Clinical, Functional and Kinematic Correlations using the Virtual Reality System Toyra® as Upper Limb Rehabilitation Tool in People with Spinal Cord Injury

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Abstract: The aim of this study was to prove the validity and efficacy of the Virtual Reality (VR) System Toyra® as an assessment and rehabilitation tool for people with tetraplegia. We analysed the correlation between clinical and functional parameters with kinematic variables of upper limbs during a training protocol using Toyra®. Eighteen patients with cervical spinal cord injury (SCI) were selected to perform the study by comparing 2 treatments: patients in an intervention group (IG) conducted a program that included 12 sessions with Toyra® Activities of Daily Living (ADLs) module for 3 weeks, while a control group (CG) only had the traditional rehabilitation. Kinematic variables (shoulder, elbow and hand joint range of motion) were correlated to clinical [Motor Index (MI), Muscle Balance (MB)] and functional [Functional Independence Measure (FIM), Spinal Cord Independence Measure II (SCIM II), Barthel Index (BI)] evaluation scores. The results of the study showed a high correlation between these variables and also statistically significant differences (p=0.039) in a kinematic parameter (wrist extension), after treatment and in the follow-up evaluation. Toyra® system has been validated as upper limb assess and rehabilitation tool in people with SCI, to measure the patient´s functional evolution and improve the movement in upper limbs.

1 INTRODUCTION

The worldwide estimate of the prevalence of spinal cord injury (SCI) is 223-755 per million people, with an incidence of 10.4-83 per million individuals per year (Wyndaele and Wyndaelem, 2006). Fifty percent of the patients with SCI are diagnosed as complete, with one-third of them reported as tetraplegic.

In tetraplegia, the arm and hand function is affected to varying degrees, depending on the level and severity of the injury (Harvey et al., 2001).

Studies have shown that one of the greatest needs of patients with tetraplegia is the improvement in upper limb function (Snoek et al., 2004).

In this respect, therapy aimed at upper extremities in people with tetraplegia is of paramount importance.

Considerable efforts have been directed towards the development of new upper limb (UL) function rehabilitation therapies using robots, virtual reality (VR), passive workstations (passive antigravity orthosis), and functional electrical stimulation (FES) systems (Oess et al., 2012).

Specifically, in an effort to promote task oriented and repetitive movement training of motor skills the use of VR with simulated environments has emerged as a useful tool (Stewart et al., 2007).

Using VR, users are able to interact with images, manipulate virtual objects, and perform other actions in a way that allows them to "immerse" themselves within the simulated environment and thereby create a feeling of "presence" in the virtual world (Weiss et al., 2006). In comparison with conventional rehabilitation, VR technology increases the range of possible tasks, while partly automating and quantifying therapy procedures, and improving patient motivation using real-time task evaluation and reward (Eng et al., 2007).

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To measure the effectiveness of such techniques, an evaluation, using clinical and functional scales, is performed before and after the treatment program to identify motor and functional recovery. In evaluation studies of upper extremity function in people with tetraplegia, a functional test supplemented with a test in which the subject is asked to perform several activities of daily living (ADL) are used (Van Tuijl et al., 2002). Two of the most commonly used functional evaluations, for patients with tetraplegia, are the Functional Independence Measure (FIM) and the Spinal Cord Independence Measure II (SCIM II). There tests are valid and reliable, and show strong correlation with each other.

However, a better understanding of human movement requires more objective testing and accurate analysis of motion, to accurately describe the arm movements during functional activities. Kinematic analysis is one method that can provide this understanding (Alt Murphy et al., 2006).

The study carried out by Cacho et al. (2011) showed correlation between some kinematic variables and clinical measures, in people with SCI, during the execution of ADLs (Cacho et al., 2011).

The objective of the current study is to analyse the correlation between clinical and functional assessments and the kinematic variables of UL. This is performed by comparing the results from a treatment based on VR with those from a conventional rehabilitation treatment in patients with complete tetraplegia.

2. MATERIAL AND METHODS

2.1 Participants

Twelve intervention subjects (4 females and 8 males; aged 33.58±14.11 years, 3.67±1.78 months after injury) and 6 control subjects (3 females and 3 males, aged 42±13.56 years, 6.67±2.16 months after injury) participated in the study. The subjects' demographic and clinical characteristics are showed in the Table 1.

Eligible participants met the following criteria: (1) at least 18 years of age; (2) less than 12 months from the injury; (3) complete spinal cord injury according to the ASIA´s impairment scale at the level of C5 to C8 (A-B ASIA level); (4) no history of traumatic or cognitive pathology that can affect the UL movements; (5) normal or corrected-to-normal vision and hearing; (6) no history of technology addiction; and (7) no history of epilepsy and pregnancy. Each subject gave informed consent voluntarily which was approved by our local Ethics Committee.

Table 1: Subjects´ demographic and clinical characteristics (mean and standard deviation).

	Control Group (n=6)	**Intervention Group (n=12)**
Gender (female/male)	3/3	4/8
Age [years]	42±13.56	33.58±14.11
Dominance (right/left)	3/3	5/7
Level of injury (C5-C8)	C5 (4), C6 (1) , C7 (1)	C5 (5), C6 (3), C7 (3), C8 (1)
ASIA (A-D)	A(3),B(3)	A(8), B(4)
Time since injury [months]	6.67±2.16	3.67±1.78
Etiology of damage (traumatic/postsurgical/vascular)	6/0/0	11/1/0

2.2 Experimental Design

This is a research study comparing 2 treatments. Patients in intervention group (IG) took part in a treatment program that included 12 sessions with Toyra® ADLs module using 3 levels of difficulty for 3 weeks. Simultaneously to Toyra® treatment, patients also received a daily session of conventional Occupational Therapy and Physiotherapy. Patients assigned to the control group (CG) only had the conventional treatment without receiving the described Toyra® sessions.

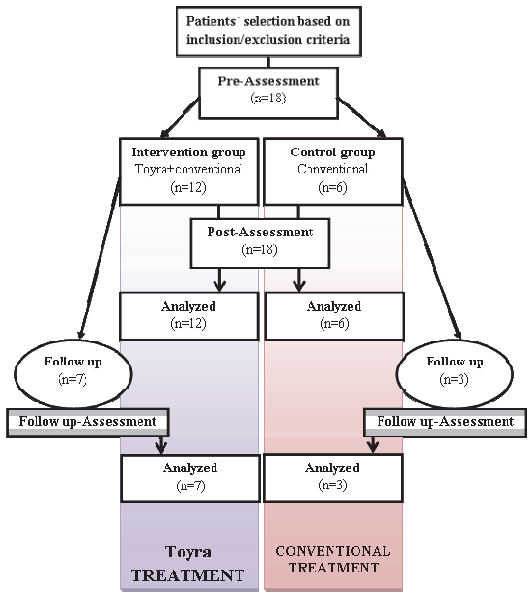

Figure 1: Experimental Design. The flowchart represents the experimental design followed during the study.

Every subject (CG and IG) was evaluated twice: at the beginning of the study and at the end, using both the VR system and the clinical and functional scales. A small sample from each group was followed up and assessed 3 months after the study, to measure if there were kinematic, functional or clinical changes during this period (Figure 1).

In order to prove the validity of the VR system Toyra® as an assessing tool, we correlated clinical and functional evaluations with kinematic variables of UL movements in patients with tetraplegia at three different points: before and after the treatment, and 3 months later (follow-up).

2.3 Treatment

The treatment system used was the VR Toyra®, which was comprised of motion capture elements that reproduce, in real time, the movements of the patient through an avatar displayed on an LCD screen, the characteristics of the system having been described previously (Gil-Agudo et al., 2012). A series of objects are shown, and the avatar, which represents the patient, has to touch them, while following predefined treatment goals.

In the current study we have conducted one type of interactive therapy session with the Toyra® system:

- Activities of Daily Living (ADLs) Session: The main objective is to achieve the maximum degree of autonomy that is possible while performing ADLs training in the VR system. In this session the monitor displayed several objects (spoon, fork, comb, sponge), asking the patient to reproduce the movements necessary to perform the corresponding ADL activities (eating with spoon, eat with a fork, combing hair and wash your face with a sponge).

2.4 Assessment

For the kinematic capture process we used a motion capture system based on inertial sensors MTx Xsens Company (Xsens Ic, Netherlands) which comprised of a gyroscope, an accelerometer and a magnetometer, which allowed us to know the position in Cartesian space. For this application we used 5 inertial sensors located on the head, trunk, arm, forearm and hand. The captured inertial sensor data and UL anthropometric data was used to develop a biomechanical model that has been previously reported (Gil-Agudo et al., 2011).

The kinematic assessment protocol consists of the performing of one test, The Evaluation Session, described as follows:

- Evaluation Session: The principal objective is to assess the patient's functional capacity. This is carried out by recording the kinematic variables for the different degrees of freedom during the execution of analytical movements of the UL. The ranges of motion (ROM) of the shoulder, elbow and wrist joints were analysed with MATLAB® (MATLAB R2009a, 2009), a mathematics software tool.

Neurological examinations of all the patients were performed according to the ASIA standards (Marino, et al., 2003). The right and left motor indexes were determined from the sum of the muscle strength (MB) of C5 and T1 segments from right and left extremities, respectively. For each motor index, scores ranged from 0 to 25.

The functional examination was carried out using four scales. FIM consists of 18 items organized into six categories, four corresponding to motor functions (self-care items, sphincter control, mobility items, and locomotion) and two corresponding to cognitive functions (communication, psychosocial, and cognitive). The lowest and highest scores of the total ranged from 18 to 126 (Hamilton et al., 1991). The second scale was SCIM II that has 16 items divided into three functional areas: self-care, respiration and sphincter management, and mobility. Total score can vary from 0 (minimal) to 100 (maximal) (Catz et al., 1997). The Barthel Index (BI) consists of 10 tasks: eating, bathing, grooming, dressing, bowels, bladder, toilet use, transfers (bed to chair and back), mobility (on level surfaces) and stairs. Total score is from 0 to 100 (Mahoney and Barthel, 1965.). The fourth assessment scale was the UL part of Motor Index (MI) that assesses the power and range of active movement, which are rated for shoulder abduction, elbow flexion, and pinch between the thumb and index finger. Each movement is rated on a 0-100 point scale (Demeurisse et al., 1980).

2.5 Data Analysis

The Pearson correlation coefficient was used to correlate kinematic variables (shoulder, elbow and wrist ROM) with clinical and functional variables. A significance level of p less than 0.05 was used. To compare the mean values of the kinematics, clinical and functional variables between groups, the nonparametric Mann-Whitney test was used. The statistical analysis was done with the program SPSS 17.0[17].

3 RESULTS

Since no differences were found in any of the analyzed variables, obtained from the first assessment session using the Toyra® system and the battery of scales, we conclude that the initial functional status was similar between the groups.

When comparing the kinematic data, obtained from the Toyra®, of both groups after treatment we found a statistically significant difference (*p*=0.039) in the wrist extension ROM. No statistically significant difference was obtained in any of the clinical and functional variables. However, notable differences, more than one point between the groups, were found when the pre and post evaluations were compared using the parameters for BI and MI dominant arm, showing higher scores for the IG. Furthermore, for most of the items in the follow-up evaluation (3 of the 5 items) and the ´follow-up after´, obtained from the subtraction of the ´after´ from the ´follow-up´, (4 of the 4 items) patients from the IG presented larger scores than those from the CG (Tables 2 and 3).

Positive correlations between clinical and functional measures and the kinematic variables were found in the CG before treatment: FIM and elbow flexion complete (r=0.966, p=0.034), MB and elbow flexion complete (r=0.971, p=0.029), MI and elbow flexion complete (r=0.999, p=0.001); after treatment: MI and elbow extension (r=0.995, p=0.005);and in the follow up evaluation: SCIM and elbow extension (r= 0.998, p=0.041), MB and wrist supination (r=0.999, p=0.024).

In relation to the IG we also found positive correlations between clinical and functional measures and the kinematic variables before treatment: MB and wrist extension (r=0.642, p=0.045), MB and wrist ulnar deviation (r=0.654,p=0.040), MI and shoulder abduction by steps (r=0.610, p=0.046), BI and shoulder flexion by steps (r=0.618, p=0.043), BI and wrist extension (r=0.611, p= 0.046); after treatment: MB and wrist pronation (r=0.649, p=0.031), FIM and wrist pronation (r=0.747, p=0.013); and in the follow up evaluation: SCIM and elbow flexion by steps (r=0.808, p=0.028).

Negative correlation in the IG between FIM and wrist extension after treatment (r=-0.665, p=0.036) were obtained in the IG. The results are shown in Table 4.

Table 2: Clinical and functional parameters in both groups before and after treatment program. The table shows the results of each group (mean and standard deviation) and the differences between groups (p) in different stages of the protocol. The parameter "Follow up – After" is obtained by subtracting "after treatment" from "follow-up". *Statistically significant differences.

	Before treatment			After treatment		
	CG	**IG**	***p***	**CG**	**IG**	***P***
SCIM [0-100]	25±9.6	24.42±7.24	**0.851**	29.83±6.17	27.75±4.91	***0.605***
FIM [18-126]	63±4.76	60.20±5.86	**0.395**	65.00±6.68	61.80±4.36	***0.395***
BI [0-100]	19.17±12.81	17.92±13.39	**0.813**	23.33±16.02	23.75±12.27	***0.668***
MB DOMINANT ARM [0-25]	12±6.35	14.09±5.99	**0.511**	13.83±6.91	14.82±5.67	***0.646***
MI DOMINANT ARM [0-100]	71±15.01	66.33±13.95	**0.639**	78.33±20.08	75.50±15.16	***0.572***
	Follow-up			**Follow up – After**		
	CG	**IG**	***p***	**CG**	**IG**	***P***
SCIM [0-100]	26.00±4.58	36.29±8.75	***0.052***	-2.00±2.64	7.57±9.91	***0.086***
FIM [18-126]	59.67±3.51	65.57±6.87	***0.203***	-2.33±4.04	4.43±3.99	***0.067***
BI [0-100]	29.50±2.88	27.86±8.59	***0.246***	-3.33±2.88	-0.71±6.72	***0.410***
MB DOMINANT ARM [0-25]	13.33±7.76	13.43±5.19	***1.00***	0.33±2.30	0.14±1.67	***1.00***
MI DOMINANT ARM [0-100]	79.67±24.13	79.29±14.24	***0.817***	2.67±4.61	2.71±12.61	***1.00***

Table 3: Kinematic variables in both groups before and after treatment program. The table shows the ROM results in each group (mean and standard deviation) and the differences between groups (p) in different protocol stages.

	CG	IG	*p*
Before treatment			
abdshoulder_s	90.56±39.10	88.92±37.73	**0.896**
abdshoulder_c	93.67±34.49	101.46±45.63	**0.896**
fshoulder_s	139.96±63.84	133.70±47.91	**0.794**
fshoulder_c	130.32±60.73	129.21±41	**1.000**
felbow_s	129.69±15.04	116.14±23.99	**0.361**
felbow_c	130.31±14.58	121.77±13.46	**0.361**
exelbow	137.88±23.46	136.67±20.87	**0.896**
rotshoulder	121.24±40.02	103.05±29	**0.361**
exwrist	56.35±16.60	58.12±18.57	**0.433**
supwrist	138.89±20.20	148.73±69.94	**0.361**
pronwrist	38.11±21.33	54.33±11.66	**0.192**
rdwrist	28.33±12.42	25.19±8.86	**0.602**
udwrist	20.38±14.68	31.53±11.85	**0.240**
After treatment			
abdshoulder_s	99.99±40.20	99.94±38.70	***0.0808***
abdshoulder_c	96.57±33.10	108.86±38.47	***0.544***
fshoulder_s	128.46±67.56	151.73±42.96	***0.396***
fshoulder_c	124.94±66.02	150.64±40.99	***0.544***
felbow_s	141.21±13.69	127.39±28.96	***0.332***
felbow_c	135.21±13.97	125.39±19.21	***0.275***
exelbow	141.89±20.40	141.01±29.08	***0.903***
rotshoulder	106.17±49.24	134.81±81.54	***0.467***
exwrist	50.19±12.70	74.39±25.39	***0.039****
supwrist	149.66±29.98	143.57±30.33	***0.716***
pronwrist	34.04±11.91	47.67±22.63	***0.332***
rdwrist	40.92±29.58	38.73±17.24	***0.903***
udwrist	34.53±35.28	36.30±14.78	***0.396***
Follow-up			
abdshoulder_s	80.35±21.21	126.57±46.54	***0.305***
abdshoulder_c	79.65±21.22	121.17±41.47	***0.210***
fshoulder_s	114.14±67.49	161.75±25.90	***0.425***
fshoulder_c	109.15±64.92	151.67±21.25	***0.305***
felbow_s	150.19±17.46	142.65±5.70	***0.425***
felbow_c	141.64±17.21	134.26±18.06	***0.732***
exelbow	154.43±37.08	145.53±22.23	***0.732***
rotshoulder	165.37±114.77	143±60.93	***0.909***
exwrist	56.89±4.74	66.56±14.47	***0.138***
supwrist	133.27±23.92	177.54±80.85	***0.210***
pronwrist	38.09±26.18	68.90±22.13	***0.138***
rdwrist	27.46±10.82	57.29±49.76	***0.425***
udwrist	27.17±9.92	34.42±19.04	***0.732***

abdshoulder_s: shoulder abduction by steps; abdshulder_c: shoulder abduction complete; fshoulder_s: shoulder flexion by steps; fshoulder_c: shoulder flexion complete; felbow_s: elbow flexion by steps; felbow_c: elbow flexion complete; exelbow: elbow extension; rotshoulder: shoulder rotation; exwrist: wrist extension; supwrist: wrist supination; pronwrist: wrist pronation; rdwrist: wrist radial deviation; udwrist: wrist ulnar deviation.

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Table 4: Statistically significant differences found in the correlation between clinical and functional variables with kinematic variables in CG (a) and IG (b) in the different protocol stages.

	SCIM	FIM	MB	MI
felbow_c		r:0.971 p:0.029 *b*	r:0.971 p:0.029 *b*	r:0.999 p:0.001 *b*
exelbow	r:0.998 p:0.041*f*			r:0.995 p:0.005 *a*
supwrist			r:0.999 p:0.024 *f*	

a. CG correlations (r= Pearson correlation coefficient; p= significance level). Protocol stages: b= before treatment, a=after treatment, f=follow up.

	SCIM	FIM	BI	MB	MI
abdshoulder_s					r:0.610 p:0.046*b*
fshoulder_s			r:0.618 p:0.043*b*		
felbow_s	r:0.808 p:0.028*f*				
exwrist			r:0.611 p:0.046*b*	r:0.642 p:0.045*b*	
prowrist		r:0.747 p:0.013*a*		r:0.649 p:0.031*a*	
udwrist				r:0.654 p:0.040*b*	

b. IG correlations (r= Pearson correlation coefficient; p= significance level). Protocol stages: b= before treatment, a=after treatment, f=follow up.

4 CONCLUSIONS AND FUTURE WORK

The present study shows a work based on the validity of the VR system Toyra®, in measuring the changes in kinematic variables by comparing them with clinical and functional results. We have also measured the efficacy of this system as a rehabilitation tool. The VR system Toyra® has proved to be valid and consistent not only as an assessing tool, but also as a rehabilitation device.

In a previous study (Gil-Agudo et al., 2012), we found trends indicating improvements in kinematic, functional and clinical variables after treatment in the IG. Statistically significant differences were found between the groups from the results of a test that assessed the manipulative skill, coordination and fine grip. The trend obtained from the patients in this study, where the values of the functional and clinical upper limb parameters were increased in the IG, corroborating the findings from the preliminary study. Muscle strength could be a good indicator of functional and clinical conditions of patients with tetraplegia. Some researchers (Beninato et al., 2004), have shown the specific contribution that each muscle group has on the accomplishment of motor tasks, assessed by FIM, in patients with low cervical lesions. The positive trends found in the scales that assess both power and range of active movements (MI) and activities of daily living (BI), after the ADLs training with the VR system, support these theories.

It is important to highlight that the IG maintains better results, in the clinical and functional scales, than CG from the results obtained by subtracting after treatment from follow-up. This means that people in IG continue improving even after the treatment, while CG patients lost most of the improvements.

In addition, there was a statistically significant difference between groups after treatment for the wrist extension ROM. The Toyra® system requires from the patient through the execution of arm and hand activities, like eating with a spoon or combing their hair wrist movements. Our proposed hypothesis is that due to this training, the patients have increased their hand dexterity.

We also think that the small sample size and the short time of intervention with the Toyra® system are contributing factors to the lack of statistical significance in the others scales.

In this study, the correlations between functional and clinical variables and kinematic parameters, in different treatment times, were studied in order to know the kind of relation and the system effectiveness as measure tool.

First of all, we want to highlight that we have found correlations in every evaluation stage and in all the kinematic, clinical and functional variables in both groups.

The functional scales used in this study (FIM, SCIM and BI) showed positive correlations with the kinematic variables and corroborate the findings of studies that present a relationship between functional and kinematic variables (Tsao and Mirbagheri, 2007).

The negative correlation found between FIM and kinematic variables after treatment in the IG could be due to the limitations of the FIM with regards to a subpopulation of SCI where the motor score is not capable of adequately discriminating the neurological level. This could be explained by the fact that it is not evaluation specific for SCI (Cacho et al., 2011).

The correlation between strength and kinematic parameters, measured with MB, indicate that muscle function in SCI has an important role in characterizing movements of those patients.

This leads us to believe that both strength and kinematics performance, are requirements for a smooth and harmonious movement (Cacho et al., 2011).

The relationship between MI and kinematic variables showed the strongest positives correlations. This may be due to the fact that as the motor level is higher, the ROM is bigger.

In most cases, the correlations indexes (CCI) are higher than 0.70, which is the lower limit to be considered reliable. Furthermore, there are several parameters with a CCI higher than 0.80 which indicates a very reliable correlation (Baydal-Bertomeu et al., 2010).

This study allows us to open a new area of research based on the validation of different motor capture systems not only as kinematic but also functional tools, making it possible to measure activities of daily living in an objective way. These results can inform the clinicians on the efficacy of the different rehabilitation methods and their impact on the patients' functionality.

Another future field of work is the development of functional motor models, for use with robotic and virtual reality rehabilitation programs based on activities of daily living as well as the opportunity to adapt each treatment to suit the individual functional characteristics of the patients.

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