KINEMATIC ASSESSMENT OF TRANSFER OF PARAPLEGIC SUBJECTS FROM THE WHEELCHAIR

Karina Cristina Alonso[1], Eliza Regina Ferreira Braga Machado de Azevedo[1], Enio Walker Cacho[1], Renato Varoto[2], Alberto Cliquet Júnior[1,2]

ABSTRACT

Objective: To evaluate the transfer strategy of paraplegic subjects from their wheelchairs. Methods: Twelve thoracic spinal cord injured subjects participated in this study (T2 to T12). The subjects were able to independently transfer from a wheelchair to a one square meter (m2) platform, half a meter in height. Images of reflexive anatomic markers were captured by six ProReflex infrared cameras and processed using a QTRac Capture software. Kinematic parameters of the trunk, head, shoulders and elbows were evaluated. Results: The data analyzed compared the subjects' preferential side for performing transfers, according to the functions performed by each body segment. Angular displacement of the head on sagittal plan (y-z), and the shoulders on the transversal plan (x-y), showed statistical differences ($p<0.05$). Conclusion: The data obtained on this study showed that there are differences in transfer strategies of paraplegic subjects to their preferential side, in comparison with the non-preferential side. Level of Evidence II, Development of diagnostic criteria on consecutive patients (with universally applied reference "gold" standard).

Keywords: Kinematics. Wheelchair. Paraplegic.

Citation: *Alonso KC, Azevedo ER, Cacho EW, Varoto R, Cliquet Junior A. Transfer kinematics assessment of paraplegic subjects from the wheelchair. Acta Ortop Bras. [online]. 2011;19(6):346-52. Available from URL: http://www.scielo.br/aob.*

INTRODUCTION

The wheelchair maximizes the functional locomotion, confidence, independence and comfort of its user, and is therefore used by most physically disabled individuals. During the rehabilitation phase these patients are trained to carry out activities of daily living (ADLs). Transfer tasks are part of this training and occur from different heights, with or without the help of a board.[1,2]

The spinal cord injured subject is capable of independent transfer after acquiring good trunk balance and an adequate pushup. For this purpose, there is specific training for the different levels and types of lesions, ensuring the adequacy of the patient to the technique, as well as stimulating their creativity and maintaining their physical integrity.[1,2]

The inclusion of spinal cord injured subjects in society is increasing on a daily basis, making the use of wheelchairs as a means of locomotion and independence essential. Therefore, transfers are part of the daily routine of independent paraplegic subjects. These on average perform approximately 14 to 18 transfers a day. Whether it is from the wheelchair, from the bed, from the car, from platforms, bath chairs or adapted toilets.[3]

Spinal cord injured subjects need their upper limbs (UL) for the performance of ADLs, locomotion and transfers, which leads to the commonplace appearance of pain and lesion in the shoulder, ranging between 30% and 50% in paraplegic people. There is diminished functional capacity of body segments in these subjects, altering the existing communication between the upper extremities and the trunk, which can generate an increase of overload imposed on the glenohumeral joint, muscle imbalance and biomechanical abnormalities in this joint.[4-6]

Studies demonstrate that in subjects with thoracic spinal cord injury, there is diminished activity of trunk stabilizer muscles, including the erector spinae muscles. Therefore, it becomes necessary for these individuals to adopt new postural patterns for trunk stability and/or mobility of the body segments, which involves the combination of muscles of the trunk and of the shoulder girdle. In high thoracic lesions, some muscles acting in the shoulder girdle, such as the latissimus dorsi and trapezius, undergo changes of function and start to aid in trunk stabilization.[7-10]

Forslund et al.[11] evaluated arm strength and the body kinematics of paraplegic subjects, during transfer from a platform to the wheelchair. This author and collaborators noted that the

All the authors declare that there is no potential conflict of interest referring to this article.

1- Department of Orthopedics and Traumatology. Faculdade de Ciências Médicas, Universidade Estadual de Campinas (UNICAMP) – Campinas, São Paulo, Brazil.
2- Department of Electrical Engineering, Universidade de São Paulo (USP) – São Paulo, SP, Brazil.

Study conducted in the Department of Orthopedics and Traumatology of Faculdade de Ciências Médicas da Universidade Estadual de Campinas (UNICAMP).
Mailing address: Universidade Estadual de Campinas, Faculdade de Ciências Médicas. Rua: Tessalia Vieira de Camargo, 126. Departamento de Ortopedia e Traumatologia/FCM. Cidade Universitária. CEP: 13083-970. Campinas, SP. Brazil. E-mail: ka.kcalonso@gmail.com

Article received on 7/28/10 and approved on 8/2/10.

strength generated in the upper limb that remains resting on the platform (contralateral limb) is greater than in the upper limb that rests on the wheelchair (leading UL), suggesting that paraplegic subjects with different strengths between the upper extremities, use the weakest side as a leader for transfers, thus diminishing the incidence of pain and injury. According to Gianni et al.[1], subacromial impingement is the pathology that most often affects the upper limb of spinal cord injured subjects, and according to recent studies, muscle imbalance is primarily responsible.

Ninomyia et al.[12] conducted a clinical and ultrasonographic analysis of the shoulders of spinal cord injured subjects and found greater incidence of lesion in the subscapularis of the paraplegic individuals, which is unusual, since in the individuals without spinal cord injury, the supraspinatus is the most severely impaired. According to the same author, this is probably due to the considerable demand for internal rotation of the shoulders, especially during the propulsion and independent transfer of the individual from wheelchair to bed and vice versa. The author also reported that 25% of the study participants did not have a clinical history of pain, yet the lesion was present in the ultrasound image.

Perry et al.[13] used electromyography to analyze the muscle activity of the shoulder girdle of paraplegics with low injury, during transfer from the wheelchair. They observed that we should not neglect muscle activity during all the phases of transfer, particularly if the patient's clinical history shows presence of disease and muscle weakness of the glenohumeral joint.

Gagnon et al.[14] assessed patterns of muscle movements and demands of spinal cord injured individuals (C7 - L2) during subsequent transfer tasks. The study showed that the muscle solicitation in subsequent transfer to elevated surfaces was slightly greater, not significant when compared with transfer in the opposite direction on the same surface.

The aim of the study is to evaluate the independent transfer strategies used by the paraplegic subjects, comparing their preferential side for transfer with the non-preferential size.

MATERIAL AND METHODS

Subjects

The study group was composed of 12 male spinal cord injured subjects, with age bracket between 21 and 61 years, and dysfunctional diagnosis of complete or incomplete high (T2-T5) and low (T6-T12) paraplegia, with more than one year of lesion. (Chart 1).

The participants were able to accomplish the transfers independently. The "preferential side for transfer", was called this to characterize both the side on which the patients feel safest, to perform the transfer tasks in their ADLs, and the upper extremities chosen to perform the role of leader (UL that rests first on the platform) and that of contralateral limb (UL that rests on the wheelchair, throughout the transfer task). For example: the preferential side for subject 1, as shown in Chart 1, is the left, i.e., in most independent transfers that this patient performs, the left UL is the leader and the right UL the contralateral. This designation bears no relation to the dominance side of the subjects' limbs (right-handed or left-handed). The survey was carried out in the Spinal Cord Rehabilitation Outpatient Clinic of the University Hospital (Hospital Universitário).

MEASURING INSTRUMENTS

Clinical

The individuals underwent an assessment consisting of anamnesis and physical examination with verification of the range

Chart 1. *Characteristics of the participants.*

Subjects	Age	Time of lesion (years)	Height	Body Mass (Kg)	Level of Lesion	Asia Scale	No. of transfers/day	Preferential side for transfer
1	23	6	1.73	78	T9	A	30	Left
2	61	15	1.75	74	T4	A	12	Left
3	34	3	1.58	64	T5	A	20	Right
4	24	3	1.65	56	T2	A	10 – 12	Right
5	25	7	1.85	82	T6	A	10	Right
6	27	9	1.92	82	T9	A	10	Left
7	35	21	1.75	96	T6	C	4	Left
8	37	4	1.70	68	T3	A	25-30	Left
9	29	10	1.73	75	T4	A	15	Left
10	33	2	1.66	63	T12	A	25-30	Right
11	21	2	1.87	85	T3	A	10 – 12	Left
12	42	11	1.81	80	T11	A	10	Left
Mean	32.58	7.75	1.75	75.25			15.67	
SD	10.97	5.83	0.10	11.07			8.50	

of motion of the upper limbs in accordance with the American Academy of Orthopedic Surgeons,[15] presence of pain and/or lesion and postural attitude in the seated position. Moreover, motor and sensory alterations were verified according to the classification of the American Spinal Cord Association (ASIA).

Kinematics

For kinematic evaluation we used a platform measuring one square meter in area by half a meter in height, and six ProReflex infrared cameras (Qualisys Inc., Glastonbury, CT, USA), with a system of cables and tripods for capturing images, which were processed through a computer with the QTrac capture software in version 2.5 (sampling frequency of 240 Hz). (Figure 1)

The images captured by the cameras were of reflective spherical markers with a diameter of 20 millimeters, placed at points previously determined by the researcher. The study used 12 of these markers that were fastened with adhesive tape at an external point close to the wheelchair, as well as anatomical points on the patients' bodies, such as: center of the head; radial styloid processes; lateral epicondyles; acromions; sternum; spinous process of the seventh cervical vertebra and anterior superior iliac spine.

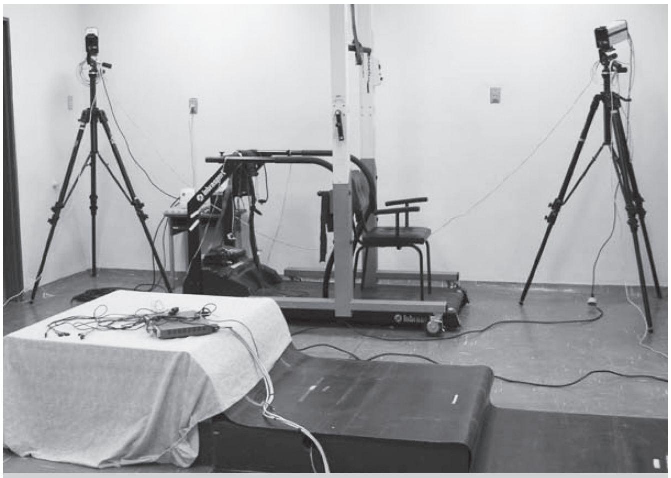

Figure 1. *Instruments for kinematic acquisition.*

Experimental Procedure

The study was approved by the Institutional Review Board. The individuals who agreed to take part in the survey were given verbal instructions about the entire procedure and signed a consent form.

The reflective markers were placed bilaterally at predetermined anatomic landmarks. The researcher instructed each participant to position their wheelchair next to the platform, and to remove or fold the footrests and armrests that were facing the platform, to position their feet on the ground and to place their hands on their respective thighs. The subjects were asked to transfer independently from the wheelchair to the platform according to their strategy and time. After these procedures the collection was initiated.

The experiment was carried out bilaterally. Therefore, the left and right arms performed two functions, both of leading UL and of contralateral UL. This made it possible to analyze and compare the behavior of the head, trunk and upper extremities in the transfer with the preferential and non-preferential side. The procedure was repeated five times for each side and intervals were created between transfers to avoid fatigue. (Figure 2)

The transfer was divided into three phases: 1. Preparation or Pre-raising Phase: the participant leaves the posture previously determined by the researcher and rests the leading limb on the platform and the contralateral limb on the wheelchair and starts the raising movement; 2. Raising Phase: when the buttocks are in the air; 3. Post-raising Phase: return of the buttocks to the platform and hands on thighs.

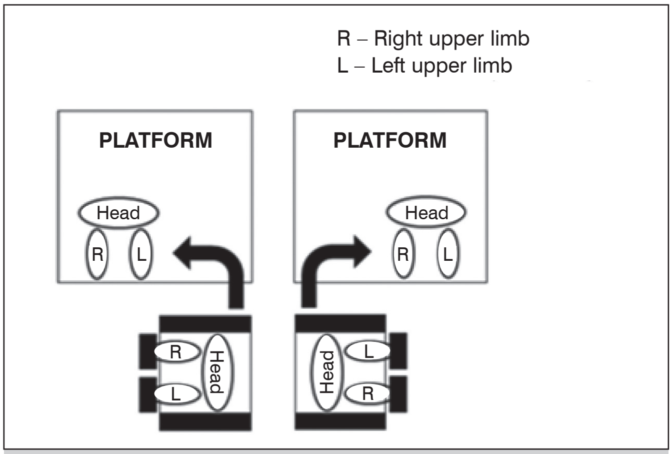

Figure 2. *Bilateral transfer: right and left upper limb acting as leader, consecutively.*

The wheelchair was positioned next to the platform in accordance with three coordinate axes (x, y and z), which together form the 3D Cartesian coordinate system. The x-axis is a straight horizontal line that lies in the same direction as the wheelchair backrest; the y-axis is a straight horizontal line that lies in the direction of the chair's arms; the z-axis is a segment of vertical straight line perpendicular to the x and y junction. (Figure 3)

The images captured by the cameras and recorded in 3D, over the course of the transfer task, enabled the acquisition and analysis of some variables such as: total transfer time; length of trajectory (route taken by a body in space, based on a predefined coordinate system), distance covered (physical unit that measures the displacement of one or more objects between two points) and the curvature index (responsible for measuring the curvature of a line, the closer to 1, the more rectilinear the movement) of the head and of the sternum; mean speeds and accelerations of the head and of the sternum; angular displacement (AD) [difference in degrees between the initial and final angular position, can be positive (clockwise) or negative (anticlockwise)] of shoulders, elbows and head. The angles of the shoulders and elbows were analyzed in the transverse (x-y) and sagittal (y-z) planes, and those of the head in the sagittal (y-z) and frontal (x-z) planes. The angles were determined in the local coordinates and the axes rotate according to the local plane analyzed, therefore the movements of the body segments performed in this study are not related to the existing anatomical planes. The Qtrac View, Qtools, Matlab, Biostatistic 4.0 and Origin programs were used for these analyses.

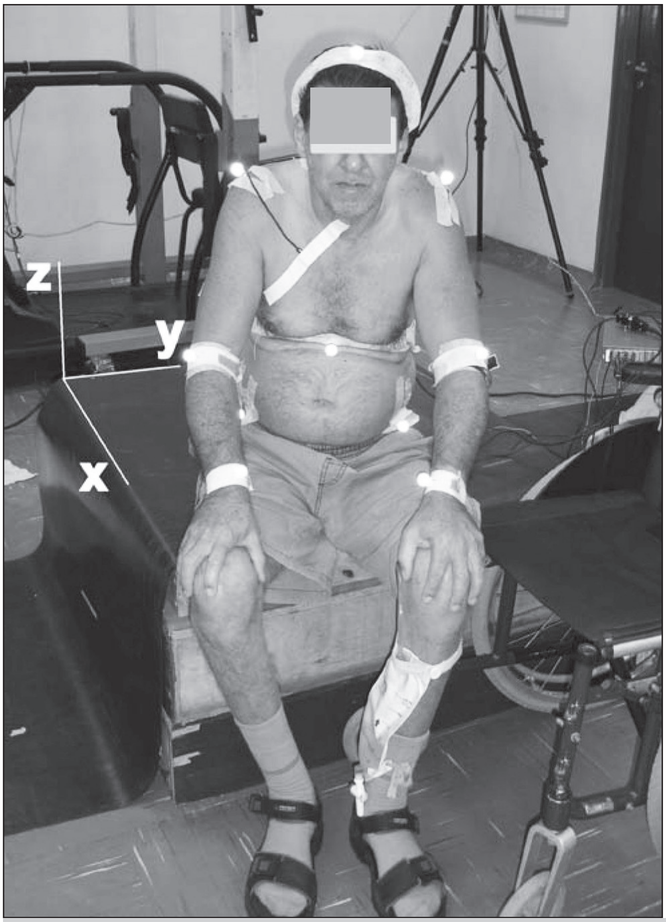

Figure 3. *Bilateral transfer: right and left upper limb acting as leader, consecutively.*

Statistical Analysis

The investigated variables were compared taking into account the participant's preferential side of transfer with the non-preferential side. The statistical analysis used the mean of three of the five images collected for each side of each subject. The variables described were: characteristics of the participants, total duration of the transfer tasks, distance covered, curvature index, length of trajectory, angular value (minimum and maximum) and angular displacement of shoulders, elbows and head, mean speed and acceleration. The quantitative data were calculated through Wilcoxon's test for related samples with significance level of 5%, i.e., $p<0.05$.

RESULTS

The transfer tasks for all the study subjects were performed both with their preferential side and with their non-preferential side. Therefore, both the left and the right upper limb performed different roles, either as leading or as contralateral limb.

The mean and the standard deviation (SD) of the total duration of transfer to the preferential side was 14.38 (5.88) seconds, while for the non-preferential side it was 13.63 (6.24) seconds. In the comparison of the two values we obtained $p=0.129$.

The body segment movements analyzed throughout the transfer were as follows: in the Preparation or Pre-raising phase the participants took their hands off their thighs. The leading limb was directed at the platform, performing abduction with shoulder flexion and internal rotation as well as elbow and wrist extension. The contralateral limb performed the same movement, yet while resting on the arm or on the seat of the wheelchair. Succeeding this movement, there was anterior flexion with tiling of head and trunk; the Raising phase was initiated by the anterior lever movements of the head and trunk followed by an impulse of the upper limbs. The trunk increased its anterolateral tilt and rolled to the side of the platform, approaching the leading shoulder. At this time, the leading elbow flexed and the buttocks approached the platform. The contralateral limb was brought away from the trunk and with extension of wrist and elbows. In the Post-raising phase, the buttocks rested fully on the platform and the hands returned to the respective thighs.

The Mean and Standard Deviation values of the distance covered, length of trajectory, curvature index, mean speed and acceleration of the head and of the sternum are present in Tables 1 and 2.

Angular displacement of lateral head tilt (y-z plane) showed significant difference ($p<0.05$), represented in Table 3 and Figure 4. Some statistical significances ($p<0.05$) were observed in the leading and contralateral shoulders and elbows during the comparison of the preferential side with the non-preferential side, respectively. In the x-y plane we observed differences in the angular displacement values of the leading (AD: 134° and 13°) and contralateral shoulders (AD: 146° and 31°), as shown in Table 4 and Figure 5.

Table 1. *3D analysis – distance covered, length of trajectory and curvature index.*

	Preferential side		Non-preferential side	
	Head	Sternum	Head	Sternum
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
"Distance covered (mm)"	401.35 (133.38)	505.29 (78.24)	438.12 (154.26)	622.64 (253.62)
"Length of trajectory (mm)"	2,373.19 (644.19)	1,735.65 (432.40)	2,628.07 (900.83)	2,139.39 (1,534.99)
"Curvature index (mm / mm)"	6.38 (2.26)	3.45 (0.81)	6.91 (3.03)	3.59 (1.48)

Table 2. *Mean and standard deviation of mean speed and acceleration of the head and of the sternum in relation to the fixed point.*

	Preferential side			Non-preferential side	
	Head		Sternum	Head	Sternum
	Mean (SD)		Mean (SD)	Mean (SD)	Mean (SD)
"Speed (mm/s)"	304.92	(79.48)	222.12 (59.40)	338.34 (82.89)	235.62 (53.57)
"Acceleration (mm/s)"	17,959.23	(4,915.04)	19,595.12 (3,370.95)	19,745.38 (9,869.78)	20,080.24 (5,845.41)

Table 3. *Minimum and maximum angular values, and angular displacement of head.*

	Preferential side			Non-preferential side		
	Minimum	Maximum	AD	Minimum	Maximum	AD
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
"y-z plane Head (°)"	137 (88)	190 (79)	47 (21)*	82 (152)	156 (139)	82 (47)*
"x-z plane Head (°)"	-30 (115)	168 (71)	187 (118)	-87 (130)	119 (53)	189 (124)

* P < 05 among the same variables from the preferential side compared with the non-preferential side.

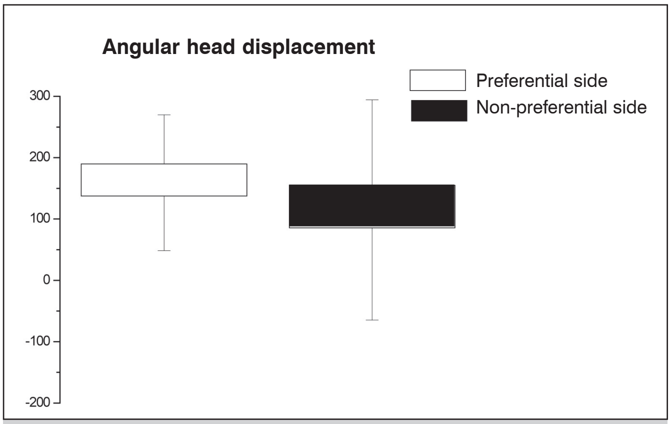

Figure 4. *Angular displacement of head in y-z plane (preferential and non--preferential side).*

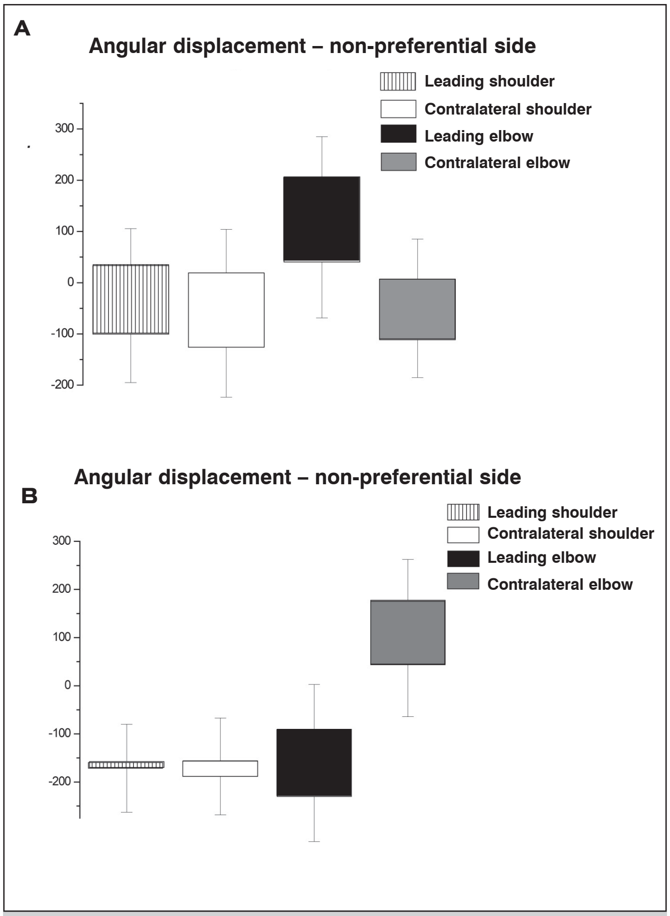

Figure 5. *Angular displacement of shoulders and elbows in x-y plane: A) Angular displacement of the preferential side; B) Angular displacement of the non-preferential side.*

Table 4. *Minimum and maximum angular values and angular displacement of shoulders and elbows.*

	Preferential side			Non-preferential side		
	Minimum	Maximum	AD	Minimum	Maximum	AD
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
x-y plane						
Leading shoulder (°)	-101 (94)	33 (71)	134 (40)*	-170 (92)	-156 (76)	13 (57)*
Contralateral shoulder (°)	-126 (96)	19 (84)	146 (50)*	-186 (81)	-155 (88)	31 (42)*
Leading elbow (°)	39 (108)*	207 (77)	167 (84)	-230 (93)	-189 (92)	140 (65)
Contralateral elbow (°)	-111 (73)*	7 (77)	119 (69)	43 (107)	178 (84)	135 (60)
y-z plane						
Leading shoulder (°)	-38 (11)	63 (62)	102 (63)	-43 (16)	49 (19)	93 (30)
Contralateral shoulder (°)	-51 (17)	49 (11)	101 (11)	-60 (36)	63 (25)	121 (44)
Leading elbow (°)	123 (125)	73 (65)	197 (139)	-56 (67)	83 (56)	139 (48)
Contralateral elbow (°)	-44 (65)	162 (109)	207 (71)	-106 (107)	117 (144)	180 (115)

* *p < 0.05 among the same variables from the preferential side compared with the non-preferential side.*

DISCUSSION

This study involved a 3D evaluation of the independent transfer strategies of paraplegic subjects. This confirms that the kinematic assessment is a sophisticated resource, which demonstrates in detail the movements of the body segments and their interactions with the proposed tasks.

The values of the total times, speeds, accelerations and distance covered, length of trajectory and curvature index of the study showed differences, but not significant. However, during the collections it was verified that the individual strategies adopted for the transfers and the participant's preferential side for their performance, directly influence agility and safety for their execution. Transfers performed with the non-preferential side generated insecurity in 75% of the participants (n=9). In the Preparatory phase, in the same collection, these participants made several attempts to rise from the chair up to the point when they felt secure about the transfer. This happened with all the subjects with high thoracic lesion (n=6) who had a trunk balance deficit. Moreover, during the execution of the Raising phase, and after several attempts, 50% of all the participants transferred quickly in a non-harmonic movement and as a block. These facts influenced the reduction of the total time and the increase of speed, acceleration, distance covered, length of trajectory and curvature index of the head and of the sternum on the non-preferential side. This increase can also be observed, but significantly, in the lateral head tilt (y-z plane). In addition, there was a significant reduction of angular displacements of the shoulders in the x-y plane.

The body posture adopted by the participants of this study was previously determined by the researcher and collaborators taking into account the functional position of some body segments so that the values of the studied variables would not suffer so many influences and would, therefore, come close to the real values. According to Kapanji et al.[17], the functional position of the shoulder, state of balance of the periarticular muscles, happens when the longitudinal axis of the arm is in flexion of 45°, abduction of 60° (scapular plane) and internal rotation of 30° to 40°. The elbow is at 90° of flexion with neutral prono-supination. Therefore, the posture adopted by the participants of this study was head and trunk in a neutral position according to the postural attitude of each one, i.e., head and trunk centralized, without tilt, rotation, flexion and extension. Arms at the sides of the trunk with elbow flexion and hands resting on the respective thighs on each side. In the study by Forslund et al.[11], it was determined that the initial position of the survey participants would be with the contralateral arm close to the trunk, resting on the strength platform and the leading limb positioned on the strength platform located on a slightly distant surface, generating a tilt and rotation of the trunk towards the leading arm. This also occurred in the study by Gagnon et al.[3], when the transfer was executed from one platform to another, and with varied heights. The study by Perry et al.[13] resembles ours when we compare with the fact that the transfer was performed from the wheelchair to a platform, yet the initial posture determined by the researcher was different, i.e., the leading arm was resting on the platform and the contralateral arm on the chair, which generated a tilt with trunk rotation. Seelen et al.[10] found in their study that the activity of the latissimus dorsi muscle was increased during lateral inclination of the trunk and of the pelvis. The author also observed that in subjects with low spinal cord injury, the erector spinae was used to stabilize the trunk in the seated position and, therefore, the latissimus dorsi and trapezius were not so strongly solicited. However, in high thoracic injuries there was greater activation of the erector spinae in association with an increase in the solicitation of the latissimus dorsi and trapezius, and slight activation of the pectoralis major. This shows that in these individuals there is a functional change of some muscle groups from the shoulder girdle.

The postural assessment in the seated position of the study participants showed that all the individuals sit on their sacrum, a position that generates concavity in the spinal column, and prolonged stay in this position can alter its physiological curvatures. The shoulders were projected forwards with shortening of the pectoralis and with increased internal rotation. The space of the cervical region was diminished and the head was projected forwards 45mm on average. In most of the participants, the scapulae were abducted and shifted upwards vertically. This postural attitude that is adopted can be influenced both by muscle imbalance and by the mechanical structure of most wheelchairs, which cause individuals to sit on their sacrum. These muscle imbalances may occur, since subjects with spinal cord injury solicit the internal rotators more than the external ones for the performance of their ADLs. In association with this, the shoulder anatomy features a natural imbalance in the quantity of internal rotatores, which is more numerous than the external rotatores. Therefore, although some values from the study do not attain statistical differences, we should not neglect some particularities that occur in individuals with spinal cord injury, especially in high thoracic cases, to avoid possible lesions.

CONCLUSION

The study was the first of its kind in the kinematic evaluation of paraplegics during wheelchair transfers, comparing the preferential and non-preferential sides for the accomplishment of transfers. Although some variables did not have statistical significance, it was noted that there are differences in the transfer strategies on one side in comparison to the other. The results obtained with the study facilitated the biomechanical comprehension and description of the characteristics of movements of the upper limbs, head and trunk of spinal cord injured subjects, during the transfer tasks. Therefore, the kinematic assessment of the transfer may act as a supporting factor for the clinic, furnishing parameters for more precise diagnoses and/or to facilitate the preparation of new protocols for rehabilitation of spinal cord injured subjects. Future studies should be conducted for a better understanding of the body behavior of paraplegic individuals during independent transfers.

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