ORIGINAL ARTICLE

Use of Visual Force Feedback to Improve Digit Force Direction During Pinch Grip in Persons With Stroke: A Pilot Study

Na Jin Seo, PhD, Heidi W. Fischer, MS, OT, Ross A. Bogey, DO, William Z. Rymer, MD, PhD, Derek G. Kamper, PhD

ABSTRACT. Seo NJ, Fischer HW, Bogey RA, Rymer WZ, Kamper DG. Use of visual force feedback to improve digit force direction during pinch grip in persons with stroke: a pilot study. Arch Phys Med Rehabil 2011;92:24-30.

Objective: To investigate whether visual feedback of digit force directions for the index fingertip and thumb tip during repeated practice of grip force production can correct the digit force directions for persons with stroke during grip assessments. Following stroke, the paretic fingers generate digit forces with a higher than normal proportion of shear force to compression force during grip. This misdirected digit force may lead to finger-object slip and failure to stably grasp an object.

Design: A case series.

Setting: Laboratory.

Participants: Persons (N=11) with severe chronic hand impairment after stroke.

Interventions: Four training sessions during which participants practiced directing the index finger and thumb forces in various target directions during pinch using visual feedback.

Main Outcome Measure: Digit force direction during pinch and clinical hand function scores were measured before and immediately after the training.

Results: Study participants were able to redirect the digit force closer to the direction perpendicular to the object surface and increase their hand function scores after training. The mean ratio of the shear force to the normal force decreased from 58% to 41% (SD, 17%), the mean Box and Block Test score increased from 1.4 to 3.4 (SD, 2.0), and the mean Action Research Arm Test score increased from 10.8 to 12.1 (SD, 1.3) ($P<.05$ for all 3 measures).

Conclusions: Repeated practice of pinch with visual feedback of force direction improved grip force control in persons with stroke. Visual feedback of pinch forces may prove valuable as a rehabilitation paradigm for improving hand function.

Key Words: Biofeedback, psychology; Fingers; Hand; Rehabilitation; Feedback, sensory; Stroke; Touch.

STROKE IS A LEADING cause of long-term disability in the United States, affecting more than 6.5 million people.[1] The impairment and functional loss induced by stroke are often severe in the hand,[2-5] reducing independence and diminishing quality of life. The severity of the problem demands that effective hand rehabilitation interventions be developed based on impairment mechanisms. Although one side of the body is largely unaffected by the stroke, many tasks of daily living require bimanual coordination. Restoration of even the ability to stably grip objects with the paretic hand, while the object is manipulated by the contralateral hand (eg, opening a bottle, pulling out dental floss from a container, zipping up a pocket, removing a cap from a pen), would significantly improve the capacity to perform activities of daily living.

Unfortunately, stable grip is typically difficult to achieve in persons with severe hand impairment. Successful grip generation requires that forces generated by the digits are properly scaled and directed with respect to the grasped object surface.[6-9] After stroke, force scaling is impaired during grasp-and-lift tasks.[10-13] Additionally, grip strength is reduced,[14] force fluctuation during tasks is increased,[10] and the ability to execute predictive grip force control is diminished.[15,16]

Recently, we have shown that force misdirection also plays a substantial role in grasp impairment,[17] often resulting in the object slipping out of the person's grasp. Stroke survivors with severe hand impairment tend to produce large shear forces, parallel to the object surface, in relation to the force normal to the object surface (eg, persons with stroke generated a shear force of 5N while generating a maximum pinch force of 12N with the paretic hand, whereas healthy persons generated a shear force of 6N while generating a maximum pinch force of 45N).[17] Thus, although the person may possess sufficient strength to grip the object, the improper force direction (ie, high ratio of shear force to normal force) causes the object to

List of Abbreviations

ANOVA	analysis of variance
ARAT	Action Research Arm Test
BBT	Box and Block Test
EDC	extensor digitorum communis
FDI	first dorsal interosseous
FDS	flexor digitorum superficialis
IP	interphalangeal
MANOVA	multivariate analysis of variance
MVC	maximum voluntary contraction

From the Department of Industrial Engineering, University of Wisconsin-Milwaukee, Milwaukee, WI (Seo); Sensory Motor Performance Program, Rehabilitation Institute of Chicago, Chicago, IL (Seo, Fischer, Bogey, Rymer, Kamper); Department of Physical Medicine and Rehabilitation, Northwestern University, Chicago, IL (Bogey, Rymer); and Department of Biomedical Engineering, Illinois Institute of Technology, Chicago, IL (Kamper).

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Correspondence to Na Jin Seo, PhD, Dept of Industrial Engineering, University of Wisconsin-Milwaukee, PO Box 413, Milwaukee, WI 53201, e-mail: *seon@uwm.edu*. Reprints are not available from the authors.

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slide away from the digits.[18] The mean ratio of shear force to normal force at the thumb and the index finger tips during static grip against a fixed object was almost 3 times as great for persons with stroke as for age-matched, neurologically intact persons and the nonparetic digits of the persons with stroke.[17] One of the sources for digit force misdirection may be lesions affecting the corticospinal tract resulting in altered muscle activation patterns (ie, diminished excitation of intrinsic muscles and extrinsic extensor muscles, and relatively hyperexcited long finger flexor muscles[17,19,20]). Such alteration in muscle activation patterns can cause the digit force to be directed close to the distal direction from the fingertip (as opposed to the palmar direction) and, thus, more tangentially than orthogonally relative to the grip surface during pinch grip.[8,21-23] Alternatively, impaired perception of sensation caused by lesions affecting somatosensory and motor cortices can contribute to digit force misdirection as described below.

Digit force coordination uses tactile feedback from the skin of the finger.[6,7,24,25] Reduced sensation and consequent impairment in the closed-loop control[26-28] after stroke may contribute to the altered digit force direction (ie, abnormally high shear to normal force ratio). Persons with stroke may not realize that they are producing finger forces with excessive shear force. Salient task-relevant sensory feedback[29,30] has shown promise in improving motor recovery after stroke.[31-35] For instance, persons with chronic stroke could reduce excessive grip force after training using visual feedback of their actual grip force in relation to a target grip force.[31]

The objective of this study was to investigate whether visual feedback of digit force directions for the index fingertip and thumb tip during repeated practice of grip force production can correct the digit force directions for persons with stroke during grip assessments. The effect size in the shear to normal force ratio was 17%, which is half of the difference in the force ratio between the paretic hands and asymptomatic hands in the previous study,[17] assuming that feedback training only compensates for the sensory impairment, not motor impairment. An instrument to measure and display 3-dimensional digit forces was developed and used in a 4-session training protocol. Force direction and performance of clinical assessments were evaluated before and after completion of the training protocol in persons with chronic hand impairment after stroke.

METHODS

Study Participants

Eleven persons with chronic hemiparesis subsequent to stroke participated in this study. The inclusion criteria were (1) the occurrence of a single stroke at least 9 months before the study; (2) severe hand impairment as indicated by a rating of stage 2 to 3 for the Hand section of the Chedoke-McMaster Stroke Assessment[36]; and (3) the ability to produce a 5-N pinch force (equivalent to approximately 8% of the mean pinch strength for healthy older adults[37]) against a fixed instrumented object (fig 1A) with the distal phalanges of the paretic thumb and index finger. Subjects were permitted to pinch through their preferred digit orientation (ie, producing force with either the palmar or lateral aspects of the digits). The exclusion criteria were (1) cognitive dysfunction that precluded comprehension of experimental tasks; and (2) history or clinical signs of concurrent medical problems such as an orthopedic condition in the hand.

Time elapsed since stroke ranged from 2 to 20 years. The mean age ± SD was 56±9 years (range, 38–69y). Eight participants exhibited sensory deficits for the paretic fingertip pads, determined by the 2-point discrimination test (with the threshold distance ≥6mm).[38,39] Three participants did not exhibit sensory deficits for the paretic digits. Nonparetic digits did not demonstrate sensory deficits for any participant. All participants signed the consent form approved by the Institutional Review Board before beginning participation in the study.

Procedure

To evaluate the effect of training with visual feedback, each subject participated in 4 training sessions, along with 2 evaluation sessions. The 1-hour training sessions were spread over 2 weeks. Evaluation sessions were performed before the first training session and immediately after the last training session. Outcomes were compared between the 2 evaluation sessions (before vs after training) for each study participant. The study participants did not receive additional therapy during the 2 weeks.

Training. Participants were seated with the elbow flexed at 90°, the forearm strapped to a horizontal table, and the wrist held in the neutral posture with a splint. The training consisted of controlling forces applied by the paretic thumb and index finger to an instrumented object (see fig 1A). This instrumented object[17] consisted of 2 independent plates, each connected to a miniature load cell (Nano17, Mini40).[a] The load cells measured the 3-dimensional forces applied by the thumb and the index finger separately. The grip surfaces on the plate were covered with a sheet of rubber with a coefficient of friction of 0.9 with respect to the skin[40] to minimize finger-object slip. The distal segments of the index finger and thumb were positioned against the plates.

During the training, participants strove to control the shear and normal forces applied to the instrumented object with each of the 2 digits. Visual feedback was displayed on a computer screen (fig 1B) with a refresh rate of 0.1Hz. Namely, 2 glasses were shown, each representing each digit force (one for the thumb and the other for the index finger). The magnitude and direction of the shear forces were represented by the location of the bottom of the glass. Thus, the (Fx,Fy) shear forces were mapped to the (x,y) glass location. Zero shear force mapped to the origin in the center of the screen. Normal force was represented as the water level in the glass.

Participants were instructed to attempt to position the bottoms of the 2 glasses within the shown target circle, while keeping the water level in the glass (actual normal force) above the tick marks (required normal force) (see fig 1B). The goal was to maintain this magnitude and direction of force for a period of at least 1 second. The software controlling the display was written in MATLAB.[b]

A given trial ended when the participant accomplished the task or when the maximum allowed period of 30 seconds passed, whichever came first. On the completion of a trial, the lowest ratios of absolute shear force error to normal force for each digit were recorded. Shear force error was computed as the norm of the vector from the required (Fx,Fy) shear forces for the glasses to be at the center of the target circle to the actual shear forces.

Each training session had a total of 84 trials (14 consecutive trials per block × 6 blocks per session). A minimum of 3 minutes of rest break was provided between consecutive blocks. The center of the target circle was at the origin for 6 of 14 trials in a block. For the other 8 trials, the center of the target circle was at 1 of the 8 positions surrounding the center circle (see fig 1B). The distance between the origin and the center of each of the 8 surrounding target circles was set equal to 50% of the target normal force. The target normal force was 20% of the normal force recorded during maximum grip during the pre-