Robotic assessment to quantify HIV-related episodic disability in stroke

Kevin D. Bui[1,2], Michelle J. Johnson[1-3]

[1]*Department of Bioengineering, University of Pennsylvania,* [2]*Rehabilitation Robotics Lab (GRASP), University of Pennsylvania,* [3]*Department of Physical Medicine and Rehabilitation, Perelman School of Medicine, University of Pennsylvania*

BACKGROUND

Despite the successes of antiretroviral therapy (ART) in extending the lifespan of the HIV population, other HIV-associated comorbidities now pose an increased risk to the aging HIV population, such as HIV-associated neurocognitive disorders (HAND) and HIV-associated stroke (HAS). This is a global problem as stroke and HIV are leading causes of death and disability around the world [1,2]. The prevalence of mild forms of HAND remains high, while HIV has simultaneously been shown to be an independent risk factor for stroke [3-6]. Additionally, the HIV population is aging, with over 50 percent of the population projected to be over 50 years of age by 2020 [7]. The presence of HIV or HAND can fundamentally alter the characteristics of stroke and the subsequent recovery process in currently unknown ways. To date, there have been no studies that examine the combined effects of HIV and stroke on physical or cognitive domains from a neurorehabilitation perspective. This is an important issue to address because stroke rates continue to rise in low and middle income countries (LMICs), where HIV is more prevalent [4]. A current barrier to progress in this area is the lack of understanding of the episodic nature of HIV on various components of disability [8]. Episodic disability is defined as periods of good health interrupted by potentially debilitating periods of disability, which can lead to fluctuations in performance on multiple timescales over the course of living with HIV, impacting activities of daily living or the ability to hold a job [9]. This is a critical barrier to address in order to design effective neurorehabilitation strategies for the HIV/stroke population dealing with the unique combination of physical, cognitive, and social restrictions that may result from the two diseases. This gap between need and solution persists because of the lack of quantitative tools that are able to assess physical and cognitive functions across the HIV and stroke spectrum and the lack of neurorehabilitation successes in the HIV population — for which there is a huge need — compared to the stroke population. Based on the needs and complexities of the HIV/stroke population, a multidisciplinary approach is needed to address the gaps in knowledge.

PROPOSED SOLUTION

Robot-based neurorehabilitation strategies originally targeted to the stroke population provide a potential avenue to studying the HIV/stroke population in a quantitative way that can lead to new treatment strategies. Rehabilitation robotics has been shown to be as effective as high-intensity physical therapy by providing consistent treatment over long periods of time [10]. These technologies can reduce the load on rehabilitation professionals, collect vast amounts of data, and maximize access to treatment. More importantly, the quantitative information these strategies can provide are a potential way to explore the complex range of impairments across the HIV-stroke spectrum. In a case study we conducted with one 38 year old male chronic HIV/stroke patient who underwent 12 sessions of robot-based rehabilitation over the course of four weeks, we observed a five point (40 to 45) increase in the Upper Extremity Fugl-Meyer score compared to the start of rehabilitation and an increase in grip strength in the impaired hand.

However, the majority of the robot-based rehabilitation strategies to date have focused mainly on recovery of motor function and apply more explicit learning strategies for recovery without taking into consideration potential cognitive deficits. Research has shown that there is an association between cognition — particularly executive function and memory — and motor recovery, thus necessitating a focus on the cognitive aspects as well during rehabilitation [11]. Non-robot based strategies combining cognitive strategy and task-specific training demonstrated transfer of improvements to untrained activities and better performance compared to regular occupational therapy in stroke patients [12]. Transfer of improvements to activities of daily living has also been a challenge in rehabilitation robotics. A better understanding of the cognitive aspects of impairment and how they affect motor recovery is important for designing rehabilitation strategies for the HIV/stroke population and beyond going forward. While neuropsychological and screening tests often separate the assessment of motor and cognitive domains, robot-based strategies are an opportunity to provide assessment and rehabilitation of tasks that engage motor and cognitive domains both separately and together. We previously explored the utility of the less impaired arm as a measure of cognitive impairment, but found that a motor-based task did not provide enough information about the cognitive side [13].

Our proposed approach to developing treatment strategies applicable across the HIV-stroke spectrum is to develop methods to measure the effects of episodic disability on various functional domains. A first step to doing this is to develop a set of robot-based metrics capable of measuring both physical and cognitive impairment in a way that can span the entire spectrum of impairments seen across HIV, stroke, and when the two are present together. These metrics can then be used to assess longitudinal performance over the course of an extended amount of time. Once a better understanding of HIV-related episodic disability is achieved, rehabilitation strategies can be developed for the HIV population, and its effects on stroke recovery can be better elucidated.

METHODS

Haptic TheraDrive

The Haptic TheraDrive (Fig 1; left) is a one degree-of-freedom robot originally designed by our lab for upper limb stroke rehabilitation [14]. It includes an adaptive controller for user-specific therapy and haptic feedback to supply assistive or resistive forces. The user operates TheraDrive by manipulating a vertically mounted crank handle equipped with force sensors and an optical encoder. For assessment purposes, it is run in zero-impedance mode. In this mode, the forces applied by the user's arm onto the end-effector – as measured by Takkstrip force sensors (Takktile LLC, Cambridge, MA) in the handle – are used to calculate the necessary response by the motor in order to give the sensation that there is no resistance when the user pushes or pulls on the handle. This is implemented using a force-dependent proportional-integral-derivative (PID) impedance controller.

Motor Assessment Task

Each subject performs a set of trajectory tracking tasks on the Haptic TheraDrive (Fig. 1; right). A single task consists of the user moving the crank arm forward and backward to move a triangular cursor left and right on the screen, respectively, to follow a pre-programmed, pseudo-random sinusoidal path for 15 seconds. The cursor can only move in a single dimension while the sinusoidal trajectory continuously scrolls down the screen. For visual feedback, there is a box that demonstrates an acceptable region to be within while following the trajectory. When the cursor is in this box, the cursor is green. Once outside of the box, the cursor becomes red. This task is repeated on the dominant/unimpaired and non-dominant/impaired side for all subjects.

Performance on each tracking task is quantitatively assessed by calculating the root mean square error (RMSE) of angular position from the sinusoidal trajectory in degrees. RMSE has been previously shown to have a direct correlation to clinical measures of motor ability [15]. The RMSE for each trial is normalized by the RMSE resulting from the condition where no handle movement occurred during the task. The RMSE values are then used to calculate two different measures – a mean performance error score and the motor learning rate. For the first measure, the normalized RMSEs are averaged. Motor learning is assessed by fitting an exponential curve to the normalized RMSE values over all the trials. Kinematic measures can also be calculated, such as mean or peak

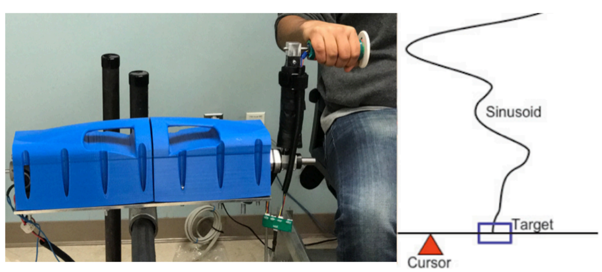

Figure 1. Haptic TheraDrive and tasks. Left: The Haptic TheraDrive robot used for assessment. **Right:** The trajectory tracking task for motor assessment.

velocity, acceleration, jerk, smoothness, and total path length.

Cognitive Task

The N-back test is commonly used in the cognitive neuroscience field as a test of working memory and working memory capacity. In our version, the subject is presented with a sequence of ten stimuli, which consist of the numerical digits 1-4 displayed at an interval of 3 seconds between each stimulus (Fig 2). For the 0-back condition, the subject indicates when the current stimulus shown on the screen is the number '2.' For the 1-back and 2-back conditions, the subject indicates when the current stimulus matches the stimulus shown one stimulus or two stimuli earlier, respectively. The subject indicates a match by pushing a button attached to the handle on the

TheraDrive. Each subject performs 12 total trials, cycling through the 0-back, 1-back, and 2-back conditions four times. It is then repeated using the other hand operating the TheraDrive to assess for differences in performance. The displayed sequences were pseudo-randomly generated beforehand and each subject is shown the same set of sequences. If the subject correctly indicates a match, they will receive visual feedback in the form of the number flashing green. If they are incorrect, the number will flash red. The metrics that are recorded include the number of correct responses, the number of incorrect responses, the longest streak of correct responses, and reaction time.

	Pre-sequence		Sequence of ten stimuli									
0-back example			4	**2**	1	**2**	**2**	1	3	**2**	4	4
1-back example		1	4	**4**	2	3	1	**1**	4	1	**1**	**1**
2-back example	3	2	**3**	**2**	1	3	**1**	**3**	4	1	**4**	4

Figure 2. N-back sample sequences. Example sequences for the 0-back, 1-back, and 2-back conditions. The highlighted boxes indicates when the user should press the button.

Cognitive-Motor Task

The spatial span test is a test of visuospatial working memory. In our version, there is an added motor component that is more involved than the N-back test. A 3x3 grid of tiles is displayed to the user on a screen, and a random sequence of tiles is displayed that the user must repeat by operating the TheraDrive (Fig 3). Each tile is mapped to an angular range of motion over a span of 180 degrees on the TheraDrive in order to allow the user to traverse the entire grid. The tile that corresponds to the user's angular position is highlighted in blue, and leaving a tile highlighted for one second indicates the selection of a tile. If the user successfully repeats the sequence by selecting the correct tiles in order, the next displayed sequence increases in length to make the task more difficult. If the user is unsuccessful, the sequence decreases in length. 16 trials are conducted, with the first trial used as training. The extracted metrics include sequence length, the total number of correct selections, the total number of incorrect selections, longest correct sequence, and shortest correct sequence. Kinematic data such as actual distance traveled, mean velocity, peak velocity, and smoothness are extracted for each sub-movement from one tile to another and grouped by tile distance in order to allow for comparisons between patient groups. Together, these metrics are meant to encompass aspects of both cognitive and motor impairment.

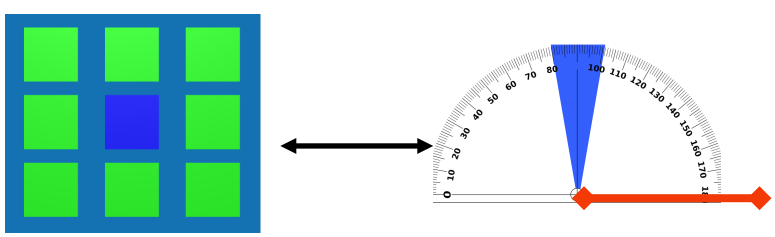

Figure 3. Spatial Span Task. This task is designed to assess both motor and cognitive function. The red line represents the TheraDrive handle at the start position at the beginning of the task, and the blue triangular region represents the angular range for the corresponding highlighted tile on the 3x3 grid.

FUTURE DIRECTIONS

We plan on using these tasks to gather data from healthy, HIV, stroke, and HIV-stroke populations. These will identify the most useful metrics that can be used across the different populations. In order to quantify the effects of episodic disability due to HIV, we will collect longitudinal data and examine how episodic disability affects certain domains. Another goal will be to implement this system in resource-limited environments, such as

Botswana, Costa Rica, and Jamaica, where we already have established connections with local partners. This system sets up future research that will expand the fields of rehabilitation robotics, HIV-related disability, and global health.

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