Interdisciplinary Stroke Rehabilitation Delivered by a Humanoid Robot:
Simultaneous vs. Alternating Therapy Schedules

Rehabilitation technology has the great potential to enhance intensity and accessibility of therapy services for stroke patients who are challenged by aphasia and hemiparesis. Despite the frequent co-occurrences of speech and physical impairments among stroke survivors, no previous research has utilized technology to address their multiple disabilities. The current study is implementing a humanoid robot (i.e., a robot that resembles the shape of a human body) in interdisciplinary stroke rehabilitation where the robot delivers both speech and physical therapy activities.

Interdisciplinary research in stroke rehabilitation is rare. The few previous studies on interdisciplinary stroke rehabilitations have reported positive outcomes (Lincoln et al., 2004). Despite the positive reports on "working together" with other disciplines, it is largely unknown how the intervention in one discipline affects the progress in other areas. More specifically, it is unclear how various therapies should be scheduled to maximize the recovery of stroke patients who are challenged by persisting aphasia and hemiparesis. For example, speech and physical therapies can be provided either simultaneously (e.g., patients receive speech AND physical therapies for 4 weeks) or in an alternating fashion (e.g., patients receive speech therapy for 4 weeks AND THEN receive physical therapy for 4 weeks). The current study is comparing the effects of the two schedules of interdisciplinary stroke rehabilitation. The intervention is implemented through the use of a humanoid robot.

In comparing the two therapy schedules, greater outcomes are predicted from the simultaneous schedule than from the alternating schedule. This prediction is supported by recent research findings on a common cortical area for speech and limb movements (Rizzolatti & Craighero, 2004). Broca's area, previously known as the motor speech area, is now considered to play a role in understanding and planning hand gestures (Binkofski & Buccino, 2004). This close link between speech and limb motor control was also observed at the behavioral level (Gentilucci et al., 2001). Given the tight connection between speech and hand movements at the cortical and behavioral levels, it is likely that effective intervention in one domain has a positive impact on the other.

This paper presents preliminary data from an on-going study that compares simultaneous and alternating schedules of interdisciplinary stroke rehabilitation delivered by a humanoid robot.

Methods

Participants

A 72-year-old male (RB) with chronic aphasia and hemiparesis is participating in the study. Table 1 summarizes his demographic profiles. RB suffered from a stroke 9 years ago. He received a doctoral degree and formerly worked as a school superintendent. He speaks in short phrases and sentences, and writes single words and numbers. RB has right hemiparesis, and ambulates with a cane.

During the pre-treatment phase, RB's speech-language functions were assessed by administering the *Western Aphasia Battery – Revised* (Kertesz, 2007), the *Cognitive Linguistic Quick Test (CLQT)* (Helm-Estabrooks, 2001), and the *Apraxia Battery for Adults – Second Edition* (Dabul, 2000). Table 2 provides an overview of the test results. RB presented with moderate transcortical aphasia, mild verbal apraxia, and mild cognitive-linguistic deficits. RB's upper-extremity functions were assessed by the *Fugl-Meyer Assessment* (Deakin et al., 2003;

Fugl-Meyer et al., 1975) and the *Wolf Motor Function Test* (Wolf et al., 1989 & 2010). RB received 31 out of 66 potential points on the *Fugl-Meyer Assessment* and completed three out of fifteen tasks of the *Wolf Motor Function Test*.

Stimuli

Speech and physical therapy activities are presented through uBot-5, a humanoid robot developed at the Laboratory for Perceptual Robotics at the University of Massachusetts Amherst. As depicted in Figure 1 (a), the uBot-5 is a bi-manual mobile manipulator that is about 1.5 feet tall and weighs about 35 pounds. Each arm has 4 degrees of freedom. The robot can move and dynamically balance on two wheels.

The speech practice program is visually presented on the uBot-5's monitor screen. Sound output is played through speakers placed at the level of the robot's waist. The primary task for the robot-mediated speech practice is confrontation naming. To make the task functionally relevant, word stimuli were selected by RB and his wife. RB's ability to name target pictures prior to the treatment phase was probed at the baseline assessment. Each verbal response was scored using a modification of the *Porch Index of Communicative Ability* scoring system (Porch, 1981). Table 3 summarizes the 16-point scoring system. Additionally, to control the motivation and motor demands of the selected words, an importance rating of the target words and the articulatory demand on consonant production were obtained. Based on the initial assessments, sixty target items were divided into three experimental conditions: simultaneous (speech & physical), alternating (speech-only), and no practice (control). Forty words in the two practice conditions were programmed for computerized practice by using Microsoft PowerPoint software. Each target word is presented on six consecutive slides with an increasing level of support. Appendix A presents examples of practice slides.

The focus of the robot-mediated physical therapy is on the dominant right arm and hand functions. RB engages in three therapy exercises: Task 1 – holding his hands together and stretching his arms to reach for the robot's hand presented at various points on the vertical plane, as demonstrated in Figure 1 (b); Task 2 – flexing and extending the elbow joint to touch the robot's hand presented at various points on the horizontal plane; and Task 3 – rotating the forearm to touch the robot's hand presented slightly above RB's hand and at various points on the horizontal plane. Each task is presented in blocks of three to ten minutes. The total number of blocks and the duration of each block are adjusted to the level where RB finds the tasks challenging but attainable with effort. Throughout the practice session, the robot plays video files of the physical therapist providing various instructions (e.g., "Clasp your hands together and reach out to touch my hand." and "Nice work! It's time to take a break.")

Procedure

The robot-mediated speech therapy is following a multiple baseline design with two treatment periods: alternating (Speech Only) and simultaneous (Speech & Physical). RB's ability to name sixty target words is assessed before and after each treatment period. Figure 2 visually summarizes the 16-week study plan. RB has completed four weeks of Speech Therapy Only period. He is currently attending physical therapy sessions.

Results

Figure 3 depicts RB's progress from Baseline Assessment 1 to Post-treatment Assessment 1 in the three practice conditions. A statistical analysis was conducted using Wilcoxon signed-ranks tests. When the data from the three practice conditions were separately analyzed, significant improvements were found only in the Speech Therapy Only condition.

When all sixty words were analyzed as a whole, the overall improvements reached a statistical significance. Table 4 summarizes the results of the Wilcoxon signed-ranks tests.

Discussion

RB practiced naming functionally relevant items presented by a humanoid robot. Four weeks of the robot-mediated practice yielded significant improvements mainly on trained items. This preliminary result suggests the feasibility of a humanoid robot as a treatment tool for individuals who are experiencing stroke-induced aphasia. The planned analysis on the expected data from Baseline Assessment 2 and Post-treatment Assessment 2 will answer the main research question: should speech and physical therapies be provided simultaneously or in an alternating fashion?

References

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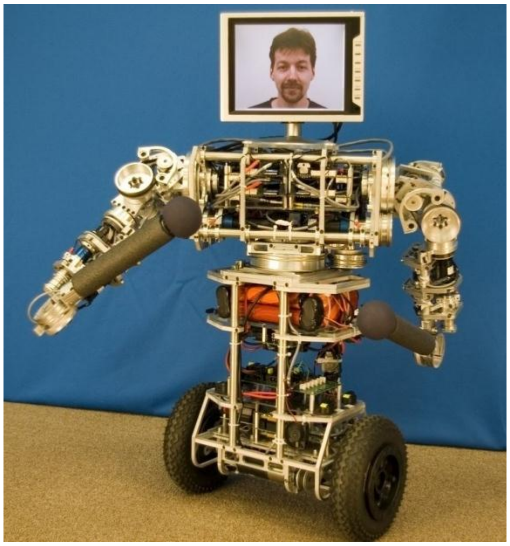
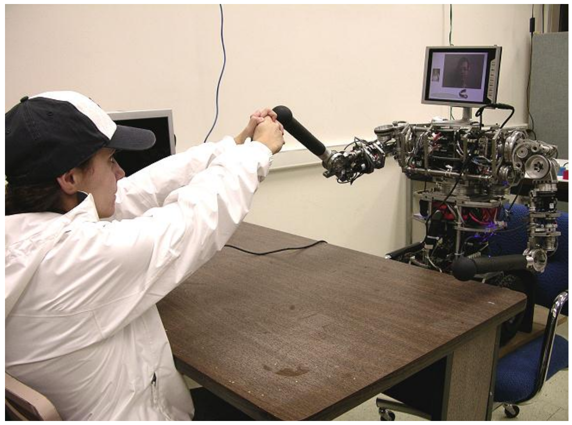


(a) Full view of uBot-5



(b) Research assistant demonstrating Task 1

Figure 1. uBot-5

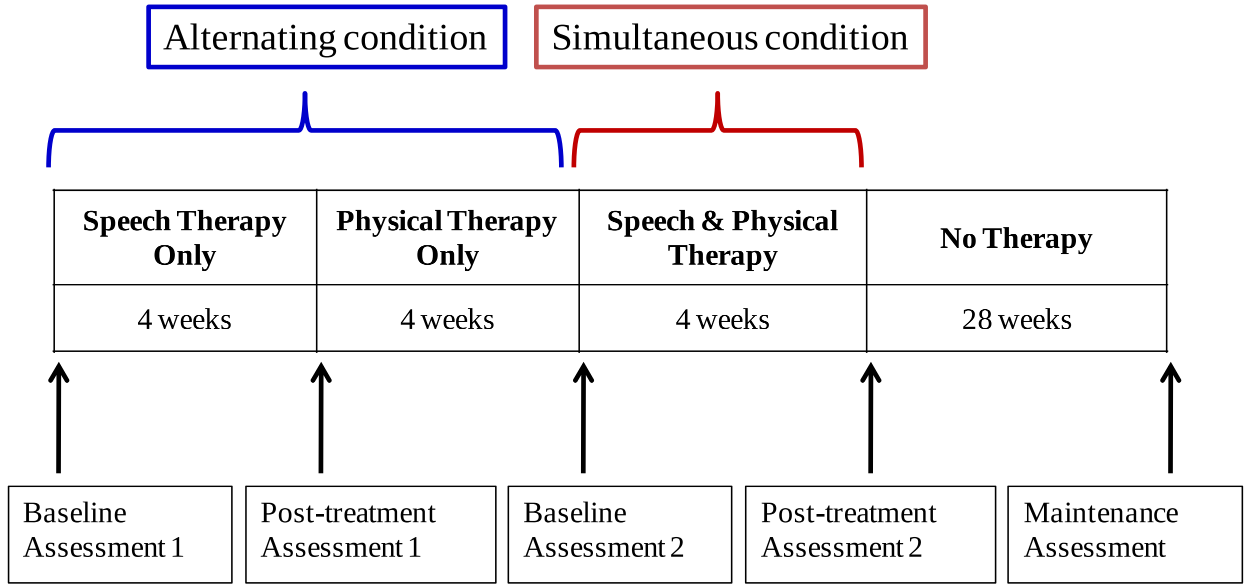


Figure 2. Study Plan

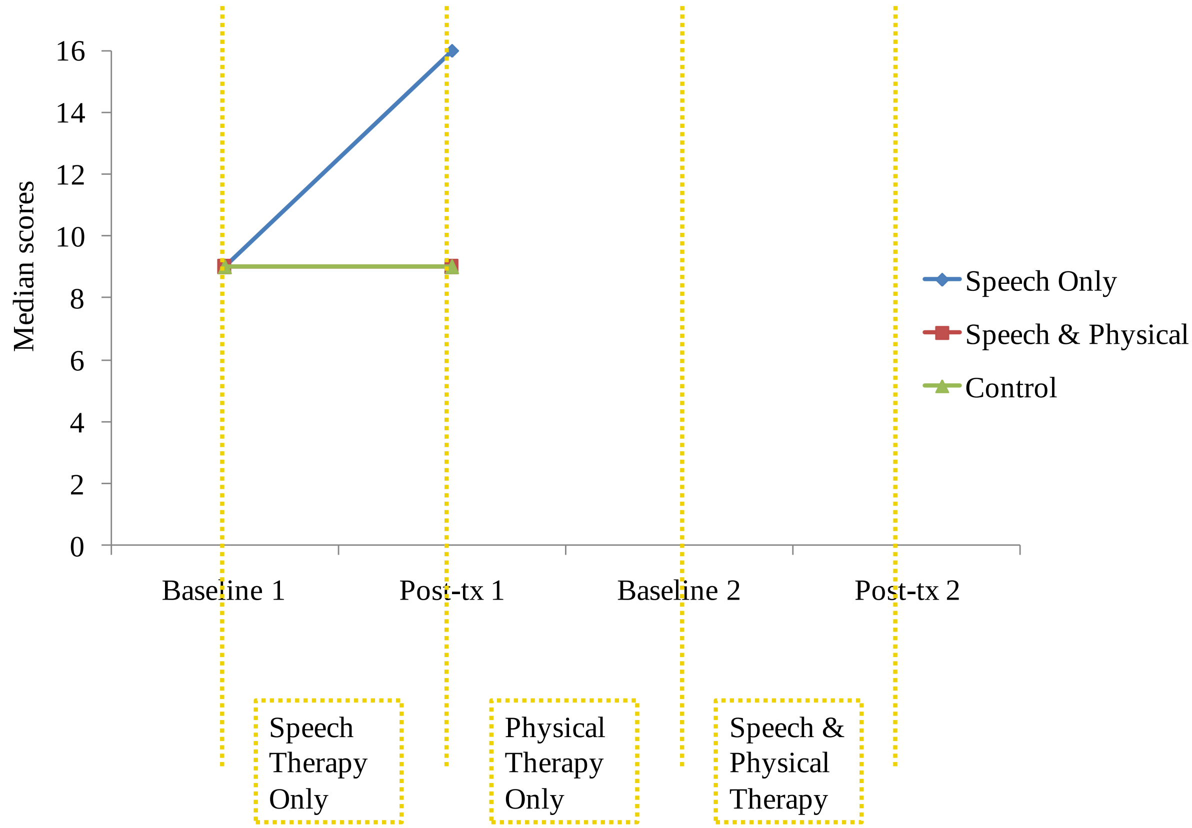


Figure 3. Median Scores of Words Assigned to each of the Three Practice Conditions

Table 1
Demographic Characteristics of the Study Participant

Etiology	Gender	Age	Time Postonset (yrs; mos)	Years of Education	Former Occupation
L CVA	M	72	9;3	21	School superintendent

Table 2
Overview of the Standardized Test Results

Western Aphasia Battery – Revised		*Apraxia Battery for Adults – Second Edition*		*Cognitive Linguistic Quick Test*
Aphasia Quotient	Aphasia Type	Verbal apraxia	Limb/Oral apraxia	Composite Severity Rating
73.7	Transcortical Motor	None – Mild	None	Mild

Table 3

Hierarchical Scoring System for Naming Responses

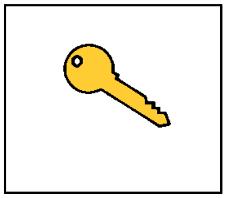
Score	Response Type	Category	Description
16	Complete	Spontaneous	Correctly says the target word without any cue within three seconds.
15	Delayed	Spontaneous	Correctly says the target word without any support but after more than three seconds' delay.
14	Phonemic Error	Spontaneous	Incorrect phonemes are pronounced but spontaneously corrected (e.g., "tat……cat" for a target 'cat').
13	Delayed Phonemic Error	Spontaneous	After more than three seconds' delay, incorrect phonemes are pronounced but spontaneously corrected.
12	Self-Corrected	Spontaneous	Responds with a wrong word and then self-corrects (e.g., "dog….cat" for a target 'cat').
11	Semantic Cue	Cueing	Correctly says the target word after a phrase or sentence providing a semantic cue (e.g., "it meows" for the target 'cat').
10	Word Shape Cue	Cueing	Correctly says the target word when an initial letter and total number of letters are given in a written form (e.g., 'c_ _' for a target 'cat').
9	Whole Word Written Cue	Cueing	Correctly says the target word when the whole word is presented in a written form.
8	Initial Sound Cue	Cueing	Requires initial sound cue (e.g., the /k/-sound for a target 'cat') before correctly producing the target word. The cue can be repeated once on request.
7	Lip Shape Cue	Cueing	Requires seeing a clinician silently mouth the word before correctly producing the target word. The cue can be repeated once on request.
6	Whole Word Spoken Cue	Modeling	Correctly says the target word after it has been spoken by the clinician. Modeling may be repeated once by request.
5	Repeated Presentation	Modeling	Correctly says the target word after watching the clinician repeat the word five times.
4	Simultaneous Production	Modeling	Correctly produces the target word during five times of in unison repetitions with the clinician.
3	Tactile Cue	Tactile	Correctly produces a target word with touch cues in conjunction with in unison repetitions from the clinician.
2	Incomplete	Not Produced	Produces an approximation but cannot completely produce the word.
1	Incorrect	Not Produced	Produces none of the phonemes in a target words.
0	No Response	Not Produced	Produces no response or unrelated response (e.g., stereotypic utterance).

Table 4

Results of Wilcoxon Signed Tests Comparing Baseline Assessment 1 to Post-treatment Assessment 1 in each of the three treatment conditions and all sixty words as a whole

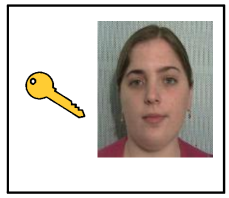
Speech-only	Speech & Physical	Control	Overall
3.312 $p = .001$*	0.677 $p = .498$	1.289 $p = .197$	3.580 $p < .001$*

APPENDIX A
EXAMPLE OF SLIDES OF SPEECH PRACTICE PROGRAM



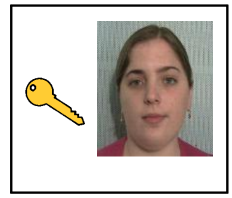
Auditory cue: What is this?

[Slide 1]



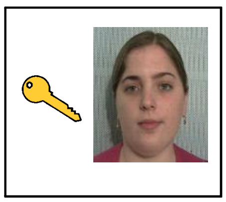
Auditory cue: You open a lock with this. What is this?

[Slide 2]



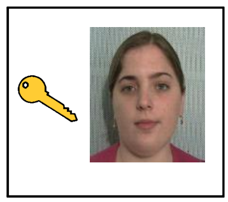
Auditory cue: It starts with /k /. What is this?

[Slide 3]



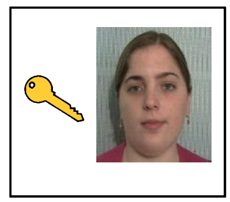
Auditory cue: It's Key. Say Key.

[Slide 4]



Auditory cue: Listen to me say it. Key (x5). What is this?

[Slide 5]



Auditory cue: Now say it with me. Key(x5). What is this?

[Slide 6]