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A Novel Core-Strengthening Program for Improving Trunk Function, Balance and Mobility after Stroke: a Case Study*

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***Abstract*— The objective of the current investigation was to evaluate the feasibility of a core-strengthening program delivered to a chronic stroke participant using a novel robotic device, *AllCore360º*, which targets trunk muscles through a systematic, consistent, high-intensity exercise. A 58-year old male with hemiplegia post stroke (time since injury: 18 years) was enrolled and performed 12-sessions of the core-strengthening program on *AllCore360º*. The participant completed a total of 142 360º-rotating-planks (called as 'spins') at four inclination angles, over 12 sessions. Assessments at baseline and follow up included posturography during quiet standing, electromyography (EMG) during *AllCore360º* spins, and assessments for trunk function (Trunk Impairment Scale (TIS)), balance (Berg Balance Scale (BBS) and mobility (Timed-Up and Go (TUG), 10-meter Walk test (10MWT), 6-minute Walk Test (6MWT)). Clinically meaningful improvements were observed in the TIS (73%), the BBS (45.2%), and the TUG test (22.7%). Medial-lateral Center of Pressure (MLCoP) data showed reduced RMS and range by 32.3% and 29.2%, respectively. EMG data from left and right rectus abdominis (RAB) muscles showed increased levels of activations for both inclination angles, 65º (LRAB: 74%, RRAB: 48.4%) and 55º (LRAB: 22.3%, RRAB: 28.7%). The participant rated the core-strengthening program 71 (scale: 0-126) on Physical ACtivity Enjoyment Scale at the follow up, showing a high level of satisfaction and engagement toward the training program. The preliminary results suggest that the novel robotic design and enhanced engagement of neuromuscular mechanisms features of *AllCore360º* core-strengthening program could facilitate improvements in trunk function, balance and mobility post stroke. A study with a large sample and an appropriate control group needs to be performed in the future.**

***Clinical Relevance*— The majority of clinical programs include core-stability exercises for improving trunk function. The current investigation presents a novel robotic-device based core-strengthening program that can provide systematic, consistent, and repetitive practice for optimal functional gains.**

I. Introduction

Hemiplegia, a secondary consequence of stroke, is characterized by severe unilateral muscle weakness and is linked to compromised mobility, balance, and activities of daily living (ADL), resulting in the loss of independence [1]. Trunk control is the ability of the trunk muscles to allow the body to remain upright, perform weight shifts to maintain balance during static and dynamic postural tasks [2]. Trunk impairment after stroke is multidirectional in hemiplegic patients [2]. Previous studies have reported muscle weakness and delayed activity of the trunk muscles, significant error in sensing trunk position, inadequate control of the center of pressure (CoP), decreased trunk performance and trunk kinematic asymmetry during gait [3]. Trunk impairment persists even into the chronic phase post stroke. Research shows weakened activations of trunk flexors and extensors muscles and lower peak torques during the chronic phase compared to healthy individuals [4].

It is widely accepted that an efficient state of the trunk provides appropriate proximal stability or controlled mobility to support optimal task or postural performance [5]. Trunk muscles play a major role in maintaining anti-gravity postures (sitting, standing). Although leg muscles may assist in stabilizing the trunk in the anterior-posterior (AP) direction, lateral sitting balance almost completely depends on trunk muscles [6]. Due to such a critical role of trunk muscles in maintaining posture, the weakness of trunk muscles after stroke has a significant influence on balance and mobility post stroke. The evidence suggests that the ability to balance and walk after stroke depends on the trunk function and in fact, the trunk function is the important functional predictor at discharge after stroke [7-9].

According to a recent review, most of the trunk training programs involve core stabilizing, reaching, weight-shift or proprioceptive neuromuscular facilitation exercises and trunk training is a good rehabilitation strategy for improving dynamic sitting balance [5]. However, the information on the effectiveness of electromechanical devices in trunk training is still lacking [5]. Further, the heterogeneity in applied training exercises, intervention dosing restricts the interpretations for the standardization of treatment [5]. Variability in the dosing of delivered intervention could also result from variability in the assistance provided by the therapists and/or devices.

Considering the current limitations of trunk rehabilitation and the major role trunk plays in re-gaining functional independence post stroke, it is important to investigate novel approaches that could provide systematic, consistent, and repetitive training that specifically targets the trunk muscles

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and trunk function. The objective of the current investigation was to evaluate the feasibility of a core-strengthening program delivered through a novel robotic device, *AllCore360º* (AllCore360º, GA, USA), specifically designed to target trunk muscles through a systematic, consistent, high-intensity exercise. We hypothesized that a 4-week core-strengthening program would result in improved clinical outcomes of trunk function, balance and mobility for a 58-year-old individual with hemiplegia. Our secondary hypothesis was that the training program would also result in altered neuromuscular mechanisms of trunk control assessed using electromyography (EMG).

II. METHODS

A. Participant

Inclusion criteria for the stroke participant were, 1) must have sustained a stroke at least six months prior to enrollment; 2) no history of injury or pathology for uninvolved limb within the last 90 days; 3) be able to walk independently for 10 meters without any assistive device; 4) medically stable for three months and with the expectation that current medication can be maintained without drastic change for at least two months; and 5) adequate cognitive function to give informed consent, understand instructions, and provide feedback. Exclusion criteria were, 1) severe cardiac diseases such as myocardial infarction or congestive heart failure; 2) fluctuating blood-pressure; 3) pregnancy (confirmed by pregnancy test); 4) uncontrolled pre-existing history of seizure disorder prior to the most recent episode of stroke; 5) additional orthopedic, neuromuscular, or neurological pathologies that would interfere with the ability to perform the intervention; 6) difficulty following or responding to commands that would limit the study participation; 7) Currently enrolled in another research study or therapy (from a licensed physical therapist) that is likely to affect the outcomes of the current investigation. All study procedures described in this paper were approved by the Institutional Review Board.

A 58-year old male with hemiplegia post stroke (time since injury: 18 years) was enrolled and performed 12-sessions of the core-strengthening program on a novel robotic device, *AllCore360º*.

B. Intervention – Core-Strengthening Program

The *AllCore360º* rotates the body in a plank position in 360 degrees without depending on the extremities (Fig. 1). It allows the core muscles to engage and strengthen without putting weight on the extremities. The participant is secured into a seat from the waist down with the body at a 90° in a seated posture. The participant may also be secured using a trunk strap that is sufficiently loose to allow enough space between the back and the backrest for controlled trunk movements. The participant is required to hold the posture rigid (back not touching the backrest) against the gravity while the *AllCore360º* tilts back to a predefined inclination angle (between 0º to 90º) and rotates 360º as shown in Fig.1B-D, in a clockwise (CW) or counter-clockwise (CCW) direction. The participant completes a 360º rotating plank, called a 'spin'. Each spin can be customized to present a

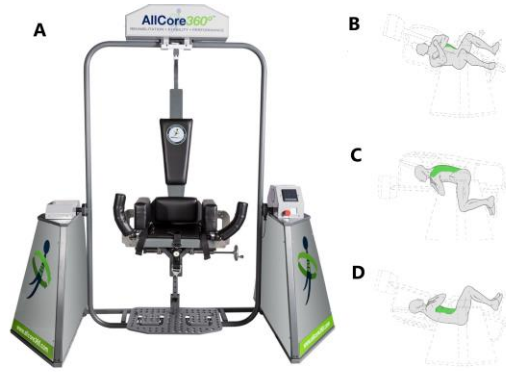

Figure 1. (A)The AllCore360º device, and (B-D) different regions of the core targeted during a single rotation of the AllCore360º.

challenge at various inclination angles (90º – easiest with sitting in a chair upright, 0º - hardest with back parallel to the ground) based on the individual's own abilities. Each spin takes one minute at a constant speed (i.e., 1 RPM).

For the study participant, the inclination for the *AllCore360º* spins was determined based on his comfort, safety and visual determination of participant's ability to maintain the correct posture i.e. hold the posture without touching the backrest. At the baseline visit, the stroke participant performed three spins at 65º, 55º and 45º to test the feasibility of performing the spins in a repeated manner. As he successfully performed the spins, these inclination angles were chosen as the starting points for the intervention and were adjusted as the training progressed. The minimal criteria for the intended dosing was to complete at least 10 rotations (5 CW and 5 CCW directions) per session, three times a week, for a total of 4 weeks (12 sessions = 120 spins). The participant completed a total of 142 spins over a 4-week period. The details on the directions, inclination angles and number of spins are given in Table 1. Sufficient breaks were given at regular intervals or whenever asked for by the participant. A single session lasted for about 30 minutes including the breaks.

TABLE I. ALLCORE360º ROTATIONS (SPINS) PERFORMED OVER 12 SESSIONS OF INTERVENTION

Direction	Inclination angle (deg)				*Total*
	65	*55*	*45*	*40*	
Clockwise	1	20	34	16	71
Counter-clockwise	1	20	34	16	71
Total	2	40	68	32	**142**

C. Outcome Measures

The following assessments were performed at the baseline and follow up visits which were 4-weeks apart.

Trunk Impairment Scale (TIS). The TIS measures the motor impairment of the trunk after a stroke through the evaluation of static and dynamic balance and coordination tasks.

Berg Balance Scale (BBS). A 14-item clinical scale is used to evaluate static and dynamic balance. Each item is scored from 0 (lowest level of function) to 4 (highest level of function), with a maximum total score 56.

Timed Up and Go (TUG). TUG is a clinical test of functional mobility and is scored as time (seconds) required to complete the mobility task consisting of sit-to-stand, walk, and stand-to-sit tasks.

10-Meter Walk Test (10MWT). The 10MWT measures time to complete the 10 meter walk at a self-selected safe pace.

6-Minute Walk Test (6MWT). The 6MWT evaluates endurance and measures the distance walked on a flat, hard surface, indoors, in a period of 6 minutes.

Posturography. The assessment included standing on a balance-assessment platform (Neurocom Equitest Clinical Research System, Natus Inc.). The CoP data were recorded during 120 seconds of quiet standing (QS). Anterior-posterior (AP) and medial-lateral (ML) CoP range and root-mean-square (RMS) were computed.

Electromyography (EMG). EMG data were collected from selected trunk muscles bilaterally during three CW spins at 45°, 55°, and 65°, at baseline and follow-up. Rectus abdominis (RAB), latissimus dorsi (LD), superior erector spinae (SES) were recorded bilaterally at 2520 Hz using Noraxon DTS wireless EMG system (Noraxon, Scottsdale, AZ). Left LD (LLD) EMG data was excluded from analyses due to the channel malfunctioning. The data were band-pass filtered between 20 to 350 Hz (4th order Butterworth), rectified, and smoothed (5 Hz low-pass filtered). The 45° spin was considered as the maximal volitional contraction (MVC) trial for all muscle groups and was used to normalize EMG amplitudes during 55° and 65° spins. The rationale behind this was based on the fact that the 45° spin requires the highest level of neuromuscular effort to maintain the correct posture. The RMS values of the EMG signal during each spin were computed for the baseline and follow up visits.

Physical ACtivity Enjoyment Scale (PACES). PACES is an 18-item scale to assess the enjoyment of physical activity in adults [10]. Scores were determined using a 7-point bipolar rating scale with a maximum possible score of 126. Higher scores reflect a greater level of enjoyment for the training program. PACES was administered at the follow up visit only.

III. Results

Functional outcomes – Table 2 shows the changes in the outcomes assessing trunk function, balance and mobility after completing 12 sessions of core-strengthening program. The TIS increased by eight points from baseline to follow up– a clinically meaningful increment of 73% [3]. The BBS increased by 45.2% from baseline to follow up with a clinically meaningful increment of 14 points [11]. The TUG score decreased from baseline (22.6 sec) to follow up (17.5 sec), surpassing the minimum detectable change of 3.5 sec [12]. However, these functional improvements were also accompanied by a 5.6% reduction in walking speed measured during 10MWT and a 4.5% reduction in endurance, measured using 6MWT (Table 2).

TABLE II. FUNCTIONAL AND POSTUROGRAPHY OUTCOMES AT BASELINE AND FOLLOW UP

Assessments	*Baseline*	*Follow up*	*% change*
TIS	11	19	72.7 [a]
BBS	31	45	45.2[a]
TUG (sec)	22.6	17.5	-22.7 [a]
10MWT (sec)	12.6	13.3	5.6
6MWT (m)	250	240	-4.5
APCoP (RMS) (cm)	0.8	0.88	11
APCoP (range) (cm)	6.26	6.16	-1.5
MLCoP (RMS) (cm)	0.9	0.61	-32.3
MLCoP (range) (cm)	6.16	3.92	-29.2

a. clinically meaningful change

Posturography Outcomes – QS data showed reduced CoP excursions at the follow up visit (Fig. 3). This reduced postural sway was more apparent in the ML direction where MLCoP RMS and MLCoP Range reduced at follow up by

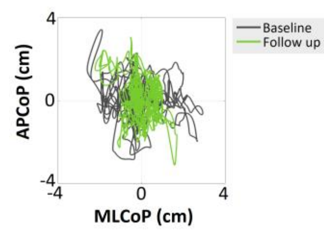

Figure 3. Statokinesiogram during 2-minute QS showing reduced postural sway at the follow up

32.3% and 29.2%, respectively (Table 2). The APCoP range also decreased at the follow up, by 1.5% while APCoP RMS increased by 11% (Table 2).

Electromyography Outcomes – Fig. 4 shows the polar representation of RAB EMG recorded from the affected (left) side. The muscle was at its maximal activation during the first (0°-90°) and the last quarter (270°-360°) of the spin as the significant effort was required to maintain the correct posture against gravity during these regions (Fig. 4). Further, the inclination angle of 45° (highest difficulty) elicited higher levels of activations compared to 65° (lowest difficulty) and correlation between the inclination angles and the levels of induced muscle activation was visually observed (Fig. 4 and

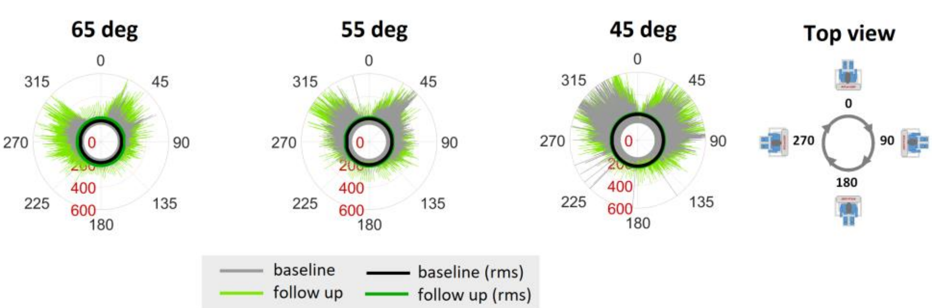

Figure 4. Left RAB (LRAB) EMG plotted on the polar axes to illustrate the activation profile in relation to the 360° spins at three inclination angles (65°, 55° and 45°). The circles represent the RMS values (%MVC) during the entire spin at baseline (black) and follow up (dark green). The radius axis (red) represents the activation levels in %MVC.

5). These observations were consistent for RRAB, RLD, LSES and RSES as well. As 45^o spins were used for EMG normalization, the EMG RMS amplitudes for 55^o and 65^o were compared between the visits (Fig. 5). At the follow up, left and right RAB muscles were the only muscles to show increased levels of activations, for both inclination angles, 65^o (LRAB: 74%, RRAB: 48.4%) and 55^o (LRAB: 22.3%, RRAB: 28.7%) (Fig. 5).

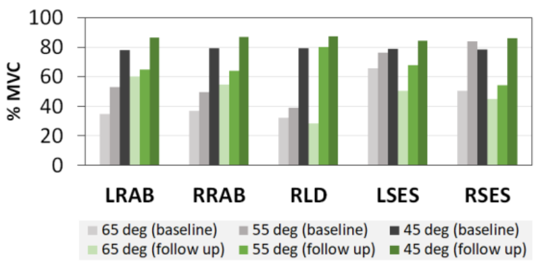

Figure 5. RMS EMG amplitude comparisons at three inclination angles at baseline and follow up visits.

Physical Activity Enjoyment Scale (PACES) - The participant scored 71 on PACES (scale range: 18 to 126) at the follow up showing high satisfaction levels while performing *AllCore360^o* spins.

IV. DISCUSSION

The objective of the current investigation was to evaluate the feasibility of a core-strengthening program delivered through a novel robotic device that specifically targets trunk muscles through a systematic, consistent, high-intensity exercise program. In a comprehensive review by Criekinge et al., a large amount of heterogeneity was found across studies evaluating trunk training protocols in terms of the type of exercises, intensity and duration of training [5]. Core-stability training is a major component of trunk rehabilitation but suffers from variability in the aforementioned factors, making the standardization of the treatment and interpretation of outcomes across studies challenging. The *AllCore360^o* intervention has three major strengths – systematicity, consistency and repeatability. The *AllCore360^o* core-strengthening program achieves the systematicity with its novel robotic design that enables the presentation of various, difficulty levels (in terms of inclination angles) based on patient's need, comfort and safety. Further, these difficulty levels directly modulate the neuromuscular response (Fig. 4 and 5) and hence can be used to maximize the engagement of muscles and their outputs. Trunk impairments have been suggested to be associated with the insufficient recruitment of high threshold motor units at high angular velocities and disuse of muscles [4]. The *AllCore360^o* offers a unique opportunity to not only engage the core muscles that may be underutilized but also enhance their activations using the gravitational forces in a no-impact, balanced, and coordinated fashion. Further, the resistance provided is always consistent as opposed to therapist-provided resistance. The robotic design provides the repeatability to enhance dosing and target neuroplasticity for optimal outcomes.

The changes observed in some of the functional outcomes post intervention were clinically meaningful. The change of +8 points in TIS is highly significant and clinically meaningful given that previously reported statistically significant differences in TIS post trunk rehabilitation intervention in the stroke population has been much smaller [3]. A change of +14 in BBS is almost three-times more than widely accepted clinically meaningful change of five points in the stroke population [11]. A change of 22.7% in TUG which surpasses the minimum detectable change for chronic stroke population was also observed [12].

While the results of the current single-subject case investigation are promising, these results need to be interpreted cautiously. In the future, a large-sample design should be implemented with an appropriate control group to truly understand the effectiveness of the *AllCore360^o* intervention. A larger sample will also enable further analysis and comparisons of EMG and fatigue. Nonetheless, the novel robotic design and enhanced engagement of neuromuscular mechanisms suggests the potential of *AllCore360^o* core-strengthening program to improving trunk function, balance and mobility post stroke.

REFERENCES

[1] C. Patten, J. Lexell, and H. E. Brown, "Weakness and strength training in persons with poststroke hemiplegia: rationale, method, and efficacy," *J Rehabil Res Dev,* vol. 41, pp. 293-312, May 2004.

[2] S. Karthikbabu, M. Chakrapani, S. Ganeshan, K. C. Rakshith, S. Nafeez, and V. Prem, "A review on assessment and treatment of the trunk in stroke: A need or luxury," *Neural Regen Res,* vol. 7, pp. 1974-7, Sep 5 2012.

[3] K. Haruyama, M. Kawakami, and T. Otsuka, "Effect of Core Stability Training on Trunk Function, Standing Balance, and Mobility in Stroke Patients," *Neurorehabil Neural Repair,* vol. 31, pp. 240-249, Mar 2017.

[4] S. Tanaka, K. Hachisuka, and H. Ogata, "Muscle strength of trunk flexion-extension in post-stroke hemiplegic patients," *Am J Phys Med Rehabil,* vol. 77, pp. 288-90, Jul-Aug 1998.

[5] T. Van Criekinge, S. Truijen, J. Schroder, Z. Maebe, K. Blanckaert, C. van der Waal, *et al.*, "The effectiveness of trunk training on trunk control, sitting and standing balance and mobility post-stroke: a systematic review and meta-analysis," *Clin Rehabil,* vol. 33, pp. 992-1002, Jun 2019.

[6] I. J. van Nes, B. Nienhuis, H. Latour, and A. C. Geurts, "Posturographic assessment of sitting balance recovery in the subacute phase of stroke," *Gait Posture,* vol. 28, pp. 507-12, Oct 2008.

[7] E. Duarte, E. Marco, J. M. Muniesa, R. Belmonte, P. Diaz, M. Tejero, *et al.*, "Trunk control test as a functional predictor in stroke patients," *J Rehabil Med,* vol. 34, pp. 267-72, Nov 2002.

[8] C. L. Hsieh, C. F. Sheu, I. P. Hsueh, and C. H. Wang, "Trunk control as an early predictor of comprehensive activities of daily living function in stroke patients," *Stroke,* vol. 33, pp. 2626-30, Nov 2002.

[9] G. Verheyden, A. Nieuwboer, L. De Wit, H. Feys, B. Schuback, I. Baert, *et al.*, "Trunk performance after stroke: an eye catching predictor of functional outcome," *J Neurol Neurosurg Psychiatry,* vol. 78, pp. 694-8, Jul 2007.

[10] J. W. Hung, C. X. Chou, Y. W. Hsieh, W. C. Wu, M. Y. Yu, P. C. Chen, *et al.*, "Randomized comparison trial of balance training by using exergaming and conventional weight-shift therapy in patients with chronic stroke," *Arch Phys Med Rehabil,* vol. 95, pp. 1629-37, Sep 2014.

[11] V. Hiengkaew, K. Jitaree, and P. Chaiyawat, "Minimal detectable changes of the Berg Balance Scale, Fugl-Meyer Assessment Scale, Timed "Up & Go" Test, gait speeds, and 2-minute walk test in individuals with chronic stroke with different degrees of ankle plantarflexor tone," *Arch Phys Med Rehabil,* vol. 93, pp. 1201-8, Jul 2012.

[12] P. P. Chan, J. I. Si Tou, M. M. Tse, and S. S. Ng, "Reliability and Validity of the Timed Up and Go Test With a Motor Task in People With Chronic Stroke," *Arch Phys Med Rehabil,* vol. 98, pp. 2213-2220, Nov 2017.