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Assessing Impaired Arm Use and Learned Bias after Stroke Using Unimanual and Bimanual Steering Tasks

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Abstract— **Learned nonuse is often seen in stroke survivors with hemiparesis. In these cases, stroke survivors exhibit a bias for using the less impaired arm on daily living tasks despite latent functionality as measured by clinical motor function. We used the TheraDrive system, a low-cost, stroke rehabilitation system using commercial force-feedback steering wheels along with unimanual and bimanual steering tasks, to quantify the motor impairment, arm use bias and the effect of functioning levels on tracking performance. We present the methodology and tracking results that support the use of steering tasks to detect the presence of motor impairment in the contralateral side of the brain injury, the presence of learned nonuse, the relationship between level of functionality (low-to-medium versus high stroke) and these measures and the effect of handedness and side of injury after stroke.**

I. INTRODUCTION

Stroke is a leading cause of disability among adults in the United States [1]. Hemiparesis involves a certain degree of paralysis in the contralateral side of the brain injury. The side ipsilateral to the brain injury also gets affected but the severity of impairment is more on the contralateral side. The paralysis results in decreased ability to perform smooth coordinated bimanual movements and disrupts the ability to perform many daily living tasks such as eating with a knife and fork [2]. To adapt, many stroke survivors develop a maladaptive functional pattern for daily tasks that is characterized by decreased use of their impaired arm and an increased bias for using their less-affected arm. The behavior of not using their impaired side even in the presence of latent functional capacity is termed learned nonuse [3]. Learned nonuse is the "gap" between impairment and functional ability or real arm use. As a result, it could be a measure for the effectiveness of robot-assisted therapy. Our goal is to develop new strategies to help further understand how learned nonuse and other compensatory behaviors that reduce the reliance and awareness of the impaired arm [4]. To overcome these impairments and behaviors, objective quantification and detection becomes very important. Uswatte and colleagues have used accelerometers to quantify real arm use on daily living tasks. They examined data before and after intense stroke rehabilitation therapy called constraint-induced movement therapy, which is focused on non-use of the less-affected arm through binding and practice of daily activities [5]. The relative difference between accelerometer levels indicates a change in impaired arm-use activity due to the intervention. Despite these efforts, there is a need for more precise methods of assessing learned nonuse and spontaneous arm use.

Force and position-based metrics derived from steering tasks have been used to quantify impairment after stroke. Jones and colleagues have used a steering wheel environment to measure strength, movement time, reaction time, speed of movement and to quantify predictive motor planning in Parkinson's disease. The experiment involved three types of tracking tasks. Preview pseudorandom sine tracking was one of the many used [6]. Nair and colleagues used commercially available force feedback steering wheels for the assessment and training protocols. Subjects were asked to track a maze of paths of different difficulty levels and frequencies. A measure of error was used to differentiate between the desired and actual tracking at each time was compared [7]. Johnson and colleagues [6] used Driver's SEAT, a custom steering environment with a split-steering wheel to measure torques exerted by the dominant and non dominant arm of subjects during bimanual and unimanual steering. They compared % effort for non dominant arm in the unimanual and bimanual tasks. Differences in these torques indicated the presence of learned nonuse. Feedback distortion can also be used as quantification method to quantify learned nonuse after stroke. Brewer and colleague have developed a virtual environment that distorted the perception of the visual feedback and quantified learned nonuse [8]. Subjects were encouraged by the distortion to apply effort beyond their initial capacity.

We report on a study that examined the use of the impaired arm and the less-affected arm during unimanual and bimanual steering tasks, which builds on the concept described in [6]. We used the TheraDrive system which is a low-cost, stroke rehabilitation system that uses robotic principles, commercial force-feedback steering wheels along with unimanual and bimanual steering tasks to quantify the motor impairment, arm use bias and the effect of functional ability on tracking performance [9]. The root mean square

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(RMS) error metric was derived from tracking performances and compared within and across stroke groups on two functional levels. We hypothesized that RMS errors will be higher for impaired arm (ND) tracking tasks than for both less-affected (D) and bimanual (BI) tracking tasks and this will be more pronounced in low functioning subjects. If a bias exists and the impaired arm is also not used during bimanual steering, the errors for the D steering will be no different from the BI steering and ND errors will be greater than both.

II. METHODOLOGY

A. Experimental Setup

The TheraDrive system as shown in fig. 1 was used as the experimental apparatus for the study. The system consisted of a Logitech force-feedback wheel mounted on a height-adjustable metal frame. The wheel is connected to the software platform [10], which records the angular movement of the wheel as subjects' complete tracking tasks displayed on the screen. Subjects were seated at a comfortable distance from the wheel. The wheel was tilted through 20 degrees from the vertical to create the real driving environment. The maximum angle through which the wheel can rotate is 270 degrees. To standardize the group, subjects held on to a Vertical-gripper to complete the unimanual as well as bimanual steering task.

B. Subjects

Chronic stroke survivors with hemiparesis who are at least six months post-stroke and have stable, low-to-medium impairment and functional levels were recruited for the study. Seven stroke survivors gave informed consent and participated in this study (Table 1). The study was approved by the Institutional Review Board (IRB) of the Clement J. Zablocki VA medical center Milwaukee (WI). Motor impairment levels were measured in the impaired arm using the upper extremity Fugl-Meyer (UE-FM) scale, a reliable measure of motor function (scores: 0-66), and functional disability levels were measured by the functional hand evaluation (UE-FT). Subjects were classified as high functioning if (UE-FM>57 and UE-FT>level 5) and if (UE-FM≤57and UE-FT≤ level 5) they were classified as low-to-medium functioning. Out of seven subjects, three were low-to-medium functioning and four were high functioning. A parallel study at Carroll College was approved by the IRB of Carroll College Waukesha (WI). Two able-bodied subjects have participated in that study so far with informed consent.

C. Procedure

A two-day protocol was conducted for both the groups. Day one was a training session and day two was the actual assessment day. Patients were asked to perform pseudo-random sine tracking as shown in the fig. 1(b) where they moved the wheel to keep pace with a square box that moved in a randomized sine pattern. Figure 2 is a representative plot of the movement for a subject. Subjects were asked to perform three trials of each task [9] [11]. Subjects (Low: S7, S11 and High: S5) wore a harness in Day 2.

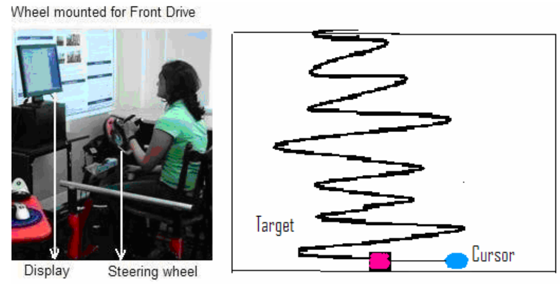

Fig. 1. a) Experimental setup for TheraDrive System. The wheel is mounted on the metal frame and tilted through 20 degrees to vertical. b) A pseudo Random Sine tracking task is shown where subjects are asked to move the cursor to the target in the x-direction. The wave is generated vertically with three different amplitudes at frequencies (1 Hz, 2Hz and 3Hz)

TABLE 1: Raw clinical data for stroke subjects and able bodied subjects tested: Data shows impairment and disability scales for stroke subjects and other information such as age and handedness for stroke and able bodied subjects. The stroke subjects are divided as low-to-medium and high functioning based on these scores.

Subject	Impaired Arm	Dominant Arm (Befor Stroke)	Age	Clinical scores UE-FM 66	UE-FT 7-Levels
S Low					
S3	L	R	62	56	4
S7	L	L	60	24	4
S11	L	R	55	56	5
S High					
S1	L	R	55	66	7
S5	L	L	58	66	7
S9	R	R	55	66	7
S10	R	R	58	66	7
S Norm					
S1	NA	R	59	NA	NA
S3	NA	R	68	NA	NA

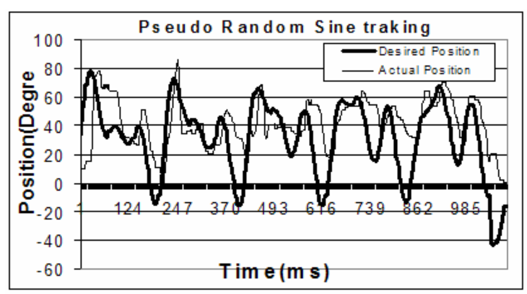

Fig. 2. Pseudo Random Sine Tracking shows the comparison between the desired position and actual position subjects tracked.

D. Data Analysis

The desired movement of the cursor as well as actual movement was plotted and the error between actual and desired was calculated in terms of degrees of rotation of the wheel. The three trials were averaged. The averaged RMS data were presented for each subject. These errors were calculated for low-to medium functioning, high functioning, and normal subjects. The RMS error was calculated by taking the square root of the squared difference between the desired-position signal (track) and the actual-position signal (arm movement). We evaluated the effects of the harness on tracking and saw that the harness did not significantly enough to affect the general grouping of subjects into low and high across the harness. The mean squared errors were compared within and across the groups using a repeated measure ANOVA, Tukey-Kramer post-hoc tests and unpaired t-test to establish significant differences.

III. RESULTS

A. Detection of Motor Impairment and Difference between Functioning Levels

Table 2 shows the average RMS error comparison of unimanual dominant (D) steering, unimanual nondominant (ND) steering and bimanual (BI) steering. Figure 3 plots these comparisons. ANOVA results indicate that errors were close to significantly different (p=0.07) across subjects and across arm use (p=0.05). It can be seen from fig. 4 that the level of functional ability of the subjects has tendency to affect their tracking performance and their arm use. Although there was a tendency towards significant difference, the average errors made by low-to-medium functioning subjects in ND were not significantly higher than the errors in ND made by high functioning subjects. The average errors in the unimanual ND is typically higher than unimanual D steering (p=0.1803) and BI steering (p=0.1543) for all subjects; this is especially true for low-to medium functioning strokes (ND and D p=0.21, ND and BI p=0.099). Greater errors in ND steering suggest the presence of motor impairment in the ND due to stroke.

TABLE 2: RMS errors in degrees for all stroke patients in ND, D and BI mode of steering. Error and standard deviation (in parenthesis) on tracking performance for all subjects.

	Subject	Pseudo Random Sine Tracking(No Force) RMS Error(Degrees)		
		ND	D	BI
S(low-to-medium)	Sub3	29.3(1.44)	27.82(5.14)	21.41(0.82)
	Sub7	41.53(13.04)	27.26(1.65)	30.65(2.73)
	Sub11	20.72(0.6)	15.79(1.82)	18.15(2.39)
	AVG	30.51	23.62	23.40
S(high)	Sub1	23.52(1.89)	23.24(2.46)	20.40(0.93)
	Sub5	13.29(1.39)	12.87(1.67)	13.42(0.93)
	Sub9	13.07(1.75)	11.65(0.7)	13.80(1.37)
	Sub10	13.21(0.94)	14.69(1.17)	15.85(1.5)
	AVG	15.77	15.61	15.87
S(norm)	Sub1	12.54(2.55)	11.73(0.69)	11.59(1.56)
	Sub3	12.79(1.85)	9.93(0.93)	10.24(0.58)
	AVG	12.67	10.83	10.91

B. Detection of arm use bias and possible nonuse

Figure 4 shows the average performance across groups and arm use. For all subjects, the average errors in unimanual D steering were not significantly different (p=0.99) from BI steering errors, suggesting that the dominant arm was used to control the wheel in both the D and BI steering. For high and control subjects the ND errors were not significantly different from D (high functioning p=0.80) and BI (high functioning p=0.943) mode of steering. Although low-to-medium functioning subjects ND errors were not significantly different from D (p=0.21) and BI (p=0.09) mode of steering, the non-dominant arm was in general used less. The results suggest that steering tasks can detect a bias. For low-to-medium functioning subjects, the likelihood is that we are detecting learned bias and not just the natural bias due to handedness.

C. Handedness and Impairment

The role of handedness was investigated to further clarify whether the differences seen were related to which arm was impaired. Figure 5 shows the errors made by subjects that had impairment on their pre-stroke dominant side(subjects 1, 3and11) versus those that had an impairment on their pre-stroke non-dominant side (subjects 5,7,9,10). It can be seen that average error for subjects who had injuries in their dominant arm are slightly higher than subjects who have injuries in their non dominant, but no significant difference was seen (p=0.56). In fact no significance was reported across ND, D, BI for all the data set (p=0.09). Thus side of injury may not matter in assessing the degree of impairment and arm use.

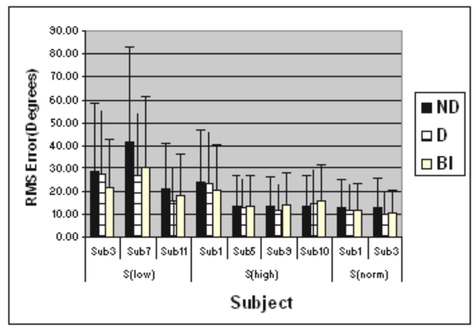

Fig. 3. Comparative RMS error plot for individual stroke subjects recorded during ND, D and BI steering tasks.

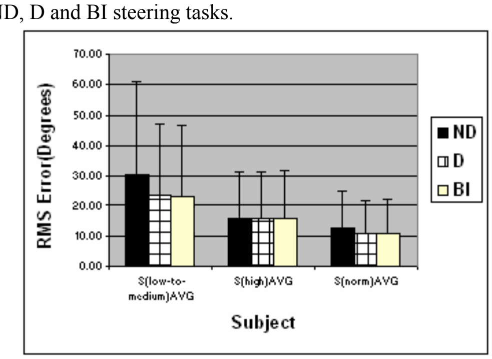

Fig. 4. Comparative RMS error plot for low-to-medium functioning, high functioning and normal subjects comparing the average errors recorded during ND, D and BI steering tasks.

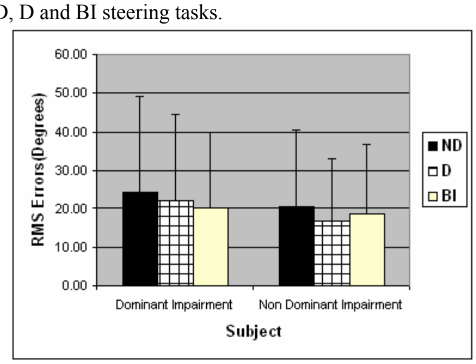

Fig. 5. Comparative RMS error plot for dominant arm impaired subjects and non dominant arm impaired subjects comparing the average errors recorded during ND, D and BI steering tasks.

IV. Discussion

The general hypothesis of the study was that differences observed in the single and coordinated use of both the arms after stroke was a consequence of leaned nonuse due to weakness and decreased awareness of the contralateral side of the brain injury [12-14].

Some limitations of the study must be kept in mind when interpreting the results. The sample size was limited to seven stroke patients, with heterogeneous types of impairments and two able-bodied subjects this might have affected the standard deviations of individual subjects, though the average data showed sharper trend. During the study, the ipsilateral side is considered as the healthy side, which is not the case in real life. There are impairments present in the contralateral side of the brain injury; the impairments are less severe on the ipsilateral side as compared to the contralateral side [2]. Although not significant, the higher average errors in ND steering as compared to D and BI steering were seen. This tendency shows impairment in the ND arm. The ND arm is not as efficient in performing the task when compared to the D arm. This trend was supported by other studies. It has been seen that weakness and lack of coordination are factors which limit motor performance of the contralateral side after stroke [12-14].

Another factor is handedness; we divided the stroke group in dominant impaired and non dominant impaired on the basis of their handedness before stroke and impairment after stroke. The average error in the D arm steering and BI arm steering for low-to-medium functioning as well as high functioning subjects was not significantly different. This combined with the fact that ND errors were greater than both D and BI suggests that ND was used less than D in BI steering mode [12]. Higher average errors in low-to-medium functioning patients than high functioning patients confirm the effect of degree of impairment on performance [2]. This study partially supports results presented by Johnson and colleagues that in bimanual steering with no force-feedback if an arm use bias exists, the impaired arm will most likely be under-used during bimanual steering than unimanual steering [3].

V. Conclusion

Despite our small numbers, we can confirm that steering tasks are useful for identifying preference for using the D arm over the ND. This study provides a good foundation for the development of low-cost assessment and training protocols aimed at decreasing learned bias after stroke. The results of the present study confirm that the presence of learned bias after stroke may be a factor in motor performance and needs further investigation. Research is still needed to distinguish between bias due to handedness and those truly due to learned nonuse. The next phase of the project is the Bi-TheraDrive, an extension of TheraDrive system environment, with two uncoupled wheels. We expect that an arm use preference after stroke will be seen and exaggerated even further. The nature of the two-wheeled system should further clarify the role of the ND arm in bimanual steering.

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