand Outcome Measure, (Hudak, Amadio, & Bombardier, 1996). The DASH is a 30-item questionnaire that evaluates functional disability in everyday activities, work, and sports, and includes symptoms, physical, social, and psychologic function. A DASH score of 0 indicates good shoulder function, or no disability, and the maximum score of 100 indicates no function at all.

2.2 Instruments and experimental setup

Three-dimensional kinematic data were captured using 5-camera optoelectronic ProReflex Motion Capture System (MCU240 Hz, Qualisys AB, Sweden). The 3-dimensional coordinate positions of the markers are calculated instantly in camera units with high spatial resolution throughout the measured movement. The system was calibrated prior to every measurement session. The data were collected automatically by Qualisys Track Manager and then were transferred to Visual 3D software for further analysis.

Fourteen spherical 12 mm and 19 mm reflective markers were attached to the skin with double-sided tape. Markers were positioned on superficial bony prominences to

reduce the effect of skin movement and to facilitate their replacement in repeated testing (Alt Murphy, Willen, & Sunnerhagen, 2011), as follows: four on the wrists (on the styloid process of ulna and radio of each side), four on the elbows (on the lateral and medial epicondyle of each side), two on the shoulders (in the middle part of left and right acromion), two on the thorax (on the spinous process of T2 and on xiphoid process), two on the pelvis (left and right anterior-superior iliac spine). Thorax markers were used as a reference point to control the amount of trunk displacement during measurements.

2.3 Experimental procedures

All patients were tested by the same examiner which was a skilled physiotherapist. Subjects were tested three times for each side, starting from the unaffected or less affected limb. The examiner fully explained the whole procedure before starting. Subjects were seated on a chair without back support and were asked to maintain the arm relaxed while the physiotherapist took the limb to 90° of flexion -or less if pain was present- in the scapular plane which constitutes the starting position of DAT (Ostor et al., 2004). If the subject complained for pain or had mobility impairment starting position was adapted. Subject was asked to slowly lower the arm. The physiotherapist instructed the patients to avoid as much as possible compensations like side flexion of the trunk or elevation of the shoulder.

2.4 Ethics

Ethical approval for this study was obtained from S. João Hospital Ethics Committee of Porto, Portugal. All participants freely signed an informed consent form which explained the purpose and the procedures of the study, in conformity with the Declaration of Helsinki of The World Medical Association of 2008.

2.5 Data Analysis

Each subject performed DAT for three times in both limbs (injured and healthy limb). The first repetition was meant to make the patient familiar to the movement, and the last repetition could have been affected by fatigue and pain for the repeated action therefore the mid repetition data were chosen to be analyzed.

For kinematic analysis purposes, the following variables were extracted: time of execution of the test (from the highest point reached to the position with the arm relaxed), maximum and minimum angle reached for each limb.

Median and standard deviation values, total amplitudes and angular velocities were then calculated. Three classes of lesion severity were created (Table IV). DASH and visual analogic scale (VAS) data were used as quantitative variables, the classes of lesion severity were considered as a qualitative ordinal variable.

In order to study smoothness of movement, endpoint velocity of the radial epicondyle of the wrist was extracted and SPARC function was applied to these data using the program Matlab version 9.0 R2016a.

Report on positivity or negativity of DAT was not provided by the physiotherapist who performed the tests, these data were then deducted by the authors in a second moment by visual investigation of Visual 3D reconstruction and are shown in Table V.

2.6 Statistics

Statistical analyses were performed with IBM Statistical Packages for Social Sciences, 22.0, SPSS Inc, Chicago, IL. The level of significance was set at $p < 0,05$.

A Shapiro-Wilk test was conducted to assess the normality of data. As not all the variables presented normal distribution, non-parametric tests were chosen for further analysis.

A Wilcoxon signed-rank test was conducted to compare the highest point in shoulder extension degrees on the scapular plane reached at the beginning of the test (MAX), mean velocity of shoulder motion (VEL) and estimate of movement smoothness (SPARC) in the painful shoulder and in the uninvolved shoulder (Table VI).

A Spearman's rank-order correlation was computed to assess the relationship between all the variables (Table I).

Table I - Variables

Both limbs	VEL	mean velocity of shoulder motion
	MAX	highest point in shoulder extension degrees on the scapular plane reached at the beginning of the test
	SPARC	estimate of movement smoothness
Affected limb only	DASH	DASH Scale, measure of function of the painful side
	VAS	Visual Analogic Scale, measure of pain in the affected side
	GRA	gravity of lesion coefficient (1,2,3) of the painful side
	(p)	related to the painful side
	(u)	related to the unaffected limb

Table I: Legend of extracted variables for further analysis

3 Results

3.1 Sample

Table II - Sample characterization

Subject	Gender	B.M.I.	Painful side	Age	Weight (kg)	Height (m)	DASH outcome	
1	M	33.80	L	63	100	1.72	44	
2	F	26.67	R	54	60	1.5	12.5	
3	F	36.89	L	50	83	1.5	44	
4	F	19.29	L	39	40	1.44	56.3	
5	F	30.91	R	57	67.7	1.48	73.2	
6	M	27.25	R	49	87.3	1.79	30.4	
7	F	26.75	L	60	61.8	1.52	57.8	
8	F	29.26	R	63	73.5	1.585	44	
9	F	23.76	R	48	59.7	1.585	54.3	
10	F	37.98	L	67	88.9	1.53	58	
11	F	30.54	L	68	64.2	1.45	70.7	
12	F	35.99	R	58	96.8	1.64	36.2	
13	F	27.27	R	56	63	1.52	45.7	
14	F	30.21	R	74	69.8	1.52	43.3	
15	F	33.20	R	63	85	1.6	46.6	
16	F	26.44	R	53	59.5	1.5	61.2	
17	F	31.64	R	58	80	1.59	67.9	
18	F	24.45	R	66	59.5	1.56	36.6	
19	F	22.88	L	49	50.8	1.49	55.2	
20	F	33.79	R	55	83.3	1.57	60.7	
				57.5	71.7	1.55	49.9	Mean
				±8.3	±15.8	±0.1	±14.6	±S. D.

Table III - Age of subjects

Age (years)	Number of subjects	%
39-49	4	20
50-59	8	40
60-74	8	40
Total	20	100

Table II and III: Information on gender, age, Body Mass Index (B.M.I.), affected side, VAS and DASH scales outcome with relative means and standard deviation (S.D.).

The large majority of subjects (80%) were older than 50 years, and 40 % of the sample were between 60 and 74 years old. Only two men were included in the study (10% of the sample). As shown, mean VAS outcome was 7.4, and mean DASH outcome was 49.9.

Table IV - Injury level data

Classes of lesion	Number of subjects		Type of lesion
1	5	5	<i>Tendinosis or fissuration</i>
2	13	6	<i>1 partial/complete rupture</i>
		7	<i>2 partial/complete ruptures</i>
3	2	1	<i>3 partial/complete ruptures</i>
		1	<i>4 partial/complete ruptures</i>
Total number	20		

Table IV: Subjects were divided in three classes of lesion: patients not affected by tendon ruptures were included in Class 1, those who had one or two ruptures belong to Class 2, while individuals with 3 or 4 tendon ruptures were assigned to Class 3.

As shown most of the patients presented partial to complete ruptures, especially one or two ruptures, and were included in class 2.

Table V - DAT outcome

Positive tests		
Painful side	Uninvolved side	Impossible to get starting position
3 out of 14	4 out of 20	6 out of 20
21.43%	20 %	30 %

Table V: for 30% of patients it was impossible to reach starting position. Positive DAT outcome were 21.43% in the painful side and 20% in the healthy side.

Due to pain 30% of the patients were unable to reach the expected starting position for DAT, and even uninvolved side demonstrated to be positive for DAT.

3.2 Comparisons between painful and uninvolved limb

Table VI - Means and medians of MAX, VEL AND SPARC

	Median	Mean	±SD
(u)MAX	78.810	84.849	±20.7359
(p)MAX	72.285	75.366	±19.3074
(u)VEL	10.460	12.792	±7.6413
(p)VEL	7.736	8.521	±5.0001
(u)SPARC	-10.1569	-10.6929	±4.51133
(p)SPARC	-9.7305	-10.8735	±3.49044

Table VI: Medians, means and standard deviation (SD) of MAX, VEL and SPARC in painful (p) and unaffected (u) limb.

While comparing both limbs the scores for (p)MAX (Median= 72.285) were significantly lower than the scores for (u)MAX (Median=78.810); $Z=-2.203$, $p= 0.028$.

We also found a significant difference in the scores for (p)VEL (Median= 7.736) that were lower while compared with the scores of (u)VEL (Median=10.460); $Z=-3.061$, $p=0.002$.

Concerning SPARC no statistical significant differences were found between the two shoulders. Median SPARC rating was -9.7305 for the painful shoulder and -10.1569 for the healthy shoulder; $Z=-1.12$, $p= 0,263$.

3.3 Correlations between all variable

There was a moderate approaching strong positive correlation between (u)VEL and (u)SPARC ($r=0.698$, $N=20$, $p=0.001$) and between (u)VEL and (p)SPARC ($r=0.675$, $N=20$, $p=0.001$), (Figure I).

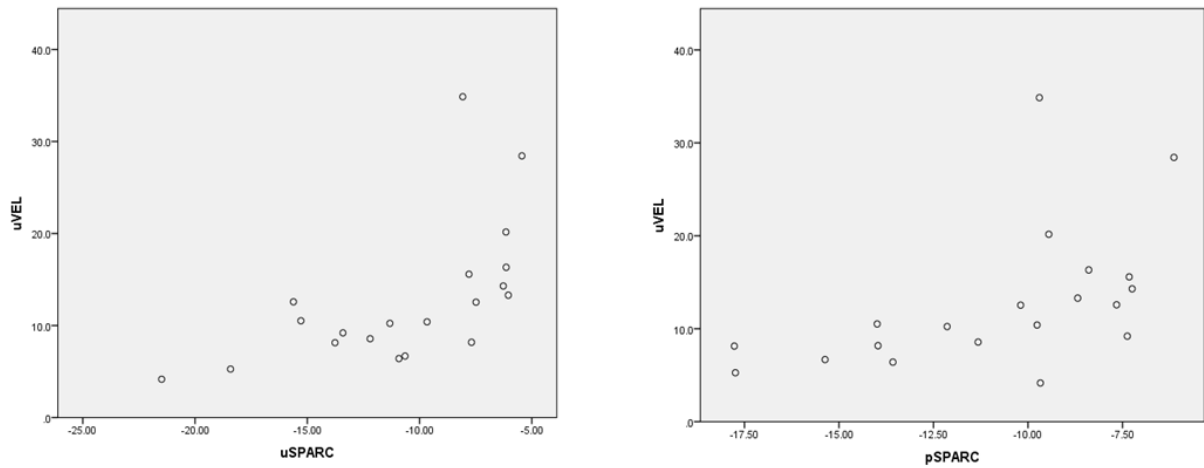


Figure I - Graphical representation of the two pairs of mildly to strongly correlated variables, (u)VEL-(u)SPARC and (u)VEL-(p)SPARC.

There was a moderate positive correlation between (p)VEL and (u)VEL ($r=0.621$, $N=20$, $p=0.003$), (p)MAX and (p)VEL ($r=0.558$, $N=20$, $p=0.011$); (p)MAX and (u)MAX ($r=0.556$, $N=20$, $p=0.011$); (p)DASH and (p)VEL ($r=0.514$, $N=20$, $p=0.021$); (p)VEL and (u)MAX ($r=0.504$, $N=20$, $p=0.024$); (p)SPARC and (u)SPARC ($r=0.481$, $N=20$, $p=0.032$), (Figure II).

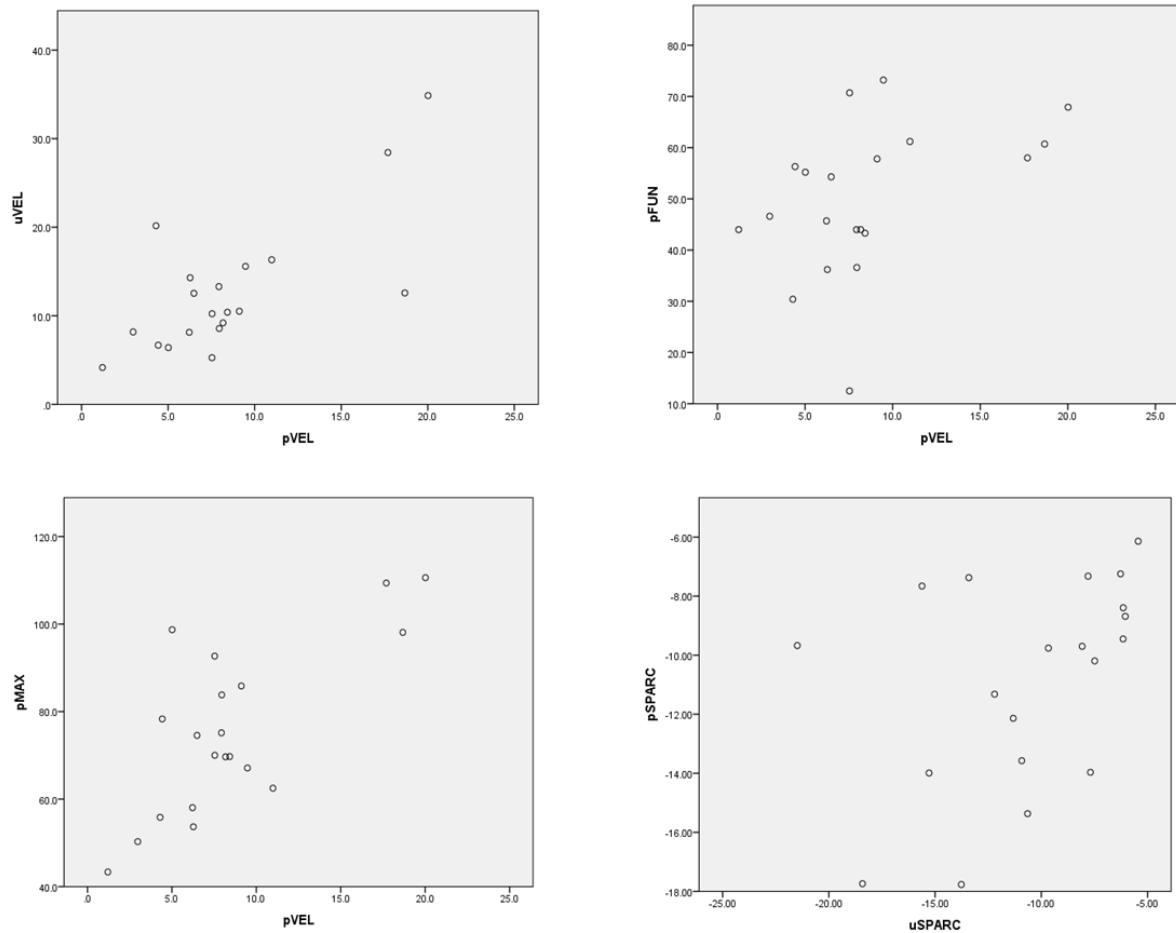


Figure II -Graphical representation of four pairs of mildly positive correlated variables: (u)VEL-(p)VEL, (p)DASH-(p)VEL, (p)MAX-(p)VEL, (p)SPARC-(u)SPARC.

The following findings were approaching significance: the relationship between (p)DASH and (u)MAX ($r= 0.444$, $N=20$, $p=0.05$); and between (p)VEL and (p)SPARC ($r= 0.444$, $N=20$, $p=0.05$).

There was not a significant correlation between the other observed variables.

4 Discussion

The goal for this study was to verify the correlation between the presence of rotator cuff injury, lesion severity, function level and kinematic characteristics of DAT such as the arc of movement and velocity, obtained with a system of motion capture, taking into consideration both the injured and the healthy limb and also to study the level of smoothness in this test using the best measure of smoothness proposed in recent literature, and verify the correlation between smoothness and the other variables.

4.1 Velocity

Subjects performed the test in a faster way when lowering the asymptomatic arm.

This may be intended as a paradox answer to the test as subjects were asked to “slowly lower the arm to side”, and the unaffected arm is supposed to be able to more adequately fulfill this request. These results show instead that in almost the totality of cases the painful shoulder performed the slowest movement. The variable of the arch of movement can contribute to explain this difference. In the tests of the painful side, velocity was higher in subjects who reached higher degrees of shoulder flexion as a starting position. This may suggest that subjects tended to move in a faster way when the arch of movement was bigger, even if the oral indication given was always to slowly lower the arm to side.

(Postacchini et al., 2015) compared a target reaching task in patients with shoulder arthroplasty and in a group of healthy subjects at self-selected speed, finding that the mean target-approaching velocity was significantly higher in the control group. Also in our study we observed that the healthy limb moved faster, but comparisons were made intra-subjects and not with a group of controls. Our results can integrate those of a paper that aimed to characterize upper limb motor strategies in individuals with and without shoulder impingement during reaching at both natural and higher speed (Roy, Moffet, & McFadyen, 2008). One of the objectives of that study was to determine whether any group differences were dependent on speed, which, differently from our study, was a controlled variable. The intergroup differences observed were, however, comparable during both speed conditions (natural and higher), therefore suggesting, differently from the results of our study, that adaptation to speed is similar for the individuals with and without impingement.

In our study velocity was also found to be related to the level of function: a moderate correlation showed that **subjects with more disability** (higher scores in the DASH scale) **tended to move the painful arm faster**. Similar results have been reported in studies involving target pointing movements in neurological patients (Formica et al., 2014; Papaxanthis, Pozzo, & McIntyre, 2005), therefore only limited comparisons can be done. Formica et al. (2014) suggested that higher speed in a lowering movement of the more affected arm could be due to the fact that subjects did not control properly downward arm movement, letting gravity and inertia forces to drive passively their limb. Similarly, we can hypothesize that in our sample higher velocity is a result of the lack of motor control that subjects with less functional ability may have, nevertheless further studies focusing on orthopedic conditions should verify this assumption.

In our sample, as predictable, the maximum point reached was statistically higher in the tests of the healthy side, that got more easily to the starting position. The moderate positive correlation between the maximum point of the unaffected and painful side allows us to think that individuals tended to have similar arches of movements in both sides. The moderate positive correlation between velocity of painful and healthy side also suggests that subjects tended to adopt a similar level of velocity for both sides. The interpretation of these results is not clear but can suggest that **subjects tended to move in a uniform way in the right and left arm**, similarly to the findings of Hébert, Moffet, McFadyen, & Dionne (2002) that studied a sample of subjects with unilateral impingement and found no significant differences in 3D scapular attitudes between the symptomatic and contralateral asymptomatic shoulders. In that study, both shoulders of affected subjects had a similar behavior that was different from healthy subjects.

4.2 Smoothness

As an initial consideration it has to be noted that, differently from other measures, in pilot studies SPARC measure has shown no difference in the smoothness estimates between fast and slow movements, which would have been a problem if using other measures such as log dimensionless jerk that tend to underestimate the smoothness of slower movements than the faster.

Our values of smoothness for all subjects seem to be far lower than the standard scores proposed by the authors of SPARC measure, that report a score of around -1.6 as a possible value of normal smoothness in a point-to point reaching tasks. This is not necessarily surprising, as this type of tasks are the only well-studied in the literature, and the authors themselves claim that more studies are required to obtain estimates of the normative ranges for different tasks (Sivakumar Balasubramanian et al., 2015). In DAT the subject is asked to move the hand from a point in the air to side, so if we merely look at the presence of a starting and ending position in it can be considered as a “point-to-point” reaching exercise, but actually it is very different. Firstly because it is not a functional movement like taking a glass, and secondly because it is not target-oriented, as the subject is only instructed to slowly lower the arm and did not have a precise objective to reach.

From the results it seems that injured limbs did not move with less smoothness than uninvolved ones.

This may be due to several factors:

- All subjects suffered from pain in the shoulder since at least 6 months. Compensation strategies that subjects may have learned could have therefore played an important role in making the performance of the affected shoulder as smooth as in the other side
- It is also to consider the possibility that SPARC measure cannot properly estimate smoothness for this kind of movement. Even though it seems to be the best measure in comparison to other like peaks or jerk, it was introduced quite recently and has been mainly used to study the improvement of neurological subjects in point-to-point tasks.

A relation between the levels of smoothness in the painful and uninvolved limb was found, suggesting, like in the case of the arch of movement and velocity, that subjects of our sample tended to move in quite a uniform fashion between the two sides.

There was a moderate positive correlation between velocity of unaffected side and SPARC of the painful side and between velocity and SPARC of the unaffected side : it looks like smoothness of both arms was better in presence of higher speed in the uninvolved limb.

Smoothness of movement is an almost unexplored aspect in the assessment of orthopedic patients (Arzi, Krasovsky, Pritsch, & Liebermann, 2014), comparisons between our results and the literature are limited therefore by the fact that most of previous studies

that investigate movement smoothness targeted neurological conditions such as cerebral palsy, and because of difference in the chosen measure (Cesqui, Macrì, Dario, & Micera, 2008; Colombo et al., 2014; Postacchini et al., 2015; Schneiberg, McKinley, Gisel, Sveistrup, & Levin, 2010). To our knowledge, this is the first study that uses SPARC to evaluate patients with an orthopedic condition of the shoulder. Uri, Pritsch, Oran, & Liebermann, (2015) studied different levels of smoothness in two groups of patients suffering from shoulder instability that had undergone two different types of surgery, and healthy subjects. While performing a smoothness-based analysis (acceleration-to-movement time ratio, peak-to-mean velocity ratio, and number of velocity peaks) they could detect subtle subclinical changes in arm kinematics that could not be detected by traditional methods of proprioceptive assessment. Their results showed that smoothness improved with the less invasive surgery, but the reference parameter was not the uninvolved limb, as in our study, but healthy subjects. Also Postacchini et al. (2015) compared patients that had undergone shoulder arthroplasty with a control group of healthy subjects, finding similar levels of smoothness, evaluated using normalized jerk, and deducing therefore that surgery had restored a good fluidity.

Arzi et al. (2014) compared a point-to-point movement in slow, preferred and fast speed of movement in a sample of subjects operated for shoulder instability and in a healthy subjects control group. Interestingly patients more closely followed the maximal smoothness criterion than healthy controls did. Furthermore, this trend was more evident while moving slower compared with preferred or faster speeds of movement, which is counterintuitive since healthy people are expected to outperform patients in all cases (i.e., they should perform smoother arm movements. Affected subjects in that study performed faster and smoother movements than healthy controls did, in other words fragmentation of movement was somewhat reduced in patients compared with healthy subjects). The hypothesis of the authors was that these patients, perhaps because of instability, have a tendency to move faster and therefore implement a feedforward strategy of control based on a structured motor plan driven by the intention to move as smoothly as possible. Similarly, this hypothesis can be adopted as a possible explanation for the fault of difference between smoothness levels in painful and healthy limb of our subjects.

4.3 Severity of lesion, function and pain

The level of severity of the lesion did not seem to play a role in determining the performance during the test, i.e. lower values of the gravity coefficient were not associated to differences in velocity, smoothness, function, pain and not even to smaller arches of movement. This goes in the direction of the results of several other studies that emphasize the lack of correlation between the level of pain reported by patients and any anatomic measure of rotator cuff tear severity (Dunn et al., 2014).

In our study the level of function was found to be related to velocity: a moderate correlation showed that **subjects with more disability tended to move the painful arm faster**. This can be interpreted as a result of the lack of motor control that subjects with less functional ability may have. We could add that, from the results of the small sample of this study (twenty subjects), the level of function and pain do not present correlation with smoothness.

Surprisingly **VAS outcome was not correlated with any other variable, indicating that in our small simple pain does not seem to be related to the quality of movement while performing DAT**. Nothing can be said on pain during the execution of tests because this information was not collected, although from visual investigation of 3D videos several cues (trunk compensations, little falls in the lowering phase, intermittency of movement) could suggest in various cases the presence of pain. Also Sengul, Karagoz, Nacir, & Erdem (2014) found that the severity of pain and shoulder pathologies had no statistically significant correlation in a sample of seventy-six patients. All these findings support the hypothesis that presence of pain is not required to diagnose rotator cuff disease, because patients with a chronic full-thickness rotator cuff tear may have painless loss of active motion (Hermans et al., 2013a). In another study (Yamaguchi et al., 2006) 588 patients with unilateral shoulder pain were evaluated with ultrasound with regard to the presence and size of rotator cuff tears in each shoulder. The demographic factors that were analyzed included age, gender, side, and cuff thickness and their correlation with pain was evaluated. A high correlation between the onset of rotator cuff tears (either partial or full thickness) and increasing age was found. Bilateral rotator cuff disease, either symptomatic or asymptomatic, was found to be common in patients who presented with unilateral symptomatic disease. Data showed that 35.5% of the patients who presented with a full-thickness tear on the painful side had a full-thickness tear on the non painful, contralateral side. Those findings can furnish an explanation to the tendency observed in our sample to perform similarly in both arms, suggesting that the uninvolved limb actually may have

been affected too. **The high rate of bilateral disease can be important during the assessment of an individual who presents with unilateral shoulder pain.**

4.4 Limitations

There are several study limitations: first of all, we don't have ultrasound information of both shoulders, but only of the symptomatic one. It is of common knowledge that in the general population, especially over 65 years old, the prevalence of asymptomatic rotator cuff tear is high. Then the rotator cuff tear of one side cannot be assumed as the underlying cause of any difference between healthy and painful side, as we could have an asymptomatic injury on the other side. Secondly, ultrasound is not the best diagnostic instrument to assess presence and level of tendon lesions, MRI assessment would have been more sensitive and precise, nevertheless recent evidence showed that both diagnostic methods perform well for full-thickness tears; however, for partial rotator cuff tears, MRI has the best sensitivity and specificity (van Kampen et al., 2014).

Moreover, information on presence of pain during the execution of the test and on its positivity or negativity was not provided by the physiotherapist who assessed subjects, therefore the last data had to be deducted by the authors in a second moment by visual investigation of Visual 3D reconstruction. On one hand this method should be quite precise and adherent to "real test" because of high quality 3D analysis, on the other hand evaluating the positivity or negativity just during the performance of the test itself would have been more similar to normal clinical context.

Finally, as shown from DAT performances and considering the age of our sample (8 out of 20 were between 60 and 70 years old), also the uninvolved side in many cases seemed to have pain or limitations. In this study though we only compared the most painful shoulder with indifferently the unaffected or less symptomatic side. This kind of comparison should not be intended as a case-control analysis, indeed we have to considerate that bilateral comparisons may lead to inaccurate conclusions because the dominant and non dominant arms differ in terms of motor performance, haptic sense and nociception. (Uri et al., 2015).

For the same reason, and because of the small size of the sample, we could not deduct conclusions on the validity of DAT, i.e. nothing can be said on sensitivity, specificity and

likelihood of the test due to the absence of subjects truly without the condition in exam and to the fault of the more appropriate golden standard evaluation for the level of lesion of rotator cuff tendons, that may have been MRI.

Future studies on rotator cuff lesions should take into account information on both sides including imaging data –preferably MRI-, presence and level of symptoms. It is also advisable that further research on DAT kinematics and smoothness include pain during the test as a variable to be analyzed. Finally, most of research on smoothness of movement has been conducted on neurological subjects, more studies are needed to study this parameter in musculoskeletal conditions of the shoulder.

5 Conclusions

Subjects performed the test in a faster way when lowering the asymptomatic arm, even though DAT test requires to slowly lower the arm to side. Conversely, subjects with more disability tended to move the painful arm faster. Affected and unaffected limbs were not statistically different in terms of smoothness. Furthermore, the level of injury severity did not seem to play a role in determining the performance during the test, similarly, pain was not correlated with any other variable. A relation between the level of smoothness, the arch of movement and velocity in the painful and uninvolved limb was found, suggesting that subjects of our sample tended to move in quite a uniform way between the two sides. It is to remark that the high rate of bilateral disease can be important during the assessment of an individual who presents with unilateral shoulder pain.

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