NUS School of Computing AY2015/2016 Semester II

IS4250 Group 06
Final Project Report

Paper based on Research Topic:

Robot-Assisted Rehabilitation of Hand Function After Stroke with the HapticKnob and the HandCARE

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Contents

1. Introduction

The paper studies how biomechatronics can aid in rehabilitation of specifically the hand function, after patients suffer from stroke and have difficulty in performing activities of daily living (ADL). Biomechatronics is the interdisciplinary study of biology, mechanics, electronics and control. It focuses on the research and design of assistive, therapeutic and diagnostic devices to compensate (partially) for the loss of human physiological functions or to enhance these functions.

The use of biomechatronics in rehabilitation therapies may be addressed simply as Robot-Assisted Rehabilitation (RAR). The purpose of using RAR provides mechanical assistance, or in worse cases, support to the patients while they perform various dictated tasks during the therapy process. While RAR benefits patients with movement disorders by administering task-orientated motor training on themselves, the computerized devices enable healthcare data scientists to be able to quantify these movement related variables and enable meaning out of these data collected, for both diagnosis and clinical assessment.

1.1 Overview of Situation: Patients' Hand Function after Stroke

The general impairments of stroke patients are muscle weakness, spasticity and compulsory co-activation of anatomical muscles at multiple joints, which causes the impairment of fingers in a flexed finger posture. The following lists general types of impairments that a stroke patient is likely to experience, which causes them to have slow and uncoordinated movements:

(i) **Basic grasp**: unable to open the hand or position the thumb opposite to other fingers.

(ii) **Finger Independence:** unable to move and generate force independently with each finger.

(iii) **Insufficient tactile sensation and impaired sensorimotor translation**: unable to feel and control finger force.

2. Robot-assisted Rehabilitation

2.1 Justifying the need for Robot-assisted Rehabilitation

A survey from the stroke patients were that handwriting, typing and operating knobs were what they would like to recover first to fulfil various simple daily activities that would otherwise require help to do so. These complex tasks are time-intensive during therapies, and the limited number of therapists would be unable to meet this demand. The growing demand for therapists has outweighed the capability in training and producing adequate therapists on time. With RAR, it helps patients to train with minimal supervision, and patients would no longer have to wait and be limited to a fixed session of therapy every time.

2.2 Benefits

RAR is useful in increasing the intensity of therapy at affordable costs, which offers other advantages as well, such as good repeatability. Repetitive movement therapy has been observed to produce positive clinical outcomes by several studies.

In addition to high intensity, practicing movements that are task-oriented and functionally meaningful to the patient can result in better motor outcomes than that of conventional therapeutic techniques. This type of therapy, however, is labour intensive and time consuming. But with the use of programmable robotic devices, some of the aspects of this therapy can be automated to relieve some burden off the therapist and expanding their ability to provide more efficient service.

In addition, robots can be easily combined with other rehabilitation technologies such as virtual-reality and haptic technology[1]. This is especially effective in motivating patients to complete the stipulated duration of the therapy diligently. The image below illustrates the use of virtual reality to motivate the patient to complete the goal of their therapy.

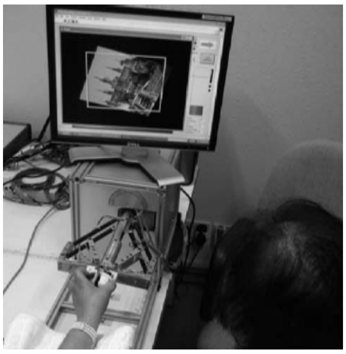

Figure 2.2 Using HapticKnob with virtual reality. Images are tilted; while patients try to turn the knob back to the correct position, the image will rotate accordingly to the patient's rotation distance.

Besides, RAR allows precisely controllable assistance and resistance during movements and enables objective and quantifiable measures of subject performance. Objective measures of subject performance with good sensitivity are very important for the therapy process. These measures will not only enable us to keep track of a subject's progress during therapy but will also be useful in evaluating the efficacy of newly developed therapy techniques.

[1] Haptics is the technology of adding the sensation of touch and feeling to computers.

3. About the Clinical Trials

3.1 Introduction

The two robots being used for experiments are HapticKnob and HandCARE. These robots are end-effector robots[2], which are comparatively mechanically simpler, easier to use and more compact than usual exoskeleton robots[3].

HapticKnob's main function is to train grasping in coordination with pronation[4] and supination[5] of the forearm. Whereas for HandCARE, it is mainly used to train the independent movement or isometric force training of each finger.

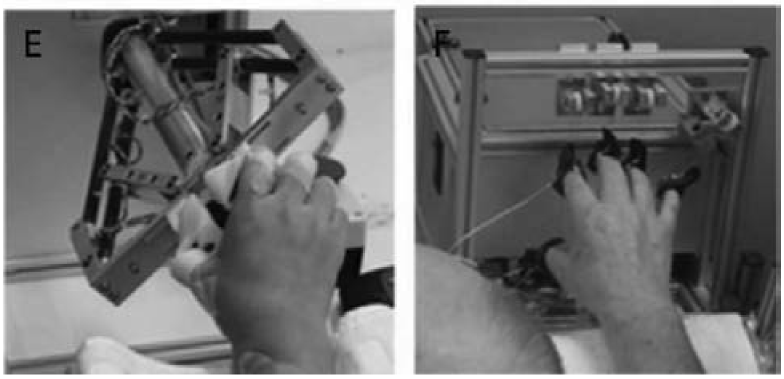

Figure 3.1.1: (left) HapticKnob (right) HandCARE

4 subjects were selected for the experiments, with several criterion:

- 43-83 years of age
- Right-handed
- Suffered from right hemiparesis
- Able to move right arm and hand, but have difficulties in performing many typical ADL

The stroke subjects went through an 8-week rehabilitation therapy with a 40-minutes session twice a week. Each session was divided into 20 minutes of training with HapticKnob and another 20 minutes with HandCARE.

3.2 Therapy 1: Improving motor function

The first part of the therapy included the use of the HapticKnob. The main purpose was to train forearm pronation and supination movement of the forearms. Patients were required to undergo the simulation of turning a doorknob, with the help of HapticKnob through applying a resistive load. The first movement was always supination, starting from the rest position of the forearm, and followed by the movement of full pronation.

An image would be displayed on the computer screen connected to the robot. The image orientation will change following the movement of the subject's forearm. Once the target was reached, the image on the monitor would reoriented to require an identical returning movement in pronation for realignment.

[2] End-effector robots interact with the user only at the level of the hand or fingers.
[3] Exoskeletons are complex mechanical structures with multiple degrees of freedom.
[4] Pronation is the inward rotation of the hands.
[5] Supination is the outward rotation of the hands.

Results

On average, the time required to perform the twisting movements significantly decreased for both supination (−25%) and pronation (−13%), while the coordination between forces applied by thumb and fingers increases. This suggests that tasks that involve hand and forearm coordination improves the motor function of stroke patients.

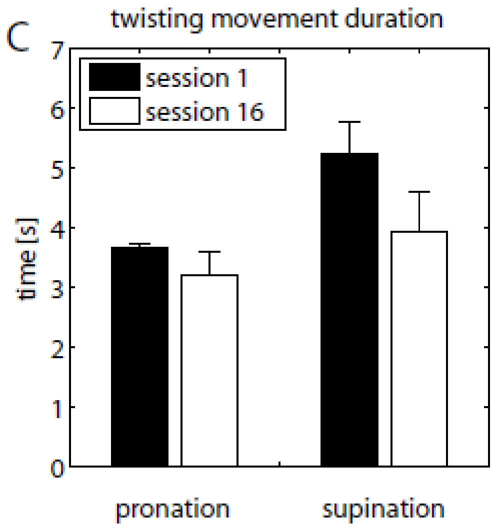

Figure 3.2 Graph showing a comparison of the time taken to perform supination and pronation of the forearm before therapy by the HapticKnob and after therapy.

A similar result was achieved when the HandCARE was used to get subjects to actively extend and flex their fingers together. There was a significant improvement for both extension [6](+31%) and flexion [7](+54%) of the fingers.

3.3 Therapy 2: Improving force control

The experiment was conducted with the subject's fingers being maintained in a fixed position by the HandCARE. The goal of this therapy was to train finger independence. Letters were then selected by isometrically applying a certain amount of force with a specific finger, i.e. Active Finger (AF), and by minimizing the force applied by the other fingers, i.e. Non- Active Fingers (NAF). The training was focused on the tripod thumb-index-middle as these fingers are most commonly used in ADL.

Results

The generated graph by the research paper shows the result of one stroke subject with limited finger impairment, whom performed this exercise during the entire 8 weeks of therapy. The stroke patient is a female, 83 years old and 6 years post-stroke.

[6] Extension of the fingers, the action of the hand reaching out
[7] Flexion of the fingers, the action of the hand bending in, for example to grab and hold onto something.

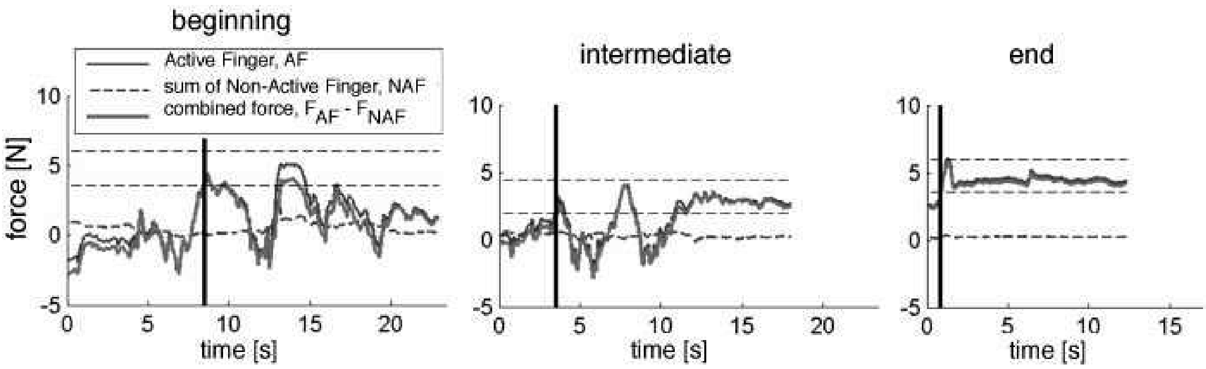

Figure 3.3: From left to right, the graphs show the force applied by AF and NAF respectively at the start, during and at the end of the entire therapy course. The vertical line represents the time taken by the subject's AF to achieve the target force.

After the trainings, the number of successful trials (i.e. correctly selected letter) increased for these three fingers (+16% for the thumb, +28% for the index, and +29% for the middle finger). The time to perform a successful trial was also largely reduced (−45%), indicating that the subject was getting used to the exercise and was able to better control forces generated by these fingers. This suggests that an intense isometric force training promotes recovery of finger function as subjects showed improvements in independently control force on their fingers.

3.4 Outcome measures quantitatively and qualitatively

Quantitative Results

To measure the effectiveness of the therapy quantitatively, the research paper in view assessed the upper limb impairment of patients using the Chedoke-McMaster Impairment Inventory (CMMII) , whereby the impairment is scaled from stage 1 (severe impairment) to stage 7 (mild impairment). The RAR showed an overall improvement according to the CMMII scale; a mean improvement of +1.05 stages (+25%) was observed in the 4 patients who participated to the pilot study.

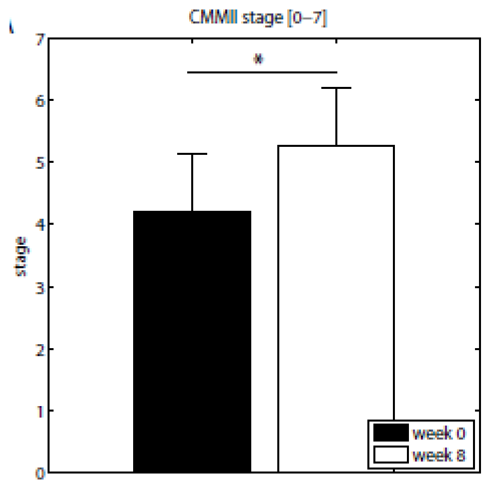

Figure 3.4.1 Clinical Outcome with CMMII

The afore results motivated a larger clinical trial with the HapticKnob on 9 subjects (59.4 ± 12.3 years, 5 females) at the chronic post-stroke stage, 3 right and 6 left hemi-paretic. The selected stroke patients in this clinical trial participated in a one-hour session 3 times a week over a period of 6 weeks, altogether 18 sessions during which they trained with the HapticKnob. Evolution in arm and hand motor function was assessed using the Fugl-Meyer Assessment of Physical Performance, Motor Function Upper Extremity (Appendix A).

A replicate of this result was plotted in R. Results of the clinical study was simulated and gathered to create the result. Section 7 will include a detail on the methodology of the replicate graph plot.

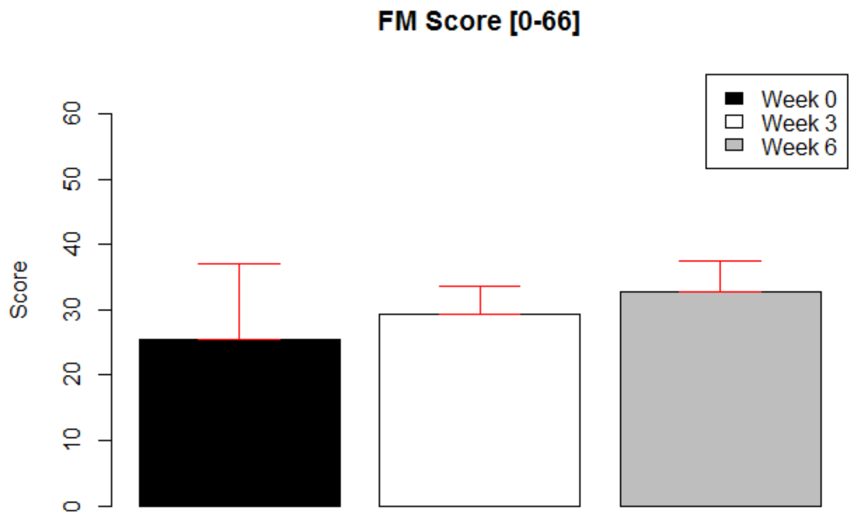

Figure 3.4.2 Clinical Outcome with FM Score; Replicate Plot.

The maximum score of 66 indicated a healthy wellbeing without any impairment and the subject is able to move freely by his upper extremity. The higher the score, the more able the stroke patient is relative to healthy subjects. After 6 weeks of therapy, a mean increase of 7.3 points (28.6%) was observed in the FM scores, indicating a positive improvement. There was a steady improvement throughout the therapy sessions as compared from week 0, to week 3 then finally week 6.

These results suggests that an intensive and repetitive training program improves motor function in stroke patients.

Qualitative Results

On a qualitative scale, there was an evident progress as patients reported improvement in their daily activities at home. They felt more secure in grasping and manipulating objects, more skilful in fine motor tasks, such as manipulating buttons or handwriting, and started to use their impaired hand more, which was believed to be crucial for further improvement.

4. Contributions Made to the Field of Health

One of the main contributions is that RAR helps to improve hand motor function and force control significantly through different trainings, like grasping, precision grip and fractionation. HapticKnob and HandCARE also trains the elbow and shoulder in the process, as these two components are needed to stabilize the arm during the trainings. By producing visible improvements, it helps patients to regain their confidence in their motor abilities as well. Besides, these end-effector based robots provide more freedom and comfort during training, compared to exoskeleton robots, as patients do not have to wear the complex device over their arms.

The aforementioned improvements suggests an acceptance attitude towards robotic devices used in rehabilitation therapies. In which, this acceptance is important to the field of health as it signifies that people are now more accepting towards RAR and the industry can look forward to the automation of many rehabilitation processes, saving costs for patients and reduce the burden on pressuring demand for more professionals in the health industry, especially towards therapists.

HapticKnob and HandCARE are comparatively less complex in terms of their structures compared to exoskeleton robots. When the complexity is lower, it means that it will be easier for patients to learn and operate with the device. In addition, the lower complexity entails a lesser cost of production and in which implies that the field of health is one step nearer to bringing low-cost automated rehabilitation machines to the stroke population, albeit making the devices available for the masses.

5. Evaluation of Robot-assisted Rehabilitation

5.1 Issues

In order for the RAR clinical trials to produce visible improvements, long periods of active participation is needed from the patients. This issue pertains till current date as continuous and effective motivation is needed in order to keep the patients going without dropping out halfway from the clinical trial.

Besides, in general, most of the stroke patients are typically older. They might not be tech savvy and may feel fatigue easily. The developer would have to design the devices around the user and enable interactive features to overcome these issues.

5.2 Challenges

There are a few challenges that HapticKnob and HandCARE would need to address in order to promote a wider usage when it goes public.

The first challenge would be a question on how to cultivate strong initial motivation and promote public acceptance for the robots. As most of the stroke patients are typically older, and they might find it hard in accepting a machine-controlled device to replace the traditional human-based therapy.

Another challenge would be to design user experience such that even the least technologically savvy people would be accepting towards these devices. The level of sophistication in the device has to be carefully managed, along with motivational visual feedback for users to accept using readily, as for example, the elderly might not all be familiar with gamification of devices, nor technological devices even.

Till recent dates, the same developers were conducting studies to overcome the aforementioned challenges. Selecting and maintaining an engaging and challenging training difficulty level in robot-assisted stroke rehabilitation remains an open challenge. Despite the ability of robotic systems to provide objective and accurate measures of function and performance, the selection and adaptation of exercise difficulty levels is typically left to the experience of the supervising therapist. (Metzger, J., Lambercy, O., Califfi, A., & Dinacci, D, 2014)

The third challenge is about designing the devices such that they are easy to be implemented by users, i.e. caretakers of stroke patients. Ideally, the public would able to set up the device with minimal or without any help from the trained therapist or technician.

Finally, the capability and ability to mass produce these RAR robots is a challenge should the devices are accepted and set to go public, the challenge would be to meet public expectations and whether or not the mass-produced robot would be able to achieve a similar effect as receiving therapies from the therapists themselves.

5.3 Limitations

Nothing is perfect and the same goes to HapticKnob and HandCARE. There are a few limitations bounded to the devices, and one of the most critical ones is certain degree of remaining motor function is still needed in order for the robotic rehabilitation to be effective.

The HapticKnob and HandCARE is built for the impairment of hand functions specifically, without total impairment of the hand function. The RAR methodology built with these devices are limited to mostly stroke patients, however less applicable to patients with neurological disorder, such as Tremor and Apraxia.

On another note, the training movements are limited by passive guidance from the therapist. In other words, patients will only train based on the instructions given by the therapist. Only limited activities will be carried out and hence, the therapy is not fully comprehensive in dealing with all kinds of real life activities.

Lastly, the experiments were limited to a fixed time frame. Hence, there remains an uncertainty that the improvements made may undo itself with time when patients stop practicing on using their hand functions.

5.4 Impacts to the world and our society

In general, HapticKnob and HandCARE are great inventions that will be producing impactful effects to the society. They can be used as a tool for studying motor control by analysing the patterns and data reflected on the computer that is being connected to the robots. The data will be useful in revising a more sophisticated solution to further improve therapy outcomes.

In addition, it is comparatively much easier to mass produce the robots than training experienced therapists in order to meet the increasing demand of therapy due to escalating population of stroke patients.

Last but not least, the devices have overturned the past perceptions that rehabilitation therapy is boring and painful. By integrating interactive features into the devices, it helps to relieve the stress of the patients when undergoing therapy activities. One of the examples will be for HapticKnob, patients can personally select pictures, like family photo, and the image will be used in the twisting training. When the patient twists his hand, the orientation of the image will be rotated according to his rotation distance as well, and eventually reaches the right orientation when the target is reached.

6. Conclusion

In summary, hand function, such as precision control and power grip, plays a very crucial role in ensuring that humans are able to carry out activities of daily living. By losing the ability to do so, the human is stripped of his ability to feel, touch and control his hand for essential activities, such as writing, typing and operating knobs. The activities mentioned were highly ranked by stroke patients whom found these activities to be most difficult and yet they desire for their hands to be able to carry them out.

Henceforth, the HapticKnob and HandCARE is an end-effector approach that will be useful in helping stroke survivors in regaining their lost hand function to a certain degree. They provide more freedom and comfort to the patients compared to exoskeleton products, as well as reduce the complexity and cost of the robotic system. However, limitations still exist, such as, a certain degree of hand function is required in order for the rehabilitation to be effective.

From the experiments, the robots were safe to use and deemed to be well accepted by the patients. However, due to the small sample size of the experiments, it is not justifiable that these robots will be receiving the similar level of acceptance from the public, especially from the elderly.

However, it is proven that these devices will be contributing significantly in enriching the user experience. Intensive and repetitive training program is the basis for improvement, however, it can be very tiring. By providing interactive features, it helps to constantly motivate the user to continue with the training in a fun environment.

Last but not least, despite the robots were only used for pilot tests, the invention represents a good kick start in the effort of engaging simple rehabilitation robot as standard therapy and assessment tool in the future.

7. Methods used in Data Replication

The Fugl-Meyer Assessment of Physical Performance, Motor Function Upper Extremity was used in this data replication to show the evolution in arm and hand motor function of the 9 stroke patients. The Fugl-Meyer score of each patient before, during and after the clinical trial was tabulated with the scoring form found in Appendix A.

Data Source

The data was retrieved from an actual clinical trial result from a similar study concerning the HapticKnob. (Ang, K. K., Guan, C., Phua, K. S., Wang, C., Zhou, L., Tang, K. Y., Chua, K. S, 2014) The result was used to replicate the data plot in R.

8. References

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9. Appendix

A: Fugl-Meyer Assessment of Physical Performance

Motor Function Upper Extremity				
TEST	ITEM	SCORE		SCORING CRITERIA
		Pre	Post	
I. Reflexes	Biceps			0-No reflex activity can be elicited
	Triceps			2-Reflex activity can be elicited
II. Flexor Synergy	Elevation			0-Cannot be performed at all
	Shoulder retraction			1-Performed partly
	Abduction (at least 90^0)			2-Performed faultlessly
	External rotation			
	Elbow flexion			
	Forearm supination			
III. Extensor Synergy	Shoulder add./int. rot.			0-Cannot be performed at all
	Elbow extension			1-Performed partly
	Forearm pronation			2-Performed faultlessly
IV. Movement combining synergies	Hand to lumbar spine			0-No specific action performed 1-Hand must pass anterior superior iliac spine 2-Performed faultlessly
	Shoulder flexion to 90^0, elbow at 0^0			0-Arm is immediately abducted, or elbow flexes at start of motion 1-Abduction or elbow flexion occurs in later phase of motion 2-Performed faultlessly
	Pronation/supination of forearm with elbow at 90^0 & shoulder at 0^0			0-Correct position of shoulder and elbow cannot be attained, and/or pronation or supination cannot be performed at all 1-Active pronation or supination can be performed even within a limited range of motion, and at the same time the shoulder and elbow are correctly positioned 2-Complete pronation and supination with correct positions at elbow and shoulder
V. Movement out of synergy	Shoulder abduction to 90^0, elbow at 0^0, and forearm pronated			0-Initial elbow flexion occurs, or any deviation from pronated forearm occurs 1-Motion can be performed partly, or, if during motion, elbow is flexed, or forearm cannot be kept in pronation 2-Performed faultlessly
	Shoulder flexion 90-180^0, elbow at 0^0, and forearm in mid-position			0-*Initial* flexion of elbow or shoulder abduction occurs 1-Elbow flexion or shoulder abduction occurs during shoulder flexion 2- Performed faultlessly
	Pronation/supination of forearm, elbow at 0^0 and shoulder between 30-90^0 of flexion			0-Supination and pronation cannot be performed at all, or elbow and shoulder positions cannot be attained 1-Elbow and shoulder properly positioned and pronation and supination performed in a limited range 2-Performed faultlessly
VI. Normal reflex activity	Biceps and/or finger flexors and triceps (This item is only included if the patient achieves a maximum score on all previous items, otherwise score 0)			0-At least 2 of the 3 phasic reflexes are markedly hyperactive 1-One reflex is markedly hyperactive, or at least 2 reflexes are lively 2-No more than one reflex is lively and none are hyperactive

TEST	ITEM	SCORE		SCORING CRITERIA
VII. Wrist	Stability, elbow at 90^0, shoulder at 0^0			0-Patient cannot dorsiflex wrist to required 15^0 1-Dorsiflexion is accomplished, but no resistance is taken 2-Position can be maintained with some (slight) resistance
	Flexion/extension, elbow at 90^0, shoulder at 0^0			0-Volitional movement does not occur 1-Patient cannot actively move the wrist joint throughout the total ROM 2-Faultless, smooth movement
	Stability, elbow at 0^0, shoulder at 30^0			0-Patient cannot dorsiflex wrist to required 15^0 1-Dorsiflexion is accomplished, but no resistance is taken 2-Position can be maintained with some (slight) resistance
	Flexion/extension, elbow at 0^0, shoulder at 30^0			0-Volitional movement does not occur 1-Patient cannot actively move the wrist joint throughout the total ROM 2-Faultless, smooth movement
	Circumduction			0-Cannot be performed 1-Jerky motion or incomplete circumduction 2-Complete motion with smoothness
VIII. Hand	Finger mass flexion			0-No flexion occurs 1-Some flexion, but not full motion 2-Complete active flexion (compared with unaffected hand)
	Finger mass extension			0-No extension occurs 1-Patient can release an active mass flexion grasp 2-Full active extension
	Grasp I - MCP joints extended and proximal & distal IP joints are flexed; grasp is tested against resistance			0-Required position cannot be acquired 1-Grasp is weak 2-Grasp can be maintained against relatively great resistance
	Grasp II - Patient is instructed to adduct thumb, with a scrap of paper inter-posed			0-Function cannot be performed 1-Scrap of paper interposed between the thumb and index finger can be kept in place, but not against a slight tug 2-Paper is held firmly against a tug
	Grasp III - Patient opposes thumb pad against the pad of index finger, with a pencil interposed			0-Function cannot be performed 1-Pencil interposed between the thumb and index finger can be kept in place, but not against a slight tug 2-Pencil is held firmly against a tug
	Grasp IV - The patient should grasp a can by oppos-ing the volar surfaces of the 1st and 2nd digits.			0-Function cannot be performed 1-A can interposed between the thumb and index finger can be kept in place, but not against a slight tug 2-Can is held firmly against a tug
	Grasp V - The patient grasps a tennis ball with a spherical grip or is instructed to place his/her fingers in a position with abduction position of the thumb and abduction flexion of the 2nd, 3rd, 4th & 5th fingers			0-Function cannot be performed 1-A tennis ball can be kept in place with a spherical grasp but not against a slight tug 2-Tennis ball is held firmly against a tug
IX.Coordination/ Speed- Finger from knee to nose (5 repetitions in rapid succession)	Tremor			0-Marked tremor 1-Slight tremor 2-No tremor
	Dysmetria			0-Pronounced or unsystematic dysmetria 1-Slight or systematic dysmetria 2-No dysmetria
	Speed			0-Activity is more than 6 seconds longer than unaffected hand 1-(2-5.9) seconds longer than unaffected hand 2-Less than 2 seconds difference
Upper Extremity Total				**Maximum = 66**

(FM, range [0-66], (Sullivan, K. J., Tilson, J. K., Cen, S. Y., Rose, D. K., Hershberg, J., Correa, A., Duncan, P. W, 2010))

10. References

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