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ON HUMAN ROBOT INTERACTION MODALITIES IN THE UPPER LIMB REHABILITATION AFTER STROKE

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***Abstract**: The paper presents an overview of the current strategies in the human robot interaction modalities implemented in robotic rehabilitation systems for the upper limb. An in-depth analysis reveals the potential benefits of the existing approaches in relation to the post-stroke stage of the patient. Using several human body anthropometric models and experimental data collected from a group of patients the motion types and amplitudes, limb segment lengths and weights are calculated. Medical protocols for the rehabilitation of post-stroke patients are proposed in correlation with the latest studies and trials. The experimental and calculated data represent a critical point in the preliminary development of new conceptual structures for robotic assisted rehabilitation to ensure an efficient recovery of the post-stroke patients.*
***Keywords**: human robot interaction, post-stroke robotic rehabilitation, control strategies, medical protocols*

1. INTRODUCTION

A stroke, as defined by World Health Organization (WHO), is a "*neurological deficit of cerebrovascular cause that persists beyond 24 hours or is interrupted by death within 24 hours*".

In Europe, according to the WHO mortality database, cardiovascular diseases (CVD) represent 42% of male deaths out of which 10% are strokes and in women the percentage of deaths due to CVD's is 51% out of which 15% represent strokes.

In Romania, according to WHO, cardiovascular diseases represent 58% of total deaths per year, with the number of deaths ranging between 20% and 45% in males aged under 70 and 10% to 25% in females aged under 70.

While the death prevention rate following a stroke has excellent perspective, the post-stroke patients suffer of neurological impairments, which spread among the following domains [15]: motor, sensory, vision, language, cognition, affect. Most common motor impairment, entitled hemiparesis, affects the movement control of the face, arm and leg on one side of the body.

Based on the European documents Strategic Research Agenda (SRA) 2014-2020 [34] issued by euRobotics AISBL and the Multi-Annual Roadmap (MAR) published in 2015 [35], healthcare is considered one of the strategic domains for the development of robotics, based on the following data:

- The EUROSTAT population projections estimates that in the European Union (EU) the percentage of population aged over 65 will increase from a value of 17.1% in 2008 to 30% in 2060 while the population aged over 80 will rise from 4.4% to 12.1% for the same period;
- One of the major disability causes among elderly people is neurological with emphasis on stroke;
- The incidence of the first stroke in Europe is 1.1 million and prevalence around 6 million;
- The post-stroke one year survival rate is around 75% with 80% of the survivors

experiencing long-term reduced manual dexterity.

Based on this data, MAR defines an acute demand for the development of new methodologies in rehabilitation that will allow physicians to treat, with better perspective, a larger number of patients. Furthermore, current projections in neurologic rehabilitation point out the following critical aspects:

- Stroke is one of the major diseases which targets especially the elderly population;
- Stroke incidence will increase with the increase of average life span of the population;
- In less than 20 years the medical system will be unable to supply sufficient medical personnel to attend stroke patients;
- Due to lack of economical sustainability and unavailable technologic solutions there are no devices specialized in the acute post stroke rehabilitation.

The robotic systems represent a viable solution which can allow physical therapists to develop patient-oriented rehabilitation programs that can maximize the therapeutic effects aiming towards an increased quality of life in the framework of Activities of Daily Living (ADL).

As demonstrated later on in the paper, the rehabilitation management differs for the different stages of stroke follow-up, the scientific and medical community accepting largely the time based classification proposed in [24]. Thus, the post-stroke stages are:

- **Acute phase**: covers the period of less than three months post-stroke;
- **Sub-acute phase**: covers the period between three and six months post-stroke;
- **Chronic phase**: covers the period of more than six months post-stroke, spreading up to two years, after which further patient progress is low and rehabilitation has only conservative role.

This paper emphasizes the work achieved until now in the development of rehabilitation robotics together with the benefits and limitations of these approaches, defining a strategy to correlate Human Robot Interaction (HRI) with the post-stroke stage and presents a set of biometric data that enables the proper definition of innovative robotic systems for upper limb rehabilitation in conjunction with the data presented prior to it.

2. INTERACTION MODALITIES IN ROBOT ASSISTED REHABILITATION

Robotic rehabilitation for the upper limb has its origin in the 1990s, with multiple devices becoming commercially available. The existing patient oriented studies have proven their efficiency in increasing upper limb motor scores and muscle strength, however very often these improvements had little to no effect upon the patient performance increase in ADL. Based on this general view, multiple reviews that covered a wide number of medical and technical papers (over 400 publications) have been analyzed to identify the weak spots in the current approaches. Based on this data, a classification of the interaction modalities in robot assisted rehabilitation is defined as result of the existing literature information [2,12,14, 19,20,26]:

- **Assistive**: the patient voluntary movement is required. The robot assists the patient by providing partial weight support or forces that lead to the task completion;
- **Active**: the robotic system acts only as a measurement device without providing any forces upon the limb;
- **Passive**: the robot performs the movement without any contribution from the patient;
- **Passive-mirrored**: a bimanual configura-tion where the unimpaired limb is guiding (through an active device) the exact/mirrored passive motion for the affected limb;
- **Active-assistive**: the task is completed by the robotic device only when the subject cannot achieve it completely. From this stage, the robot acts in a passive mode;
- **Corrective**: the subject motion is stopped when a certain error level is reached from the given task, afterwards the task is reissued and the robot works in an active mode;
- **Path-guidance**: the robot will assist the motion on a given trajectory by performing corrections when a deviation occurs;

- **Resistive**: the robot applies resistive forces against the given motion task.

Based on this classification it is clear that not all human-robot interactions can be applied for every patient and it is the physical therapist task to identify correctly the best possible treatment for a patient based on the motor evaluation scoring such as: the Fugl-Meyer score [6, 11, 32], Action Research Arm Test [22,32], Motor Activity Log [32] and others [17]. The existing HRI modalities emphasize the idea that a robotic device would not replace the human therapist, instead would allow him to individually assess patient progress, determine personalized rehabilitation regimes, and to use multiple motivational tools to encourage and support patient progress, to attend multiple subjects and many more.

3.1. Assessment of the current HRI modalities based on studies on post-stroke patients

An in-depth analysis of the current studies and reports reveal the following conclusions [1,2,7, 9,16,18,22,27, 30-32]:

- To the current day the existing data has shown that no physical therapy seem as preferable and the selection of the best rehabilitation plan depends on the physical therapist and the patient evolution;
- Most of the robotic devices that reached a maturity level of hospital testing provide a selection among the following four modalities for training: active, active-assisted, passive and resistive;
- Several studies illustrated that in some cases robotic structures have improved the motor scores and muscle strength but without positive influence on ADL;
- One possible reason for the limited transfer of motor gains to ADL is that the earlier studies on robot mediated therapy have only focused on the proximal joints of the arm, while integration of distal with proximal arm training has been recognized as essential to enhance functional gains.
- A second problem identified as progress limitation is the lack of physiological activities – some robotic systems perform only repetitive motions without any feedback from the patient, lacking a real HRI.

For acute patients the modalities with better outcome on body functions were **active** (2 out of 3 groups, 67%), **assistive** (4 out of 6 groups, 67%), **active-assistive** (5 out of 10 groups, 50%) and **passive** (6 of 13 groups, 46%). [2]

For subjects in acute phase, inclusion of **passive mirrored** and **resistive modality** *did not lead to improvements* in body functions (in none of the 4 and 3 groups, respectively). [2]

In chronic phase instead, the inclusion of **passive-mirrored modality** led to **improvement in 75% of the groups** (6 out of 8), while the inclusion **of resistive modality was effective on 71% of the groups** (12 of 17). [2, 23]

The **path guidance modality led to the best results for chronic patients** (6 out of 6 groups improved on body functions). Results for **other modalities** are similar among them, with all the other modalities being **effective on about 60% of the groups**. [2, 28]

Additionally, it is known that **post-stroke training** should include exercises that are as "**task-specific/functional**" as possible **to stimulate motor relearning**, which further supports inclusion of the hand and with proximal arm training. [2,9]

4. TECHNICAL SPECIFICATIONS CONCERNING THE MOTION AMPLITUDES FOR THE UPPER LIMB

This section presents a set of motions that cover the rehabilitation of the upper limb from the shoulder to the wrist. In order to enable the proper design of a robotic system that will enable the performing of these motions, a set of measurements were achieved on a number of 21 patients [21], compared to other literature results and corroborated with several standards that evaluate the weight and length of each body segment. This data enables the definition of the technical specifications of a new robotic system with proper motion scaling and link dimensioning and load capacity. Three widely accepted metrics were used for limb weight and length estimation:

1. The Plagenhoef model [25];
2. The R.L. Huston model [13];
3. The Contini model [8].

For the motions description the anatomic planes of the body are used, as defined by the medical community:

1. The Coronal (Frontal) plane: divides body into anterior and posterior portions;
2. The Sagittal plane: divides the body into left and right portions;
3. The Transverse (Cross-Sectional) plane: divides the body into superior and inferior portions.

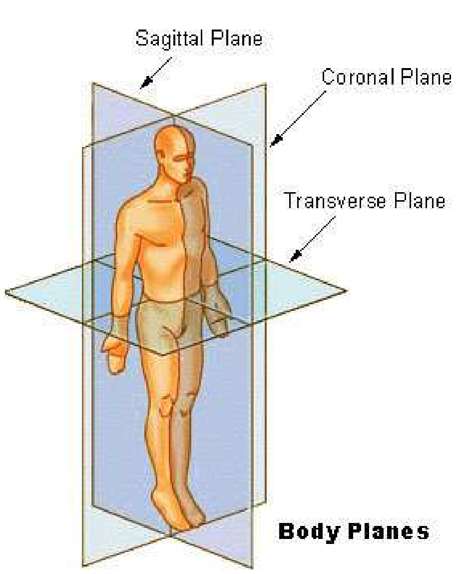

Fig. 1. The planes of the body [33]

With respect to the body planes, a corresponding Cartesian system is defined for the robotic system, as illustrated in figure 2.

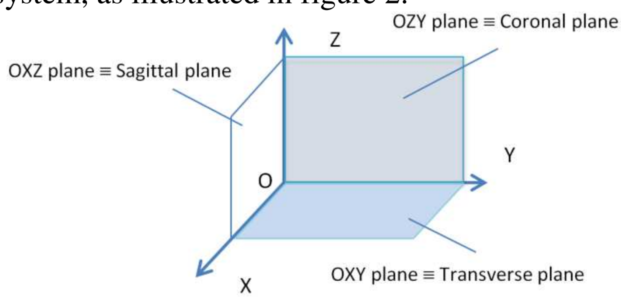

Fig. 2. Cartesian coordinate system correlated with the body planes

4.1. Shoulder Motions

At the level of the shoulder four motions are defined.

Shoulder flexion and extension (performed in a plane parallel with the sagittal plane of the body).

Starting position: patient in standing/sitting, the upper limb parallel with the body, palm faces the sagittal plane.

- **Shoulder flexion without rotation**: the upper limb, with the elbow extended is raised from the starting position towards the front of the patient without any rotation from the shoulder joint
- **Shoulder extension**: the upper limb is rotated backwards, until possible, keeping the elbow extended.

Shoulder abduction and adduction (performed in a plane parallel with the coronal – frontal plane):

Starting position: patient in standing/sitting, the upper limb parallel with the body, palm faces the coronal plane.

- **Shoulder Adduction**: from the starting position the upper limb is moved with a lateral motion and brought in front of the body
- **Shoulder Abduction**: from the starting position the upper limb is raised with a lateral motion until the maximum possible angle is reached in the shoulder, palm faces the floor.

The measurements performed on 21 patients involved in the study revealed the data presented in Table 1.

Table 1

Motion amplitudes in degrees [°] for the shoulder motions measured from the starting position

Motion type	Maximum Value		Mean Value		Minimum value	
	Left	Right	Left	Right	Left	Right
Shoulder flexion	**120**	**114**	**98.3**	**93.75**	**72**	**72**
Shoulder extension	**65**	**72**	**48.77**	**48.66**	**30**	**29**
Shoulder abduction	**114**	**102**	**90.9**	**89.15**	**68**	**74**
Shoulder adduction	**44**	**44**	**25.3**	**24.55**	**7**	**8**

4.2. Elbow Motions

At the level of the elbow three motions are defined, all performed in a plane parallel with the sagittal one.

Elbow flexion is performed alone, without the flexion as some people cannot (naturally) perform the elbow extension.

Starting position: patient in sitting/standing, the upper limb in extension, 90 degrees flexion in the shoulder, elbow fully extended, palm faces upwards.

- **Elbow flexion**: from the starting position the elbow is flexed to maximum, bringing the forearm over the arm.

Elbow supination/pronation.

Starting position: patient in sitting/ standing, the arm is parallel with the trunk, elbow is flexed to 90 degrees, and palm faces the sagittal plane:

- **Elbow supination**: the forearm and the hand is rotated, with the palm pointing upwards
- **Elbow pronation**: the forearm and the hand is rotated, with the palm pointing down.

The measurements performed in the study are summarized in Table 2.

Table 2

Motion amplitudes in degrees [°] for the elbow motions measured from the starting position

Motion type	Maximum Value		Mean Value		Minimum value	
	Left	Right	Left	Right	Left	Right
Elbow flexion	**150**	**152**	**131.1**	**137.7**	**56**	**122**
Elbow pronation	**92**	**104**	**77.75**	**81.1**	**54**	**40**
Elbow supination	**100**	**128**	**84.55**	**81.55**	**60**	**62**

4.3. Wrist Motions

For the wrist two motions are defined.

Starting position: patient in standing/sitting, the upper limb is flexed to 90 degrees in the shoulder joint, elbow and the wrist are fully extended, the arm being situated in a plane parallel with the transverse one.

1. **Wrist Flexion**: the patient flexes the wrist upwards;
2. **Wrist Extension**: the patient extends the wrist downwards.

The measurements performed in the study are summarized in Table 3.

Table 3

Motion amplitudes in degrees [°] for the wrist motions measured from the starting position

Motion type	Maximum Value		Mean Value		Minimum value	
	Left	Right	Left	Right	Left	Right
Wrist flexion	**98**	**90**	**60.7**	**58.9**	**22**	**27**
Wrist extension	**72**	**62**	**45.1**	**45.1**	**18**	**24**

5. ROBOT SPECIFICATIONS

Robot design has been widely addressed in literature, such as in [3-5], as in first design stage one has to set up design specifications (PDS) in terms of functions, performance, operation, manufacturing, environment, materials and control interfaces. The robot structure is defined based on the number of degrees of freedom required for each upper limb joint with the definition of the link lengths and associated limb weight based on the anthropometric body data.

5.1. Shoulder Motions

It is considered an OXYZ coordinate system placed with the origin in the rotating center of the shoulder (the tip of the humerus) where two degrees of freedom are required:

- one rotation around the OY axis for flexion/extension;
- one rotation around the OX axis for abduction adduction;

For the shoulder mobilization the robot can use the following two anchor points (AP) positioned on the upper limb:

- the main (actuated) anchor in the distal third of the arm;
- the support anchor in the area of the hand and the wrist.

When moving the arm from the shoulder the robot has to support the entire weight of the arm which has the following percentages of the total body weight, based on two different models, Plagenhoef [25] (table 4) and Houston [13] (table 5):

Table 4

Calculated weight for the upper limb; Plagenhoef model.

Plagenhoef (shoulder)		
	Males	Females
Total weight %	5.7%	4.97%
Examples calculated in kilograms [kg]		
70 kg	**3.99**	**3.48**
80 kg	**4.56**	**3.98**
90 kg	**5.13**	**4.47**
120 kg	**6.84**	**5.96**

Table 5

Calculated weight for the upper limb;Houston model.

RL Houston (shoulder)			
Males			
Distribution	5th%	50th%	95th%
Total weight	3.41%	4.14%	4.96%
Examples calculated in kilograms [kg]			
70 kg	**2.387**	**2.898**	**3.472**
80 kg	**2.728**	**3.312**	**3.968**
90 kg	**3.069**	**3.726**	**4.464**
120 kg	**4.092**	**4.968**	**5.952**
Females			
Distribution	5th%	50th%	95th%
Total weight	2.59%	3.15%	3.81%
Examples calculated in kilograms [kg]			
70 kg	**1.813**	**2.205**	**2.667**
80 kg	**2.072**	**2.52**	**3.048**
90 kg	**2.331**	**2.835**	**3.429**
120 kg	**3.108**	**3.78**	**4.572**

When fixing the anchor points, the limb length must be taken into consideration, with some average data being presented below, extracted from two different studies (Plagenhoef [25] in table 6 and Contini [8] in table 7) and completed also with the specific values for most common total body height.

Table 6

Calculate anchor points for the shoulder; Plagenhoef model.

Plagenhoef (shoulder)				
Male – calculated value for different heights				
Segment	TBH [%]	160 cm	170 cm	180 cm
Upper arm	17.2	**27.52**	**29.24**	**30.96**
Forearm	15.7	**25.12**	**26.69**	**28.26**
Hand	5.75	**9.2**	**9.775**	**10.35**
Active AP	11.47	**18.35**	**19.49**	**20.64**
Passive AP	36.72	**58.76**	**62.43**	**66.10**
Female – calculated value for different heights				
Segment	TBH [%]	150 cm	160 cm	170 cm
Upper arm	17.3	**25.95**	**27.68**	**29.41**
Forearm	16	**24**	**25.6**	**27.2**
Hand	5.75	**8.625**	**9.2**	**9.775**
Active AP	11.53	**17.30**	**18.45**	**19.61**
Passive AP	37.14	**55.72**	**59.43**	**63.15**

Table 7

Calculated anchor points for shoulder, Contini model.

Contini (shoulder)				
Male – calculated value for different heights				
Segment	TBH [%]	160 cm	170 cm	180 cm
Upper arm	18.9	**30.24**	**32.13**	**34.02**
Forearm	14.5	**23.2**	**24.65**	**26.1**
Hand	12.8	**20.48**	**21.76**	**23.04**
Active AP	12.60	**-20.16**	**-21.42**	**-22.68**
Passive AP	37.60	**-60.16**	**-63.92**	**-67.68**
Female – calculated value for different heights				
Segment	TBH [%]	150 cm	160 cm	170 cm
Upper arm	19.3	**28.95**	**30.88**	**32.81**
Forearm	15.2	**22.8**	**24.32**	**25.84**
Hand	11	**16.5**	**17.6**	**18.7**
Active AP	12.87	**-19.30**	**-20.59**	**-21.87**
Passive AP	38.79	**-58.18**	**-62.06**	**-65.94**

5.2. Elbow Motions

It is considered an OXYZ coordinate system placed with the origin in the rotating center of the elbow having the OZ axis along the upper arm (when the arm is positioned along the body the OZ axis will point upwards), defining the two degrees of freedom for the elbow motions:

- one rotation around the OY axis for the flexion/extension;
- one rotation around the OX axis, considering a 90° angle between the arm and the forearm, having the arm along the OZ axis and the forearm along the OX axis.

The anchor points for the forearm are:

- active anchor point in the distal third of the forearm;
- the passive anchor point, in the distal third of the arm.

When moving the forearm, the robot has to support the weight of the forearm and the hand which has the following percentages of the total body weight based on two models, Plagenhoef [25] (Table 8) and Houston [13] (Table 9).

Table 8

Calculated weight for the forearm and hand; Plagenhoef model.

Plagenhoef (forearm)		
	Males	Females
Total weight %	2.52%	2.07%
Examples calculated in kilograms [kg]		
70 kg	**1.76**	**1.45**
80 kg	**2.02**	**1.66**

90 kg	**2.27**	**1.86**
120 kg	**3.02**	**2.48**

Table 9

Calculated weight for the forearm and hand; Houston model.

RL Houston (forearm)			
Males			
Distribution	5th%	50th%	95th%
Total weight	1.57%	1.91%	2.29%
Examples calculated in kilograms [kg]			
70 kg	**1.099**	**1.337**	**1.603**
80 kg	**1.256**	**1.528**	**1.832**
90 kg	**1.413**	**1.719**	**2.061**
120 kg	**1.884**	**2.292**	**2.748**
Females			
Distribution	5th%	50th%	95th%
Total weight	1.18%	1.44%	1.74%
Examples calculated in kilograms [kg]			
70 kg	**0.826**	**1.008**	**1.218**
80 kg	**0.944**	**1.152**	**1.392**
90 kg	**1.062**	**1.296**	**1.566**
120 kg	**1.416**	**1.728**	**2.088**

When fixing the anchor points, the limb length must be taken into consideration, with some average data being presented below, extracted from two different studies (Plagenhoef [25] in Table 10 and Cortini [8] in Table 11) and completed also with the specific values for most common total body height.

Table 10

Calculated anchor points for forearm; Plagenhoef model.

Plagenhoef (forearm)				
Male – calculated value for different heights				
Segment	TBH [%]	160 cm	170 cm	180 cm
Upper arm	17.2	**27.52**	**29.24**	**30.96**
Forearm	15.7	**25.12**	**26.69**	**28.26**
Hand	5.75	**9.2**	**9.775**	**10.35**
Active AP	10.47	**16.75**	**17.79**	**18.84**
Passive AP	-5.73	**-9.17**	**-9.75**	**-10.32**
Female – calculated value for different heights				
Segment	TBH [%]	150 cm	160 cm	170 cm
Upper arm	17.3	**25.95**	**27.68**	**29.41**
Forearm	16	**24**	**25.6**	**27.2**
Hand	5.75	**8.625**	**9.2**	**9.775**
Active AP	10.67	**16.00**	**17.07**	**18.13**
Passive AP	-5.77	**-8.65**	**-9.23**	**-9.80**

Table 11

Calculated anchor points for forearm; Contini model.

Contini (forearm)				
Male – calculated value for different heights				
Segment	TBH [%]	160 cm	170 cm	180 cm
Upper arm	18.9	**30.24**	**32.13**	**34.02**
Forearm	14.5	**23.2**	**24.65**	**26.1**
Hand	12.8	**20.48**	**21.76**	**23.04**
Active AP	9.67	**15.47**	**16.43**	**17.40**
Passive AP	-6.30	**-10.08**	**-10.71**	**-11.34**
Female – calculated value for different heights				
Segment	TBH [%]	150 cm	160 cm	170 cm
Upper arm	19.3	**28.95**	**30.88**	**32.81**
Forearm	15.2	**22.8**	**24.32**	**25.84**
Hand	11	**16.5**	**17.6**	**18.7**
Active AP	10.13	**15.20**	**16.21**	**17.23**
Passive AP	-6.43	**-9.65**	**-10.29**	**-10.94**

The negative values of the Passive AP state that the anchor point is positioned behind the origin of the coordinate system, in opposite sense with respect to the Active AP.

5.3. Wrist Motions

It is considered an OXYZ coordinate system placed with the origin in the rotating center of the wrist with the OX axis pointing towards the fingers (when the forearm is positioned horizontally the OZ axis will point upwards), defining the one degree of freedom for the hand motions:

- one rotation around the OY axis for the wrist flexion/extension.

The anchor points for the wrist mobilization are:

- active anchor point: the palm and the dorsal side of the hand;
- passive anchor point: the distal third of the forearm.

When performing the wrist mobilization, the robot has to support the weight of the hand which has the following values with respect to the total body weight based on two different models, Plagenhoef [25] (Table 12) and Houston [13] (Table 13):

Table 12

Calculated weight for the hand; Plagenhoef model.

Plagenhoef (hand)		
	Males	Females
Total weight %	0.65%	0.5%
Examples calculated in kilograms [kg]		
70 kg	**0.46**	**0.35**
80 kg	**0.52**	**0.40**
90 kg	**0.59**	**0.45**

120 kg	**0.78**	**0.60**

Table 13

Calculated weight for the hand; Houston model.

RL Houston (hand)			
Males			
Distribution	5th%	50th%	95th%
Total weight	0.43%	0.52%	0.63%
Examples calculated in kilograms [kg]			
70 kg	**0.301**	**0.364**	**0.441**
80 kg	**0.344**	**0.416**	**0.504**
90 kg	**0.387**	**0.468**	**0.567**
120 kg	**0.516**	**0.624**	**0.756**
Females			
Distribution	5th%	50th%	95th%
Total weight	0.34%	0.42%	0.50%
Examples calculated in kilograms [kg]			
70 kg	**0.238**	**0.294**	**0.35**
80 kg	**0.272**	**0.336**	**0.4**
90 kg	**0.306**	**0.378**	**0.45**
120 kg	**0.408**	**0.504**	**0.6**

For the positioning of the anchor points, the limb length must be taken into consideration, with the average data being presented below, extracted from two different studies (Plagenhoef [25] in Table 14 and Contini [8] in Table 15) and completed also with the specific values for most common total body heights.

Table 14

Calculated anchor points for hand; Plagenhoef model.

Plagenhoef (hand)				
Male – calculated value for different heights				
Segment	TBH [%]	160 cm	170 cm	180 cm
Upper arm	15.7	**25.12**	**26.69**	**28.26**
Forearm	5.75	**9.2**	**9.775**	**10.35**
Hand	2.88	**4.60**	**4.89**	**5.18**
Active AP	-5.73	**-9.17**	**-9.75**	**-10.32**
Passive AP	15.7	**25.12**	**26.69**	**28.26**
Female – calculated value for different heights				
Segment	TBH [%]	150 cm	160 cm	170 cm
Upper arm	16	**24**	**25.6**	**27.2**
Forearm	5.75	**8.625**	**9.2**	**9.775**
Hand	2.88	**4.31**	**4.60**	**4.89**
Active AP	-5.77	**-8.65**	**-9.23**	**-9.80**
Passive AP	16	**24**	**25.6**	**27.2**

Table 15

Calculated anchor points for hand; Cortini model.

Cortini (hand)				
Male – calculated value for different heights				
Segment	TBH [%]	160 cm	170 cm	180 cm
Upper arm	14.5	**23.2**	**24.65**	**26.1**
Forearm	12.8	**20.48**	**21.76**	**23.04**
Hand	6.40	**10.24**	**10.88**	**11.52**
Active AP	-6.30	**-10.08**	**-10.71**	**-11.34**
Passive AP	14.5	**23.2**	**24.65**	**26.1**
Female – calculated value for different heights				
Segment	TBH [%]	150 cm	160 cm	170 cm
Upper arm	15.2	**22.8**	**24.32**	**25.84**
Forearm	11	**16.5**	**17.6**	**18.7**
Hand	5.50	**8.25**	**8.80**	**9.35**
Active AP	-6.43	**-9.65**	**-10.29**	**-10.94**
Passive AP	15.2	**22.8**	**24.32**	**25.84**

The negative values of the Passive AP state that the anchor point is positioned behind the origin of the coordinate system, in opposite sense with respect to the Active AP.
As it can be seen for the complete set of motions of the upper limb, a set of three anchor points are defined which are either active or passive depending on the motion performed:

- the distal third of the arm;
- the distal third of the forearm;
- the palm and the dorsal side of the hand.

The defined set of anchor points enables the development of a robotic device that can perform a wide variety of motions for multiple joints of the upper limb. Based on the data presented in section 2, this approach should an increased impact on the post-stroke patient rehabilitation with positive impact upon ADL.

6. MEDICAL PROTOCOLS FOR ROBOTIC ASSISTED REHABILITATION

Due to the different management of the patient in the post-stroke stages, two separate protocols are defined.

Medical protocol for robotic assisted rehabilitation in acute post-stroke patients

1. In order to start rehabilitation, in the acute phase, the patient must be conscious, hemodynamically stable, without fever and with CT/MRI confirmation of the brain lesion (to exclude other diseases).

2. The patient is initially assessed by a physical therapist (both mechanical and dynamical) and assigned an initial post-stroke score.
   a. One of the above mentioned scoring tests can be used are repeated in a periodic cycle following the stroke, as follows: Month 1, Month 3, Month 6, Month 12. As an alternative to classical scores an evaluation chart can be developed, to cover properly the entire limb evaluation.
3. The robot motion amplitudes are adjusted based on the initial data from point 2.
4. The patient is positioned sitting on the side of the bed or on a chair if possible. For more severely affected patients, the exercises will be performed with the patient lying in bed.
5. The robotic device is attached to the patient.
6. The rehabilitation procedure is initiated, based on the physical therapist's recommendations – programmed mode - predefined exercises (5 repetitions each), or in one of the following working modes:
   a. passive;
   b. EMG proportional driven;
   c. Direct nerve potential driven;
   d. ECoG (ElectroCorticoGram) driven.
   e. For exercises, the following motion sets are defined, in different sequences and in advanced rehabilitation stages in different combinations, attempting to replicate ADL similar motions, performed in a passive HRI:
      i. Shoulder – Flexion, Extension, Abduction, Adduction (optional Rotation);
      ii. Elbow – Flexion, Extension, Supination, Pronation;
      iii. Wrist – Flexion, Extension;
      iv. Fingers - Flexion, Extension. (3 joints for fingers 2-5 and 2 for finger 1).
7. The device is detached.
8. The physical-therapist evaluates the integrity of muscles and ligaments
9. The steps 2-8 are repeated for each rehabilitation session.

Medical protocol for robotic assisted rehabilitation in sub-acute and chronic post-stroke patients

1. In the sub-acute and chronic phases, the patient has a well-known hemiparesis level with clear indication and an assessment score.
2. The patient is evaluated by the physical therapist who establishes, based on the score the rehabilitation therapy, conditioned by the limb mobility and patient overall state.
3. The robot motion amplitudes are adjusted based on the initial data from point 2.
4. The patient is positioned in an orthostatic position, sitting on a chair, where possible. This allows focus on the upper limb rehabilitation, avoiding the balance and gait problems. For more severely stroke patients which cannot support this stance, an alternative position will be used, depending on the subject capability.
5. The robotic device is attached to the patient.
6. The rehabilitation procedure is initiated, based on the -therapist recommendations in one of the following working modes:
   a. predefined exercises (5 repetitions each)
   b. passive-mirrored motions;
   c. EMG proportional driven;
   d. Direct nerve potential;
   e. ECG (ElectroCorticoGram) driven;
   f. Path Guidance: The patient must follow a trajectory on a computer screen, with the robot acting as a partial guide when the patient cannot complete the motion or as a resistive guide in later recovery stages.

   For the predefined set of exercises, the HRI modalities use are Resistive, Active, Active-Assistive, for the following motions:
      i. Shoulder – Flexion, Extension, Abduction, Adduction (optional Rotation);
      ii. Elbow – Flexion, Extension, Supination, Pronation;
      iii. Wrist – Flexion, Extension;
      iv. Fingers - Flexion, Extension. (3 joints for fingers 2-5 and 2 for finger 1).
      Path Guidance
7. The patient performs multiple exercises based on the therapeutic program.
8. At the end of the procedure the device is detached.

9. The physical therapist evaluates the integrity of the muscles and ligaments of the patient, if necessary.
10. The steps 2-8 are repeated for each rehabilitation session.
11. Based on the patient progress recorded by the robotic system the exercises are adjusted for the next session.

The evaluation of a new robot performance must be correlated to the potential patient progress following the robotic assisted therapy and it can be achieved in two ways:

1. Use a single group of patients, evaluate them before and after the therapy using a standard scoring procedure (such as Fugl-Meyer score, Action Reasearch Arm Test, Motor Activity Log) and compare the results with the literature;
2. Split the group in two, using normal therapy on the control group and robotic assisted exercises on the other comparing the FM scores before and after therapy. (This option would be preferred being conditioned only by a sufficient number of patients which would generate statistically relevant data).

7. CONCLUSIONS

Robotic assisted rehabilitation is a critical field of research which will become increasingly integrated as a common therapeutic practice in the next decade due to the natural age shifting of the population, where the role of the physical therapist will shift from the performing of the exercises with each patient to the development, programming and setup of personalized treatment plans for the post-stroke patients.

Due to the very large number of devices developed in research centers all over the world some standardization must be achieved in terms of HRI strategies, patient progress monitoring and scoring. The anthropometric characteristics of the human body critical for the efficient development of new robotic solutions for the upper limb rehabilitation have been calculated based on two different models to ensure proper data generalization.

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Modalităţi de interacţiune om-maşină în reabilitarea membrului superior în urma unui atac vascular cerebral

Abstract: Lucrarea prezintă o analiză a celor mai noi strategii în interacţiunea om-maşină care sunt implementate în sistemele robotizate de reabilitate a membrului superior. Datele existente pun în evidenţă potenţialele beneficii ale diferitelor metode de lucru în corelare cu stadiul pacientului post-AVC. Pornind de la o serie de modele antropometrice umane din literatură şi de la datele experimentale colectate de la un grup de pacienţi au fost determinate tipurile de mişcări şi amplitudinea acestora, lungimile şi greutăţile segmentelor braţului uman. Pe baza acestora se definesc protocoale de reabilitare a pacienţilor post-AVC corelate cu cele mai noi studii şi teste din literatură. Datele experimentale şi cele calculate reprezintă un element critic în dezvoltarea preliminară a unor noi structuri conceptuale pentru sisteme robotice de reabilitare care să ofere o recuperare medicală eficientă a pacienţilor care au suferit AVC-uri.

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