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Preliminary results of training with gravity compensation of the arm in chronic stroke survivors

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Abstract — **After stroke, arm function can be limited by a reduction in the selectivity of movements, due to involuntary coupling of shoulder abduction and elbow flexion, limiting the ability to reach. Gravity compensation of the arm reduces the required active shoulder abduction torques, which results in a larger range of motion instantaneously. Integration of a motivating rehabilitation game in the training program stimulates motor relearning processes during training. During 6 weeks, 8 chronic stroke survivors received 3 sessions of 30 minutes gravity compensated reach training per week using a rehabilitation game, which was evaluated by assessing motor status and a circle drawing task before and after training. After gravity compensation training, Fugl Meyer scores and the range of motion obtained from the circle drawing task had improved in a seven of the eight chronic stroke survivors. The present findings indicate that gravity compensation in combination with rehab games can be a valuable training modality for stroke rehabilitation.**

I. INTRODUCTION

After a stroke, a range of sensory and motor symptoms can be displayed, besides cognitive and emotional changes. Disturbance of the integration and generation of sensorimotor information can lead to muscle weakness, co-contraction and disturbed timing of muscle activity[1,2] This may also contribute to an impaired coordination between muscles, resulting in a limitation of selective movement control. Such stereotypical patterns of involuntary coupling of movements (i.e. synergies in flexion or extension patterns) are often observed in clinical practice[3-5]

Recent research has quantified abnormal coupling of the shoulder and elbow in chronic stroke survivors. An abnormal coupling of predominantly shoulder abduction and elbow flexion was found (in accordance with the flexion synergy), which means that with isometric shoulder abduction a certain amount of elbow flexion torque is generated simultaneously[6-8] In the case of reaching movements a similar abnormal coupling has been observed[9,10] During reach, shoulder abduction is required to lift the upper arm, which induces simultaneous elbow flexion torques. This limits the ability for elbow extension, reducing the extent of reach.

Arm support, or gravity compensation, has shown to reduce the influence of such involuntary coupling between the shoulder and elbow in cross-sectional studies. When the arm is supported, a smaller shoulder abduction torque is required, which reduces the extent to which elbow flexion torques are generated. This results in increases in planar range of motion of the arm[9-13].

During training, motor relearning processes can be stimulated by providing a motivating and challenging environment, including additional feedback on performance[14]. To this end, we implemented a rehab game (FurballHunt) in the gravity compensation training program [15] .

The objective of the present study is to examine changes in the range of motion and motor status after training with the Freebal[12], a dedicated device that reduces abnormal synergies by supporting the weight of the arm, integrated with a rehab game FurballHunt in chronic stroke survivors.

II. METHODS

A. Subjects

Nine chronic stroke survivors (time post-stroke at least 6 months) were recruited from the local rehabilitation center and included in the study if they could move the shoulder and elbow joint partly against gravity without shoulder pain, could understand and follow instructions, and had provided written informed consent. The study was approved by the local medical ethics committee.

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B. Study design

Subjects received a total of 18 sessions of gravity compensation training during 6 weeks, with 3 sessions of 30 minutes per week, supervised by a physical therapist, who was not involved in the evaluation assessments. Changes in arm function due to gravity compensation were evaluated in 2 pre and 1 post training measurements, during two weeks before and within one week after the training period.

C. Gravity compensation training

Gravity compensation was implemented by a passive device (Freebal) using spring mechanisms[12] The amount of gravity compensation was reduced when performance increased, to ensure a challenging and motivating training.

Gravity compensation training consisted of reach exercises performed within a custom designed game environment of FurballHunt (figure 1), based on motion capturing using a webcam[15] In the game, birds had to be chased away by movements of the arm. The faster the birds are chased, the more points are awarded. Game difficulty can be adjusted by the physical therapist by changing the positions of the reach targets, game speed, and predictability.

Figure 1. Gravity compensation device 'Freebal' (on the right) in combination with rehabilitation game ‘FurballHunt’ (table display)

D. Evaluation task

To examine changes in arm function due to gravity compensation training, motor status and movement performance of a circle drawing task were evaluated before and after training. Motor status of the arm was evaluated using the upper extremity part of the Fugl-Meyer (FM) assessment (66 points is the maximal score, indicating fully selective movement control).[5]. Researchers (GP + TK) were blinded to the training results. The FM was taken by TK. The evaluation task consisted of a circle drawing task. During the circle drawing task subjects drew five consecutive circles. Although the subjects were strapped in the Dampace[16], some movement of the trunk was possible, mainly because of loosening of the safety belt due to the great effort some subjects had to make to perform the movements. Since hand positions were calculated relative to the shoulder position, the recorded hand position were not affected by these compensatory trunk movements. The area of each circle was defined as the area enclosed by the projection of the hand path onto the table surface. Begin and end positions of the circle were connected.

E. Data recording

Kinematic data were recorded with the use of a robotic device (Dampace)[16] The Dampace is an exoskeleton (two splints along the upper and lower arms with hinges at the location of the shoulder and elbow joints) which is attached to the upper and lower arm by soft straps. The length of the upper and lower arm parts of the exoskeleton can be adjusted to the person’s arm length. It has three movement axes at the shoulder (enabling ante-/retroflexion, ab-/adduction and endo-/exorotation) and one movement axis at the elbow (enabling flexion/extension) with integrated potentiometers and rotational optical encoders. The recorded data were translated to changes in joint angles and positions of arm segments during movement, using each person’s arm segment lengths.

Shoulder movements were described using two angles: the plane of elevation (SP; angle of humerus with a virtual line through the shoulders – upper arm pointing laterally represents -90°) and the angle of elevation (SE; angle between humerus and trunk – humerus aligned with trunk represents 0°). The elbow angle was defined as the angle between the humerus and forearm (extension represents 180°).

F. Data analysis

The FM scores the enclosed area of a circl drawing taks were used as outcome measures. All outcome measures were compared between the evaluation sessions before (average of the two sessions) and after training within each stroke survivor.

III. RESULTS

A. Subject characteristics

One subject (s3) did not complete the training, because of a too high physical burden, mainly caused by the distance he had to cover, travelling from his house to the rehabilitation center. Of the remaining 8 stroke survivors (3 male, 5 female), mean time post-stroke was 30 months (range 8-58 months). All but one patients suffered from a first-ever ischemic stroke in the cerebral arteries. Subject 6 had a cerebellar infarction. Only subject 1 and 2 received conventional occupational therapy besides gravity compensation training. The chronic stroke survivors in the present study included a wide range of stroke severity, according to initial FM scores ranging from 7 to 61 points.

B. Changes in motor status

After training, FM scores had increased in 7 of 8 stroke survivors (table 1). In 3 of those 7 survivors, the increase was at least 6.5 (up to 8) points, achieving a clinically relevant increase of 10%[17] The average change on group level was an increase of 3.3 points.

Table 1. The two baseline and post-training FM scores per subject

Subject	*Age (yrs)*	*Time post stroke(months)*	*B1 FM*	*B2 FM*	*Post FM*	*change in FM*
1	53.3	58	9	15	20	+8.0
2	72.2	13	43	48	53	+7.5
4	55.4	27	10	10	11	+1.0
5	53.0	24	42	47	51	+6.5
6	62.4	30	60	62	64	+3.0
7	64.2	39	45	46	47	+1.5
8	69.1	39	7	7	10	+3.0
9	55.3	8	25	26	21	-4.5

C. Changes in Range of Motion

All subjects except subject 9 increased their active range of motion during a circle drawing task (Fig. 2). The enclosed handpaths corresponded well with the initial Fugl Meyer scores. Baseline values of both the Fugl Meyer scores and the active range of motion were no good indicators for the training effect.

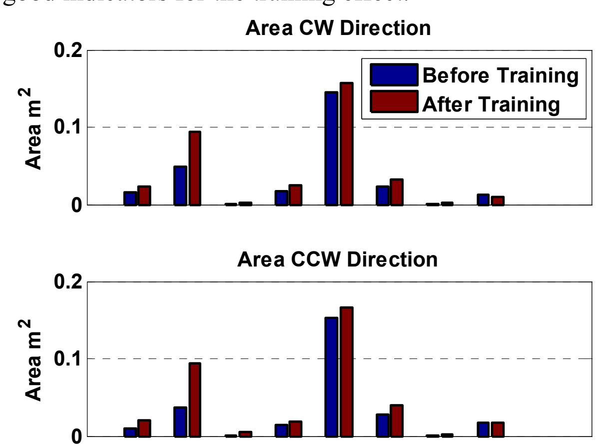

Figure 2. The enclosed area while drawing a circle in clock wise (top panel) and counter clockwise direction (bottom panel) before and after training for subject 1 to 9 (from left to right).

IV. Discussion

Although the results have to be interpreted carefully, since data of only 8 survivors are available, the present study does indicate that a combination of gravity compensation and virtual reality can be a promising and valuable training modality for stroke rehabilitation, especially because the training intensity was not very high. This is supported by positive results of a few other studies examining the effect of training using arm support as separate training modality. A study applying gravity compensation training using a passive exoskeleton during virtual functional exercises resulted in an improved motor status and reaching distance of the arm[24]. Another study using the same gravity compensation device in a larger group of stroke survivors also showed improved arm movement ability[25]. In addition, reach training by de-weighting the arm via sling suspension resulted in modest improvements of motor status of proximal arm function[26].

The present findings were slightly more pronounced than in the study applying sling suspension, with respect to motor status[26] However, that study had only half as much training sessions as the present study (9 sessions of 30 minutes during 3 weeks), which greatly reduces the total amount of training. Also, the exercises performed with sling suspension involved separate or combined shoulder flexion and extension and elbow flexion and extension, which does not involve highly task-specific and meaningful exercises. In contrast, the improvements in motor status and reach distance in the present study were somewhat smaller than those in the study by Sanchez et al[24] This may be related to a higher training intensity (3 sessions per week of 45 minutes during 8 weeks). Another factor can be the functional nature of the exercises. In the study by Sanchez et al., arm training involved 2D functional exercises in a virtual environment, including a grip sensor to incorporate hand function exercises. Although the present study did involve a virtual environment, our training program focused on the proximal arm, and did not include specific exercises for the hand. The increase in motor status of the arm in the study by Housman et al., with a larger training intensity (3 sessions per week of 1 hour during 8 weeks), was also slightly higher than in the present study. These discrepancies highlight the potential benefit of a higher training intensity and implementation of functional exercises, including the hand, to increase task-specificity.

Although the preliminary results are encouraging, follow up measurements are needed to investigate whether the gains are sustainable. The finding that one out of eight of the subjects presented a decrement in the FM score and enclosed area stresses the need for more and better assessments of motor impairments like spasticity and increased muscle tone. We can not exclude the possibility that for this subject the great effort required by the exercise produced a worsening of the subject's arm functioning. In this study the amount of weight support was adjusted by the therapist based on the judgment of the performance of the stroke survivor. An improvement would be to automatically adjust the amount of support based on standardized metrics of the performance associated with the exercise.

V. Conclusion

Despite the small number of participants, the present explorative study suggests that training with gravity compensation in combination with a rehab game has the potential to improve unsupported arm movement of chronic stroke survivors with a variety of impairments, ranging from mild to severe hemiparesis.

References

[1] Chae J, Yang G, Park BK, and Labatia I, "Muscle weakness and cocontraction in upper limb hemiparesis: relationship to motor impairment and physical disability," *Neurorehabil Neural Repair*, vol. 16, pp. 241-248, 2002.

[2] Chae J, Yang G, Park BK, and Labatia I, "Delay in initiation and termination of muscle contraction, motor impairment, and physical disability in upper limb hemiparesis," *Muscle Nerve*, vol. 25, pp. 568-575, 2002.

[3] Brunnstrom S . *Movement therapy in hemiplegia, a neurophysiological approach*, New York: Harper & Row, Publishers, 1970.

[4] Twitchell TE , "The restoration of motor function following hemiplegia in man," *Brain*, vol. 74, pp. 443-480, 1951.

[5] Fugl-Meyer AR, Jääskö L, Leyman I, Olsson S, and Steglind S, "The post-stroke hemiplegic patient. A method for evaluation of physical performance," *Scand J Rehab Med*, vol. 7, pp. 13-31, 1975.

[6] Dewald JPA, Pope PS, Given JD, Buchanan TS, and Rymer WZ, "Abnormal muscle coactivation patterns during isometric torque generation at the elbow and shoulder in hemiparetic subjects," *Brain*, vol. 118, pp. 495-510, 1995.

[7] Beer RF, Given JD, and Dewald JPA, "Task-dependent weakness at the elbow in patients with hemiparesis," *Arch Phys Med Rehabil*, vol. 80, pp. 766-772, 1999.

[8] Beer RF, Dewald JPA, and Rymer WZ, "Deficits in the coordinaton of multijoint arm movements in patients with hemiparesis: evidence for disturbed control of limb dynamics," *Exp Brain Res*, vol. 131, pp. 305-319, 2000.

[9] Dewald JPA and Beer RF, "Abnormal joint torque patterns in the paretic upper limb of subjects with hemiparesis," *Muscle Nerve*, vol. 24, pp. 273-283, 2001.

[10] Beer RF, Dewald JPA, Dawson ML, and Rymer WZ, "Target-dependent differences between free and constrained arm movements in chronic hemiparesis," *Exp Brain Res*, vol. 156, pp. 458-470, 2004.

[11] Sukal TM, Ellis MD, and Dewald JPA, "Shoulder abduction-induced reductions in reaching work area following hemiparetic stroke: neuroscientific implications," *Exp Brain Res*, vol. 183, pp. 215-223, 2007.

[12] Stienen AHA , Hekman EEG, Van der Helm FCT, Prange GB, Jannink MJA, Aalsma AMM, and Van der Kooij H, "Freebal: dedicated gravity compensation for het upper extremities," *Proceedings of the 10th International Conference on Rehabilitation Robotics (ICORR),* June 13-15, 2007, Noordwijk aan Zee, the Netherlands, pp. 804-808.

[13] Prange GB, Stienen AHA, Jannink MJA, Van der Kooij H, IJzerman MJ, and Hermens HJ, "Increased range of motion and decreased muscle activity during maximal reach with gravity compensation in stroke patients," *Proceedings of the 10th International Conference on Rehabilitation Robotics (ICORR),* June 13-15, 2007, Noordwijk aan Zee, the Netherlands, pp. 467-471.

[14] Winstein CJ and Campbell Stewart J. Conditions of task practice for individuals with neurologic impairments. In: *Textbook of neural repair and rehabilitation. Medical Neurorehabilitation Volume II*, eds. Selzer M, Clarke S, Cohen L, Duncan P, and Gage F. Cambridge, UK: Cambridge University Press, 2006.pp. 89-102.

[15] Prange GB, Krabben T, Molier BI, Van der Kooij H, and Jannink MJA, "A low-tech virtual reality application for training of upper extremity motor function in neurorehabilitation," *Proceedings of Virtual Rehabilitation 2008; 25-27 August 2008,* Vancouver, Canada, (DOI 10.1109/ICVR.2008.4625113)

[16] Stienen AHA , Hekman EEG, Van der Helm FCT, Prange GB, Jannink MJA, Aalsma AMM, and Van der Kooij H, "Dampace: dynamic force-coordination trainer for the upper extremities," *Proceedings of the 10th International Conference on Rehabilitation Robotics (ICORR),* June 13-15, 2007, Noordwijk aan Zee, the Netherlands, pp. 820-826.

[17] Gladstone DJ, Danells CJ, and Black SE, "The Fugl-Meyer assessment after stroke: a critical review of its measurement properties," *Neurorehab Neural Repair*, vol. 16, pp. 232-240, 2002.

[18] Kwakkel G, Wagenaar RC, Twisk JWR, Lankhorst GJ, and Koetsier JC, "Intensity of leg and arm training after primary middle-cerebral-artery stroke: a randomised trial," *Lancet*, vol. 354, pp. 189-194, 1999.

[19] Feys HM, De Weerdt WJ, Selz BE, Steck GAC, Spichiger R *et al.*, "Effect of a therapeutic intervention for the hemiplegic upper limb in the acute phase after stroke. A single-blind, randomized, controlled multicenter trial," *Stroke*, vol. 29, pp. 785-792, 1998.

[20] Barreca S, Wolf SL, Fasoli S, and Bohannon R, "Treatment interventions for the paretic upper limb of stroke survivors: a critical review," *Neurorehabil Neural Repair*, vol. 17, pp. 220-226, 2003.

[21] Prange GB, Jannink MJA, Groothuis CGM, Hermens HJ, and IJzerman MJ, "A systematic review of the effect of robot-aided therapy on recovery of the hemiparetic arm after stroke," *J Rehabil Res Dev*, vol. 43, pp. 171-184, 2006.

[22] Kwakkel G, Kollen BJ, and Krebs HI, "Effects of robot-assisted therapy on upper limb recovery after stroke: A systematic review," *Neurorehabil Neural Repair*, vol. 22, pp. 111-121, 2008.

[23] Johnson MJ, "Recent trends in robot-assisted therapy environments to improve real-life functional performance after stroke," *J Neuroengineering Rehabil*, vol. 3, 2006.

[24] Sanchez RJ, Liu J, Rao S, Shah P, Smith R *et al.*, "Automating arm movement training following severe stroke: functional exercises with quantitative feedback in a gravity-reduced environment," *IEEE Trans Neural Syst Rehabil Eng*, vol. 14, pp. 378-389, 2006.

[25] Housman SJ, Le V, Rahman T, Sanchez RJ, and Reinkensmeyer DJ, "Arm-training with T-WREX after chronic stroke: Preliminary results of a randomized controlled trial," *Proceedings of the 10th International Conference on Rehabilitation Robotics (ICORR),* June 13-15, 2007, Noordwijk aan Zee, the Netherlands, pp. 562-568 (DOI 10.119/ICORR.2007.4428481), 2007.

[26] Amirabdollahian F, Loureiro R, Gradwell E, Collin C, Harwin W *et al.*, "Multivariate analysis of the Fugl-Meyer outcome measures assessing the effectiveness of GENTLE/S robot-mediated stroke therapy," *J Neuroengineering Rehabil*, vol. 4, 200