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Preliminary Investigation into the Effects of Visual Feedback Distortion on Range of Motion

Kelli A. Supple, Bambi R. Brewer, *Member, IEEE*

Abstract— **In this study, a robotic orthotic device with one degree of freedom was used for assessment of individuals with chronic stroke and resultant hemiparesis. The specific aim was to investigate the effect of visual feedback distortion on range of motion (ROM) at the elbow and wrist joints as measured by the Arm IntelliStretch platform from Rehabtek LLC. It was hypothesized that introducing visual feedback distortion in increments under the just noticeable difference of two degrees would directly correspond to an increase in ROM at both the wrist and elbow joints when compared to ROM measured by the IntelliStretch system without visual feedback distortion. Ten individuals an average of 11 years post stroke (SD: 9.7) participated in this study. At the elbow joint, repeated measures ANOVA showed a significant effect of distortion ($F(4, 36) = 2.69$, $p < 0.047$). Similar trends were seen at the wrist joint, though these results were not statistically significant.**

I. INTRODUCTION

Each year, over 750,000 strokes occur; in the United States; it is the third leading cause of death and the primary cause of long-term adult disability [1]. In the upper limb, stroke often impairs motion at the elbow and wrist joints that is essential for fine motor skill and balance. Immediately following a stroke, individuals often have more restricted motion than several months into recovery. It is estimated that due to this, learned nonuse occurs in 20-25% of individuals [2]. With rehabilitation, it is possible to initiate long-term cortical reorganization and overcome learned nonuse to reduce impairment and improve upper limb motion [3-5].

The repetitive nature of robotic therapy makes it an effective tool that results in improvements similar to those seen with traditional therapy [6]. Increases in movement and strength have been observed even in individuals with moderate to severe motor deficits [7-9]. It has also been shown that visual feedback distortion less than the just noticeable difference can influence the forces and movements produced by in both controls and individuals with brain injury [10-11]. The just noticeable difference (JND) is the smallest detectable difference between two forces or movements, but much larger amounts of distortion can be imperceptible if reached through a series of gradual steps [10-13]. These results suggest that visual distortion in a robotic environment may be an effective way to encourage individuals with stroke to move beyond the habitual limits of learned nonuse, which could improve both assessment and therapy for the upper extremity.

The objective of this study was to investigate the effect that visual feedback distortion has on range of motion (ROM) for individuals with chronic stroke. This was done using Rehabtek LLC's Arm IntelliStretch system with a subject population of adults greater than one year post-stroke with resultant hemiparesis. It was hypothesized that introducing visual feedback distortion in distortion steps of 2^o, the JND for both joints, would directly correspond to increased ROM at both the wrist and elbow joints when compared to ROM measured by the IntelliStretch system without visual feedback distortion.

II. METHODOLOGY

A. Subjects

Ten individuals with chronic stroke ranged in age from 38 to 85 (average 58.4 ± 14.1 SD) and were, on average, 11 years post stroke (± 9.7). All participants had limited ROM at the wrist and elbow joints of their hemiparetic side. Six of the ten participants were affected on their dominant side. The experiment consisted of a single experimental session lasting 90 minutes. Protocol and procedures were approved by the Institutional Review Board of the University of Pittsburgh. Subjects were recruited with the assistance of the Western Pennsylvania Patient Registry. All subjects provided written informed consent.

B. Experimental Enironment

Rehabtek LLC's IntelliStretch system is an active orthosis that can be used for passive, active-assisted, and active-resisted movements of the elbow or wrist joint. It has a single degree of freedom and measures joint angular displacement. The system is capable of providing force feedback, but this feature was not utilized in this experiment. For elbow measurements, the IntelliStretch system was

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K.A. Supple is with the University of Pittsburgh, Pittsburgh, PA USA (phone: 585-338-8111; email: kas252@pitt.edu).

B.R. Brewer is with the University of Pittsburgh, Pittsburgh, PA USA (phone: 412-624-6475; email: bbrewer@pitt.edu).


(a) (b)

Figure 1. IntelliStretch system set up in a) elbow configuration, restraining the joint proximally around the biceps and distally around the forearm; and b) wrist configuration, with restraint proximally around the forearm and distally at the hand.

configured to restrain the arm above and below the elbow (Figure 1a). For wrist measurements, a separate distal brace restrained the hand while the same proximal portion was used to restrain the forearm (Figure 1b). The distal orthoses were interchanged between elbow and wrist measurements while the subject rested.

C. Protocol

The assessment protocol consisted of 30 trials for each of the elbow and wrist joints. During each trial with the IntelliStretch, the subject moved the joint through his or her active flexion and extension ROM while the angular position of the joint was measured by the IntelliStretch system. Data was recorded at 1000 Hz; high frequency noise was eliminated with a 10 Hz low pass filter. The arm being tested was hidden from view by a curtain while a computer screen provided feedback pertaining to performance. Thus, visual feedback on the computer screen and joint proprioception were the only sources of feedback available to users. The elbow was always tested before the wrist. A rest was provided between wrist and elbow assessment. Video instructions ensured consistency for all subjects.

The visual feedback shown on the computer screen was a red bar that changed in position with subjects' real time joint angular displacement (Figure 2). As the assessment protocol progressed, the visual feedback was gradually distorted so that the subject had to move through a larger ROM in order to produce the same change in the visual feedback bar.

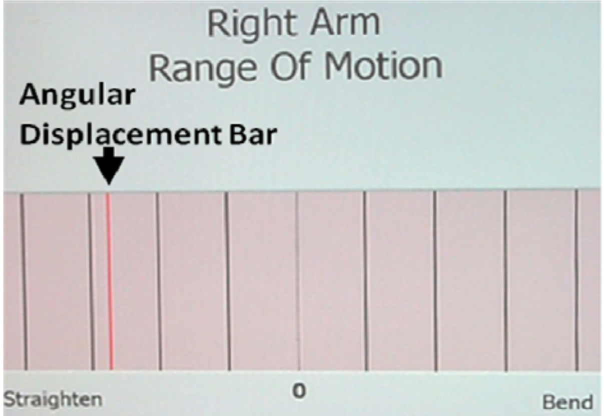

Figure 2: Visual feedback display with displacement bar noted

Testing consisted of ten trials without any distortion, followed by five trials at each of four levels of distortion. Each distortion step increased the maximum extension and decreased the minimum flexion represented on the visual feedback bar by 2°, the JND calculated for healthy individuals at the wrist and elbow joints [14]. For example, after two distortion steps, the maximum extension represented on the feedback bar increased by 4° (i.e., 75° to 79°) while the minimum flexion represented decreased by 4° (i.e., 30° to 26°). A maximum of 8^{o} of distortion was used for both flexion and extension, giving an overall maximum of 16^{o} distortion through each flexion-extension movement in trials 26-30.

Trials 1-5 of each 30 trial group were discarded due to acclimation to the device. Five trials were analyzed for each distortion step (including zero degrees). Peak flexion and extension values were determined for each trial and averaged across each block of five trials. The difference between the average peak flexion and the average peak extension was considered the average ROM for each distortion step. In order to more easily compare subjects, this ROM was then normalized for each individual based on the overall mean of all subject ROMs. Normalized ROMs as a function of distortion were plotted with confidence intervals for both the elbow and wrist.

Statistical analysis was performed using a repeated-measures ANOVA in SPSS. The within-subjects factor was distortion step (0°, 4°, 8°, 12°, or 16°) and the outcome variable was ROM. Linear trend analysis was also performed to determine whether ROM increased linearly with distortion.

III. RESULTS

A. Elbow Joint

Table 1 presents the normalized elbow ROM as a function of distortion. This table shows that seven of the ten subjects increased elbow ROM during the course of the thirty trials with progressively increasing visual feedback distortion. As this data shows, ROM performance did not often improve steadily throughout the thirty trials for subjects. Rather, there was variation with a general increasing trend. This was likely due to the effects of fatigue and spasticity occurring over the course of the experiment. Normalized elbow ROM as a function of distortion is plotted in Figure 3. A 95 % confidence interval for the mean normalized ROM is also presented to indicate the spread of data.

Data for elbow ROM met the assumption of sphericity. The repeated-measures ANOVA showed a significant effect of distortion ($F(4, 36) = 2.69$, $p = 0.047$). This indicates that the mean ROM, changing from 62^{o} in the first group of trials to 67^{o} in the last, increased as the amount of distortion increased. However, the results of the linear trend analysis did not quite reach significance: $F(1,9) = 4.33$, $p = 0.067$. This implies that, while close, there was not a statistically

		Degrees of Distortion				
		0°	4°	8°	12°	16°
ROM (degrees)	Subject 1	55.25	64.97	70.33	65.96	68.59
	Subject 2	59.04	67.34	63.22	66.65	68.85
	Subject 3	60.17	65.20	63.16	63.84	72.73
	Subject 4	62.79	66.43	65.87	66.72	63.28
	Subject 5	68.98	64.12	66.93	65.82	59.25
	Subject 6	69.45	65.89	61.42	63.17	65.17
	Subject 7	67.88	65.73	62.02	63.89	65.59
	Subject 8	57.37	63.55	61.28	70.31	72.59
	Subject 9	54.46	59.19	67.58	75.52	68.35
	Subject 10	61.26	61.63	66.30	65.73	70.18

Table I. Normalized elbow ROM as a function of distortion

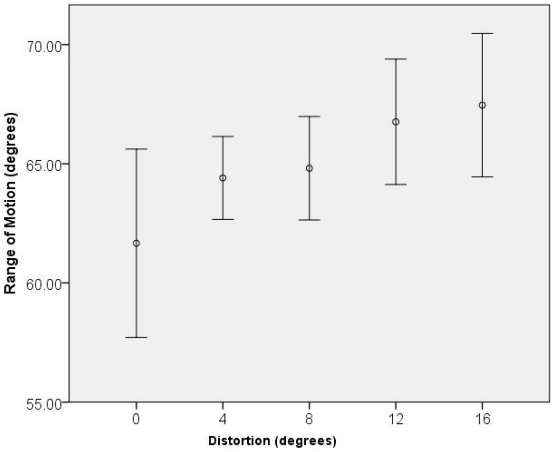

Figure 3: Normalized elbow ROM as a function of distortion

significant linear change in elbow ROM as a function of distortion.

B. *Wrist Joint*

Of the ten subjects included in this study, eight participated in the wrist portion. Data from Subject 1 was not included because technical difficulties with the Rehabtek device occurred during wrist testing. In addition, Subject 9 could not produce active wrist motion while in the Rehabtek system, so data was not collected. Of the remaining eight subjects who participated in the wrist portion of the protocol, seven showed increased ROM during the course of the thirty trials at the wrist joint.

The data for wrist ROM did not meet the assumption of sphericity, so the Greenhouse-Geisser correction was applied for the repeated-measures ANOVA. There was no significant effect of distortion ($F(1.308, 9.154) = 1.77$, $p = 0.1630$). In addition, there was no significant linear trend in ROM as a function of distortion ($F(1,7) = 2.317$, $p = 0.172$).

IV. DISCUSSION

The Arm IntelliStretch system was used in subjects ranging from 38 to 85 in age and who were, on average, 11 years post stroke. Because of this and the nature of stroke, the severity of affect was relatively broad in subjects. Screening did limit the subject population, but spasticity and weakness played significant roles in data acquisition. Spasticity was unpredictable and often spontaneous. Trials where subjects achieved particularly large flexion-extension movements were often followed immediately by trials with significantly reduced ROM. In addition, joint migration within the brace was observed, particularly at the elbow.

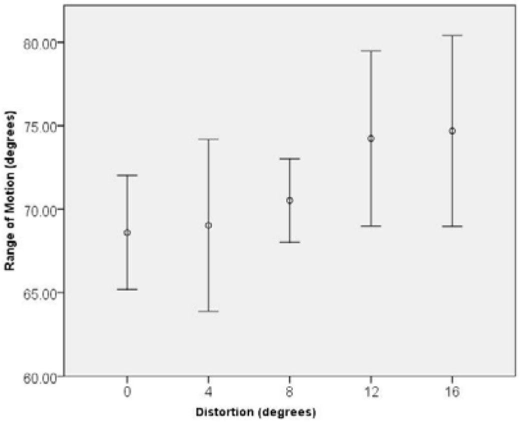

Figure 4: Normalized wrist ROM as a function of distortion

Despite these difficulties, this study found that introducing visual feedback distortion in steps of 2^{o} did correspond to statistically significant changes in the mean elbow ROM for individuals with chronic stroke, as hypothesized. While the statistics reported for the wrist were not significant, this may be due to including fewer subjects in the analysis as well as greater variation in the data. Despite this, results still had important implications as they showed similar trends to those at the elbow joint.

Other groups have also considered the use of various types of distortion in the context of a robotic rehabilitation paradigm. For individuals with chronic stoke, Patton, Kovic, and Mussa-Ivaldi [15] measured the error between an individual's path to a target and the ideal straight line path. A force was then exerted that increased this error as the individual continued to practice moving to the target. When the perturbing force was removed, the resulting aftereffect reduced the error between the actual and ideal path relative to the initial error value. Further, Rozario et al. [16] examined a rehabilitation paradigm in which individuals with chronic stroke attempted to track target movements generated in real-time by a therapist; errors between the actual and target movements were magnified using visual and haptic feedback. Initial results showed greater improvements for individuals who received the error augmentation before a control condition without the error augmentation. The work presented here is distinct from these previous studies in that only visual distortion is used and that the distortion focuses only on the result of the movement, rather than the path.

The current works shows that visual feedback distortion can be used to encourage individuals with stroke to improve motor performance in a robotic environment. With further research, robotic therapy systems such as the Arm IntelliStretch platform may be used effectively in conjunction with progressively increasing visual feedback distortion as a rehabilitation technique for stroke patients with hemiparesis and resultant difficulty performing everyday activities requiring motion at the elbow and wrist joints. Results of this study pertaining to visual feedback distortion are encouraging for researchers looking to improve ROM in individuals experiencing chronic stroke using this method. Future work will explore the use of visual distortion in a multi-week home rehabilitation protocol using a low-cost robotic or sensing device. The goal of this study will be to compare performance in the rehabilitation protocol with and without visual distortion. Hypothetically, distortion will improve performance within a single session. Over time, this single-session improvement may also improve the overall functional outcome of rehabilitation. This will also be tested in future work.

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