31st Annual International Conference of the IEEE EMBS
Minneapolis, Minnesota, USA, September 2-6, 2009

The Effects of Asymmetric Tonic Neck Reflex during Reaching Movement following Stroke: Preliminary Results

S. Lee, *Student Member, IEEE*, J. Yao, *Member, IEEE*, A.M. Acosta, *Member, IEEE*, J.P.A. Dewald, *Member, IEEE*

***Abstract*—Previous studies and clinical observations reveal that stroke survivors show the resurgence of the asymmetric tonic neck reflex (ATNR) both in static and dynamic conditions during maximal efforts. This observation may imply more reliance on the brainstem pathways following stroke. However, the effect of ATNR during a dynamic condition that represents more natural movement, such as reaching, has not been studied before. During reaching movements, the application of a robot controlled haptic environment is important to quantify the effect of ATNR following stroke. Therefore, this paper reports the use of a novel setup using the ACT^{3D} robotic device to investigate and quantify this reflexive behavior. Our preliminary results demonstrate that the effect of ATNR is significant in the stroke population when abducting the shoulder at 25% of maximum ability. These results show that the ATNR affects reaching distance especially when shoulder loading in abduction is required. In conclusion, these preliminary results provide evidence that the effect of ATNR in stroke subjects during reaching task can be quantified by using a novel 3-D robotic setup.**

I. Introduction

FOLLOWING stroke, individuals experience different degrees of abnormal co-activation of shoulder and elbow muscles. Such abnormal co-activations have been shown between shoulder abductors with elbow flexors and shoulder adductors with elbow extensors [1, 2, 3, 4, 5]. One of the hypothesized neural mechanisms underlying these abnormal muscle co-contraction patterns is an increased reliance on brainstem pathways [6]. In animal studies, Magnus and de Kleijin [7] reported postural reflex patterns, i.e. tonic neck reflexes, of the decerebrate animal in which more extension patterns of the limbs were observed on the jaw side of the rotated head but more flexion patterns of the limbs were observed on the skull side of the limb. Such tonic neck reflexes including asymmetric tonic neck reflex (ATNR) are also observed in a newborn baby or people following brain damage such as stroke [10, 11, 12, 13, 14].

In the clinic, the ATNR is used to evaluate the development of the nervous system. The ATNR can be evaluated via head rotation. The expression of the ATNR is defined as an increase in elbow extension when the person rotates the head toward the arm and an increase in elbow flexion when the head is rotated away from the arm. The expression of the ATNR in individuals more than one year after the birth indicates a neurological dysfunction. The resurgence of this reflex has been reported in patients with stroke or other traumatic brain injury [2, 14]. Such pattern may imply that head rotations can excite reticular formation following stroke. As a consequence, it affects the excitability of elbow flexor and extensor motor neuron pools at the cord [8, 9, 10]. Previous studies reveal that chronic stroke survivors show the evidence of the ATNR during both static [12] and dynamic conditions [13]. Research in our lab has provided solid evidence showing that maximum elbow flexion/extension torques generating abilities are significantly affected by head rotation in chronic hemiparetic stroke survivors [12]. A dynamic study in 1949 [13] demonstrated the presence of ATNR in a reaching task; however, the researchers only considered maximum single joint (one degree-of-freedom) movements (elbow flexion/extension direction, EF/EE) but no multi-joint (multi-degree-of-freedom) movements (EF/EE and shoulder abduction/adduction direction, SAB/SAD). Up to now, no experimental setup has allowed the investigation of the effect of ATNR during multi-joint movements with various shoulder abduction levels. Such investigation requires a novel 3D haptic robotic environment while allowing free movements of the arm. Due to the lack of such experimental setup, it is still unknown whether the effect of ATNR is also expressed in stroke population at sub-maximal shoulder abduction levels.

In order to investigate the effect of the ATNR during reaching movements with various sub-maximal shoulder abduction forces, we have designed novel experimental setup using the Arm Coordination Training 3-D (ACT^{3D}) device (patent-pending). Briefly, the ACT^{3D} is a modified HapticMaster robot (Moog, The Netherlands) with the integration of a Biodex experimental chair (Biodex Medical Systems, Shirley NY) [15, 16]. This novel robotic setup allows us to record endpoint kinematics and forces while creating a haptic environment that allows subjects to move their limb while generating different shoulder abduction forces. In addition to this advantage, the system provides visual feedback of the subjects' arm and targets displayed on a HD computer monitor (Fig1). Details about the

Manuscript received June 10, 2009. This work was supported in part by the NIH R01 grants, 5R01HD039343-07 and 5R01HD047569-05.

Song Joo Lee is with Northwestern University, Chicago, IL 60611; e-mail: song-lee@ northwestern.edu).

Jun Yao is with Northwestern University, Chicago, IL 60611; e-mail:j-yao4@ northwestern.edu).

Ana Maria Acosta is with Northwestern University, Chicago, IL 60611; e-mail:a-acosta@northwestern.edu).

Julius Dewald is with Northwestern University, Chicago, IL 60611; e-mail:j-dewald @ northwestern.edu).

experimental setup and protocol are further described in the 'methods' section.

To test the effectiveness of this novel experimental setup, nine different conditions (three different head positions with three different shoulder abduction force levels) were considered to investigate the effect of ATNR during reaching movements for different shoulder abduction loads.

II. METHODS

A. Subjects

Three stroke subjects and one healthy subject (table 1) were tested using a reaching protocol (see the section below). The stroke subjects had Fugl-Meyer scores between 20-55, which indicates severe to mild impairment.

TABLE I
SUBJECT INFORMATION

SUBJECT	AGE	GENDER	AFFECTED /DOMINANT	FM SCORE	SENSORY LOSS
S1	52	F	R	12/66	NO
S2	63	M	R	16/66	NO
S3	65	M	L	43/66	NO
C1	52	M	R	N/A	NO

S are stroke subjects, C is control subject. M=male, F=female, R=right, L=left, N/A=not available

B. Static Setup- Maximum Voluntary Forces

The maximum voluntary abduction force generated by the subject's paretic or dominant limb was measured in a static setup for use in the reaching tasks. Subjects were seated in a Biodex chair (Biodex Medical Systems, Shirley, NY) with the trunk completely supported and strapped to the chair to restrain movement. Subjects' limbs were casted and attached to a 6-DOF load cell (JR^3 Model No. 45E15A, JR^3 Inc., Woodland, CA) to ensure a secure connection that transmits all forces and moments. The arm configuration in the static setup was 85º shoulder abduction, 40º shoulder flexion, and 90 º elbow flexion angle. Subjects were asked to generate maximum muscle contraction in shoulder abduction while being encouraged verbally.

C. Reaching Protocol- The ACT3^D

The ACT3^D robot was used to simulate a virtual or haptic table, and to provide different support levels. Three shoulder loading conditions were tested in this study: table condition, 0%, and 25% shoulder abduction force (SAB). The table condition was defined such that subjects were able to glide on the virtual table; under the 0% and 25% SAB conditions, subjects were asked to lift off the virtual table so that they did not generate shoulder abduction/adduction torques (0%) or had to actively generate shoulder abduction torque (25%).

D. Reaching Protocol- Experimental Setup

Prior to starting the reaching trials, three locations for the computer screen (visual feedback) were defined (Fig 2). These three locations of the screen determined the three different head rotations for each subject: the straight position, where subjects looked straight at the screen in front of them, and a head position 'toward' or 'away' from the tested arm, where the subject's head was rotated toward or away from the impaired/dominant arm at the maximum head rotation angle minus 5 degrees to reduce the possibility of subject discomfort over time [12].

Once the desirable locations for the screen were defined, the subject' paretic/dominant forearm/hand was strapped into a light-weight orthosis and the trunk was strapped to the chair to prevent movement of the trunk from affecting the reaching tasks and also to minimize shoulder girdle movement.

E. Reaching Protocol- Reaching Tasks

Subjects were asked to perform a set of training trials to minimize learning effects during the actual trials. A total of nine conditions (three different head positions × three different shoulder abduction forces) were tested in a randomized order. Subjects were asked to move their paretic/dominant limb as fast as they could from the home position to the target position. The home position was defined as 85º shoulder abduction, 40º shoulder flexion, and 90º elbow extension. The reaching target was defined as adding 70º elbow extension and 50º shoulder flexion from the home position (Fig 3). In order to keep the visual feedback the same for all nine different conditions, the arm was covered and thus in all conditions the only visual feedback was from the screen showing the same virtual limb (Fig 3). Subjects repeated the exact same reaching tasks for 7-10 trials for each of the nine different conditions in the same shoulder position.

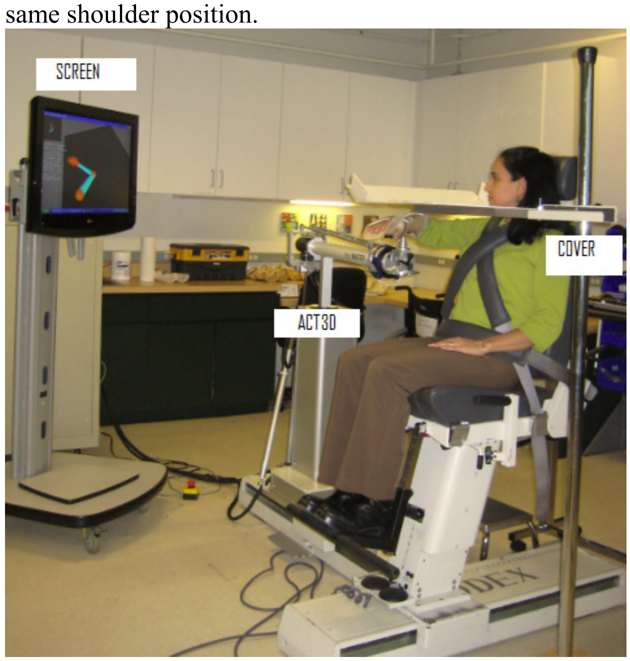


Fig. 1. The ACT^{3D} Robotic setup with the custom-made cover to block visual feedback of the limb.

F. Data Analysis

Custom-made Matlab software was developed to analyze the kinematic data. The time of the beginning and end of trials were defined as the time when the velocity reached 2%

of peak resultant velocity. The maximum distance from the home position per trial was computed within the beginning and end of trial time window. Subsequently, we normalized the maximum distance by dividing the maximum distance by the distance from the home position to the target, which is different for each individual depending on his/her arm length.

Fig. 2. ATNR screen locations with respect to the tested arm: away (left panel), straight (middle panel), and toward (right panel).

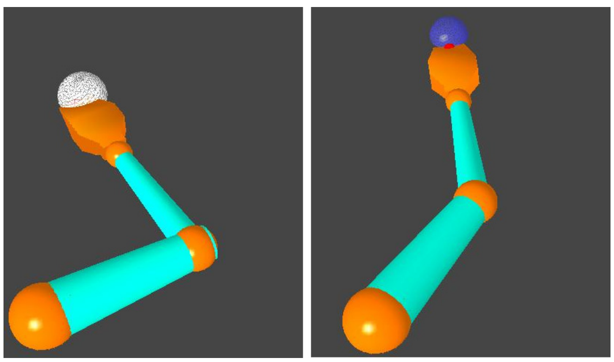


Fig. 3. Home (left) and the reaching target (right) with a virtual limb that reflects the actual limb movements.

G. *Statistical Analysis*

One way ANOVA (head rotations) was used to test the effect of head position on the normalized maximum distance within each of the loading conditions in the stroke group. Furthermore, a two way ANOVA (head rotations and limb loading) was used to test the significance of the interaction between head position and shoulder loading. A p value less than 0.05 indicates a significant difference. Post hoc tests (Bonferroni correction) were also performed for the one way ANOVA (head rotations) and the two-way ANOVA (head rotations and loading conditions).

III. PRELIMINARY RESULTS

The hand trajectories of nine different conditions of a stroke subject can be seen in Fig 4. As seen from Fig 5A, the normalized maximum distances measured in stroke subjects decreased as shoulder abduction drive increased during the reaching tasks. However, such a change was not observed in the healthy subject. The effect of ATNR is significant ($p=0.03$) when subjects were asked to maintain 25% of their maximum shoulder abduction force while reaching; this effect did not reach significance in the other two conditions with smaller shoulder loads ($p=0.3$ and 0.5, respectively). The post hoc tests reveal that the effect comes from the difference between the away and toward condition ($p=0.026$).

The two way ANOVA test reveals that head rotation ($p=0.016$) and shoulder abduction drive ($p=0.000$) have a significant effect on reaching distance and that the interaction between the head rotation and shoulder abduction drive ($p=0.019$) is also statistically significant.

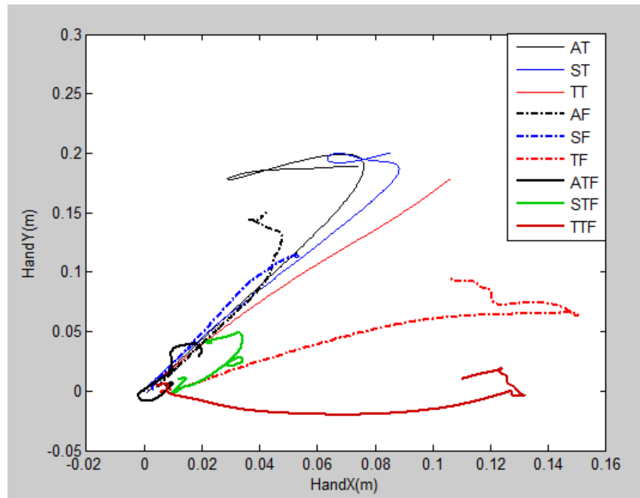
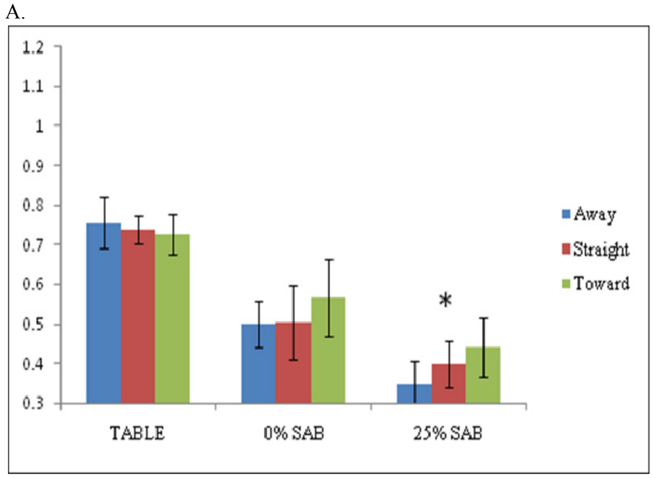


Fig. 4. Mean hand trajectories of a stroke subject. AT: away from the paretic arm on the table, ST: straight on the table, TT: toward the paretic arm on the table, AF: away from the paretic arm 0% SAB Max, SF: straight 0% SAB Max, TF: toward the paretic arm 0% SAB Max, ATF: away from the paretic arm 25% SAB Max, STF: straight 25% SAB Max, TTF: toward the paretic arm 25% SAB Max.

A.



B.

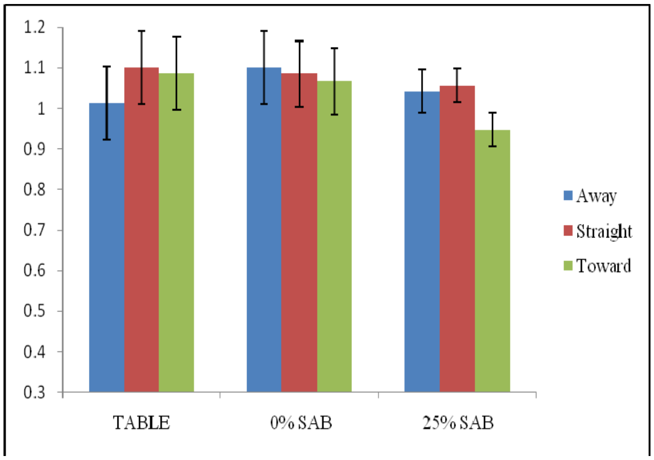


Fig. 5. Normalized Average Maximum Distance with ± 1 mean standard deviation (error bars) of stroke subjects (A, N=3) and a healthy subject (B, N=1) *= p<0.05.

IV. DISCUSSION

The effect of ATNR is evident in the 25% of shoulder abduction drive condition based on our preliminary results. Previous studies [12, 13] were designed such that maximum efforts during three different head rotations (away, straight, and toward the paretic limbs) were considered. These preliminary observations demonstrate that when elbow extension is most compromised, as during 25% of max shoulder abduction, the effects of the ATNR on movement distance are most apparent. Furthermore, consistent with previous results, increasing shoulder abduction reduces reaching distance due to reductions in elbow extension and to a lesser extent shoulder flexion [15, 16, 17].

This preliminary finding demonstrates that the effect of ATNR can be quantified during a reaching task that requires subjects to generate a sub-maximal shoulder abduction force using a novel robotic set-up, ACT^{3D}. Using this set-up, experiments in more subjects and using shoulder abduction load that demonstrates the effect of ATNR in a clear way is part of future study. Furthermore, the fact that these effects are only seen in hemiparetic stroke survivors and not in controls provides evidence to support the hypothesis of an increased reliance on bulbospinal pathways in brain injured individuals.

ACKNOWLEDGMENT

We would like to thank Carolina Carmona for her help in data collections and subject recruitment and Mike Ellis for his help in developing the research protocol.

REFERENCES

[1] T.E. Twitchell, “The restoration of motor function following hemiplegia in man,” *Brain,* vol. 74, pp. 443-480, 1951.
[2] S. Brunnstrom, *Movement therapy in hemiplegia: a neurophysiological approach*. New York: Harper & Row, 1970.
[3] J.P Dewald and R.F. Beer, “Abnormal joint torque patterns in the paretic upper limb of subjects with hemiparesis,” *Muscle & Nerve* vol. 24, pp. 273-283, 2001.
[4] J.P Dewald, P.S. Pope, J.D. Given, T.S. Buchanan, W.Z. Rymer, “Abnormal muscle coactivation patterns during isometric torque generation at the elbow and shoulder in hemiparetic subjects,” *Brain* vol 118, pp.495-510, 1995.
[5] J.P. Dewald, V.Shershadri, M.L. Dawson, R.F. Beer, “Upper limb discoordination in hemiparetic stroke: implications for neurorehabilitation,” Topics in Stroke Rehabilitation vol.8, pp.1-12, 2001.
[6] J.G. McPherson, M.D. Ellis, C.J. Heckman, J.P. Dewald, “Evidence for increased activation of persistent inward currents in individuals with chronic hemiparetic stroke,” *J Neurophysiol.*, vol. 106 (Pt 6), pp.3236-43, 2008.
[7] R. Magnus, A. de Kleijin, “The influence of the position of the head on the tone of the muscles of the extremities,” *Pfluger Arch. Physiol*, vol. 145, pp.455-546, 1912.
[8] F.J. Schulte, *Brain mechanisms and motor behavior. In: Stave U, ed. Physiology of the perinatal period. Functional and biochemical development in mammals.* New York: Appleton Century Crofts, pp. 815, 1970.
[9] A.G. Davidson, M.H. Schieber, J.A. Buford, “Bilateral spike-triggered average effects in arm and shoulder muscles from the monkey pontomedullary reticular formation,” *J Neuroscience* , vol. 27 (Pt 30), pp.8053-8058, 2007.
[10] P.V. Marinelli, “ The Asymmetric Tonic Neck Reflex: Its presence and significance in the Newborn,” *Clin Pediatr (Phila)*, vol. 22, p544, 1983.
[11] F. Vassella, B. Karlsson, “Asymmetric Tonic Neck Reflex: A review of the literature and a study of its presence in the neonatal period,” *Develop Med Child Neurol*, vol. 4, pp363-369, 1962.
[12] J.P. Dewald, M.D. Ellis, T. Keller, “Asymmetric tonic neck reflexes induced changes in joint torque generation in the hemiparetic upper extremity: preliminary result,” *NACOB*, 2008.
[13] L.J. Yamshon, O. Macheck, and D. Covalt, “The tonic neck reflex in the hemiplegic,” *Archives of Physical medicine*, Vol. 30 (Pt 11), pp.706-711, 1949.
[14] K. Sawner, J. Lavigne, *Brunnstrom’s movement therapy in Hemiplegia : a neurophysiological approach*. Philadelphia : J.B. Lippincott Company, 1992.
[15] T.M. Sukal, M.D. Ellis, J.P. Dewald, “Shoulder abduction-induced reductions in reaching work area following hemiparetic stroke: neuroscientific implication,” *Exp Brain Res*, vol. 183, pp.215-223, 2007.
[16] T.M. Sukal, J.P. Dewald, M.D. Ellis, “Use of a novel robotic system for quantification of upper limb work area following stroke,” *IEEE EMBS*, 2005.
[17] M.D. Ellis, T. Sukal-Moulton, J.P. Dewald, “Progressive shoulder abduction loading is a crucial element of arm rehabilitation in chronic stroke,” *Neurorehail Neural Repair*, doi: 10.1177/154968309332827, 2009.