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# The Influence of Physical Activity on the Shoulder Load and Ultrasonography Findings in Manual Wheelchair Users

**Gil-Agudo A[1*], Mozos MS[1], Crespo-Ruiz B[1], del-Ama Eng AJ[1], Pérez-Rizo E[1], Segura-Fragoso A[2] and Jiménez-Díaz F[3]**

**Abstract**

The aim of this study was to determine whether physical activity affects the forces applied on the shoulder and the development of shoulder ultrasonography abnormalities in manual wheelchair users. Following a high intensity wheelchair propulsion test, changes in shoulder kinetics and ultrasound variables were compared in a group of 17 physically active (PA) and in 12 less physically active (LPA) wheelchair users (WUs). The variables analysed were shoulder kinetics and ultrasound variables at the beginning and at the end of the test. In both groups, the test increased the peak shoulder forces and moments in almost all directions, although these changes were stronger for horizontal and superior forces in PAWUs. By contrast, no differences in the ultrasound parameters were found before and after performing the test. A greater short axis supraspinatus thickness was associated with a higher superior peak shoulder force ($r$=0.706, p<0.01) in PAWUs and a higher medial shoulder peak force ($r$=0.730, p<0.05) in LPAWUs. Therefore, it was concluded that the increase in shoulder forces after an intense propulsion task is greater in PAWUs, although this increase was not associated with changes in ultrasound parameters.

**Keywords**

Spinal cord injury; Manual wheelchair propulsion; Ultrasonography; Biomechanics; Sport for disabled

## Abbreviations

MWUs: Manual Wheelchair Users; AIS: Asia Impairment Scale; PAWU: Physically Active Wheelchair User; LPAWU: Less Physically Active Wheelchair User; CG: Control Group; SCI: Spinal Cord Injury; ISB: International Society of Biomechanics; VAS: Visual Analogue Scale; WUSPI: Wheelchair User's Shoulder Pain Index; ACD: Acromioclavicular Distance; CHI: Cholewinski Method (Acromio-Humeral Distance Using the Distance between the Acromion and the Greater Tuberosity of Humerus); LBTT: Long Axis Biceps Tendon Thickness; SST: Short Axis Supraspinatus Thickness; ACSM – American College of Sports Medicine

***Corresponding author:** Angel Gil-Agudo, MD, PhD, Biomechanics and Technical Aids Unit, Department of Physical Medicine and Rehabilitation, National Hospital for Paraplegics, SESCAM, Toledo, Spain, Tel: +34 925247763; Fax: +34925247745; E-mail: amgila@sescam.jccm.es

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## Introduction

Shoulder pain is a very common problem in manual wheelchair users (MWUs). Indeed, structural and functional changes of the shoulder joint are more severe in individuals with long term spinal cord injury (SCI) than in age-matched controls, and the risk of developing shoulder girdle damage is significantly higher [1]. Although most studies report a prevalence of about 33% in paraplegics and slightly higher numbers for quadriplegics, up to 78% of subjects with SCI have been reported to have shoulder pain [1-7].

Several factors are thought to influence the aetiology of shoulder pathologies. The continuous use of upper limbs for weight bearing and propulsion by MWUs represents a biomechanical challenge to joints that are not specialized for such actions, joints that were designed for mobility rather than for stability [4]. This mechanical stress can lead to overuse syndrome [8], and muscle weakness or imbalance around the shoulder joint is also thought to contribute to the development of shoulder disorders in MWUs [9]. Identifying shoulder pathologies in wheelchair users will help to understand wheelchair propulsion mechanics and assist in identifying the factors that contribute to such pathologies.

The benefit of sport and physical activity to enhance both the functional capacity and rehabilitation potential of MWUs is clear [10], decreasing hospitalizations and skin breakdown [11]. However, the benefits and the damage of increasing the demands on the shoulder when performing sports or physical activity are yet to be fully defined. Indeed, repetitive stress and shoulder loads are increased by performing most sports, particularly those involving speed like basketball or racing [12]. Previous studies of shoulder pain in wheelchair athletes (WA) or non-athletic wheelchair users (NWA) indicate that the prevalence of pain is high in both populations. Interestingly, in a large study comparing 257 subjects including WA and NWA [13], active exercise was seen to decrease shoulder pain and to offer more functional pain-free periods. However, a further study indicated that practicing athletics neither increases nor decreases the risk of shoulder pain in MWUs. Thus, more research would seem to be necessary to define the effect of wheelchair sport on shoulder pain, whereby the increased strength and endurance of athletes, and a more refined wheelchair propulsion technique must compensate the increased demands on the shoulder joint.

Acute changes in shoulder tendons that might be provoked by the strong demands of propulsion could contribute to chronic shoulder pathologies and pain. Indeed, acute exercise induces changes in tendon metabolism and it augments inflammation [14]. Such acute changes can be rapidly screened for with ultrasound immediately after completing the propulsion task in a controlled environment, particularly since acute tendon injuries after different tasks have already been studied [15-17]. However, to our knowledge no studies have focused on changes that might occur after a controlled and intense manual wheelchair propulsion task, comparing physically active wheelchair users (PAWUs) and less physically active wheelchair users (LPAWUs).

Thus, the main aim of this study was to investigate the changes in shoulder joint forces and moments after a high intensity manual

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wheelchair propulsion test, both in PAWUs and LPAWUs. In addition, the possible changes to the shoulder provoked by performing this task were assessed by ultrasonography. We hypothesized that shoulder joint forces and moments would increase in both cases, and that they would produce changes that could be detected by ultrasound and that would allow parameters of the risk of presenting tendon related pathologies in the shoulder to be identified. Linking ultrasound images and kinetic information may also help interpret the shoulder pathologies associated with manual wheelchair propulsion. The secondary objective of this study was to examine how the ultrasound parameters might be related to the kinetic findings and the functional characteristics of the subject's.

## Material and Methods

### Subjects

Male subjects with SCI (n=31) were recruited from the discharge records of a monographic SCI in-patient hospital. The inclusion criteria were: traumatic SCI at level T2 or below; AIS grade A or B [18]; age between 18 and 45 years; and at least 18 months since injury. The subjects should use manual wheelchairs as their primary means of mobility, and they were excluded if they had had: fractures or dislocations in the non-dominant shoulder at any time; upper limb pain that prevented them from propelling a manual wheelchair; progressive or degenerative disability; or a history of cardiopulmonary disease. To be included in the PAWU group the individuals had a physical activity level between 4 and 6, which involves regular training lasting between 45 minutes to 3 hours (2-3 times a week), in accordance with the latest ACSM (American College of Sports Medicine) recommendations for physical activity that extends to individuals with disabilities [19]. The average age of these subjects (n=17) was 34.41 ± 6.01 years, their mean height was 1.79 ± 0.05 m and their mean weight was 70.67 ± 10.73 kg. The data from these PAWU subjects were compared to an age, sex and anthropomorphologically matched SCI group considered as LPAWUs (n=14): male subjects with an average age of 35.5 ± 8.51 years, a mean height of 1.73 ± 0.05 cm and a mean weight of 66.80 ± 9.38 kg (Table 1). This study was approved by the ethics review board at our centre and all the participants signed an informed consent form prior to their enrolment. Human experimentation has been approved by the local institution and it all complies with the Helsinki declaration.

### Instrumentation

All subjects used a standard adjustable wheelchair (Action3 Invacare, Invacare Corp, Elyria OH, USA) that was fitted correctly to each subject, and it was placed on a treadmill (Bonte Zwolle B.V., BO Systems, Netherlands). The force transducer location, custom dead weight and the pulley system was all as described previously (Figure 1) [20].

Non-dominant upper limb kinematic data were collected at 50 Hz (maximum recording frequency) using passive markers and four camcorders (Kinescan-IBV, Instituto of Biomecánica of Valencia, Valencia, and Spain). All the subjects were right-hand dominant so that the left upper limb was analysed, and the spatial marker co-ordinates were smoothed out using a procedure of mobile means. The reflective markers were positioned following ISB recommendations to define local reference systems on the hand, forearm and arm [21], the axes of which have been described previously [22]. The wheels of the chair were replaced by two SMART$^{\text{Wheels}}$ (Three Rivers Holdings, LLC, Mesa, AZ, USA) to balance the inertia characteristics of both axes and to ensure symmetrical propulsion. Kinetic data were recorded at a frequency of 240 Hz and filtered using a Butterworth, fourth-order, low-pass filter with a cut-off frequency of 20 Hz and a zero phase lag. Spatial marker coordinates were interpolated by cubic spline to synchronize with the kinetic data.

### Data collection

A visual analogue scale (VAS) was used to measure current pain, with 0 indicating a painless shoulder and 100 indicating an intensely painful shoulder. Functional status was assessed using the Wheelchair User's Shoulder Pain Index (WUSPI: [23]). Subjects then underwent a baseline ultrasound screening of the non-dominant shoulder before completing the wheelchair propulsion test, and another ultrasound screening immediately after finishing it.

Before testing, the subjects were allowed to familiarize themselves with the wheelchair and the experimental set up. Once the rolling resistance was determined, the propulsion power output could be regulated with an additional external force on the wheelchair user that acted via a pulley system (Figure 1). The propulsion power output (PO external) was calculated in accordance with our previous experience [20]. The treadmill speed was calculated to a PO external of 20W for all subjects. Discrete increases of 5W were introduced every two minutes, with no rest between the stages, by varying the dead weights in the pulley system. The trial was finished when the subject was exhausted and could not propel the wheelchair any longer. The maximum criteria were then obtained following ACSM guidelines [24]. A subjective perception of fatigue, the Borg scale, was also recorded immediately after completing each protocol [25].

### Measures of shoulder pathology

An expert physician with more than 15 years training and experience in musculoskeletal ultrasonography carried out the ultrasound examination using a General Electric Healthcare (Logiq S8) apparatus and an 8-12 MHz linear array transducer. External reference landmarks were taped to the skin of the shoulder and to increase reliability, they were left in place until the second ultrasound examination was performed after the wheelchair propulsion task [26]. The protocol used to examine the structures in the shoulder was the same in both ultrasound examinations and it was based on previously described techniques [27-29]. To examine the transverse image of the biceps tendon, the subject´s hand was placed on their thigh with the palm facing upwards. This supination of the hand with external rotation of the shoulder improved the visualization of the bicipital groove, and the transducer was then turned 90º to obtain an image of the biceps tendon along the long axis. The supraspinatus tendon was observed with the hand placed behind the back and with the shoulder in internal rotation, and the acromiohumeral distance was also recorded with the arm in internal rotation.

### Data analysis

**Biomechanical data:** We used the previously described inverse dynamic model to calculate the shoulder joint forces and moments [22,30]. The model was used to calculate the net shoulder joint forces and moments from the segment kinematics, the forces acting on the pushrim, and the subject's anthropometric measurements. More information about registering the biomechanical data can be found elsewhere [20].

**Ultrasound data:** The anatomical shoulder references, and

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**Table 1:** Subject characteristics, mean (s.d.)

| | Physically Active Wheelchair users (PAWUs) | | | Less Physically Active Wheelchair users (LPAWUs) | | |
|---|---|---|---|---|---|---|
| **N** | 17 | | | 14 | | |
| **Sex** | 17 male | | | 14 male | | |
| **Age (y)** | 34.41 (6.01) | | | 35.5 ( 8.51) | | |
| **Weight (kg)** | 70.67 (10.73) | | | 66.80 (9.38) | | |
| **Height (m)** | 1.79 (0.05) | | | 1.73 ( 0.05 ) | | |
| **Time Since Injury (months)** | 139.88 (92.71) | | | 107.71 (93.34) | | |
| **Shoulder Pain (No pain/Pain)** | 7/10 | | | 7/7 | | |
| **WUSPI (0-150)** | 23.24 (24.94)<br>Subjects with no pain: 9.17(14.24)<br>Subjects with pain: 43.35 (23.51) | | | 20.25 (20.77)<br>Subjects with no pain: 6.85 (5.22)<br>Subjects with pain: 33.65 (22.11) | | |
| **VAS (0-100)** | 21 (21.5) | | | 27.9 (16.6) | | |
| | Pain: 32 (26) | | | Pain: 28.7(14.5) | | |
| | No Pain: 10 (12) | | | No Pain: 27.1 (19.6) | | |
| **Level Injury** | D2–D6 | D7–D11 | D12-L3 | D2–D6 | D7–D11 | D12-L3 |
| | 7 | 4 | 6 | 5 | 5 | 4 |

**Figure 1:** Overview of the test set-up where the subject is working against extra resistance applied through a pulley system and in which the positions of the markers are shown.

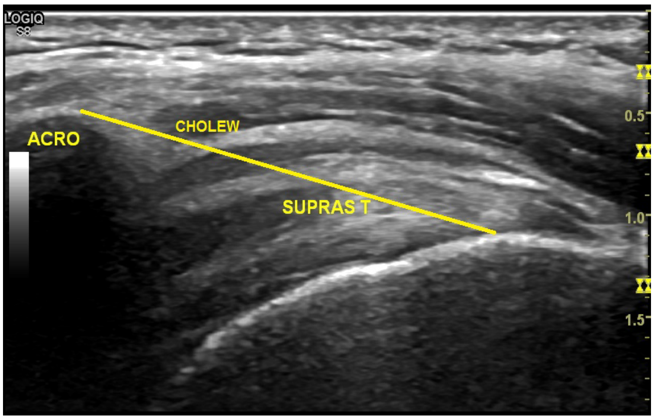


**Figure 2:** Measurement of the greater acromion tuberosity distance (Cholewinski Index).

the characteristics of the biceps and supraspinatus tendon, were analysed with custom software written in Matlab (The Mathworks Inc., Natick, MA, USA). Although an increase in the gleno-humeral joint space is the most common ultrasound finding related to the shoulder of SCI MWUs [31] a comprehensive analysis of shoulder ultrasound parameters was performed, including anatomical references such as the acromioclavicular distance (ACD) and the acromiohumeral distance assessed by the Cholewinski (CHI) method (acromion to greater tuberosity of humerus, Figure 2). Several tendon characteristics were also analyzed, such as the long axis biceps tendon thickness (LBTT) and short axis supraspinatus thickness [32]. In the longitudinal images of the biceps tendon, a 2 cm length was selected that included the part of the tendon located inside the bicipital groove and the average diameter of this section was calculated [15].

**Statistics:** A descriptive analysis, including the means and standard deviation (SD) for the continuous variables, was performed initially to describe the subject's characteristics. The shoulder joint forces, moments and ultrasound parameters were analyzed before and after the wheelchair propulsion test. All the statistical analysis was carried out using SPSS® V.17 for Windows (SPSS Inc., Chicago, IL, USA).

Peak shoulder forces and moments were averaged to create a representative value for each direction. Shoulder joint kinetics was calculated as the average of the peak force or moment for the wheelchair propulsion test, and the differences between early and late propulsion were analysed. In order to calculate the differences in shoulder joint forces and moments, a Shapiro-Wilk test was applied to the normal distribution of the sample. A Student's t-test for independent samples was applied to those variables that followed a normal distribution. A Bonferroni correction for multiple comparisons was applied to the kinetic and ultrasound data obtained before and after the test. A Mann-Whitney U test for independent samples was used to compare those variables with a non-parametric distribution. Spearman´s correlation was used to investigate relationships between continuous measurements, including each ultrasound parameter selected and the demographic data (e.g., height, weight, age, years since injury, WUSPI and VAS score). The level of significance was set at $P<0.05$.

## Results

### Subjects

This study was carried out on 17 male PAWUs with SCI and 14 male LPAWUs in the control group (CG, Table 1), recording their performance in a high intensity propulsion test (Table 2). The demographic parameters of the subjects were compared to confirm that the two groups could be considered homogeneous in terms of these variables (Table 1). The PAWUs withstood longer sessions on

**Table 2:** The performance of both groups in the high intensity wheelchair propulsion test, mean (s.d.).

| | Test duration (minutes) | Speed (Km/h) | Power output (W) | Increasing steps (Kg) | Borg Scale (0-20) |
|---|---|---|---|---|---|
| **PAWUs** | 15.18 (1.59) | 1.41 (0.10) | 53.23 (3.92) | 1.28 (0.10) | 17.41 (1.12) |
| **LPAWUs** | 11.85 (2.14) | 1.40 (0.14) | 46.78 (4.20) | 1.26 (0.12) | 17.93 (0.82) |

**Table 3:** Raw biomechanical variables for PAWUs and NPAWUs in the high intensity propulsion test, mean (sd)

| | | **Physically Active Wheelchair Users (PAWUs)** | | | **Less Physically Active Wheelchair Users (LPAWUs)** | | | |
|---|---|---|---|---|---|---|---|---|
| | | **Before test** | **After test** | **Relative change (Before-After)** | **Before test** | **After test** | **Relative change (Before-After)** | **Relative change between groups (PAWUs vs LPAWUs)** |
| **Fx (N) (+anterior, -posterior)** | **Max** | 46.21 (11.54) | 59.14 (13.96) | 12.93 (9.82)[a] | 37.75 (12.31) | 45.32 (12.44) | 7.56 (5.10)[a] | + |
| | **Min** | -38.29 (11.29) | -76.59 (19.40) | -38.29 (19.42)[a] | -44.68 (10.94) | -76.52 (20.94) | -31.84 (18.24)[a] | + |
| **Fy ( N) (+superior, -inferior)** | **Max** | -4.77 (11.94) | 18.28 (22.89) | 23.06 (23.08)[a] | 1.96 (17.00) | 19.83 (13.55) | 17.87 (15.18)[b] | + |
| | **Min** | -51.38 (13.33) | -72.53 (21.19) | -21.14 (16.66)[a] | -42.83 (10.94) | -66.27 (29.43) | -23.44 (21.52)[b] | + |
| **Fz (N) (+lateral, -medial)** | **Max** | 13.93 (4.58) | 19.65 (7.35) | 5.72 (8.79)[c] | 15.36 (9.22) | 15.31 (7.35) | -0.05 (8.51) | |
| | **Min** | -11.92 (5.52) | -19.70 (13.08) | -7.78 (10.58)[b] | -12.30 (14.09) | -19.16 (8.78) | -6.86 (11.23) | |
| **Mx (N.m) (+adduction, -abduction)** | **Max** | 2.29 (1.54) | 4.76 (5.77) | 2.47 (5.55) | 2.64 (2.70) | 3.75 (3.84) | 1.10 (3.09) | |
| | **Min** | -5.29 (2.13) | -8.34 (4.34) | -3.04 (2.78)[a] | -5.23 (2.77) | -7.37 (4.02) | -2.15 (2.87)[c] | |
| **My (N.m) (+int. rotation, -ext. rotation)** | **Max** | 2.72 (1.44) | 4.83 (2.47) | 2.10 (2.38)[b] | 3.04 (2.99) | 5.42 (3.12) | 2.38 (2.79)[c] | |
| | **Min** | -2.65 (1.65) | -4.68 (2.99) | -2.03 (2.21)[b] | -2.89 (2.14) | -4.13 (1.48) | -1.23 (1.99) | |
| **Mz (N.m) (+flexion, -extension)** | **Max** | 11.38 (4.68) | 23.70 (8.01) | 12.31 (6.60)[a] | 11.61 (2.90) | 20.09 (4.57) | 8.48 (4.45)[a] | + |
| | **Min** | -8.07 (3.05) | -13.79 (6.39) | -5.72 (5.87)[a] | -7.13 (3.04) | -12.07 (7.47) | -4.94 (5.01)[b] | |

Differences within groups [a]<0.001, [b]<0.01, [c]<0.05;
Differences between groups *<0.01, [+]<0.05 Bonferroni correction p<0.002

**Table 4:** Raw ultrasound values for MWUs and control subjects mean (sd).

| | **Physically Active Wheelchair users (PAWUs)** | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Before test** | **After test** | **Relative change (Before-After)** | **Before test** | **After test** | **Relative change (Before-After)** | **Relative change between groups (PAWUs vs LPAWUs)** |
| **LBTT** | 0.353 (0.05) | 0.355 (0.04) | 0.001 (0.03) | 0.351 (0.03) | 0.354 (0.03) | 0.002 (0.03) | + |
| **ACD** | 0.664 (0.17) | 0.685 (0.13) | 0.021 (0.09) | 0.745 (0.11) | 0.717 (0.11) | -0.027 (0.06) | |
| **CHI** | 2.412 (0.50) | 2.458 (0.57) | 0.046 (0.20) | 2.620 (0.43) | 2.627 (0.41) | 0.007 (0.18) | |
| **SST** | 0.620 (0.08) | 0.599 (0.08) | -0.020 (0.03) | 0.648 (0.12) | 0.632 (0.11) | -0.016 (0.02) | |

LBTT=Long Axis Biceps Tendon Thickness, ACD=Acromioclavicular Distance, CHI=Cholewinski Index, SST=Short Axis Supraspinatus Thickness,
Differences between groups [+]<0.05
Bonferroni correction p<0.005

the treadmill than the LPAWUs (15,18 +/-1.59 min vs. 11.85+/-2.14 min) and they generated more power ( 53.23 +/- 3.92 W vs. 46.78 +/- 4.20 W).

## Biomechanics

After the high intensity test, significant increases in peak shoulder forces and moments were observed in the PAWU group in all directions, except for adduction moment (Table 3). In the LPAWUs, the forces in all directions increased except the lateral, medial and adduction forces, and the external rotation moments. The increases in the anterior, posterior and superior peak forces, and in the flexion moment at the shoulder, were higher in the PAWUs than in the LPAWUs, while the increase in the inferior force was higher in the LPAWUs (Table 3).

## Ultrasound values

While the ultrasound parameters were similar in both groups before and after the manual wheelchair propulsion test (Table 4), the increase in the LBTT after the test was greater in the LPAWUs than in the PAWUs (Table 4). Considering the changes in the kinetic and ultrasound parameters before and after the test, a thicker SST was associated with a higher superior peak force and a higher adduction moment in the PAWUs ($r$=0.706, $p<0.05$ and $r$=0.619, $p<0.05$, respectively), and with a higher medial peak force and extension

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**Table 5:** Statistically significant correlations between shoulder joint kinetics and ultrasound variables.

| | LBTT | | ACD | | CHI | | SST | |
|---|---|---|---|---|---|---|---|---|
| | R. Spear | p | R. Spear | p | R. Spear | p | R. Spear | p |
| **Physically Active Wheelchair users (PAWUs)** | | | | | | | | |
| Fymax (superior) | | | | | | | ,706 | <0.01 |
| Fymin (inferior) | ,701 | <0.01 | | | | | | |
| Fzmax (lateral) | | | | | | | | |
| Mxmax (adduction) | | | | | | | ,619 | <0.05 |
| **Less Physically Active Wheelchair users (LPAWUs)** | | | | | | | | |
| Fxmax (anterior) | | | ,801 | <0.05 | | | | |
| Fzmin (medial) | | | | | | | ,730 | <0.05 |
| Mymax (int. rotation) | | | ,801 | <0.05 | | | | |
| Mymin (ext. Rotation) | | | | | | | | |
| Mzmin (extension) | | | | | | | ,710 | <0.05 |

LBTT=Long Axis Biceps Tendon Thickness, ACD=Acromioclavicular Distance, CHI=Cholewinski Index, SST=Short Axis Supraspinatus Thickness

moment in the LPAWUs ($r$=0.730, p<0.05 and $r$=0.710, p<0.05, respectively). A thicker LBTT was associated with a higher inferior peak force in the PAWUs alone ($r$=0.701, p<0.01), whereas the increase in the ACD was associated with an increased anterior peak force and internal rotation moment in the LPAWUs ($r$=0.701, p<0.05 in both cases). In terms of the functional parameters in PAWUs, only the increase in the CHI was significantly correlated with higher values in the Borg scale ($r$=0.587, p<0.05) and in the LPAWUs, the increase in CHI was associated with an increase in the WUSPI ($r$=0.720, p<0.05; Table 5).

## Discussion

The objective of this study was to determine whether physical activity has an effect on the forces applied on the shoulder and on the development of shoulder ultrasonography abnormalities in MWUs after performing a high intensity manual propulsion test. One of the two main findings from this study is that performing the test produced an increase in the peak shoulder forces and moments in almost all directions. However, in the PAWUs these changes were stronger in the anterior, posterior and superior forces, and in the flexor moment, whereas they were greater for the inferior forces in the LPAWUs. These differences imply that the forces exerted on the shoulder in the PAWUs were greater than in the LPAWUs. Secondly, despite the stronger increase in the forces exerted in the PAWUs, no ultrasound changes were evident in the soft tissues of the shoulder in these subjects. Moreover, a greater increase in the LBTT was observed in the LPAWUs, suggesting stronger inflammatory changes than in the PAWUs. By contrast, the higher force and force moments apparent in the shoulder of the PAWUs was probably due to their improved performance in the test, given that the PAWUs withstood longer sessions and they generated more power Thus, MWUs that practice a sport appear to propel themselves better, which enables them to perform intense propulsion for longer, generating more power and with higher force peaks in the shoulder, particularly in reference to the anterior, posterior and superior forces, although with no apparent morphological alterations in the soft tissues when analysed by ultrasound.

When increasing the intensity of manual wheelchair propulsion, all shoulder joint forces and almost all moments also increase, such as when increasing speed or inclination [12,33-35]. In the current study, shoulder joint forces and moments increased in the PAWUs except for the adduction moment. However, the ultrasound parameters of both groups did not differ before and after the propulsion test. This may be due to the fact that shoulder lesions are more likely to appear after activities that last longer, as opposed to shorter yet more intense activities. Thus, our protocol might have been too short to provoke such morphological changes.

Although it has been suggested that the high incidence of shoulder pain in MWUs is primarily due to overuse, this does not appear to be the only factor involved. If this were the case, the demands of physical activity would augment the effects of overuse, yet physical activity does not appear to increase the risk of shoulder pain [11,13]. Indeed, practising sport may even have a protective effect on the shoulder since athletes suffer less pain and experience more pain-free years than non-athletes [13]. In our study, we confirmed that physical activity did not promote damage in the soft tissue of the shoulder and thus, our data support the proposal that unlike physical activity, transfer, propulsion and reaching overhead might be among the activities most closely associated with shoulder pain [13].

The pathogenesis of shoulder symptoms in these PAWUs is multifactorial [9,29], and scapular kinematics and muscle imbalance may predispose MWUs to develop shoulder pathologies. The combination of forceful manual propulsion, control of the wheelchair and repeated overhead activities may increase the incidence of shoulder pain in sports like tennis [36]. Apparently, overhead movements are those most directly related to the development of pathologies. A recent study that focused on shoulder muscle imbalance indicated that those with weaker muscle strength at baseline, particularly in the shoulder adductors, and those who were less physically active were more likely to develop shoulder pain [37].

The secondary objective of this study was to examine the relationship between the subject's demographic characteristics, shoulder pain and ultrasound parameters. Distinct ultrasound parameters increased upon augmenting the forces and the moments of the forces exerted on the shoulder. For example, the SST increased in the PAWUs along with the anterior forces or that of the adductor moment, and the LBTT along with the inferior forces. Similarly, the SST increased along with medial force and the extensor moment in the LPAWUs, while the increase in the ACD was associated with that of the anterior force and the moment of the internal rotator. The confirmation of the relationship between some ultrasound and kinetic variables, whereby the increase in certain kinetic values in the

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shoulder is related to an increase in the ultrasound values, suggest the appearance of local inflammatory phenomena, which may well have been assumed prior to performing this study. However, we would have hoped to better understand the features underlying this association between these increments in the forces and the changes in the ultrasound in both groups. The interpretation of these findings is one of the limitations of this study, as well as in terms of the relationship between the ultrasound parameters and the demographic variables. In the PAWUs, the increment in CHI was associated with the values of the Borg scale, probably because the PAWUs exert more effort and perform the task better.

### Study limitations

One limitation of this study is that 3 PAWUs experienced pain, while none of the LPAWUs made any reference to shoulder pain, such that pain could introduce a bias that is difficult to avoid when analysing the data. Another issue that could be improved in future studies would be to include female MWUs and controls, since all the subjects analysed here were male. Indeed, further studies will be necessary to determine the reasons underlying the associations between the kinetic and the ultrasound values mentioned here in each group.

## Conclusion

Most shoulder joint forces and moments increase after an intense propulsion task in physically active and less active MWUs. The increases in the anterior, posterior and superior shoulder joint forces after an intense propulsion task were stronger in PAWUs. By contrast, the intense manual propulsion test did not produce changes in either the acromiohumeral distance or the tendinous structure of the supraspinatus and the brachial biceps in either group. The largest increases in the forces encountered in the shoulder of the PAWUs were not reflected by ultrasound changes in soft tissues. Better understanding shoulder kinetics and their relationship with structural findings may help to better define the relationship between physical activity and shoulder pain.

## Disclosure Statement

The authors have no conflict of interest to declare or any financial interest or benefit arising from the direct applications of their research.

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c. Vishay Revere Transducers BV, Breda, The Netherlands
d. Instituto de Biomecánica de Valencia, Valencia, Spain
e. Three Rivers Holdings, LLC, Mesa, AZ, USA
f. General Electric Healthcare
g. The Mathworks Inc., Natick, MA, USA
h. SPSS Inc., Chicago, IL, USA

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## Author Affiliation

Top

[1]*Biomechanics and Technical Aids Unit, Department of Physical Medicine and Rehabilitation, National Hospital for Paraplegics, SESCAM, Toledo, Spain*

[2]*Health Sciences Institute of Castilla-La Mancha, Talavera de la Reina (Toledo), Spain*

[3]*Laboratory of Performance and Sports Rehabilitation, Faculty of Sport Science, University of Castilla-La Mancha Toledo, Spain*