Virtual Reality and Hand Rehabilitation Part II: Physiotherapy for Hypoplastic Thumb Using Computer Simulation

Bassem G. El Nahass,Sc.D., R.P.T., and Manal M. Ismail, M.Sc.
Department of Traumatology and Orthopaedic Physical Therapy, Faculty of Physical Therapy, Cairo University.

ABSTRACT

A child with congenital thumb hypoplasia is not likely to develop an effective function after reconstruction. The effects of training by a computer simulation program after reconstruction were investigated. Nineteen children (26 hypoplastic thumbs) participated in the study. They were randomly assigned to two groups: the experimental and the control group. Twelve sessions were conducted for the experimental group. Each session consisted of training of different grasp pattern (two point palmar pinch, tip pinch, lateral pinch) using the computer simulation program. The student "t" test was used to compare the measured value of pinch strength, accuracy and time of grasp pattern of the experimental group with that of the control group. It was found that the percentage of accuracy of two point palmar pinch, tip pinch and lateral pinch was 77%, 78% and 75% respectively, which was significantly higher than the control group. The time taken for ten trials of the three types of pinch was not statistically different from that of the control group. Concerning strength, it was 35.1% of the opposite side in the control group and 73.5% of the opposite side in the experimental group, which is significantly improved. It was concluded that the developed computer simulation program produces better results concerning the hand function. It was an interesting and motivating tool for the children.

Key words: Hypoplastic thumb, Reconstruction, Hand Rehabilitation, Computer Simulation. Hand assessment.

INTRODUCTION

The hypoplastic thumb is a defective digit incomplete in its development. The degree of hypoplasia can range from minimal shortening to complete absence of the thumb. Type I is a short thumb, type II is an adducted thumb, type III is an abducted thumb, type IV is a floating thumb and type V is an absent thumb. The soft tissue is involved, and deficiencies of the intrinsic and extrinsic structures contribute to the disabilities of the thumb. Grasp and prehension are significantly decreased in the hypoplastic thumb[1,2,11,17].

Reconstruction should be designed to restore function. This usually requires tendon transfers, correction of skin deficiency, and soft tissue structures, and stabilization of inadequate joints. Type IV (pouce flottant) and type V (absent thumb) require pollicization. The postoperative function of pollicized digit is related to the preoperative condition of the index finger [3,13,22].

The concept of body image was explained by giving the example of the phantom limb phenomena. It is logical to presume that there is body image of "normal hand", which gradually gets hazy the longer a paralysis lasts. This gives an explanation of the inability to use the reconstructed thumb after pollicization. Hence, reeducation after surgery is important. It was suggested that when available, an EMG visual feedback would be a good method in reeducation therapy [16].

EMG biofeedback techniques have been successfully used as an adjunct to standard treatment techniques with various neuromuscular disorders[7,9].

EMG biofeedback was used for muscle reeducation in cases of facial palsy. Substantial improvement in facial symmetry was achieved [4,6].

EMG biofeedback was used for reeducation of the abductor hallucis muscle in normal subjects. It was found that EMG biofeedback was very effective in increasing EMG activity in the abductor hallucis muscle and in increasing the low initial range of motion. EMG biofeedback was found to be highly effective when subjects had little initial use of the target muscle [15].

The importance of biofeedback and tapping or stroking to provide proprioceptive input to help the patient to activate his transfer initially was considered. The use of electrical stimulation for the same purpose was also proposed[21].

Simulation can be applied for rehabilitation of specific disorders by training exactly those functions that are disturbed. Creating virtual scenarios, in which series of motor tasks are generated, can do this. This will produce a motivating effect for patients arising from the precise feedback of their success in real time [10].

Virtual reality (VR) is synonymous with simulation. Simulation that tickles all the senses and uses all the latest technology [20].

The purpose of this study was to investigate the effectiveness of the computer simulation program to improve hand functions after reconstruction of the hypoplastic thumb.

MATERIALS AND METHODS

Subjects

Ninteen patients with reconstructed hypoplastic thumbs participated in the study. Seven of them were bilaterally affected while twelve were unilaterally affected. These patients were randomly assigned to two groups, the control group and the experimental group. The control group consisted of ten hypoplastic thumbs, and received only an assessment procedure; and the experimental group consisted of fiften hypoplastic thumbs. Also four normal children with age ranged from 18 months to 7.5 years participated in the study for comparison in the case of bilateral affection.

Instrumentation

The instrumentation consisted of a hardware system, a software system and accessory tools. The hardware system was an IBM compatible personal computer (PC) system (Pentium 100), with 16 MB RAM. The components of the hardware were Data Acquisition System (DAS), a preamplifier and surface EMG electrodes (Silver-Silver-Chloride), Force Sensing Resistors (FSR's) box, a falling object detector, an Electrical Muscle Stimulator (EMS) and EMS carbon adhesive electrodes, that can be easily cut to fit any small area, and an adaptor card. The software system included the simulation program and the database module (previously described in part I).

The following tools were used as accessory equipment to complement the use of the software system:

A set of wooden objects were designed and made. The set consists of four objects (cylinder, cube, prism and flattened ball), with four different sizes (4 cm, 3 cm, 2 cm and 1cm). Each size had four colors (red, green, yellow, and blue).

Colored paper clips, tennis ball, table tennis Ball, two hollow plastic eggs, and different jewelry copper weights (5, 10, 20, 50 gm).

TREATMENT PROCEDURE

The postoperative rehabilitation program consisted of twelve sessions carried out every other day. It started after removal of the plaster cast. The first six sessions were carried out using the EMS and its designed software. This was given as an initiation of thenar muscle reeducation. The next six sessions were carried out using the EMG signals along with its software. This was arranged as a second stage to increase muscle activity.

Each session was as follow: The child sat in front of the computer monitor (fig.1). In the first six sessions, a small EMS carbon adhesive electrode was applied on the thenar muscles, and a large one was fixed on the volar aspect of the forearm.

In the last six sessions, the surface EMG electrodes were applied on the thenar muscles with a space of approximately 1 cm between them. The ground electrode was fixed on the dorsum of the hand.

Fig. (1): The child in front of the computer monitor.

A set of 10 objects was used for the training of palmar pinch three points. The size was either 3 or 4 cm, with different shapes and colors. Another set of 10 objects was used for the training of palmar pinch two points. The size was either 1or 2 cm, with different shapes and colors. Ten colored paper clips were used for training of tip pinch. The last task to be carried out in each session is a ten trials of lateral pinch using key, coin or flat circle, triangle, and rectangle.

In the last six sessions, in addition to all these grasping trials, weights were added inside the egg according to the patient tolerance and grasped with a two point palmar pinch.

Assessment procedure

After the twelve treatment sessions, function, and strength were assessed.

Functional assessment

Percentage of accuracy and time were recorded for ten trials of each of the following patterns: Palmar pinch two point, tip pinch, and lateral pinch. The tests were repeated five times to take the average.

The measurement was repeated with the normal side, or a child with same age and body built for comparison if there was bilateral affection. If the child doesn't use the assigned pattern, the trial is considered an error. The percentage of accuracy was calculated as follow:

$$\frac{\text{Total number of trials} - \text{number of errors}}{\text{Total number of trials}} \times 100\ \%$$

Strength assessment

Concerning strength, the force exerted by the thumb was measured using the FSR in a recording time of 4 sec.

RESULTS

The collected data of pinch strength, percentage of accuracy and time for ten trails of different pinch types (two point palmar pinch, Tip pinch, and lateral pinch) were statistically treated by means and standard deviation. The two tails student's "t" test was used to study the statistical significance of differences between the experimental and control groups at a confidence level of 95% (p 0.05).

Table 1 shows different characteristics of the patients in both the control and experimental groups.

Table (1): General Characteristics for both experimental and control groups

Characteristic		Control Group	Experimental Group	Total
Average age In Months		34.20	40.87	38.2
Sex (Number)	Female	5	6	11
	Male	5	9	14
Blauth classification	Grade 3 A	2	4	6
	Grade 4 (floating thumb)	6	5	11
	Grade 5 (absent thumb)	2	6	8
Side operated Upon (number)	Lt	4	6	10
	Rt	6	9	15
Surgical procedure	Pollicization	6	8	14
	Pollicization + Centralization	2	3	5
	Muscle transfer	2	4	6

Accuracy of different pinch types

After one month (training period for the experimental group), the control group achieved 64% ± 4% as a percentage of accuracy of two point palmar pinch while the experimental group achieved a value of 77% ± 5% accuracy after training, which was significantly greater than that of the control group (t=5.0, P=0.001). Concerning the mean of accuracy for the tip pinch, it was 58% ± 3% in the control group. While in the experimental group, the mean of accuracy for tip pinch was 78% ± 4% after training, which was significantly greater than that of the control group (t=5.5, P=0.0013). For lateral pinch, the mean of accuracy in both control and experimental group was 62% ± 2% and 75% ± 3% respectively, which was significantly greater in the experimental group than that of the control group (t=5.88, P=0.00062). Table 2 and Fig. 2 show the mean of accuracy of different types of pinch in both groups.

Table (2): Means and Standard Deviation for the accuracy of different types of pinch in both groups.

	Control Group (n=10)	Experimental Group (n=15)	t value	P value
2 point palmar pinch	64% ± 4%	77% ± 5%	5.0*	0.001
Tip pinch	58% ± 3%	78% ± 4%	5.5*	0.0013
Lateral pinch	62% ± 2%	75% ± 3%	5.88*	0.00062

*A significant difference between the two means

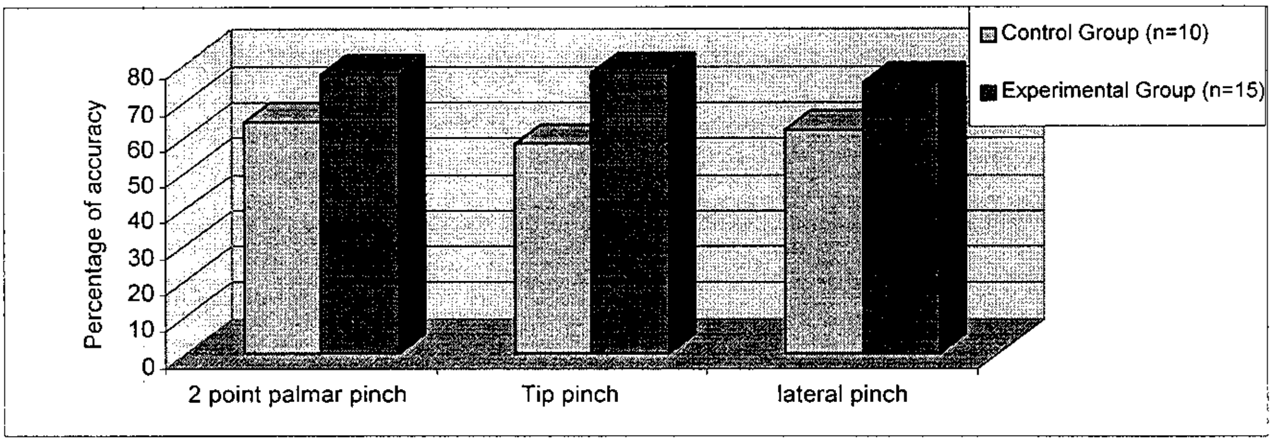

Fig. (2): Mean of the accuracy of different types of pinch in both groups.

Time for different pinch types

After the training period, the mean percentage of time for two point palmar pinch was 50% ±41% greater than normal in the control group. Regarding the experimental group , it was 81% ±38% greater than normal, after training, which were not statistically significant (t=0.25, p=0.80). Concerning the mean percentage of time of tip pinch in both the control and the experimental groups, it was found to be 71%± 38%, and 92% ±73% greater than normal respectively which were not statistically significant (t=0.27, p=0.78).

The mean percentage of time of lateral pinch was 54%± 26% greater than normal in the control group. Regarding the experimental group the mean percentage of time for lateral pinch was 40% ±21% greater than normal, after training. The difference between both groups was statistically significant (t=4.43, p=0.00021).

Table 3 and Fig. 3 show the mean percentage of time taken for ten trials of pinch types in both groups.

Table (3): Means and Standard Deviation for percentage increase in the time taken for ten trials of different pinch types

	Control Group (n=10)	Experimental Group (n=15)	t value	P value
Two point palmar pinch	50% ± 41%	81% ± 38%	0.25	0.8
Tip pinch	71% ± 38%	92% ± 73%	0.27	0.78
Lateral pinch	54% ± 26%	40% ± 21%	4.43*	0.00021

*A significant difference between the two means.

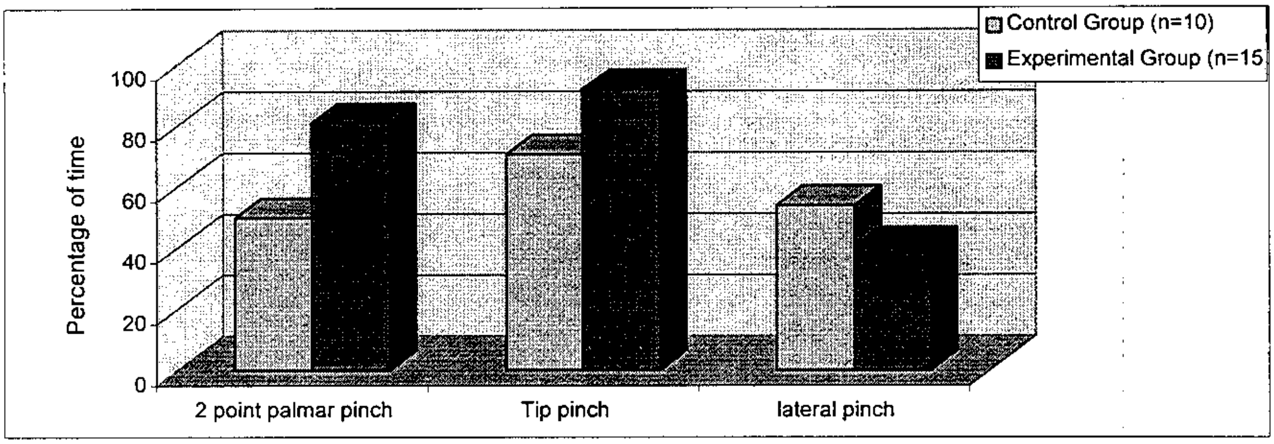

Fig. (3): Mean for percentage increase in the time taken for ten trials of different pinch types.

Strength

After the training period of the experimental group, the mean strength was 174 ± 28 grams (35.1% of the opposite side) in the control group. In the experimental group, the mean strength was 403 ±157 grams (73.5% of the opposite side). It was significantly higher in the experimental group (t=5.64, p=0.0009).

DISCUSSION

The mean accuracy for two point palmar pinch was 77% after training while the control group achieved 64% accuracy. One reason that could be given for this significant difference was the motivation and appraisal given to the child when he grasps accurately using the new thumb and in the pulp-to-pulp manner, a factor that was not present in the control group. For the tip pinch, the mean accuracy was 76% after training in the experimental group which was significantly greater than that achieved by the control group (58%). This was due to the complete flexion of the IP joint and the motivation the computer simulation program offered. With respect to the lateral pinch, there was 75% accuracy, which was significantly greater than the control group (62%). Lateral pinch was difficult for those having radial clubhand corrected by centralization, as it needs the forearm to be in mid position, otherwise it will be a pulp-to-pulp pinch rather than lateral pinch. Insufficient pronation causes difficulty in picking up pin from a flat surface because contact was towards the radial border of the finger [19]

The patients with radial clubhand use frequently the side-to-side pinch of ring and long fingers for small objects [5]. This was not frequently seen in this study for the experimental group as the feedback given to the child gave him the opportunity to correct the wrong pattern.

When patients performed activities adequately by side-to-side pinch motion using the long and ring or ring and small digits preoperatively, it should not be expected that pollicization procedure would induce them to change their established prehensile pinch patterns [12]. Pollicization could improve the usefulness of an index digit; the operation procedures didn't necessarily serve as a stimulus for the patient to alter effectively, established activity patterns [18].

In all these previous studies, no training was given to the child to alter his established pattern. In this study, there was a significant difference in the accuracy of the three types of pinch patterns tested in short duration. It was suggested that for altering an existing effective pattern, the pollicized digit must functions more effectively than the previously established pattern.

Regarding the time in which ten trials of each of the three patterns were performed. The mean percentage of time for two point palmar pinch was 81% longer than that of the contralateral side, 92% longer for tip pinch and 40% longer for the lateral pinch. It was not only longer than that of the contralateral side or another child with the same age and body built but also significantly longer than that achieved by the control group.

These results were due to the child's eagerness to achieve more accurate and precise grasp pattern, regardless the time spent, to obtain the appraisal given by the computer simulation program in a form of clapping (sound) and vision (hand motion).

For tip pinch, much more time was needed in both control and experimental group than other types of pinching. This was because those with centralization had insufficient ability to turn the forearm in the full pronation position and in some cases due to inadequate IP joint flexion range.

All other studies achieved a mean time less than that obtained in this study. One reason was that no one has taken the accuracy of pinching pattern into consideration and the time was recorded regardless of accuracy. This was confirmed by the results of the control group who performed in a less duration but with less accuracy. Another reason was the long time passed before evaluation, and the ability of the child to acquire the skill to perform in short time by growth and maturation.

After a follow up range of one to nineteen years, 22% longer time than the standard for handling small object was obtained, much more time was needed for handling large object, 40% longer for light object and 43% longer for a heavy one. Those with associated anomalies, their timed activities score was 33% longer while those without associated conditions had an average timed score which was 10% longer [14]. The time taken for activity using the pollicized digit was found to be 40 % longer [13].

The mean pinch strength for the thumb was 73.5% of the opposite side using the FSR. It was significantly greater than that achieved by the control group. Different weights were used in the training in an enjoyable manner giving the child the will to grasp and hence strengthening was achieved. Percentage of a pinch strength equal to 56% of the opposite side was recorded in some studies [8,19]. In another study the pinch strength was found to be 75% of the opposite side. The investigator referred these higher percentages to the comparison with the contralateral side, which was not always normal and was likely to have reduced strength because of radial dysplasia or other congenital abnormalities [14]. Comparison with the opposite hand is likely to inappropriately show increased of the pollicized index. To decrease the error caused by this factor, the strength values recorded for the experimental group in this study was compared to that achieved by the control group who received no training. So even if the strength tends to give a false indication of greater value when compared to the contralateral side, it was significantly greater than that of the control group whose measurement was undertaken at the same conditions at which the measurement of the experimental group was taken.

The pinch strength was found to reach only 25% of the standard normal which was very small value as it was compared to the standard value and not to the contralateral side strength value [12].

CONCLUSION AND RECOMMENDATIONS

In this study, it was concluded that previously established pattern (side to side pinch) could be changed by the recent and advanced technology of computer simulation that provided motivation and action feedback. Hence a better function of the hand was obtained. A long-term follow up is needed to investigate the effectiveness of the training over time. Also to obtain skill and automatic accurate pattern while grasping, a longer training period with the computer simulation-training program is recommended.

REFERENCES

1- Aziz, W., Noojin, F., Arakaki, A., and Kutz, JE.: Avulsion injuries of the thumb: Survival factors and functional results of replantation. Orthopedics 21(10): 1113-1117, 1998.

2- Bayne, L.G.: The hypoplastic thumb. In: Green D.P., and Hotchkiss R.N. eds: Operative Hand Surgery 3rd ed., New York: Churchill Livingstone, 1993. pp 835.

3- Brand, PW., Hollister, AM.: Clinical mechanics of the hand. 3ed ed. St. Louis, MO: Mosby, Inc., 1999. pp 88-90.

4- Brown, D.M. Nahal, F., Wolf, S. and Basmajian, J.V.: Electromyographic biofeedback in the reeducation of facial palsy. Am J Phys Med 57 (4): 183-190, 1978.

5- Buck-Gramcko, D.: Pollicization of the index finger. Methods and results in aplasia and hyoplasia of the thumb. J Bone Joint Surg 53(8): 1605-617, 1971.

6- Jankel W.R.: Bell palsy: Muscle reeducation by electromyograph feedback. Arch Phys Med Rehabil 59(5): 240-242,1978.

7- Johnson H.E. and Garton W.H.: Muscle reeducation in hemiplegia by use electromyographic device. Arch Phys Med Rehab 54:320-325,1973.

8- Kozin S.H., Minn R., Weiss A.A., Webber J.B., Betz R.R., Clancy M., and Steel H.H.: Index finger pollicization for congenital aplasia or hypoplasia of the thumb. J Hand Surg 17A(5): 880-885,1992.

9- Kukulka C.G. and Basmajian J.V.: An assessment of an audiovisual feedback device for use in motor training. Am J Pys Med 54: 194-208,1975.

10- Kulen T. and Dohle C.: Virtual reality for physically disabled people. Comput Biol Med 25(2): 205-211,1995.

11- Lester, B.: The acute hand. Stanford, CT: Appleton and Lang, 1999. pp 500-503.

12- Manske P.R. and McCarroll H.R.: Index finger pollicization for a congenitally absent or nonfunctioning thumb. J Hand Surg 10A: 606-613,1985.