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SHOLDER JOINT FORCE EVALUATION IN WHEEL CHAIR DURING TRANSFER MANEUVER

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Abstract. *During transfer maneuver the shoulder joint is a major body structures with greater potential risk for supporting body weight. In this work four major muscles, deltoid, brachial triceps, pectoral and trapeze were analyzed by means of surface electromyography and support hand forces to identify the most critical phase of the maneuver. Four participants with both sexes were selected with age between 40 and 42 years, with over 10 years experience in wheelchairs. The maneuver was performed based on 45^o of the thoracic rotation. Two participants have mild spinal cord injury (MSCI) and two others with severe spinal cord injury (SSCI). The results showed that participants with MSCI realized maneuver with peak support force near the final stage and participants with SSCI in the middle phase. However, significant difference between two (MSCI and SSCI participants) were observed in the deltoid muscle electromyography.*

Keywords: *wheelchair, transfer maneuver, electromyography, hand force*

1. INTRODUCTION

The spinal cord injury (SCI) is considered one of the most serious and severe disabling syndromes due to high degree of complexity, because depending of the local and severity level the movements control will be compromised. SCI patients have limited limb mobility and necessary to use the wheelchair for locomotion. These patients need and excessively use the upper limb, specially the shoulder during transfer maneuver movements, eg.; changing for the car or to bed, in order, they require arm movements daily resulting overload and muscular instability. Surveys have shown a higher incidence of chronic pain in upper limbs, mainly in the shoulder joint complex for SCI patients, interfering and acting directly on the reduced quality of life decreasing the social integration of this population, Tumer (2001). The wheel chair user can realized numerous activities with full autonomy as the transfer maneuver allowing its exit from the wheelchair to another seat. Van Drongelen et al (2005) reported that for the wheelchair user, the complex shoulder joint is a major body structures with greater potential for harm due to its motor requirement and continuous motor tasks request during propulsion and transfer. One of the factors that can contribute to the development of complaints in the shoulder joint is a relatively heavy and frequent load on the upper extremity during activities of daily life in a wheelchair, such as transfers maneuver and weight relief, (Perry et al. 1996; van Drogelen et al., 2005). Dalyan et. Al. (1999) reported in a study of 130 individuals with one year after suffering SCI, 58,5% with pain at the upper end and 71% had shoulder pain and that this pain interferes 65% in transfer maneuver.

Studies which examine motor behavior are carried out to greater knowledge of the biomechanics so that the harmful effects are minimized. For this purpose, the technique of electromyography (EMG) has been used for several experiments for wheelchair users. Vargas Ferreira (2012) observed a decrease in the intensity and duration of the myoelectric activity of the muscles of pectoralis major, anterior deltoid and infraspinatus for the patients with tetraplegia during the push phase on the stopped wheelchair. Gagnon et al (2003) identified that the patients with high level of SCI showed differentes motion characteristics and high muscular demand during transfer maneuver compaired to the control group with low level SCI patients. According to the authors, probably this occurs to compensate impairment of the trunk musculature and the lower limbs of this population.

This study aimed to measure the myoelectric activity of the muscles of the upper limb during transfer maneuver of SCI patients and the shoulder´s movements were monitored in terms of the measured arms angle with respect to the trunk posture. So, its is possible to estimate the muscle activation pattern during the transfer maneuver and to evaluate strategies to minimize the effects of overloading, besides reducing the joint stress and the risk of injury.

2. MATERIALS AND METHODS

The transfer maneuver of the SCI pacients requires lifting its own weight through the supported arms. These achievement is made to change seats, from the wheel chair to the other chair. The typical movements of transfer involves approach and raise the buttocks toward the initial surface, placing the feet in a stable position on the floor, leaving one hand on the initial surface (right hand) while placing the other hand on the target surface (left hand). The

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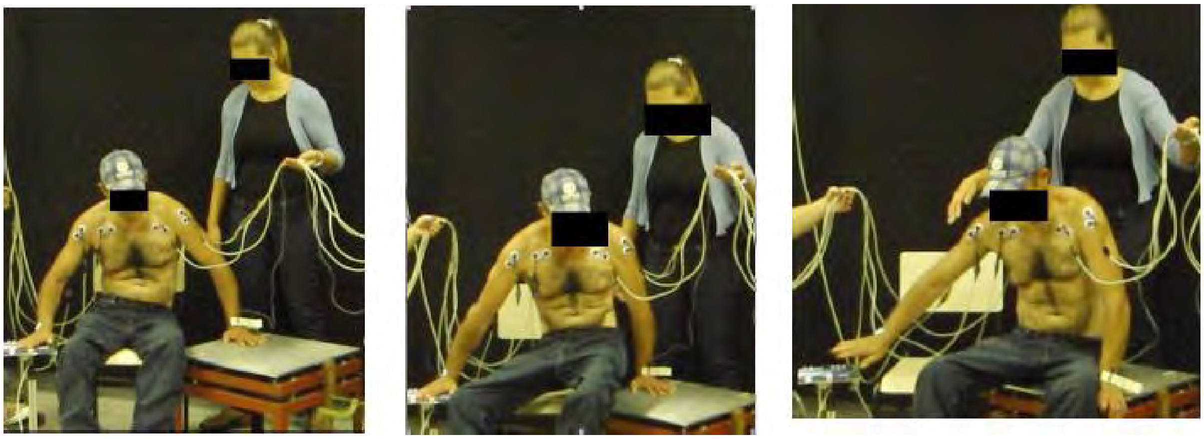
arms are used to raise the body and rotate the upper body, some subjects sway the torso towards the target and others use tilt the trunk forward depending on the injury level of the patients. Figure 1 shows the three-phase transfer with tipical wheelchair user.



(a) (b) (c)

Figure 1. Transfer maneuver of wheel chair user, a) pre-pivot phase, b) pivot phase and c) post-pivot phase.

2.1 Sample

The research was carried out with 4 adults residing in the cities of Guaratinguetá and Lorena, State of São Paulo, both sexes aged between 40 and 43 years, right-handers, Tab. 1. The participants 1 and 2 with low level injury, acquired by viruses and other 3 and 4 with high level injury, local of injury in T6 and T11 respectively caused by trauma. All of the participants uses wheelchair over 10 years. Everyone can move independently with wheelchair without help from another person. After being informed about the procedures and objectives of the study, each player signed an informed consent form.

Table 1. Antropometric data of voluntaree.

Subject	Sex	Old	Weight (N)
1	F	43	637.7
2	M	43	882.9
3	M	43	735.8
4	M	40	765.2

2.2 Trials

Participants received instructions on all the collection procedures and the process of familiarization of the motor task to be performed, which consisted of the exercises at least five times. Each subject was instructed to perform the transfer maneuver twice, the first attempt with no intention of collecting data and the second with recording. The transfer maneuver was performed according to the model established by Perry (1996). This task was divided into three phases: the first, called Pre-Pivot, its correspond to support hands on the force platform and initializing transfer movements, moving the body up. The second phase, called Pivot, moving the body to the other platform supporting the body by the arms. The third and final phase, called Post-Pivot, accommodate the weight of the body on the second platform. Before performing the transfer movement, each participant was submitted under conditions of maximum voluntary contraction (MVC) that consists in the static posture supporting the upper body by arms during at least 2-3 seconds. With the voice command, each participant started transfer movements with same velocity used for this activity, repeated 3 times with an interval of 3 minutes for each attempt. During testing, it was not allowed use of lower limbs to assist in movement to make the task closed to the real daily movement of wheelchair users. To distinguish the three phases of transfer maneuver were installed two cameras frontally participants.

2.3 Equipments

For data collection of the muscle activities, the bipolar electrodes Ag / AgCl were positioned on the muscle pectoralis major (PM) anterior deltoid (AD) and triceps brachii (TB) in accordance with the protocol proposed by Wirth

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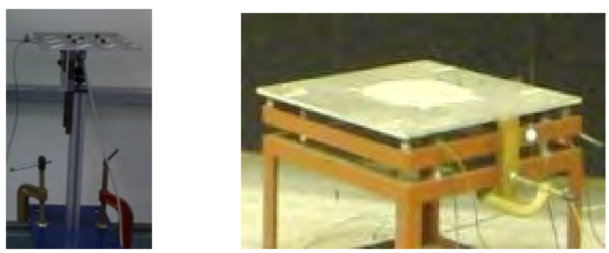
(1998). Prior to the placement of the electrodes, hairs were shaved and cleansed with isopropyl alcohol to reduce the influence of the skin impedance in the myoelectric signal. The signal was captured at a sampling frequency of 2 kHz by the signal conditioner EMGSystem, model 611c with 8 channels and filtered with a Butterworth filter of 4th order with cutoff frequencies of 20-500 Hz. The values of root mean square (RMS) of the surface electromyography signals were obtained at each time period that its correspond each phase of the Fig. 1.

For the procedure of kinematic technique was used two digital cameras from Sony (Cybershot) 30 Hz fixed and positioned the height of 1.46 m and a distance of 4m in relation to the subject. The technique of 3D kinematics based on 3D reconstruction methods, described in MATLAB program, associated with modified direct linear transformation was used to identify the 10 anthropometric points. To identify anthropometric points were fixed 10 passive markers on the upper body. The MATLAB program was used to determine the opening angle of the arms with respect to the body.
Measures of forces of the hands and upper body were recorded with their devices, Fig. 2. For measurement of the right hand force was used the load cell of type "S" manufactured in the laboratory of Biomechanics, 1045 steel body, installed with 4 strain gauges of Kyowa brand, model KFG-3-120-C1-11, Gain factor 2, was mounted between the aluminum plate with 5mm thickness and dimensions 20x20cm coated by synthetic rubber to prevent slipping contact with the hand, and aluminum column fixed to the base floor of the laboratory, Figure 2a. The calibration of the platform to support the hand showed a good response with reliability coefficient R^2 = 0.9989, sensitivity of 158.73 N / mV, in the range from 0 to 299.16 N. The second force platform used in this research was developed according to International Standards of Measurement, and has the following specifications: load capacity of 3600 N (consisting of 4 load cells); load cells with a capacity of 900 N, sensitivity of 2mV/V, 4340 steel body (using 4 pieces); 4 Strain Gauges (model J2A-06-SO38-350) with gain factor 2, from manufacturer MM; base built with an aluminum plate 5052 with 10 mm thickness, sized 500 x 500 mm. The 4 load cells were set in the corners of the platform and supported by 4 feet articulated by spherical steel at its base to avoid the influence of horizontal forces during the data collection. The calibration of the force platform was made with statically known weights. Initially, each individual load cell was evaluated with 200N, presenting a sensitivity of 449.01 ± 5.41 N/mV, with correlation coefficient R^2 = 0.9998, in the range of 0 to 794, 90NThe signal capture of 2 force platform was performed using a HBM Spider8 conditioner, with specific CATMAN software, at an acquisition frequency of 50 and 200 Hz, respectively small and large platforms.



(a) (b)

Figure 2. Force platforms and support structure for a) right hand, b) left hand and upper body.

3. RESULTS

The results in relation to the RMS of each muscle were evaluated in three phases of the maneuver in sequence, pre-pivot, pivot and post-pivot. Data on the percentage of the myoelectric activity of each muscle in each phase, average of 5 repetitions, normalized with respect to measurements performed at CVM, are presented in Table 2. During the pivot phase occurs posture similar to CVM condition that supports the body weight only by arms. Table 2 are presents root mean square (RMS) values for each phase of the transfer maneuver (dynamics) divided by the RMS values (statics), obtained in the condition of VCM , supporting upper body with arms, for 4 selected muscles.

The results of this study suggest that the second phase of motor behavior, pivot phase occurs most myoelectric activity of all muscles analyzed. A likely explanation for this finding would be the position of the shoulder joint during stress generated. In the phase of Pivot, the shoulder joint reaches its greater joint range and needs corresponding supporting torque, because at the end of the phase Pre-Pivot, upper limb is maintain rigid and with full elbow extension. This time is performed adduction of the shoulder so that the body is transferred to the large platform. Increased muscle activity during Pivot is justified by the fact that the body weight to generate a torque in elbow flexor, thus requiring, increased extensor torque for the maintenance of posture.

The openings of the arms with respect to the trunk posture in the pivot phase and the post phase are shown in Fig 3 in terms of the angles of the right arm and the left one, and that the time in the post-pivot is limited to 0.3 seconds, because after this time the participants taking relaxed posture, changing behavior of the stiffness of arms. In figure 3 can be observed less variation in the left arm and greater variation in the right arm in the Pivot phase, whereas the post-pivot presents opposite trend. This trend can be explained to follow the lateral movement of the body. In the Pivot phase would be like if the subject were performing a shoulder adduction, generating a higher rate of concentric contraction of the pectoralis major to perform its movement. At this same stage, occurs glenohumeral joint in abduction and subjected to a great need for adductor torque, provides greater displacement of the humeral head, requiring thus a high level of muscle contraction of the anterior deltoid to limit this projection forward. In this case, the anterior deltoid muscle has the primary function for the movement, but, restricting the movement of the humeral head and stabilizing the joint. The significant difference between the myoelectric activities of right and left arms was not detected in our study. In Pivot phase, The percentage of myoelectric activity presents greater activity with respect to CVM reaching close to 1.0 (maximum of 0.9887 to triceps muscle and minimum of o.6433 deltoids muscle, implying the transfer task requires great effort for wheelchair users.

Table 2. Percentage of myoelectric activity for each muscle among transfer maneuver phase.

Subject		Deltoid			Pectoralis major			Trapezius			Triceps		
		Pre-Pivot	Pivot	Post-Pivot	Pre-Pivot	Pivot	Post-Pivot	Pre-Pivot	Pivot	Post-Pivot	P Pre-Pivot	Pivot	Post-Pivot
1	Right	0,584	0,977	0,947	0,585	0,850	0,818	0,652	0,799	0,779	0,581	0,891	0,851
	Left	0,730	0,897	0,805	0,495	0,780	0,631	0,447	0,872	0,549	0,623	0,908	0,825
2	Right	0,390	0,774	0,683	0,666	0,740	0,730	0,601	0,666	0,612	0,940	0,977	0,968
	Left	0,635	0,877	0,873	0,542	0,924	0,696	0,697	0,699	0,644	0,840	0,852	0,775
3	Right	0,667	0,745	0,722	0,780	0,866	0,862	0,632	0,698	0,677	0,778	0,963	0,936
	Left	0,501	0,903	0,384	0,809	0,898	0,643	0,738	0,860	0,664	0,796	0,963	0,610
4	Right	0,611	0,643	0,316	0,816	0,945	0,925	0,766	0,914	0,850	0,860	0,925	0,924
	Left	0,751	0,946	0,222	0,939	0,961	0,883	0,791	0,813	0,792	0,949	0,988	0,985

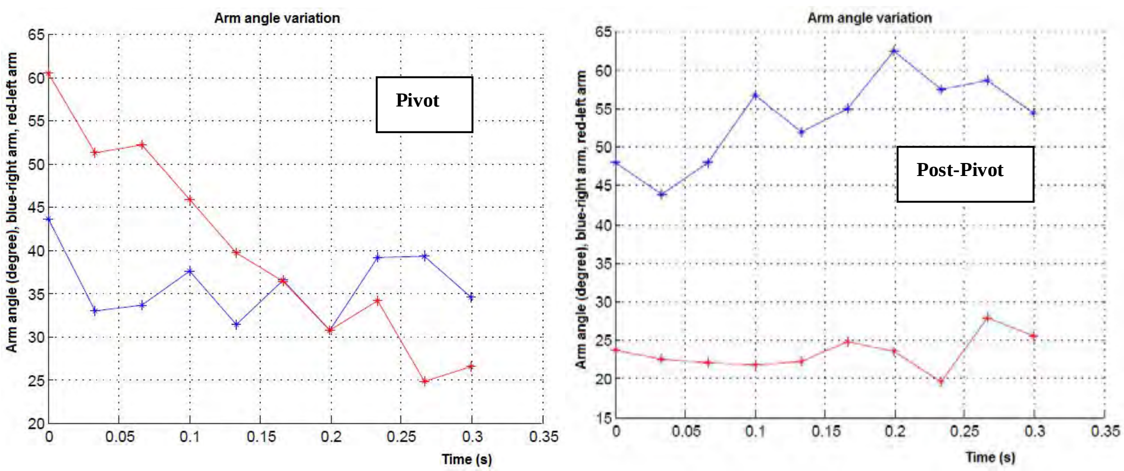


Figure 3. Arm angle variation in Pivot phase and Post-Pivot phase.

Figure 4 shows the force´s variations recorded by the larger platform with normalized time which initially receives the forces of the left hand, initial pre-pivot phase and the final phase of the transfer movements, Post-Pivot phase, with respected to the weight of the upper body and forces of the left hand. The graphs in Fig. 4 showed the peak forces in the final Pivot phase for subjects 1 and 2, person that the low level of injury with similar variation tendency, however, for subject 3 and 4, subjects with high level of injury showed peaks forces in the Post-Pivot phase and initial phase of the Pivot phase, respectively showing instability on the transfer motion. Figure 5 shows the variations of forces on the small platform supporting right arm in the normalized time. The graphs in Fig. 5 can identify that the movement of the final phase of the Pivot, near the Post-Pivot phase showed the accentuated peak forces for subjects 1 and 2. At this time the subject unloads the entire upper body weight and bends the trunk, causing significant strength reduction in the shoulder´s joints. For the subject 1 and 2, the peak forces of the two force platforms coincide in the same phases. However, for the subjects 3 and 4, the peak force for two platforms at different phases were observed, confirming the unbalance tendency observed in the larger platform.

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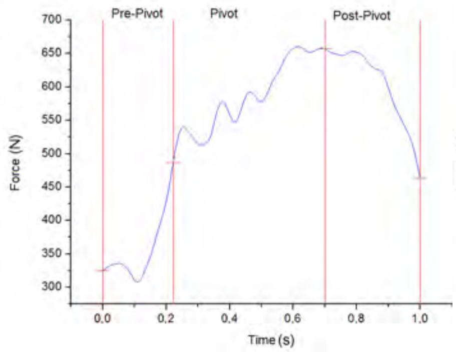
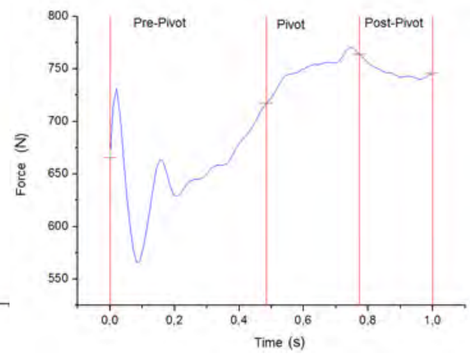
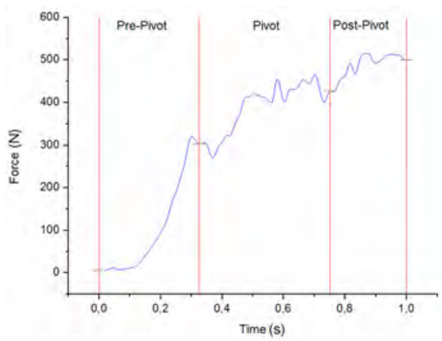


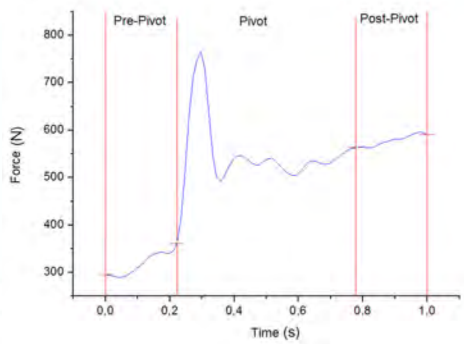
(a) Subject 1



(b) Subject 2

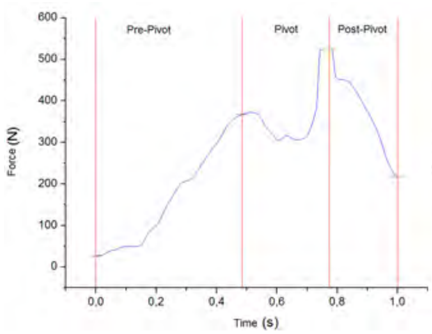


(c) Subject 3

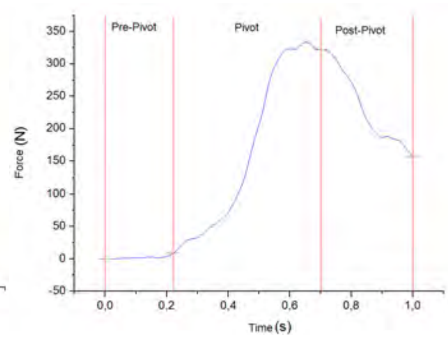


(d) Subject 4

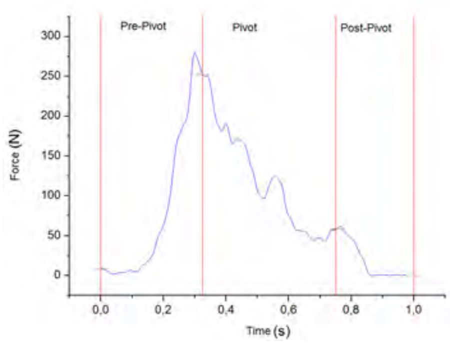
Figure 4. Reaction forces in body support plate, subject 1,2,3 and 4.



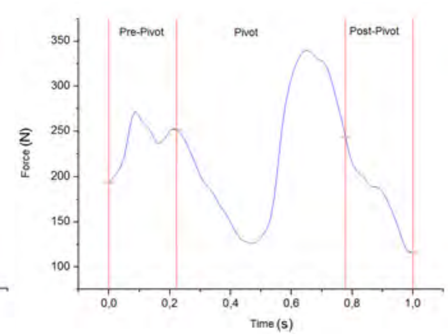
(a) Subject 1



(b) Subject 2



(c) Subject 3



(d) Subject 4

Figure 5. Reaction force in hand support plate, subject 1,2,3 and 4

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4. DISCUSSIONS

This study aimed to measure the myoelectric activity of the muscles of the upper limb during the transfer maneuver for the wheelchair users and the shoulder movements were monitored in terms of the supporting arm's angles relative to the body. Thus, it is possible to estimate the muscle activation pattern during the maneuver and develop strategies to minimize the effects of overload and the joint stress reducing the risk of injury. Generally, the greater force is associated with the greater degree of risk. The study of Curtis K. (2004) reported alarming index where 90% in female wheelchair basketball players with wheelchair, complaining of pain in the shoulder and upper torso due to intense sports activity. It is important to note that the relationship between force and degree of injury risk is modified by other work risk factors such as posture, acceleration/velocity, repetition, and duration, Herrin, et. Al. (1986). In the study of Nawoczenski et.al (2003) which concluded that movement of the wheelchair users results in transfer positions of the scapula and humerus in the direction of movement, which negatively contributes to reducing the subacromial space and may increase the risk of injury and shoulder pain for the wheelchair users.

The results of EMG show that a greater muscle activation during the Pivot phase in all muscles tested, deltoid, pectoralis major, trapezius and triceps that requires maximum performance muscle near the CVM, primarily for the triceps muscle. In the transfer maneuver, various muscles work simultaneously that its implies complex explanation of each muscle activity. However, the results of this work suggest that during the transfer maneuver, the direction of movement is also an important factor. The Post-Pivot phase presents a decreasing variation of the values of EMG, because the maximum muscle recruitment was reached at the previous phase and muscular relaxation occurs in this phase with minor angular variations of the arm was observed. Gagnon showed that by varying the hands position or placement of the trunk during transfer maneuver, there is a change in load distribution in the joints involved in this task.

In short, the EMG results were consistent with those reported by Gagnon for the transfer maneuver to the same height, finding different pattern when the transfer is realized at a greater height, presented greater muscle activity recording in pectoralis major and deltoid. Gagnon also identified that the patients with high level SCI have different characteristics and demands greater movement of the muscles, compared with patients with low levels of SCI due to the movement pattern performed to compensate for the impairment of the trunk musculature. The results of our study confirm the findings of Gagnon.

The results presented in our study are consistent in terms of CVM-EMG activity with those found by Sigholm et. al (1984), researched for the work space design, aimed to the ergonomic view in industry, who found in shoulder forces have increased with the increase of the arms angle during flexion and abduction of the arm. However, it is important to prove that the our study used the opposite direction of forces on the arm with respect to the work of Sigholm, the traction force, and our study with compressive force for the supporting arms.

The findings of this study with respect to previous research are different levels of SCI (mild and severe) take different behavior patterns during the transfer maneuver, and the presentation of muscle activation levels of the principals muscles used to maneuver (dynamic) with relation to CVM (static) that evinced the level of muscular demand.

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