Exercise intensity is increased during upper limb movement training using a virtual rehabilitation system

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***Abstract*— Upper-limb (UL) training interventions are increasingly being developed using virtual reality (VR) platforms. However, since motor recovery is related to exercise intensity and task difficulty, it is important to determine whether these factors are considered in VR applications applied in different centers for patients with different motor impairment levels. We define exercise intensity as the total number of movement repetitions divided by the total minutes in active therapy.**

The main objective of this study was to determine the training intensity of a clinically-applied treatment program using VR in 3 centers involved in a multi-site study. Our secondary objective was to determine if training intensity differed among patients with different levels of UL sensorimotor impairment.

Patients with sub-acute unilateral stroke in the middle cerebral artery area (<6 mo post-stroke) with Fugl-Meyer Assessment (FMA-UL) scores ranging from 14-57, completed 10 50-minute UL training sessions with a VR rehabilitation application over 2 weeks, in rehabilitation centers located in 3 countries. Total training time (minutes), total number of movement repetitions, and success rates were extracted from game activity logs. Intensity was calculated for each game for each participant, related to UL impairment and compared between centers.

Exercise intensity was higher in one of the 3 centers ($p<0.01$). Participants had most difficulty with the games involving bilateral coordination and lateral reaching. Participants with higher FMA-UL scores had longer total training times ($r = 0.40$, $p = 0.03$) and started the training earlier within the subacute phase ($r = -0.38$, $p = 0.04$). Participants who used the VR system later in the subacute phase trained at a higher intensity than those who started earlier ($r = 0.43$, $p = 0.02$). However, their level of training intensity was not related to UL impairment.

The level of intensity attained with this training program was much higher than that reported in current stroke therapy practice. Despite different training centers, therapists progressed patients through the training program using similar training principles. Therefore, VR rehabilitation systems can be used to deliver intensive exercise programs in a standardized way and can be tailored to individual impairment levels.

Keywords*— *exercise intensity, virtual reality, personalized exercise, arm impairment

I. Introduction

Intensity of exercise is an important component contributing to motor recovery after stroke. Evidence suggests that the intensity of practice during rehabilitation is not sufficient to improve motor and functional recovery. Some of the reasons for this may be limited rehabilitation resources, time constraints,

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and lack of early motor recovery in the arm and hand [1]. Lang et al. [2] observed physical and occupational therapy sessions in inpatient and outpatient rehabilitation centers. The average session duration was 36 ± 14 minutes, and the average number of functional upper limb (UL) repetitions was 32. The number of repetitions was smaller in inpatient (23 ± 5) compared to outpatient settings (45 ± 13). In another study, Lang et al. [3] observed 36 outpatient treatment sessions. In these sessions, the average number of repetitions per session was 39 for active-exercise movements, 34 for passive-exercise movements and 12 for purposeful movement.

A wide range of rehabilitation interventions are used to improve motor and functional recovery such as task-specific training, strength training, constraint-induced movement therapy, mirror therapy, bilateral arm therapy, interventions for sensory impairment and neuromuscular electrical stimulation [8, 9]. Virtual rehabilitation (VR) is a technology-enhanced intervention that provides a simulated practice environment, with the advantage of providing feedback on movement execution and goal achievement. VR enables people to participate in activities in environments similar to the real world [10]. One of the attributes of VR is that it can motivate the patient to perform a greater number of movement repetitions [11]. Levin et al. [12] found that improvements in UL clinical impairments and activity scores occurred in more patients who received VR therapy comparing to participants in a conventional treatment group. A Cochrane review synthesized previous reviews of interventions to improve UL function after stroke [9]. Moderate-quality evidence suggests that VR interventions delivered in conjunction with conventional therapy may have a beneficial effect on UL impairment and activity outcomes. However, it is unknown whether VR applications actually deliver higher intensity treatment than that reported in conventional therapy [2, 3]. In addition, since the intensity of treatment is not well defined and documented, it is difficult to compare sensorimotor outcomes in studies that are conducted at different sites in which only `time of treatment` is equalized. In a step to address these gaps in knowledge, our main objective was to determine the training intensity of a clinically-applied treatment program using VR in 3 centers involved in a multi-site study. Our secondary objective was to determine if training intensity differed among patients with different levels of UL sensorimotor impairment.

The definition of training intensity varies. Previous studies have indicated that intensity can be measured as the number of hours in therapy [4, 5], but this definition does not consider the amount of actual exercise performed within the allotted therapy hour. Animal and human models suggest that a high number of repetitions of a newly learned or relearned behavior is needed to induce lasting neural changes (i.e. increased synapse number, strength or reorganization; [3, 6]). This suggests that the number of repetitions may be more relevant to motor recovery than the total therapy time [7]. In this study intensity of exercise is defined as the number of movement repetitions divided by the number of minutes in active therapy.

II. Methods

A. Design

Data was extracted from the treatment intervention part of a large international multicenter study, which was a single-blind randomized controlled trial.

B. Participants

Hospitalized patients with sub-acute stroke were recruited from rehabilitation centers. Participants were included if they had/were (1) a stroke in the middle cerebral territory, confirmed by magnetic resonance imaging/computed tomography (MRI/CT), and medically stable; (2) aged 25–80 years; (3) in the sub-acute stage of stroke (3 weeks to 6 months post stroke); (4) arm paresis (2–6/7 on the Chedoke-McMaster Stroke Assessment arm score, CMSA; [13]) and able to perform at least 30° elbow flexion and extension; and (5) elbow flexor and/or extensor spasticity (>1+ out of 4 on the Modified Ashworth Scale, MAS; [14, 15]). The ethics boards of all centers approved the project. All participants were informed of the procedures and provided written consent prior to participation.

C. Procedures

The level of UL impairment of each patient was assessed with the Fugl-Meyer Assessment of the UL (FMA-UL [16]). Participants completed 10, 50-minute UL training sessions with a VR rehabilitation system (Jintronix Inc., Montreal, Canada), over 2 weeks, in 3 rehabilitation centers located in different countries (Center 1-Canada, Center 2-Israel, Center 3-India). The VR therapy was completed as an adjunctive therapy and delivered by a site clinician. Participants sat in an armless chair with their knees at 90º and feet flat on the floor. The games were viewed on a large computer screen. Movements were tracked by an integrated Microsoft Kinect II camera. Participants were instructed to use their more-affected arm (unilateral activities) or both arms (bilateral activities) as quickly and precisely as possible according to the rules of each game. Different interactive games included catching falling objects and dropping them into containers (Catch, Carry and Drop, Theme: bilateral coordination; controlling the movement of a fish in different shapes (Fish Frenzy, Theme: controlled movement), moving tomatoes from a plant to a basket (Garden Grab, Theme: lateral reaching), and placing cups and cutlery on shelves and drawers (Kitchen Clean Up, Theme: reaching forward, Fig. 1). Games were calibrated according to the available ranges of the participant's UL movement and played in a random order within each training session. In addition, there were different difficulty levels (varying movements, number of items, play time) for each game through which participants were progressed. Increases in the difficulty level of each game were determined by the clinician according to their clinical judgement and guided by game progression guidelines and patient preferences.

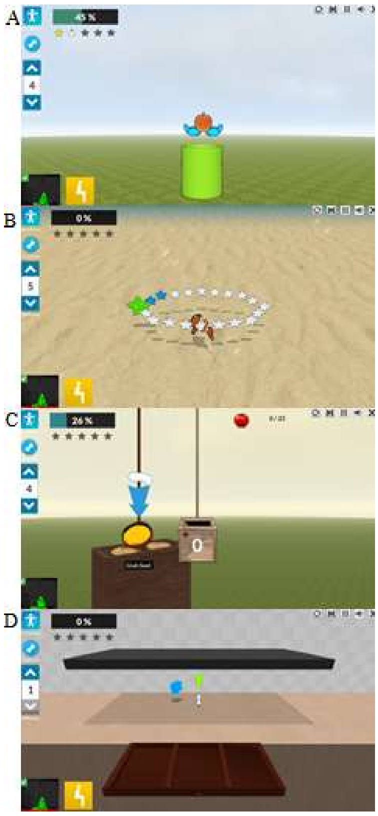

Fig. 1. Four games in the virtual rehabilitation system: A) Catch Carry Drop for bilateral coordination, B) Fish Frenzy for controlled movement, C) Garden Grab for lateral reaching, D) Kitchen Clean Up for reaching forward.

D. Data acquisition and analysis

Game activity logs from the Jintronix system were extracted that contained information about the total training time (minutes), total number of movement repetitions, and the success rate attained at each game level. Intensity was defined as the total number of movement repetitions/total training time and expressed as repetitions/minute.

E. Statistical analysis

Game activity log outcomes were summarized, compared between training centers and related to UL impairment levels based on the FMA-UL. Totals were compared between rehabilitation centers using one-way analyses of variance and Chi Square analysis, and related to impairment level using Pearson correlations (SPSS v20, SPSS Inc., Chicago, IL). Initial significance levels were set at $p<0.05$ for all statistical tests with Bonferroni corrections, where applicable.

III. Results

Thirty patients were recruited. See Table 1 for socio-demographic information.

TABLE 1. Socio-demographic and stroke information

Characteristics	*Center 1*	*Center 2*	*Center 3*
n	7	13	10
Age (years, mean ±SD)	54.4 ±10.5	57.4 ±9.7	56.8 ±8.7
Days post-stroke of treatment initiation (days)	45-146	31-132	24-153
Left-sided lesion (%)	43%	85%	60%
Ischemic stroke (%)	71%	69%	80%
Hemorrhagic stroke (%)	0%	15%	20%
Mixed stroke or unknown (%)	29%	15%	0%
Fugl-Meyer Assessment – Upper Limb (/66)	14-57	14-52	17-50

The average training time across centers was 471.1 ± 48.7 mins. Although the total training time in Center 2 was shorter compared to Center 3 ($F_{2,27} = 7.6$, $p = 0.002$), there was no difference in total training time of either center compared to Center 1 (Fig. 2). The intensity of exercise varied from 3 to 14 reps/min (average 6.6 ± 2.7 reps/min) with no differences between centers (Fig. 3).

The success rate for each game was very high across centers (Fig. 4), but there were significant differences between games ($F_{3,108} = 32.857$, $p = 0.000$; Table 2). Participants had the most difficulty with the games involving bilateral coordination and lateral reaching.

There were significant relationships between FMA-UL and total training time as well as time since stroke. A significant relationship was also found between training intensity and the time since stroke. Participants with higher FMA-UL scores had longer total training times ($r = 0.40$, $p = 0.03$; Fig. 5). These

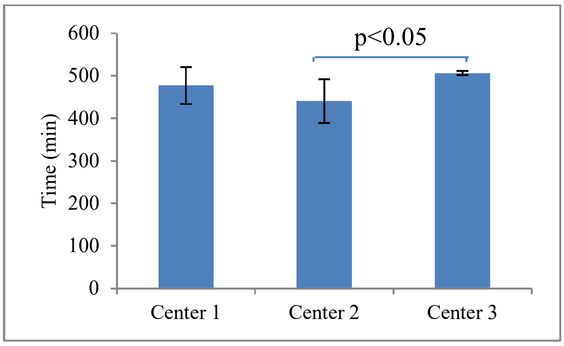

Fig. 2. Comparison of total training time between centers.

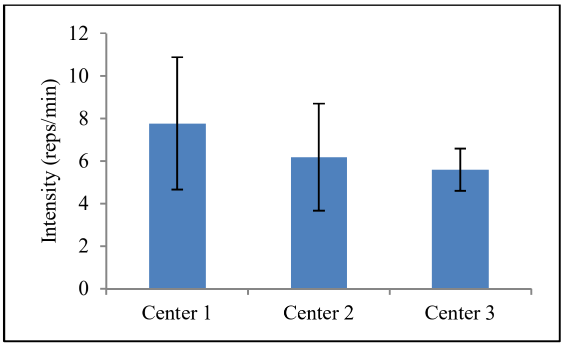

Fig. 3. Comparison of exercise intensity between centers expressed as the number of repetitions per minute.

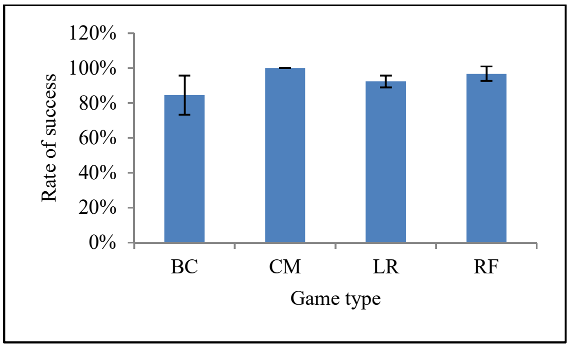

Fig. 4. Success rate for each game type.

TABLE 2. POST-HOC COMPARISONS OF SUCCESS RATES OF 4 GAMES

Game	n	Mean (%)	SD	Bonferroni Comparisons BC	CM	LR
BC	19	84.6	11.6			
CM	30	100	0	.000		
LR	30	92.2	3.2	.000	.000	
RF	30	96.6	4.3	.000	ns	.015

BC = bilateral coordination, CM = controlled movement, LR = lateral reaching, RF = reaching forward

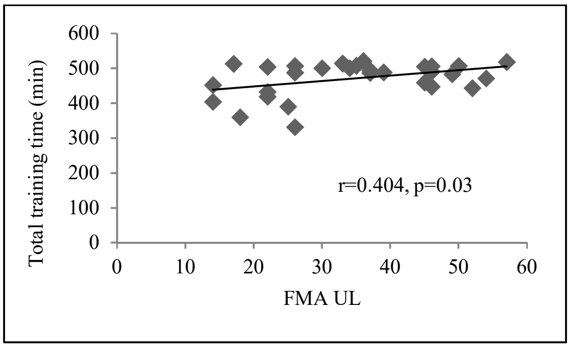

Fig. 5. Relationship between FMA and total training time.

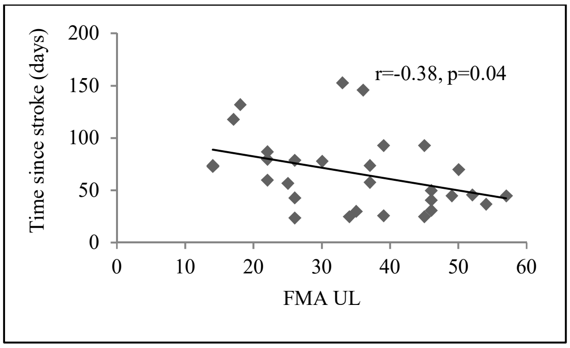

Fig. 6. Relationship between FMA and time since stroke.

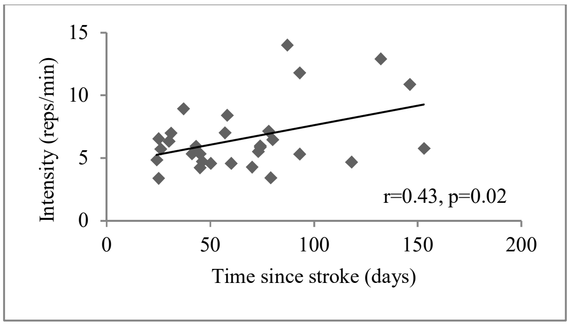

Fig. 7. Relationship between time since stroke and intensity.

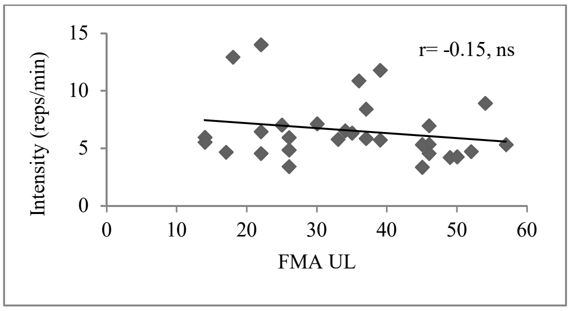

Fig. 8. Relationship between FMA and intensity for all participants

participants started training earlier within the subacute phase ($r = -0.38$, $p = 0.04$, Fig. 6). Participants who began VR training later in the subacute phase trained at higher intensities than those who began VR earlier (r = 0.43, p = 0.02; Fig. 7). However, the level of training intensity was not related to the level of UL impairment (Fig. 8).

IV. Discussion

The level of intensity attained with this UL training program in all training centers using the Jintronix VR system was an order of magnitude higher than the intensity reported for any type of therapy in current stroke interventions (i.e., 0.89 reps/min according to Lang et al. [3]). However, it should be noted that we did not compare the amount of UL training in VR in each center to that in conventional therapy at the same centers. Nevertheless, our results suggest that the VR system can be used to deliver the same level of training intensity in multiple centers located in different counties. This suggests that therapists progressed patients through the VR training program using similar training principles.

The games with the lowest success rates were bilateral coordination and lateral reaching. The bilateral task required coordination of both arms while the lateral reaching task required moving the arm across the midline. These tasks are more complicated because they require voluntary control of movements outside of the synergetic patterns [17,18].

Patients with more UL impairment have slower movements and lower endurance [19]. In order to attain 50 minutes of active training time they needed longer training sessions to account for slower movements and to incorporate rest periods.

No relationship was found between UL impairment and intensity. Participants with higher levels of UL impairment were capable of attaining the same level of intensity as those with lower UL impairment. This suggests that high levels of treatment intensity could be offered to patients with any level of UL impairment.

Future studies should directly compare UL training intensity in VR to that in conventional therapy in different centers and determine how clinicians can optimally integrate motor learning principles to enhance and progress personalized training using VR.

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References

[1] Barreca S, Wolf SL, Fasoli S, Bohannon R. Treatment interventions for the paretic UL of stroke survivors: a critical review. Neurorehabilitation and Neural Repair. 2003 Dec;17(4):220-6.

[2] Lang CE, MacDonald JR, Reisman DS, Boyd L, Kimberley TJ, Schindler-Ivens SM, Hornby TG, Ross SA, Scheets PL. Observation of amounts of movement practice provided during stroke rehabilitation. Archives of Physical Medicine and Rehabilitation. 2009 Oct 1;90(10):1692-8.

[3] Lang CE, MacDonald JR, Gnip C. Counting repetitions: an observational study of outpatient therapy for people with hemiparesis post-stroke. Journal of Neurologic Physical Therapy. 2007 Mar 1;31(1):3-10.

[4] Cooke EV, Mares K, Clark A, Tallis RC, Pomeroy VM. The effects of increased dose of exercise-based therapies to enhance motor recovery after stroke: a systematic review and meta-analysis. BMC Medicine. 2010 Dec;8(1):60.

[5] Veerbeek JM, van Wegen E, van Peppen R, van der Wees PJ, Hendriks E, Rietberg M, Kwakkel G. What is the evidence for physical therapy poststroke? A systematic review and meta-analysis. PloS One. 2014 Feb 4;9(2):e87987.

[6] Kleim JA, Jones TA. Principles of experience-dependent neural plasticity: implications for rehabilitation after brain damage. Journal of Speech, Language, and Hearing Research. 2008 Feb 1;51(1):S225-39.

[7] Lang CE, Lohse KR, Birkenmeier RL. Dose and timing in neurorehabilitation: prescribing motor therapy after stroke. Current Opinion in Neurology. 2015 Dec;28(6):549.

[8] Aşkın A, Atar E, Koçyiğit H, Tosun A. Effects of Kinect-based virtual reality game training on upper extremity motor recovery in chronic stroke. Somatosensory & Motor Research. 2018 Jan 2;35(1):25-32.

[9] Pollock A, Baer G, Campbell P, Choo PL, Forster A, Morris J, Pomeroy VM, Langhorne P. Physical rehabilitation approaches for the recovery of function and mobility following stroke. Cochrane Database of Systematic Reviews. 2014(4).

[10] Weiss PL, Keshner EA, Levin MF, Sharkey P. Applying virtual reality technologies to motor rehabilitation. Virtual Reality Technologies for Health and Clinical Applications. New York (NY): Springer. 2014:1-227.

[11] Holden MK. Virtual environments for motor rehabilitation. Cyberpsychology & Behavior. 2005 Jun 1;8(3):187-211.

[12] Levin MF, Snir O, Liebermann DG, Weingarden H, Weiss PL. Virtual reality versus conventional treatment of reaching ability in chronic stroke: clinical feasibility study. Neurology and Therapy. 2012 Dec 1;1(1):3.

[13] Gowland C, Stratford P, Ward M, Moreland J, Torresin W, Van Hullenaar S, Sanford J, Barreca S, Vanspall B, Plews N. Measuring physical impairment and disability with the Chedoke-McMaster Stroke Assessment. Stroke. 1993;24(1):58–63.

[14] Ashworth B. (1964). Preliminary trial of carisoprodol in multiple sclerosis. Practitioner. 192:540–542.

[15] Bohannon RW, Smith MB. (1987). Interrater reliability of a modified Ashworth scale of muscle spasticity. Physical Therapy. 67:206–207.

[16] Fugl-Meyer AR, Jääskö L, Leyman I, Olsson S, Steglind S (1974). The post-stroke hemiplegic patient. 1. a method for evaluation of physical performance. Scandinavian Journal of Rehabilitation Medicine, 7(1): 13-31.

[17] Brunnström S. (1970). Movement therapy in hemiplegia. NewYork: Harper and Row.
[18] Cirstea MC & Levin MF. (2000). Compensatory strategies for reaching in stroke. Brain. 123: 940-953.
[19] Duncan P, Studenski S, Richards L, Gollub S, Lai SM, Reker D, Perera S, Yates J, Koch V, Rigler S, Johnson D. (2003). Randomized clinical trial of therapeutic exercise in subacute stroke. Stroke, 34(9):2173-2180.