Studies of the Upper-Extremity Amputee

VI. Prosthetic Usefulness and Wearer Performance

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SYSTEMATIC research in limb prosthetics has, during the past decade, produced not only better prostheses but also improved techniques for their application. Similarly, programs of prosthetics education have provided a new generation of physicians, prosthetists, therapists, and associated professional personnel with a greater appreciation of the amputee's physical and emotional needs and a greater understanding of how best to meet them. But ultimately research and education in the fitting of artificial limbs have real worth only to the extent that the individual amputee can accept and utilize the prosthesis provided him.

The degree of acceptance and utilization is governed ultimately by the single consideration: *Of what value is the prosthesis to the amputee?* While the wearer himself must provide the essential elements of this valuation, his feelings and attitudes about other matters can significantly affect his opinions and judgments about the worth of his prosthesis. Accordingly, data which included both subjective amputee reactions and more objective ratings and judgments of independent observers were collected. Properly analyzed, these data provide a firm assessment of recent achievements in arm prostheses as well as some measure of the effectiveness of the techniques now recommended for the management of arm amputees.

The classification, analysis, and interpretation of the more subjective portions of the data (those collected by interrogation of amputee subjects) make up Part 1 of this two-part discussion. Presentation and support of the more objective material (that obtained by tests and observation) constitute Part 2. All of the data reported were recorded on the special forms illustrated in Appendices IIIB and IIIC of Section I of this series (ARTIFICIAL LIMBS, Spring 1958, pp. 32 through 39).

The opinions and statements reported in Part 1 and the test results and observations presented in Part 2 relate to the meaning and the value of program prostheses in various tasks normally encountered in everyday life. As a perceptive reader will note, the term "activities of daily living" is used throughout this article to denote that specific context and is not meant to be synonymous with the term "ADL," which through increasing currency has become part of the professional jargon of physical and occupational therapy. As used here, it encompasses a broader range of activities than it does when generally used in the treatment of human disability. Generally ADL is limited to tasks relating to personal independence and self-care in the home; in our context, recreational and vocational activities are included.

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Part 1

Amputee Opinions Concerning Utility of Arm Prostheses in Activities of Daily Living

In general, the prosthesis that will be most valuable to the arm amputee will be the one with which he can perform, most efficiently and with the least effort and discomfort, the greatest number of useful activities ordinarily performed with the normal upper extremity. Thus an evaluation of an arm prosthesis can be based upon the *usefulness* of a prosthesis to the patient as indicated by his need for it in performing daily activities, the *activity level* of the patient with respect to the number of activities which he performs with his arm, the *ease* with which he uses the prosthesis, and the *frequency* with which he uses it for the performance of activities which are important to him.

To obtain amputee reactions concerning the general utility of arm prostheses, the participating subjects were intensively interviewed, and the essential data were recorded on two sets of questionnaires. One set was used to record amputees' opinions of the usefulness of their arms in activities of daily living, the activity level as regards the number of different activities they performed, and the degree of ease or difficulty with which they were able to use their prostheses. The second set of questionnaires was used to collect data concerning the use of prostheses in 20 selected bimanual activities, specifically the frequency with which these activities were performed and the importance to the amputee of being able to perform these activities. With certain minor exceptions, the interrogation was conducted with respect both to the old prosthesis (Evaluation I) and to the new (Evaluation II). The time lapse between the two interviews varied for individual amputees; it was never less than six months for any, as much as 18 months for a few, and approximately 12 months for the average case.

USEFULNESS, ACTIVITY LEVEL, AND EASE OF USE IN ACTIVITIES OF DAILY LIVING

In view of the complexities of everyday human activities, almost any attempt to study the circumstances affecting prosthetic utilization is difficult. As a practical approach to the problem, however, the subjects were queried in a pattern designed to elicit their opinions concerning the value of both their old and new prostheses in the key activity areas of eating, dressing, work, social and recreational functions, and home tasks.[3] To determine general usefulness, the amputees were asked to rate their prostheses (first the old and then the new) as essential, very useful, of limited use, of no use, or as a hindrance, the purpose being to establish the amputees' own valuations of their prostheses in performing activities in the five activity areas. Secondly, the subjects rendered their own estimates as to the relative number of activities performed with old and with new prostheses, again with respect to the five key areas of activity. Finally, the subjects were asked to estimate the relative ease with which their old and new prostheses could be used in each of the same five areas.

The questionnaires regarding usefulness, number of activities performed, and ease of performance with both old and new prostheses were applied to all available types of upper-extremity amputees, unilateral and bilateral. Because the problems of the bilateral arm amputee differ from those of the unilateral, and because the number of available bilateral cases was too small to have statistical significance, the results for 349 unilateral subjects are treated first, those for the 10 bilaterals in a separate section.

UNILATERAL SUBJECTS

Among unilateral arm amputees especially, the level of use to which an arm prosthesis is put is determined to a considerable extent by

[3] The five kinds of tasks selected were considered as encompassing the major undertakings in which an arm amputee *might* use a prosthesis in the course of daily living.

the ease and convenience of performance with the prosthesis as compared with the ease and convenience of performance without it or as compared with the ease and convenience of not performing at all. If a particular activity is too difficult or too time-consuming for a given unilateral arm amputee to perform with his prosthesis, he will either avoid it completely or else find some other way of getting it done. If he elects to accomplish the activity without using the prosthesis, he may do so in any of several ways:

1. He may use the remaining sound hand, with or without assistance from other parts of the residual anatomy or from external objects. Unilateral arm amputees commonly perform with one hand many activities which under normal circumstances would be bimanual (e.g., tying necktie or shoelaces).

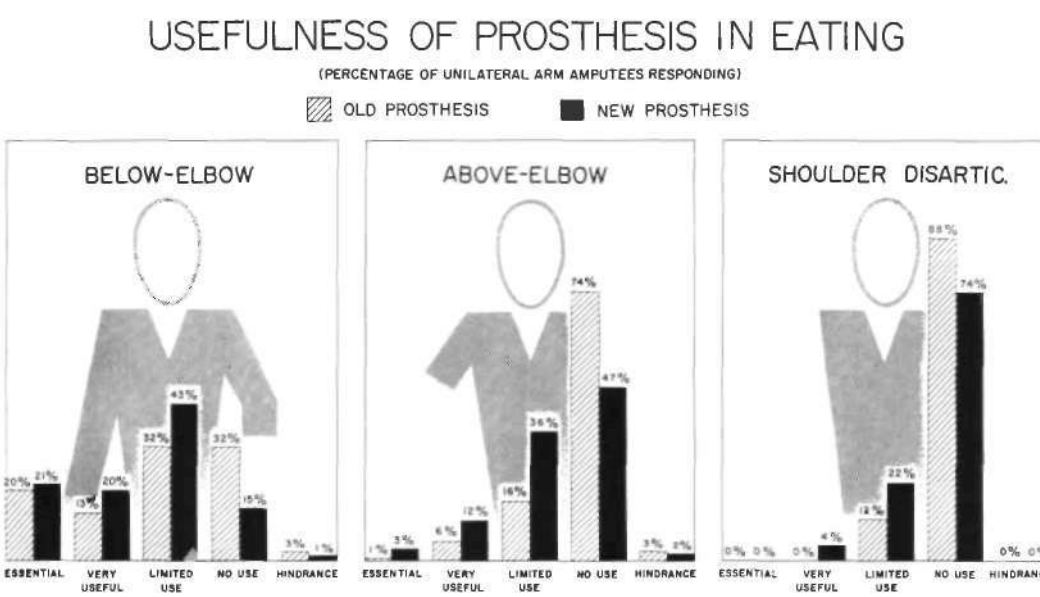
2. He may use special devices and techniques *(e.g.,* various tools intended for one-handed performance of tasks ordinarily bimanual), again with or without assistance from some other available source.

3. He may prevail upon another person either to provide assistance or to perform the task for him more or less completely.

Although any one of these alternatives may serve the purpose of accomplishing essential activities, none of them suggests adequate restoration of loss, either in terms of true personal independence or in the sense of normal appearance. In addition, factors such as temperament, disposition, motivation, and habit patterns further influence the simple "ease-difficulty" premise of prosthetic utilization. Though the true state of affairs in any particular case is a highly complicated one, there can be little doubt that the inherent "usefulness" of the prosthesis is one of the prime factors in determining the number and kinds of purposes to which an artificial arm will be put. This first series of studies was therefore designed to discover the activities for which prostheses are used by amputees with unilateral arm loss at various levels and to delineate any changes in use patterns properly attributable to the new types of prostheses fitted during the NYU Field Studies.

Eating

Usefulness. As regards eating, unilateral below-elbow amputees generally thought well of their old prostheses, above-elbow subjects



had a considerably lower opinion of their arms, and shoulder-disarticulation amputees viewed their prostheses as being of relatively little value. In almost all cases, the amputee rated the new prosthesis more useful than the old in eating. For all types of amputees, there were fewer opinions that the prosthesis was of "no use" or "a hindrance" and a greater number of opinions that it was "very useful" or "essential." While this shift in opinion was characterized primarily by a considerable decrease in the proportion of unilateral amputees (of all types) who considered their prostheses of "no use" or "a hindrance," there was also an increase in the number of those considering the prosthesis "very useful" or "essential."

Of major significance is the fact that even with the newer arms the majority of unilateral amputees (58 percent of the below-elbow amputees, 83 percent of the above-elbow amputees, and 96 percent of the shoulder-disarticulation subjects) felt that the prosthesis was of limited use or no use in eating. Since only 41 percent of the below-elbow amputees, 15 percent of the above-elbow amputees, and 4 percent of the shoulder-disarticulation subjects considered their new prostheses essential or very useful in eating activities, it must be concluded that, although there was some increase in usefulness in the "program" prostheses, considerably greater improvement is necessary if the artificial arm is to have a significant influence upon the eating activities of the majority of unilateral arm amputees.

Activity Level. Reports from all unilateral amputee groups indicated that the number of eating activities increased for a significant number of amputees while very few subjects experienced a decrease. The increase in usage was greatest for shoulder-disarticulation amputees (45 percent), less marked for the below-elbow group (34 percent), and least for above-elbow amputees (28 percent).

Ease of Use. As might be expected from the foregoing, a significant number of amputees of all types reported that eating activities were easier with the new prosthesis than with the old, although the increase in facility for the below-elbow and above-elbow groups was less marked than for the shoulder-disarticulation amputees.

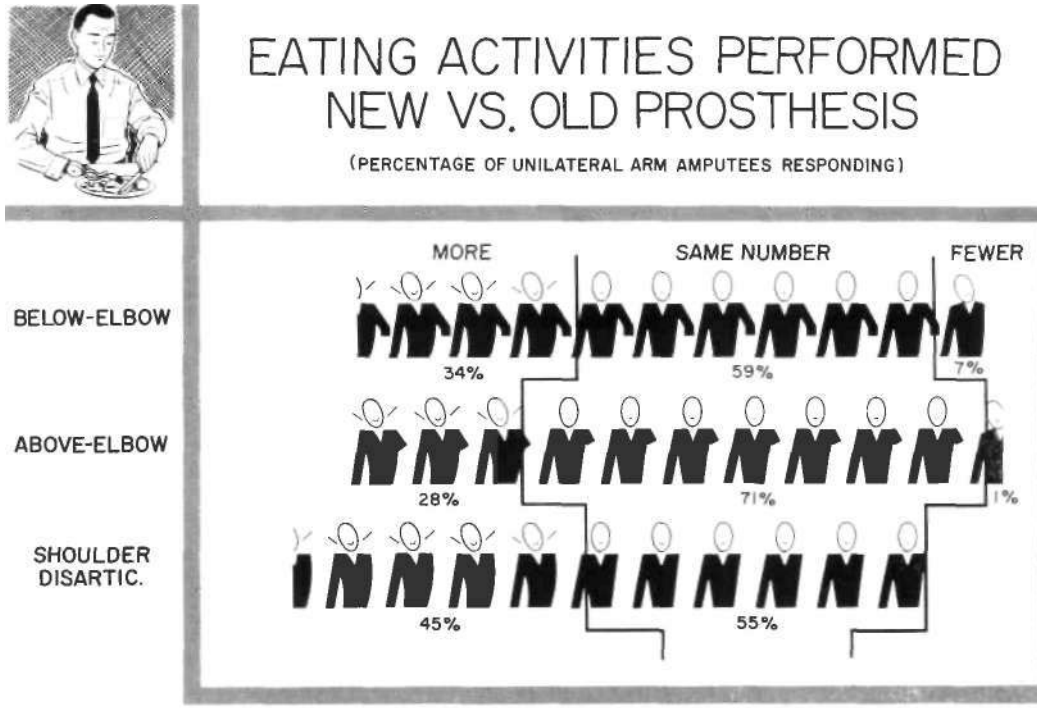
Specific Activities Performed. Table 1, based on responses from 168 below-elbow, 158 above-elbow, and 23 shoulder-disarticulation ampu-

Table 1

SPECIFIC EATING ACTIVITIES PERFORMED BY UNILATERAL ARM AMPUTEES USING A PROSTHESIS

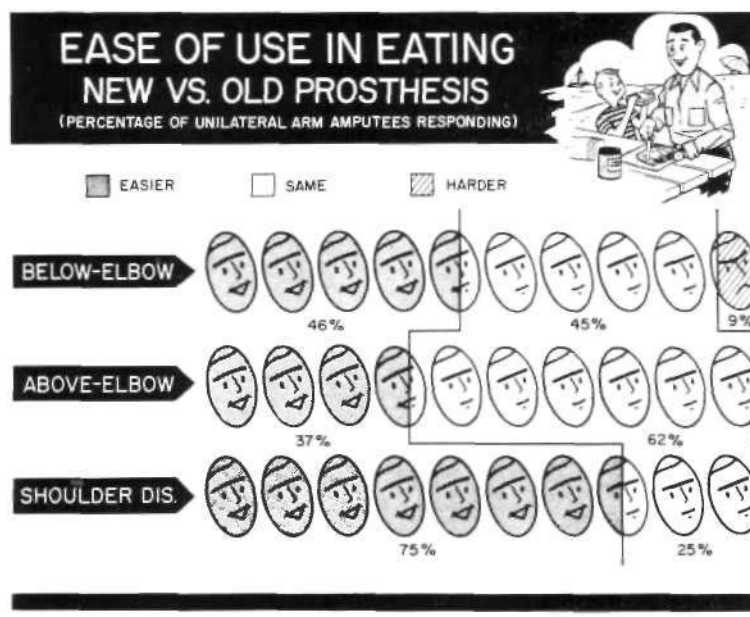
(Times Cited)

Activity	Amputation Level		
	Below-Elbow (N = 168)	Above-Elbow (N = 158)	Shoulder Disarticulation (N = 23)
Grasp knife or fork to cut meat	107	52	5
Grasp bread to butter	42	17	2
Grasp bottle or glass to hold	39	18	3
Grasp tray to carry	15	16	1
Grasp dishes to serve self	14	4	3
Grasp glass to bring to mouth	12	1	0
Hook pots and pot handles to take off stove	10	4	1
Grasp can to open	6	4	0
Grasp spoon to ladle food	5	0	0
Grasp fork to carve meat	5	3	0
Grasp orange to peel, egg to shell	4	3	0
Grasp soda bottle and bring to mouth	3	0	0
Grasp utensils to set table	3	2	0
Grasp saucer while drinking from cup	3	3	0
Grasp cabbages, tomatoes, to cut	3	2	0
Weight bread to butter	3	8	0
Support tray to carry	1	1	1



tees, presents a composite picture of the specific eating activities for which unilateral amputees of various amputation levels said they used their prostheses. Since the list of activities was compiled from amputees' responses to the unstructured request *List activities for which you use your [new] prosthesis,* and since in the experience of the authors arm amputees commonly use their prostheses more extensively than they can recall, it may be assumed to be minimal both with respect to number of activities and to incidence of performance.

The prime significance of these responses lies in their indication of use *potential* of the prosthesis. For example, the fact that in opening a soda bottle *some* below-elbow, above-elbow, and shoulder-disarticulation amputees

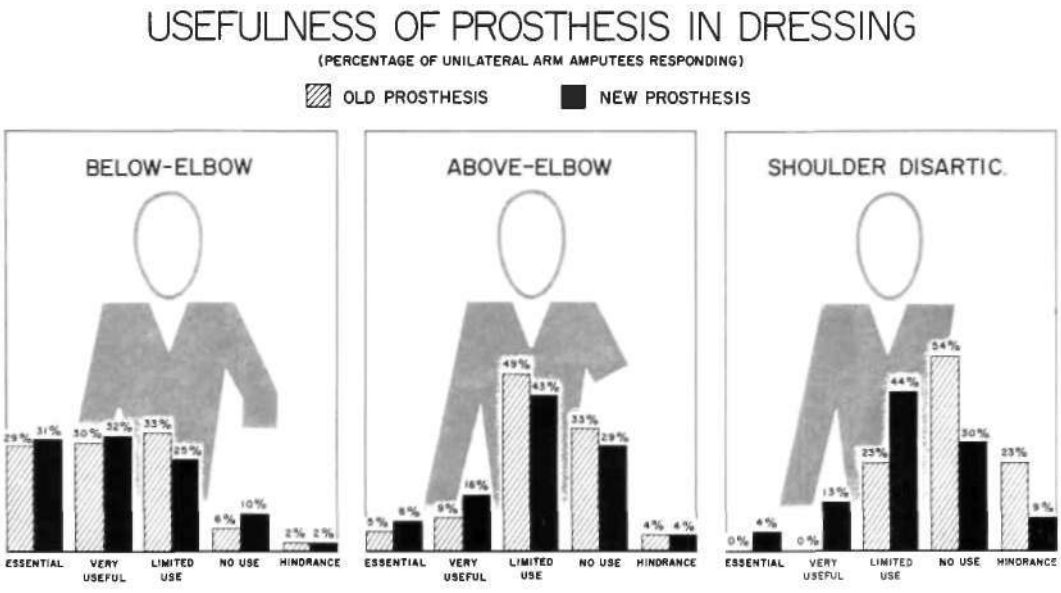


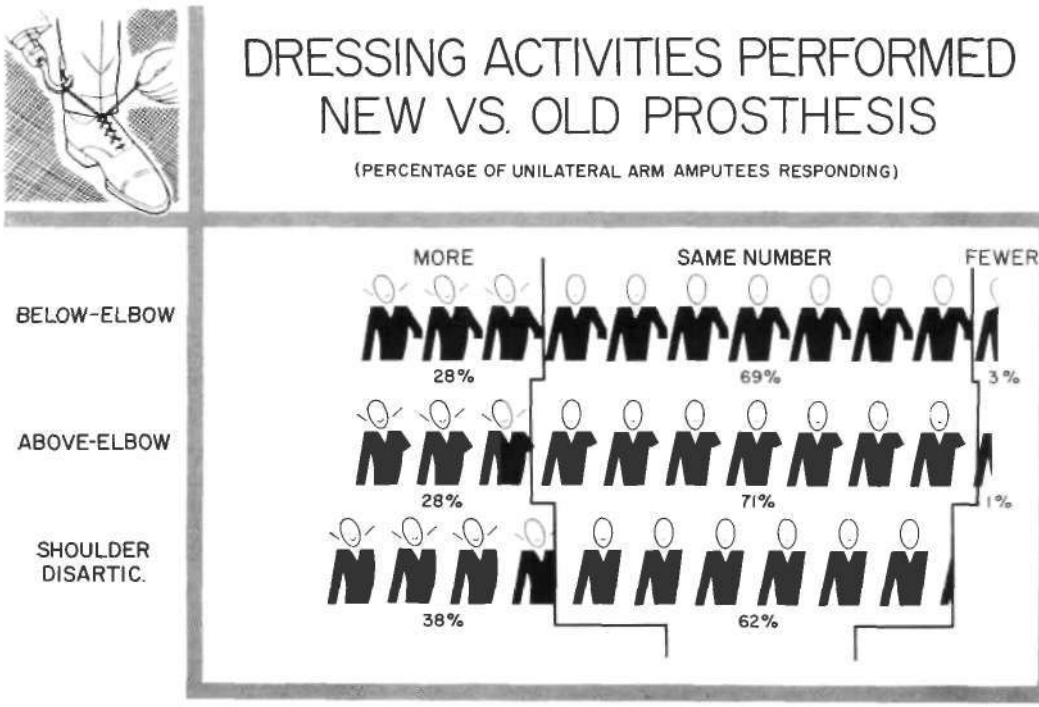
can and do hold the bottle with their terminal device suggests that this activity is not particularly difficult and that it could be performed by most amputees. Why, then, do some amputees prefer to use one hand only or to hold the bottle between the knees to take off the cap? Such questions are worthy of more intensive investigation than was possible in the NYU Field Studies.

Dressing

Usefulness. Amputees' opinions concerning the usefulness of the prosthesis in dressing show a pattern somewhat similar to that found in eating. There is a general shift of opinion toward the positive end of the scale, but the extent of the change varies with amputee type. It is slight in the below-elbow group, somewhat greater in the above-elbow group, and most marked among shoulder-disarticulation amputees. When the percentage of amputees who considered the prosthesis essential or very useful is employed as the basis of comparison, the data for new *vs.* old arm were: below-elbow, 63 percent *vs.* 59 percent; above-elbow, 24 percent *vs.* 14 percent; shoulder disarticulation, 17 percent *vs.* zero. Although because of the small number of subjects involved the data on the shoulder-disarticulation group must be interpreted cautiously, there are definite indications that a significant number of amputees considered the new prosthesis more useful than the one worn previously. It is also apparent that most groups consider a prosthesis *more useful for dressing than for eating.* The comparative percentages of amputees who considered the new prosthesis either essential or very useful were—below-elbow: dressing, 63 percent, eating 41 percent; above-elbow: dressing, 24 percent, eating 15 percent; shoulder disarticulation: dressing, 17 percent, eating 4 percent. These differences may be attributable to the larger number of discrete tasks involved in dressing as compared with eating. Despite the improved sentiment toward the usefulness of the program arms, however, a considerable proportion of unilateral amputees of all types (below-elbow, 37 percent; above-elbow, 76 percent; shoulder disarticulation, 83 percent) still considered these prostheses of limited use, no use, or a hindrance. Again it is obvious that much room for improvement still exists, particularly for the more severely handicapped above-elbow and shoulder-disarticulation groups.

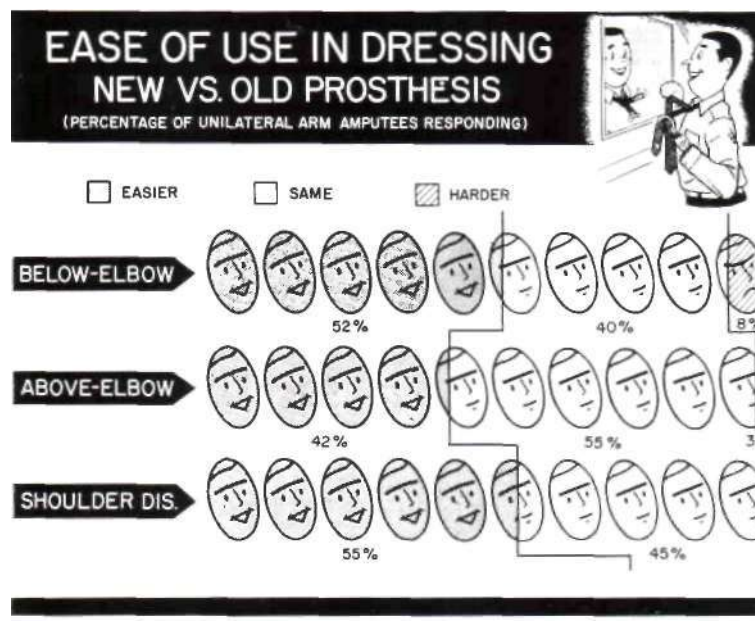
Activity Level. An increase in the number of dressing activities performed with the prosthesis was reported by all amputee groups. The proportion of amputees indicating increased use of the prosthesis ranged from 28 percent





of the below-elbow category to 38 percent of the shoulder-disarticulation sample. An insignificant number reported decreased usage.

Ease of Use. Since extent of use is undoubtedly related to ease of use, it is not surprising to find that a high proportion of the amputees considered dressing activities easier to perform with their new prostheses than with their old. Easier operation was reported by 52 percent of the below-elbow, 42 percent of the above-elbow, and 55 percent of the shoulder-disarticulation subjects. Very few subjects at any amputation level reported greater difficulty of operation with the program prosthesis, although almost one in twelve below-elbow amputees fell into this category. The use of more complex terminal devices and the change



from soft (leather) to hard (plastic) sockets may in some cases have contributed to this minority opinion.

Specific Activities Performed. Table 2 presents a tabulation of specific dressing activities in which unilateral arm amputees reported performance with their prostheses. Since this listing is based upon the responses of the subjects to open-end questions, it should be considered minimal and indicative rather than comprehensive.

Table 2

SPECIFIC DRESSING ACTIVITIES PERFORMED BY UNILATERAL ARM AMPUTEES USING A PROSTHESIS

(Times Cited)

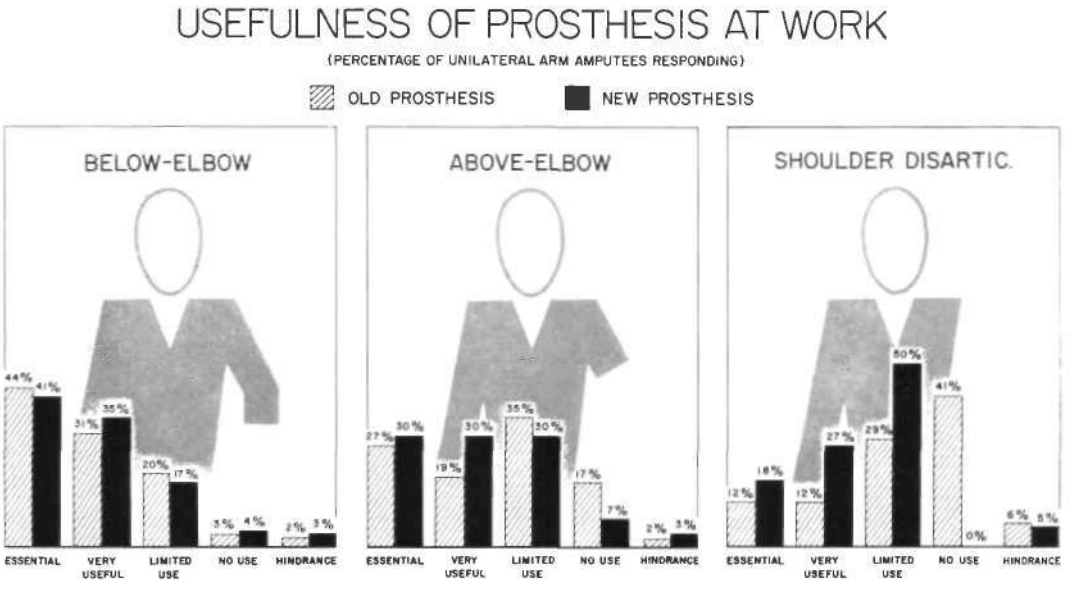
Activity	Amputation Level		
	Below-Elbow (N = 168)	Above-Elbow (N = 158)	Shoulder Disarticulation (N = 23)
Grasp shoelace to tie	105	58	1
Grasp necktie for tying	88	51	5
Grasp pants to tuck in shirt	59	29	4
Grasp and pull edge of sleeve to unbutton sleeve	54	21	1
Grasp and pull up pants	33	2	0
Grasp or support pants to pull belt through loops	28	15	1
Grasp and pull up socks	13	7	0
Grasp and pull coat off hanger	6	5	2
Grasp electric razor	4	0	0
Grasp and pull off watchband	3	2	0
Grasp and pull on glove	3	2	0
Grasp washcloth	2	0	1
Grasp shirt sleeve to remove from good arm	1	1	1
Grasp nail file for filing	1	1	0
Grasp aftershave lotion and hair tonic	1	0	0
Pull on artificial leg	1	0	1
Grasp towel to dry hand	0	1	0
Grasp comb to cut own hair	0	2	1
Grasp and pull up zipper	1	3	1

The major significance of the data in Table 2 lies in their indication of the use potential in existing prostheses. Equally important, however, is the corollary question, *Why is this potential not fully utilized by amputees?* For example, 88 below-elbow, 51 above-elbow, and 5 shoulder-disarticulation amputees claimed that they held one end of a necktie with the prosthesis while they tied the knot with their "good" hand. This circumstance would suggest that the activity is perfectly feasible for all three amputee types and that it might almost be considered a "typical" or "normal" prosthetic activity. Nevertheless, the fact remains that a considerable number of amputees tie their neckties using the "good" hand alone. Presumably it is "easier" or more convenient for them to employ the one-handed method, but whether the reason is related to prosthetic difficulty, lack of motivation to use the prosthesis, or prior habit pattern is not readily apparent. More intensive study in this area might be extremely fruitful in gaining deeper insight into the problems of prosthetic utilization.

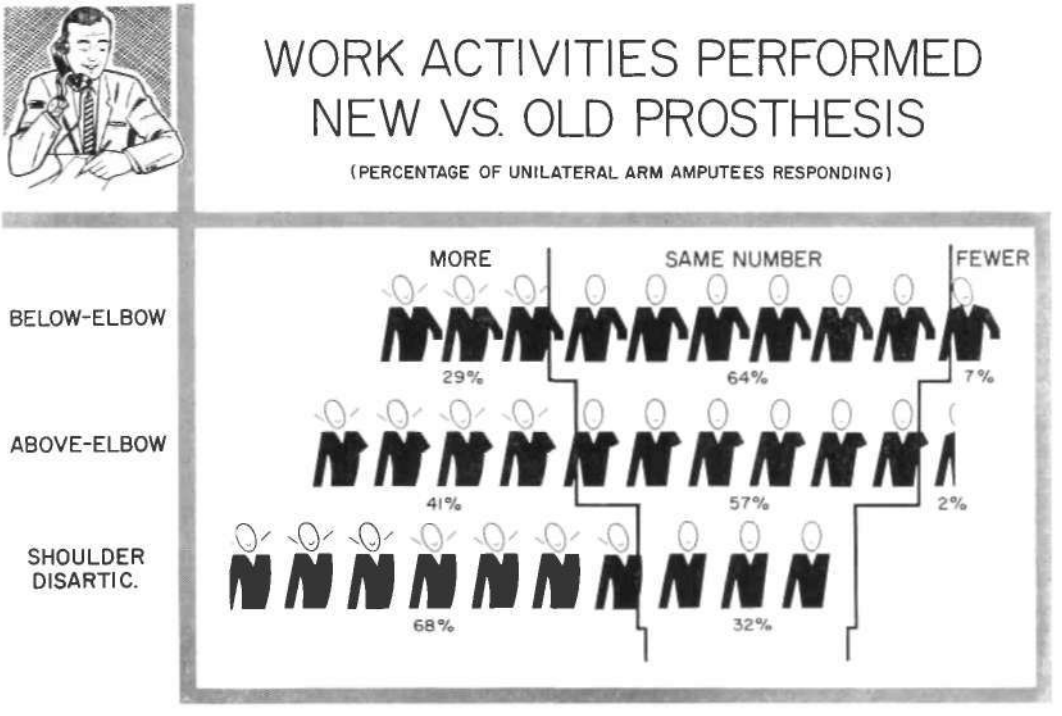
Work

Usefulness. As a result of the research program, all amputee types except the below-elbow showed an increase in positive attitude toward the usefulness of prostheses in their work. The shift in opinion was quite marked in the shoulder-disarticulation group but less apparent with the above-elbow subjects. Although the below-elbow amputees as a whole indicated little change in usefulness between the old and the new prostheses, their opinions of both prostheses were generally high.

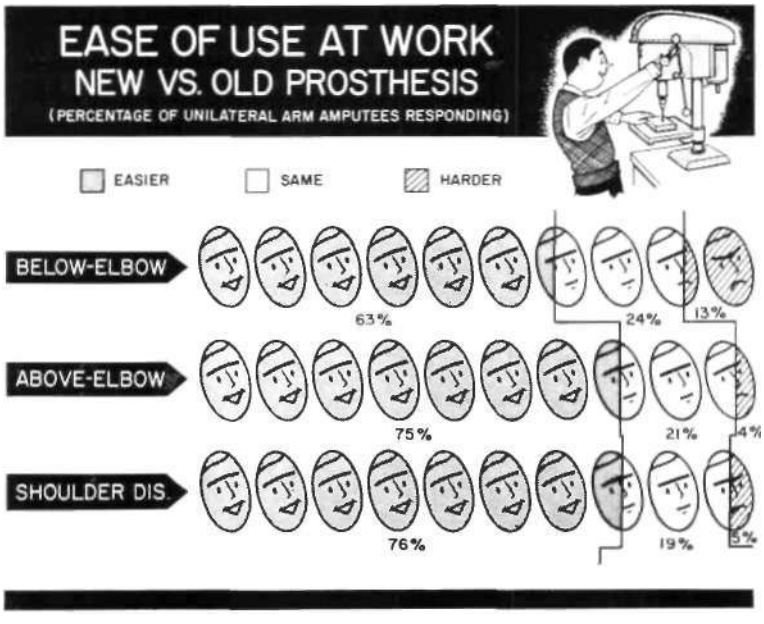
In spite of apparent improvement with the new prostheses, many of the amputees (below-elbow, 24 percent; above-elbow, 40 percent; shoulder disarticulation, 55 percent) felt that their prostheses were of little or no value to them on the job. Since, however, these percentages are much lower than the corresponding ones for the two activities previously discussed, it would appear that amputees consider



their prostheses more useful for work than for either eating or dressing. The reason may be that eating and dressing involve a relatively small number of activities, many difficult to perform with a prosthesis, while vocational activities present a much broader variety of tasks of which perhaps many can be performed better with a prosthesis than without one.



Activity Level. Sixty-eight percent of the shoulder- disarticulation subjects reported that they performed more work activities with the new prosthesis. So did 41 percent of the above-elbow and 29 percent of the below-elbow participants.



Ease of Use. A major proportion of the amputees believed that the new arm made work activities easier. Holding this opinion were 63 percent of the below-elbow subjects, 75 percent of the above-elbow amputees, and 76 percent of those with shoulder disarticulations. Although this result represents a more uniform and significant "positive shift" than that found for either eating or dressing, one in eight of the below-elbow amputees felt that

Table 3

Specific Work Activities Performed by Unilateral Arm Amputees Using a Prosthesis

(Times Cited)

Activity	Amputation Level		
	Below-Elbow (N = 168)	Above-Elbow (N = 158)	Shoulder Disarticulation (N = 23)
Light Work			
Grasp and carry papers and folders	53	48	8
Weight paper for writing	41	45	13
Grasp and sharpen pencil	22	25	4
Grasp and turn crank on pencil sharpener	2	1	0
Hook briefcase and carry	16	15	3
Grasp order book or clipboard for writing	13	11	1
Grasp telephone receiver while taking notes	13	7	0
Hook and pull open file drawers	11	5	0
Push and spread folders for filing	8	11	1
Push typewriter keys	9	3	0
Push typewriter carriage	5	2	0
Weight typewriter space bar	4	2	0
Push keys or pull handle on adding machine	4	4	1
Grasp paper to place in typewriter	2	0	0
Grasp paper to put on paper clips	5	2	0
Grasp letters for sorting	5	5	0
Grasp ink bottle	3	3	2
Push lever on stapler	2	0	0
Grasp time cards and place in position for punching	0	1	0

Table 3—*Continued*

Activity	Amputation Level		
	Below-Elbow (N = 168)	Above-Elbow (N = 158)	Shoulder Disarticulation (N = 23)
Medium Work			
Drawing (push T-squares, triangle, rulers)[a]	8	12	0
Operate industrial machine	8	4	0
Grasp rope and tie knots	3	2	0
Hook and pull handle on drill press	2	0	0
Grasp bills to make change	2	0	0
Grasp trowel to set cement blocks[a]	2	0	0
Grasp metal while operating boring machine	1	1	0
Grasp test tubes and flasks	1	3	3
Grasp and set type	1	0	0
Grasp plates to feed printing press	1	0	0
Operate truck-weighing scale	1	0	0
Heavy Work			
Hook, lift, and carry objects up to 150 lb.[a]	33	32	5
Drive tractor, general[a]	8	9	0
Drive truck, general (shift foot gears, steer)	8	4	0
Push plow[a]	5	0	1
Hook and carry bales of hay	4	6	0
Support scoop shovel for shoveling grain	1	1	0
Grasp and swing axe or sledge hammer	1	2	0
Change tires on car	1	1	0
Push or pull hand carts	0	5	1
Grasp sacks for emptying	0	2	0
Support in lifting hospital patients	0	1	0
Miscellaneous			
Grasp and tear cloth	2	0	0
Grasp grease rag for checking oil stick	1	3	0
Push or pull and lift car hood	1	2	0
Hook and carry tires	1	1	0
Grasp syringe for drawing blood	1	1	0
Grasp fire extinguisher to recharge	1	0	0
Push and pull open elevator doors	1	0	0
Weight and push material through sewing machine	0	2	1

[a] Also performed by some amputees as a home or recreational pursuit.

work activities were harder to perform with the program prosthesis. The basis for this minority opinion was not apparent from the data.

Specific Activities Performed. The specific work activities that amputees can perform with their prostheses, and the kinds of jobs they can hold successfully, are of considerable interest from the viewpoint of vocational rehabilitation. Table 3 presents a listing of vocational activities reported by the 168 below-elbow, 158 above-elbow, and 23 shoulder-disarticulation amputees involved in the study. Activities reported by the subjects have been classified arbitrarily as light work *{i.e.,* activities typical of white-collar workers), medium work *{i.e.,* activities typical of artisans and mechanics), heavy work *{i.e.,* farming and

other heavy manual occupations), and miscellaneous. Although this listing does not reveal the full story of the employability of unilateral arm amputees, it does indicate trends. While a detailed analysis of the subject is not possible at this time, it is apparent that unilateral arm amputees are capable of a wide variety of work activities and are employable in a wide range of occupations.

An additional interesting aspect of the relationship between vocation and amputation was provided by amputee responses to two questions asked at the conclusion of the study. These questions and the answers provided by 349 subjects in the study were:

HAVE YOU CHANGED YOUR OCCUPATION SINCE YOU FIRST ENTERED THE ARM PROGRAM?

	Yes	*No*
Below-Elbow	39	129
Above-Elbow	30	128
Shoulder Disarticulation	4	19
Totals	73	276

IF ANSWER IS "YES," HOW DID YOUR ARM INFLUENCE THIS CHANGE?

	Below-Elbow	*Above-Elbow*	*Shoulder Disarticulation*	*Total*
No influence	23	21	2	46
Provided greater efficiency or function	5	4	0	9
Provided better appearance	1	0	0	1
Miscellaneous	1	1	1	3
Reason not given	9	4	1	14
Totals	39	30	4	73

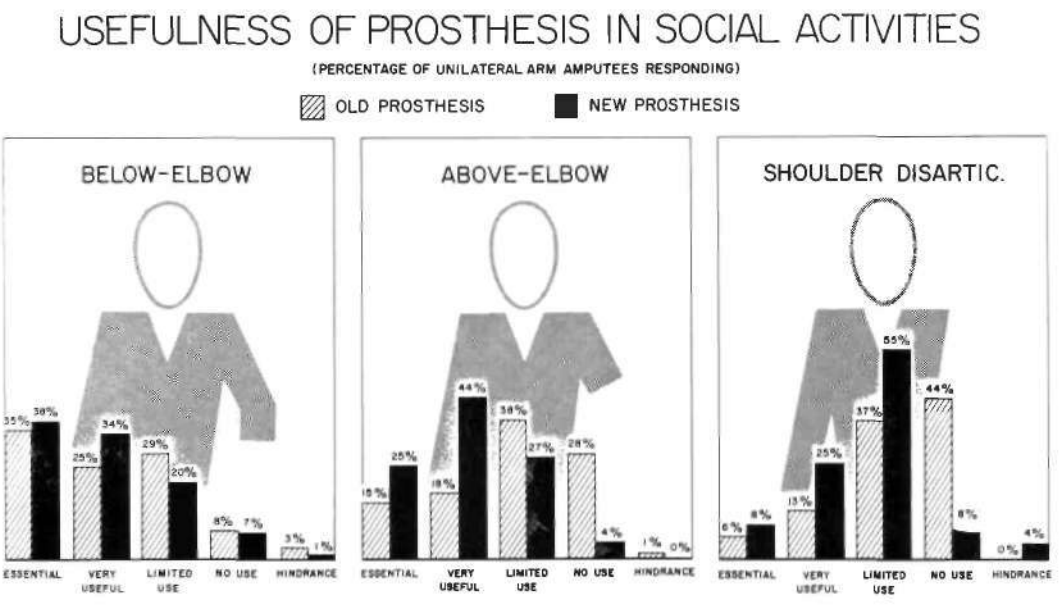
From these data it is evident that, while one in five amputees changed jobs during the course of the study, few of the changes were attributed to the new prosthesis. Of the total number of subjects in the study, therefore, very few felt that the new prosthesis affected their employment. Consideration of the type of job change made by the amputees also fails to reveal any significant trend. None of the changes reported (student to farm hand, post-office clerk to wholesale manager, hospital attendant to repairman, unemployed to guard, janitor to stock clerk) indicated any marked shift in vocational status, either positive or negative. It must be concluded, therefore, that the prostheses provided in the study had little apparent effect on the employment status of the participants.

Recreational and Social Activities

Usefulness. All amputee groups reported that in recreational and social activities the program prosthesis was an improvement over the old prosthesis. As with the activity areas previously discussed, improvement was least marked in the below-elbow subjects, but even this group showed a change for the better. For example, 72 percent of the below-elbow sample considered that their new prosthesis was either essential or very useful as against 60 percent for the old prosthesis. Shoulder-disarticulation amputees reflected a greater degree of improvement, 33 percent reporting essential or very useful for the new prosthesis as compared with 19 percent for the old. Above-elbow amputees appeared to obtain the most benefit from their new prostheses, the proportions rating their prostheses in the upper two categories of the scale being: new arm, 69 percent; old arm, *33* percent. The proportion of amputees reporting that the prosthesis was of little or no use or was a hindrance in leisure-time activities (below-elbow, 28 percent; above-elbow, 31 percent; and shoulder disarticulation, 67 percent) was greater than for vocational activities but less than for eating and dressing.

Activity Level. A significant number of amputees used their new prostheses for additional leisure-time activities. One third of the above-elbow and shoulder-disarticulation subjects and one fourth of the below-elbow subjects had found new uses. A very small proportion of above-elbow and below-elbow amputees reported decreased usefulness (3 percent and 5 percent respectively).

Ease of Use. More than 50 percent of all the amputees felt that the performance of social and recreational activities was easier with the new arm. A small number of below-elbow (7 percent) and above-elbow (3 percent) subjects felt that activities in this area were harder to do.


USEFULNESS OF PROSTHESIS IN SOCIAL ACTIVITIES
(PERCENTAGE OF UNILATERAL ARM AMPUTEES RESPONDING)
OLD PROSTHESIS
NEW PROSTHESIS
BELOW-ELBOW
35%
38%
25%
34%
29%
20%
8%
7%
3%
1%
ESSENTIAL
VERY USEFUL
LIMITED USE
NO USE
HINDRANCE
ABOVE-ELBOW
15%
25%
18%
44%
38%
27%
28%
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1%
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ESSENTIAL
VERY USEFUL
LIMITED USE
NO USE
HINDRANCE
SHOULDER DISARTIC.
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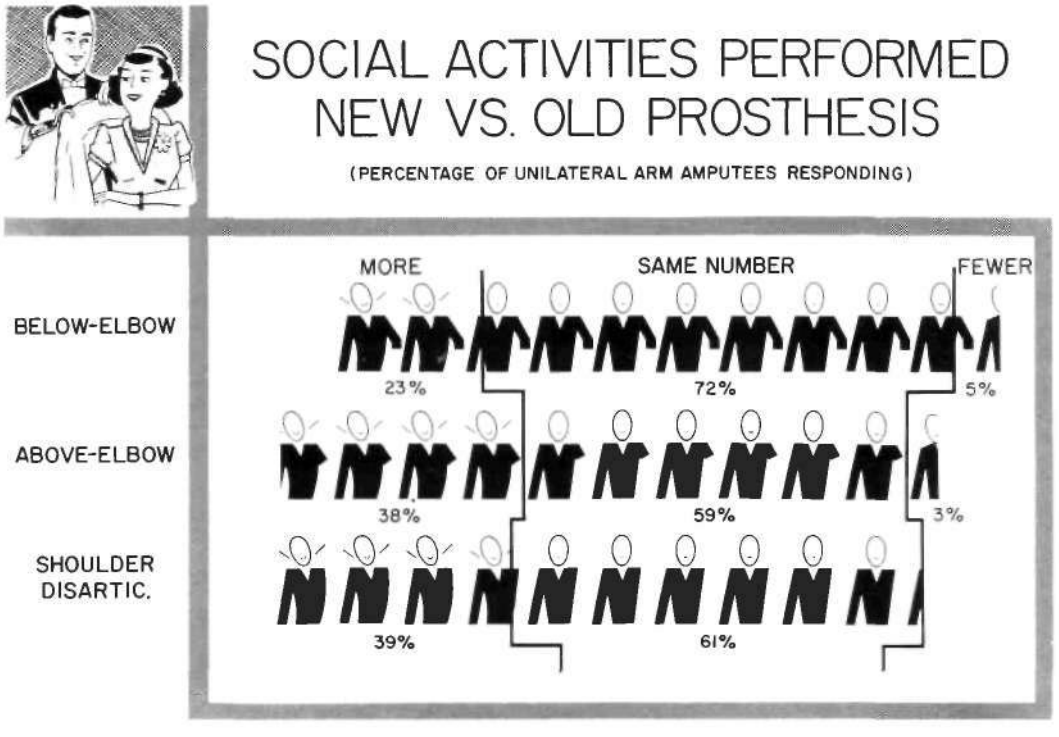
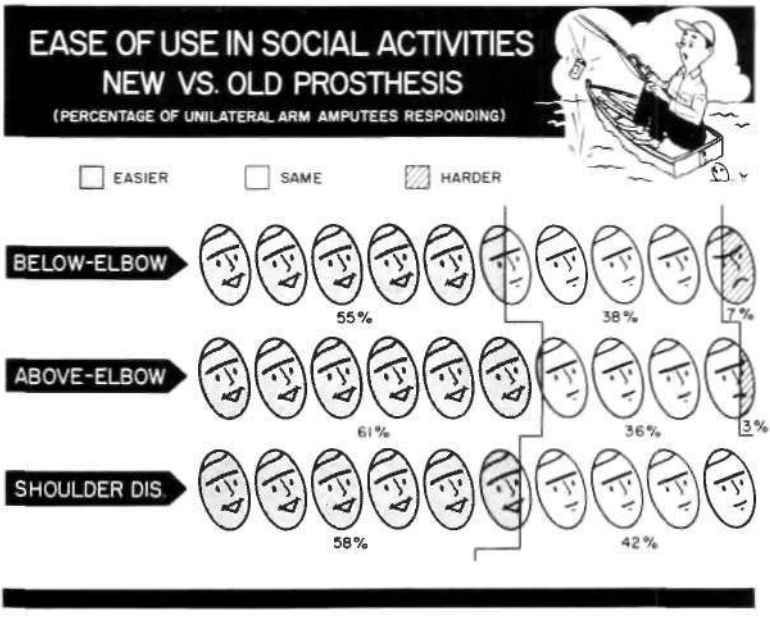
NO USE
HINDRANCE


SOCIAL ACTIVITIES PERFORMED
NEW VS. OLD PROSTHESIS
(PERCENTAGE OF UNILATERAL ARM AMPUTEES RESPONDING)
MORE
SAME NUMBER
FEWER
BELOW-ELBOW
23%
72%
5%
ABOVE-ELBOW
38%
59%
3%
SHOULDER DISARTIC.
39%
61%


EASE OF USE IN SOCIAL ACTIVITIES
NEW VS. OLD PROSTHESIS
(PERCENTAGE OF UNILATERAL ARM AMPUTEES RESPONDING)
EASIER
SAME
HARDER
BELOW-ELBOW
55%
38%
7%
ABOVE-ELBOW
61%
36%
3%
SHOULDER DIS.
58%
42%

Specific Activities Performed. Table 4 presents a listing of leisure-time activities performed by unilateral arm amputees using a prosthesis. Some of the pursuits listed are performed vocationally also, but the subjects in the study mentioned them more frequently as a hobby than as a vocation.

While an amputee's social or hobby interests are perhaps not of the same level of importance as eating, dressing, and working, they are nevertheless quite significant in his total pattern of living. It is apparent that to many arm amputees a major value of the prosthesis in leisure-time activities resides in its cosmetic contribution, this factor being mentioned most frequently by all types. In addition, many found their prostheses useful in a variety of sports and hobbies, including such relatively active endeavors as hunting, fishing, golf, and baseball.

Table 4

SPECIFIC RECREATIONAL AND SOCIAL ACTIVITIES PERFORMED BY UNILATERAL ARM AMPUTEES USING A PROSTHESIS

(Times Cited)

Activity	Amputation Level		
	Below-Elbow (N = 168)	Above-Elbow (N = 158)	Shoulder Disarticulation (N = 23)
Sports and Recreations			
Grasp fishing rod	43	51	3
Grasp hook to bait	24	34	2
Grasp and turn fishing reel	10	6	0
Grasp hook and pull out of fish's mouth	5	7	0
Grasp fishing line	0	1	0
Grasp or support rifle to shoot or reload	40	18	3
Grasp cards to play	35	24	1
Support partner in dancing	16	24	5
Grasp golf club or baseball bat to swing	7	0	0
Grasp reins to ride horse	7	2	0
Support cue stick to shoot pool	7	7	0
Use for balance in bowling	3	3	0
Grasp canoe paddle	2	1	0
Driving			
Weight steering wheel[a]	19	7	1
Hook cross piece of steering wheel or knob[a]	9	2	1
Grasp gear shift[a]	17	6	0
Grasp and pull throttle on plane	1	1	0
Miscellaneous			
Wear for appearance at church, social functions, etc.[a]	79	78	17
Support camera to take pictures	6	3	1
Grasp picture negative and place in developer[a]	2	1	0
Grasp newspapers or books to read	19	8	3
Grasp match box to light match	11	10	0
Grasp cigarette package	4	5	0

[a] Also performed as vocational activities.

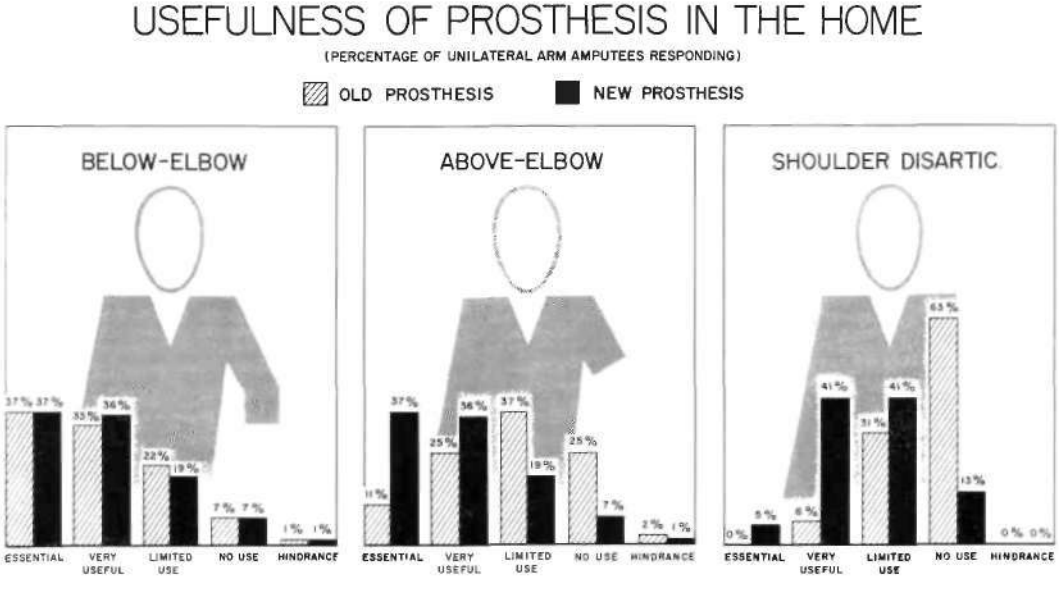
Home Tasks

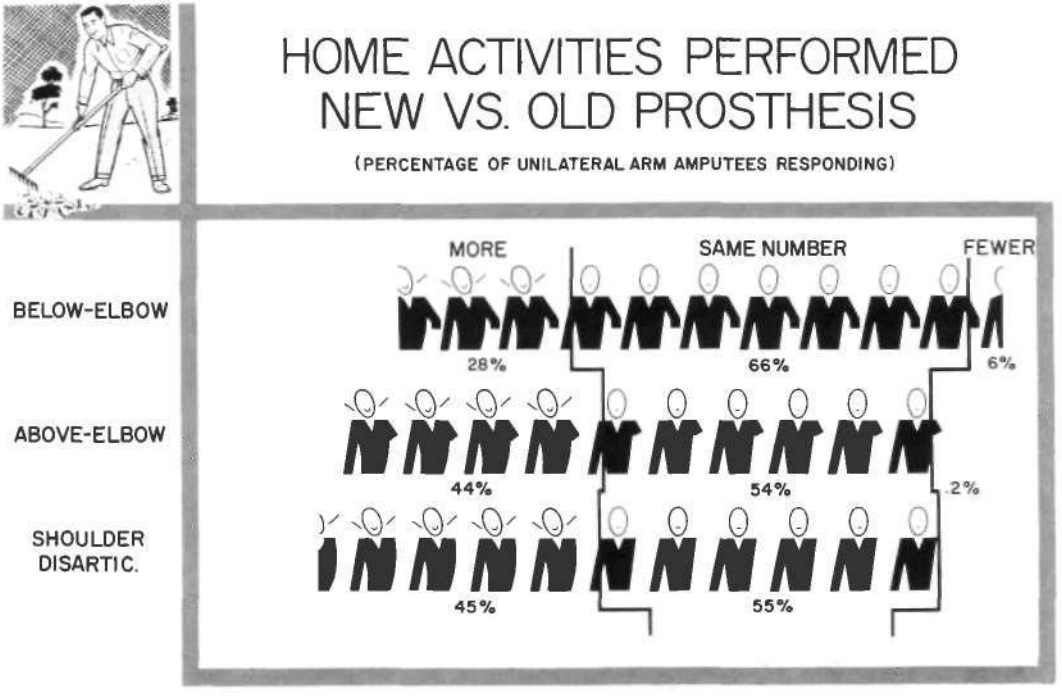
Usefulness. Use of a prosthesis at home encompasses a wide variety of tasks, from washing dishes and sweeping floors to gardening, painting, and electrical and plumbing repairs. Some of these activities are, of course, basically of a vocational nature but are performed as avocations on a part-time or intermittent basis. As for improvement in the usefulness of the prosthesis in home tasks, the shift in opinion was relatively small in below-elbow subjects but quite pronounced in above-elbow and shoulder-disarticulation amputees. In home tasks, as in other activity areas discussed previously, a high percentage of below-elbow subjects (70 percent) considered their old prostheses either essentia] or very useful, and this opinion was maintained for the new prosthesis (73 percent). It would appear that for this type of amputee there was less margin for improvement and hence less was achieved, or, the other way round, the old arms available for below-elbow amputees were relatively more satisfactory than were those available for other amputee types.

Activity Level. Nearly 45 percent of the above-elbow and shoulder-disarticulation cases and a smaller proportion of the below-elbow amputees (28 percent) found new uses in the home for their program prostheses. A small minority of the below-elbow group (6 percent) found fewer uses for their new prostheses.

Ease of Use. The proportion of amputees reporting greater ease in performance of home tasks with the program prostheses ranged between 64 and 75 percent. Shoulder-disarticulation amputees (75 percent) were most favorably impressed, followed by above-elbow (66 percent) and below-elbow (64 percent). A few below-elbow (9 percent) and above-elbow (3 percent) subjects found home tasks more difficult than before.

Specific Activities Performed. Table 5 indicates the types of home activity for which unilateral amputees used their prostheses. From the scope of activities listed, it is apparent that unilateral amputees find a wide range of uses for their prostheses in the home. While the rate or quality of performance is not indicated by the data, several of the tasks performed imply a high degree of dexterity. For example, a number of amputees undertook automobile and electrical repairs and various types of carpentry, and they made use of a wide range of tools, including power equip-





ment. Since, as mentioned earlier, many tasks performed in the home by choice or necessity are vocational in nature, a more intensive investigation of this performance pattern would throw further light on the employment potential of arm amputees.

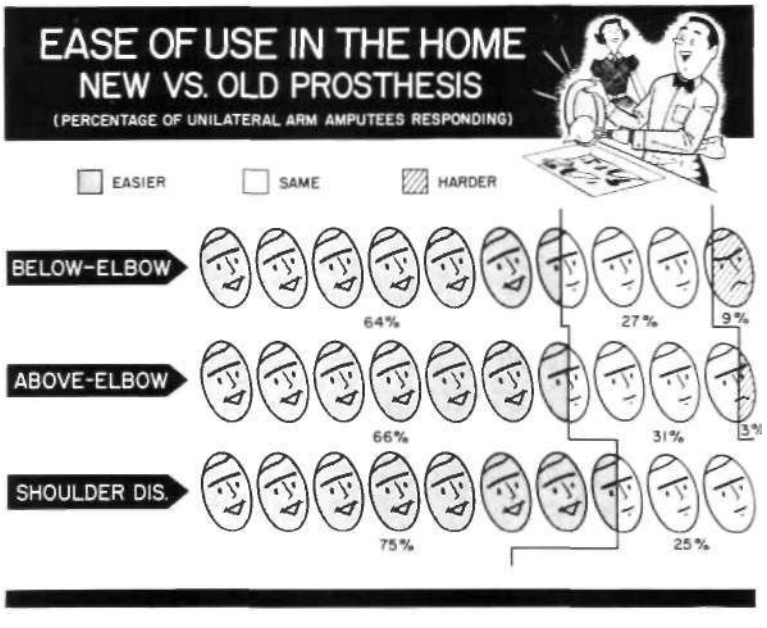


Table 5

SPECIFIC HOME ACTIVITIES PERFORMED BY UNILATERAL ARM AMPUTEES USING A PROSTHESIS

(Times Cited)

Activity	Amputation Level		
	Below-Elbow (N = 168)	Above-Elbow (N = 158)	Shoulder Disarticulation (N = 23)
Gardening			
Grasp long-handled tools (rake, broom, shovel, hoe, pitchfork)[a]	90	60	9
Grasp and push lawnmower	55	31	3
Grasp and push wheelbarrow	8	13	3
Grasp hose to water lawn or fill gas tank[a]	5	12	2
General Repairs			
Grasp nails to hammer[a]	66	55	9
Grasp short-handled tools (files, brace and bit, wrench, power tools)	50	36	5
Grasp paint buckets to carry	30	30	4
Perform general electrical repairs (radio, toaster, wiring)	18	15	1
Grasp small objects (light plugs, sockets, switches, etc.)	17	26	9
Grasp wood to saw or sand	13	15	3
Grasp screws, nuts, and bolts	12	15	2
Grasp spray gun, welding iron, or solder	10	11	1
Grasp and support lumber in carrying	10	3	2
Grasp rungs to climb ladder	10	1	1
Grasp chisel to hammer	8	2	0
Grasp and turn knobs on lathe[a]	5	0	0
Grasp knob to plane	3	2	0
Build fences	3	4	0
Push wood through power saw	3	2	0
Perform automobile repairs	3	2	0
Grasp nail to drive in wall	2	1	0
Grasp shovel to mix cement	1	0	0
Put up television aerial	0	4	0
Grasp barbed wire to string[a]	0	2	0
Hook to stabilize oneself on ladder	1	4	0
Grasp and pull leather to upholster chair	0	1	0
Domestic Duties			
Grasp storm sash, screens, curtain rods to put up	13	7	0
Support and carry groceries, packages[a]	12	29	7
Hook and carry garbage cans	11	4	2
Grasp dishes to wash and dry	9	6	3
Grasp, push, and pull vacuum cleaner	7	3	0
Grasp, push, or pull bed sheets and blanket to make beds	7	3	1
Grasp and carry furniture	4	9	2
Push furniture	3	3	1
Grasp dust pan to sweep up	3	2	0
Grasp and lift rugs	2	0	0
Grasp towel to dry dishes	2	0	0
Grasp knife to sharpen	2	1	1
Grasp picture frame to hang	1	0	0

Table 5—*Continued*

Activity	Amputation Level		
	Below-Elbow (N = 168)	Above-Elbow (N = 158)	Shoulder Disarticulation (N = 23)
Miscellaneous			
Push open and close doors	10	14	3
Support books to carry	4	5	0
Push light switch	3	3	2
Push or pull faucets	1	2	0
Push to ring doorbells	1	2	0
Grasp and pull to open doors	1	1	0

[a] Also performed by some amputees in their work

BILATERAL SUBJECTS

In the performance of bimanual activities by unilateral arm amputees, the prosthesis serves primarily, as has been seen, to assist the remaining good hand. Similarly, and for various reasons, unilateral arm amputees not infrequently perform with the one remaining hand activities ordinarily bimanual. Bilateral arm amputees quite obviously are faced with an entirely different situation. Since more or less of both upper extremities is lacking, at least one prosthesis must assume more than an assistive role, and one-handed performance of tasks normally two-handed cannot be substituted for use of a prosthesis. Manual activities required of bilateral arm amputees must therefore be done prosthetically if done at all. In a very real sense, then, the performance problems and the adaptations of bilateral arm amputees are quite unlike those of any type of unilateral amputee, and they therefore warrant separate discussion.

In the Upper-Extremity Field Studies, data were collected on 10 bilateral arm amputees (7 bilateral below-elbow, 3 bilateral above-elbow/below-elbow). Five of these subjects (4 bilateral below-elbow, 1 bilateral above-elbow/below-elbow) were wearing prostheses bilaterally when admitted. The other five had either one prosthesis only or none at all. Thus, although information as regards program prostheses was obtained on all 10 subjects, comparative data on new *vs.* old arms are available on only five subjects.

Experienced Wearers

Although the five amputees who had worn prostheses bilaterally prior to the NYU Field Studies rated their old arms quite useful in all five of the activity areas, they considered the new prostheses equally useful or slightly better than the old ones (Table 6).

As shown in Table 7, four of the five experienced wearers of bilateral prostheses indicated equivalent or increased use of their new prostheses as compared to the old, while one reported decreased use.

Table 6

USEFULNESS OF ARM PROSTHESES TO BILATERAL WEARERS

NUMBER OF SUBJECTS RESPONDING

(N = 5)

Activity Area	Rating					
	Essential		Very Useful		Limited Use	
	Old	New	Old	New	Old	New
Eating	5	5	0	0	0	0
Dressing	3	5	1	0	1	0
Work	5	5	0	0	0	0
Recreation	4	4	1	1	0	0
Home	5	5	0	0	0	0

Table 7

ACTIVITIES PERFORMED BY BILATERAL ARM WEARERS
NEW *vs.* OLD PROSTHESES
NUMBER OF SUBJECTS RESPONDING
(N = 5)

Activity Area	More	Same No.	Fewer
Eating	2	2	1[a]
Dressing	2	2	1[a]
Work	2	2	1[a]
Recreation	1	3	1[a]
Home	2	2	1[a]

[a] At Evaluation II this subject complained of the poor fit and operation of the left prosthesis provided him in the Field Studies. The deficiencies of this prosthesis are reflected in his opinions concerning extent of use and ease of operation in all activity areas. See Table 8.

As might have been anticipated, the pattern of amputee responses concerning ease of use (Table 8) of the new prostheses as compared with the old was quite similar to that concerning extent of use (Table 7). In general, the evidence indicated somewhat easier operation of the program prostheses, although the improvement was by no means universal.

Those bilateral arm amputees who reported easier operation and more extensive use of their new prostheses attributed the improvements primarily to the more secure grasp permitted by the terminal devices prescribed in the Field Studies. Neoprene-lined hook fingers and the heavy-load feature of the Northrop-Sierra two-load hook contributed greatly to this improved grasp security. Other favorable aspects of the new arms, mentioned by different subjects, were lighter weight and better control (faster operation and lower force requirement). The one subject fitted with an above-elbow arm indicated that operation of his new elbow lock was simpler and more efficient.

Table 8

EASE OF USE FOR BILATERAL ARM AMPUTEES
NEW *vs.* OLD PROSTHESES
NUMBER OF SUBJECTS RESPONDING
(N = 5)

Activity Area	Easier	Same	Harder
Eating	3	1	1[a]
Dressing	3	1	1[a]
Work	2	2	1[a]
Recreation	1	3	1[a]
Home	2	2	1[a]

[a] At Evaluation II this subject complained of the poor fit and operation of the left prosthesis provided him in the Field Studies. The deficiencies of this prosthesis are reflected in his opinions concerning extent of use and ease of operation in all activity areas. See Table 7.

New Wearers

The five amputees who had not worn prostheses bilaterally prior to the Field Studies rated their program prostheses quite useful (Table 9). For some reason, however, their ratings showed less enthusiasm than did those of the patients who had previously worn prostheses.

Table 9

USEFULNESS OF THE PROSTHESES TO NEW BILATERAL WEARERS
NUMBER OF SUBJECTS RESPONDING
(N = 5)

Activity Area	Essential	Very Useful	Limited Use
Eating	3	2	
Dressing	2	2	1
Work[a]	3	1	
Recreation	2	3	
Home	2	2	1

[a] One subject was unemployed.

Specific Activities Performed

At Evaluation II (new prostheses), information on the specific uses to which bilateral arm amputees put their prostheses was obtained from all 10 subjects for each of the activity areas under study. The activities reported by the individual amputees were given as "free responses" *(i.e.,* unprompted

and unstructured), and hence the listings may be considered more representative than complete.

The available data on the 10 bilateral subjects indicate that they used their prostheses extensively in eating and attained a relatively high level of independence. Two mentioned specifically that they performed all eating activities with their new prostheses *(i.e.,* were completely independent). Table 10 presents specific eating activities reported to be performed by the bilateral subjects.

Table 10

SPECIFIC EATING ACTIVITIES PERFORMED BY BILATERAL ARM AMPUTEES USING PROSTHESES (N = 10)

Activity	Times Cited
Use fork to bring to mouth	9
Use knife and fork to cut food	7
Pick up glass or cup to drink	7
Grasp spoon to stir coffee or for eating	5
Butter bread	3
Open bottles and drink from them	2
Grasp plates	2
Grasp and carry a tray	1
Grasp and eat an ear of corn	1

Only one of the 10 bilateral amputees claimed complete independence in dressing, although two other subjects reported the performance of all dressing activities except buttoning shirt sleeves. Two more persons performed all activities except fastening buttons, lacing shoes, and tying neckties. Table 11 lists specific dressing activities reported as performed by the bilateral subjects.

The employability or vocational-placement possibilities of bilateral arm amputees always hold considerable interest. Although the sample was in this instance exceedingly small, it may be worth noting that five of the 10 bilateral amputees were self-employed, that four worked for others, and that only one was unemployed. Of the nine employed subjects, one was a lawyer, one an engineer, one a forester, and one a quality-control inspector. Two

Table 11

SPECIFIC DRESSING ACTIVITIES PERFORMED BY BILATERAL ARM AMPUTEES USING PROSTHESES (N = 10)

Activity	Times Cited
Pull on trousers, shirt, and socks	7
Pull off shirt	7
Tie shoelaces	3
Button and unbutton shirts	3
Grasp and pull zipper	2
Shave	2
Tie necktie	1
Fasten belt	1
Fasten snaps on shoes	1
Brush teeth	1
Wash and dry face	1

were filling-station attendants, and three were farmers. The quality-control inspector, unemployed at the beginning of the program, obtained his position after receiving his new prostheses, and he credited the functional qualities of the limbs for his new employment.

Table 12 lists specific activities reported by the nine employed subjects as being performed with their program prostheses at work.

A listing of recreational activities performed by the bilateral amputees revealed that with their new arms most were able to drive a car independently and that most engaged in some form of active or passive recreational endeavor. Table 13 lists specific activities mentioned by the subjects as being performed with their prostheses.

The pattern of home activities performed by bilateral amputees (Table 14) does not differ greatly from that of unilateral except that among bilaterals there is a lesser tendency to undertake tasks requiring fine manipulation. Even allowing for the smaller number of subjects involved, it is apparent that the home activities of bilaterals run more to gross tasks, such as pushing a lawnmower or handling a broom, than to precision activities, such as electrical or radio repairing. Since the absence of "at least one good hand" would be a major handicap in work requiring manipulation of small parts, such a situation is quite understandable.

Table 12

SPECIFIC WORK ACTIVITIES PERFORMED BY BILATERAL ARM AMPUTEES USING PROSTHESES
(N = 9)

Activity	Times Cited
General Office Duties	
Grasp pencil and write	4
Grasp telephone	2
Push cash-register keys	2
Push keys to type	2
Pull lever on adding machine	1
Hook briefcase	1
Push down on stapler	1
Grasp and carry magazines, books, paper, chair	1
Grasp and sharpen pencil	1
Farming and Forestry	
Grasp hammer and drive nails	4
Grasp small tools (spade, saw)	3
Plow	2
Weed	2
Grasp hoe, dig potatoes	2
Hook and carry buckets	1
Trim trees, use hand saw	1
Grasp animals	1
Set animal traps	1
Grasp surveyor's rod	1
Grasp measuring tape	1
Plant, general	1
Garden, general	1
Bale hay	1
Gas-Station Operation	
Grasp and take off gas-tank cap	2
Operate gas pump	2
Put water in radiator	2
Check oil	2
Grasp and handle money	2
Grasp rag to wipe windshield	1
Grasp broom to sweep	1
Clean tables	1
Carry soda cases	1
Open beer bottles	1
Grasp sponge to wipe dishes	1

Table 13

SPECIFIC RECREATIONAL ACTIVITIES PERFORMED BY BILATERAL ARM AMPUTEES USING PROSTHESES
(N = 10)

Activity	Times Cited
Grasp steering wheel to drive	6
Grasp, push, and pull gear shift	6
Grasp and pull switch for headlights	6
Grasp and pull playing cards	3
Grasp fishing pole	2
Grasp cigarettes to take out of pack	2
Grasp and turn fishing reel	1
Grasp hook to bait	1
Grasp or support rifle to shoot or reload	1
Grasp camera, trip shutter, wind film	1
Grasp and pitch horseshoes	1
Grasp, pull starter, and steer motorboat	1
Grasp and throw softball	1
Push checkers to play	1
Grasp newspaper to read	1

In summary, the comparative data on five bilateral arm amputees whose preprogram prostheses were replaced by program arms appeared to indicate that:

1. The five subjects thought well of their old prostheses and used them extensively.

2. In four of the five cases there was slight but definite evidence of functional improvement over that provided by the old prostheses. Contributing largely to this improvement appeared to be the better grasp furnished by the Dorrance 5X and Northrop-Sierra two-load hooks, partly because of the neoprene-lined hook fingers and partly because of the heavy-load feature of the Northrop-Sierra device. Other favorable features mentioned by some of the subjects were lightness and ease of operation. The one amputee fitted with an above-elbow prosthesis felt that his new elbow was much more dependable and much easier to operate than the one previously worn. One subject in the group apparently had a left prosthesis very poorly fitted and functionally inadequate, a deficiency which, in view of the rigorous checkout procedures and the close control of fittings by the clinic teams, is hard to explain. Nevertheless, that particular patient was obviously fitted unsatisfactorily, and this circumstance affected his whole reaction to the prostheses provided.

Discussion

An outstanding characteristic of the data thus far presented is general consistency. For all categories of daily-living activities considered (eating, dressing, work, recreational and social life, and home tasks), and for all criteria applied (general usefulness, level of usage, and ease of use), the evidence strongly indicates that the prostheses provided in the program were more useful than those previ-

Table 14

SPECIFIC HOME ACTIVITIES PERFORMED BY BILATERAL ARM AMPUTEES USING PROSTHESES
(N = 10)

Activity	Times Cited
Gardening	
Grasp and push lawnmower	7
Grasp rake, hoe, and broom	2
Grasp hose to water lawn or garden	2
Grasp shears and trim hedges	1
General Repairs	
Hook paint bucket and grasp brush to paint	3
Grasp hammer and nails	2
General repairs	1
Rewire electrical equipment	1
Grasp saw to cut wood	1
Domestic Duties	
Grasp broom, brush, and dustpan	5
Grasp and carry groceries	2
Wash dishes	2
Make beds	2
Move furniture	2
Push vacuum cleaner	1
Grasp rug to dust	1
Hook and carry garbage cans	1
Miscellaneous	
Open doors	4
Push light switch	3
Grasp and turn faucet	1
Grasp padlock and unlock	1
Grasp brush to wash car	1

ously worn. But the material also raises a number of interesting questions of which only some can be answered satisfactorily by the available data. For example, the extent of improvement provided by the new prostheses varied considerably from amputee type to amputee type. It was least for the below-elbow subjects, and some few members of this group even expressed a preference for the old prosthesis. For the unilateral above-elbow and shoulder-disarticulation subjects, the increased usefulness of the new prosthesis was considerably more marked and dramatic.

When one speculates on the reasons for these differences, it must be borne in mind that the so-called "old" prostheses exhibited a wide range of quality from very poor to excellent. A number of the preprogram arms, particularly those for below-elbow amputees, were probably as good as, in some few cases even better than, those provided in the study. Moreover, some of the below-elbow subjects whose old leather-socket arms had some of the comfort qualities of old shoes or slippers reacted unfavorably to the new plastic sockets. Whatever the reasons, it was evident that some of the old arms provided below-elbow amputees with a relatively high degree of usefulness and that the impact of the research program on these subjects was relatively small. The reverse appears to have been true of above-elbow and shoulder-disarticulation prostheses. Taken as a whole, the old arms for these cases were of comparatively limited usefulness, and hence considerable improvement was effected by the new prostheses. Thus it may be said that the prostheses provided in the field program made the greatest contribution where improvement was most needed.

Another thought-provoking finding of the study was that the usefulness of the prostheses obviously varied from one activity area to another, sometimes quite significantly. All three unilateral groups rated their prostheses as being about equally useful in home, work, and social activities but considerably less useful in dressing and of least use in eating. An explanation of these differences may lie in the fact that eating and dressing involve a limited number of specific activities, particularly those which require bimanual effort, and that the majority of these are quite difficult to perform with an arm prosthesis. It may also be conjectured that, in the sometimes quite lengthy time lapse between amputation and receipt of an arm prosthesis, patients build strong habit patterns of one-handed eating and dressing and that these habits carry over after the prosthesis has been supplied. Work, leisure, and home tasks present a much wider and more varied range of activities. Presumably more of these require bimanual performance in which the prosthesis is of definite assistance. Bilateral arm amputees gave uniformly high ratings to their prostheses in all activity groups, but *their* performance

problems are quite different from those of unilateral arm amputees.

A third area of interest involves the matter of basic reasons for use or nonuse of the prosthesis. In numerous instances, a particular activity was performed with the prosthesis by a considerable number of amputees of a given type. Why, then, do not *all* amputees of that type perform that activity with the prosthesis? Here is a question with many implications. It has been suggested that of the factors determining prosthetic usage—such as ease and convenience of performance, motivation, habit patterns—the first named is of basic importance. If, for example, we consider some specific activity such as tying shoelaces, which with prosthetic help apparently can be performed by *some* amputees of all types, even including a few with shoulder disarticulations, we may assume that this activity presents a certain level of difficulty and inconvenience. For below-elbow subjects the level may be low enough not to discourage more than a few from performing the task with their prostheses. But it must also be high enough so that others, by reason of habit or lack of motivation or some other influence, will tie the laces one-handed, wear loafers or buckle shoes, or in some other fashion avoid use of the prosthesis. For above-elbow and shoulder-disarticulation amputees, of course, the difficulty in performing the activity rises progressively and markedly, so that even though the performance potential be available with the prosthesis fewer amputees would be inclined to avail themselves of it. Obviously, then, further study of the factors affecting prosthetic utilization is highly desirable.

A fourth area of interest has to do with the vocational potential of arm amputees. The number and variety of tasks that amputees can perform with the aid of an artificial arm is quite surprising. Extensive use of the prosthesis on the job, in activities around the house, and in hobbies suggests for arm amputees a much wider employment potential than is generally recognized. This subject too is worthy of further investigation on a more intensive basis than was possible in the NYU Field Studies.

In general, the relation between the pretreatment (Evaluation I) and post-treatment (Evaluation II) conditions of the five bilateral amputees was quite similar to the corresponding relation for the unilateral below-elbow amputees discussed previously. Since the bilateral sample included predominantly below-elbow fittings (4 bilateral below-elbow, 1 bilateral below-elbow/above-elbow), the similarity is not surprising. The over-all performance patterns of the 10 bilateral subjects would indicate that as a whole these patients achieved a high level of performance in a wide range of tasks. To a very considerable degree they appeared able to operate their prostheses effectively and to meet independently a substantial number of the requirements of daily living.

EXTENT OF USE OF ARM PROSTHESES IN TWENTY SELECTED BIMANUAL ACTIVITIES

In the preceding section, the evaluation of the utility of prostheses provided arm amputees was based upon an analysis of their usefulness in five key activity areas, changes in activity level, and ease of use. To gain further insight in this matter, additional study was made of how amputees use their prostheses in 20 selected activities which were considered significant on the basis of four criteria:

1. The activities should be important ones drawn from all five of the areas of daily living previously discussed *(i.e.,* eating, dressing, work, social life and recreation, and home tasks)
2. The activities should call for a range of work levels from floor to head.
3. The normal performance of the activities should be bimanual.
4. Prosthetic performance of the activities should be possible for all unilateral amputee types.

The tasks selected were:

1. Cut food with knife and fork
2. Sharpen pencil
3. Sweep up dirt with brush and dustpan
4. File and clean fingernails
5. Tie necktie
6. Use telephone (particularly when taking notes)
7. Assist someone with coat
8. Take bills out of wallet
9. Unbutton shirt sleeve

10. Carry several packages
11. Use "Flit" gun
12. Open bottles, jars, and tubes
13. Put on glove
14. Use paper clip
15. Carry cafeteria tray
16. Use can or bottle opener
17. Tie shoelaces
18. Play cards
19. Rewire electric plug
20. Use hammer and nails

With regard both to preprogram and to program prostheses, the subjects were asked concerning each of the selected activities five questions:

1. How often in your routine of living does the occasion arise for you to perform the activity? (Daily, weekly, monthly, other)
2. How important is the activity in your particular pattern of living? (Very important, important, of little or no importance)
3. How often do you perform the activity with your prosthesis? (Daily, weekly, monthly, other)
i. If you do not perform the activity with your prosthesis every time the occasion arises, why not? (Write-in)
5. If you never use the prosthesis to perform the activity, how do you perform it? (Write-in)

The material that follows presents amputee responses to these questions and from these responses seeks to determine the extent to which prostheses were meeting amputee needs. In the main, attention is directed toward the new prostheses provided in the study, that particular data being considered as indicative of present status and hence more meaningful. Only in regard to Question 3, and then with respect to unilateral cases only, is a comparison made between old and new prostheses.

The subjects in this study were the same as those making up the sample for the previous series of questions. Again, the data on the three unilateral amputee groups are presented first, with those for the bilateral subjects in a separate section following.

UNILATERAL SUBJECTS

As we have seen, the problem of restoring function to unilateral arm amputees varies from amputee type to amputee type, the extent of restoration generally being related inversely to the degree of anatomical loss. But all three types of unilateral arm amputees usually have left one normal arm and hand, and accordingly the prosthesis needs for the most part only to assist the remaining natural member.

Frequency of Occasion to Perform Activities

The purpose of the question "How frequently does the occasion arise to perform the activity?" was to ascertain how often amputees were called upon, or had the opportunity, to perform each of the 20 selected activities, regardless of whether they used the prosthesis in the performance of the activity or whether they even performed it at all. For instance, the question "How often do you have occasion to cut food with a knife and fork?" was interpreted as "How often do you have food which requires cutting with a knife?" Responses relative to each of the 20 activities were tabulated in four categories—at least once daily; at least once weekly; at least once monthly; and less than once monthly, or never. Separate tabulations were prepared for below-elbow, above-elbow, and shoulder-disarticulation amputees. On the basis of these tabulations, there was calculated the percentage of amputees (of each type) who reported once daily or oftener as the frequency of occurrence of a particular activity. The percentage figures were then used to arrange the 20 activities in order from those occurring most frequently to those occurring least frequently. It should be emphasized that "most frequently," as used here, means occurring on a daily basis to the largest proportion of amputees.

Table 15 presents the results for the three groups of unilateral amputees. Since these data are based on unverifiable amputee statements concerning their activities, the information in Table 15 cannot be considered as presenting any absolute answer. Nevertheless, the data are quite consistent. Percentages for the first nine activities are of the same order for all groups, and that for the tenth shows a slight variation for the shoulder-disarticulation subjects only. The 10 tasks on the lower end of the table were performed daily by the least number of amputees. These data showed

Table 15

PERCENTAGE OF UNILATERAL ARM AMPUTEES REPORTING OCCASION FOR SELECTED ACTIVITIES "AT LEAST ONCE DAILY"

Activity	Amputee Type		
	Below-Elbow (N = 168)	Above-Elbow (N = 158)	Shoulder Disarticulation (N = 23)
1. Unbutton shirt sleeve	93	87	87
2. Tie shoelaces	84	83	78
3. Cut food with knife and fork	77	87	74
4. Take bills out of wallet	80	73	78
5. Open bottles, jars, and tubes	72	70	70
6. Use telephone (particularly when taking notes)	60	75	61
7. Use paper clip	53	55	65
8. File and clean fingernails	51	48	65
9. Sharpen pencil	51	49	48
10. Use can or bottle opener	44	46	35
11. Put on glove	36	40	39
12. Tie necktie	37	35	35
13. Carry several packages	39	37	13
14. Sweep up dirt with brush and dustpan	29	28	22
15. Carry cafeteria tray	16	20	26
16. Use hammer and nails	19	19	9
17. Assist someone with coat	12	10	9
18. Use "Flit" gun	5	4	4
19. Play cards	1	6	0
20. Rewire electric plug	1	2	0

similar patterns of occurrence for each of the three types of amputees. Thus it would appear that some of the activities on the "selected" list confront a large proportion of all types of amputees on a daily basis. Other activities affect relatively few amputees as often as this.

How often an activity should occur, or how many people it should affect to be considered "significant" in the lives of amputees, is a philosophical question. On an arbitrary basis we might say that the first nine activities in Table 15, which occur daily in the lives of more than about half of the amputee population, are "significant" activities. Yet who can say that tying a necktie (occurring to one third of the group daily) or even using a hammer and nails (less than one fifth of the population affected daily) are "insignificant" activities? Obviously such tasks could be highly significant to the particular amputees involved.

Relative Importance of the Activities

In addition to the frequency of occurrence, the degree of importance subjectively attached to being able to perform a specific activity is a second significant factor in determining the usefulness of a prosthesis to its wearer. Accordingly, the ten subjects were also asked to rate each of the 20 selected activities as "very important," "important," or "of little or no importance" to them in their regular activity pattern.

Table 16 presents the percentages of amputees rating the respective activities as either "very important" or "important," the activities being arranged in the approximate order of importance on the basis of these percentages. For example, "cut food with knife and fork" was rated "very important" or "important" by more amputees within each of the three unilateral amputee groups than was any other of the 20 selected activities. Tying a necktie was second in importance to above-elbow and shoulder-disarticulation amputees but fifth in importance to the below-elbow subjects. Thus the ranking of activities in Table 16 may be thought of as indicating the general level of importance attached to the activities by the unilateral amputee population as a whole.

In these terms the 20 activities fall rather obviously into three levels of significance. The first 10 tasks are rated as important by two thirds or more of the sample, cutting food being by far the most significant activity (about 9 out of 10 subjects). The next three activities may also be considered quite significant, almost one in two amputees designating them as important. The final seven tasks may be regarded as having lower general significance, no more than one in three amputees rating them as important. With the possible exception of using a "Flit" gun, however, even these low-ranking activities cannot be considered as completely insignificant. For example, rewiring an electric

Table 16

RELATIVE SIGNIFICANCE OF ACTIVITIES TO UNILATERAL ARM AMPUTEES

(Based on Percentage of Amputees Rating an Activity Important or Very Important)

Activity	Amputee Type		
	Below-Elbow (N = 168)	Above-Elbow (N = 158)	Shoulder Disarticulation (N = 23)
1. Cut food with knife and fork	86	88	96
2. Tie necktie	63	79	87
3. Unbutton shirt sleeve	75	67	74
4. Use hammer and nails	67	62	83
5. Open bottles, jars, and tubes	64	64	83
6. Use telephone (particularly when taking notes)	58	72	83
7. Tie shoelaces	75	61	70
8. Take bills out of wallet	71	65	65
9. File and clean fingernails	67	73	61
10. Carry several packages	56	67	70
11. Sharpen pencil	57	50	52
12. Use can or bottle opener	57	47	39
13. Use paper clips	43	44	35
14. Assist someone with coat	40	27	26
15. Sweep up dirt with brush and dustpan	32	35	17
16. Play cards	35	20	39
17. Carry cafeteria tray	25	21	35
18. Put on glove	26	33	13
19. Rewire electric plug	20	23	22
20. Use "Flit" gun	13	10	9

plug, nineteenth in order on the list, is rated as an important activity by one in five unilateral amputees of all types, a fairly substantial number of people. We may conclude therefore that, while according to the criteria used in this study the 20 selected activities vary widely in importance, all, or almost all, have value to some significant proportion of unilateral arm amputees.

It is of interest to compare the data on the importance of activities with those on the frequency of occurrence discussed earlier. Table 17 presents the 20 activities in approximate order of frequency of occurrence (from Table 15) and also lists the approximate order of importance for the 20 tasks (from Table 16). A fairly consistent relationship between frequency and importance is apparent at once. Seven of the nine most important activities occur very frequently.

It can be inferred therefore that, in general, activities which occur most frequently are likely to be regarded as being the most important, but the instances where this principle does not hold are also of interest. Two out of three shoulder-disarticulation amputees said they had occasion to use a paper clip daily, but only one out of three considered the activity important. Less than one in six below-elbow amputees reported that they had occasion to use a hammer and nails on a daily basis, yet two out of three considered the

Table 17

RELATIVE INCIDENCE AND RELATIVE IMPORTANCE OF TWENTY BIMANUAL ACTIVITIES AMONG UNILATERAL ARM AMPUTEES

Incidence	Activity	Importance
1	Unbutton shirt sleeve	3
2	Tie shoelaces	7
3	Cut food with knife and fork	1
4	Take bills out of wallet	8
5	Open bottles, jars, and tubes	5
6	Use telephone (particularly when taking notes)	6
7	Use paper clip	13
8	File and clean fingernails	9
9	Sharpen pencil	11
10	Use can or bottle opener	12
11	Put on glove	18
12	Tie necktie	2
13	Carry several packages	10
14	Sweep up dirt with brush and dustpan	15
15	Carry cafeteria tray	17
16	Use hammer and nails	4
17	Assist someone with coat	14
18	Use "Flit" gun	20
19	Play cards	16
20	Rewire electric plug	19

activity important. While only one in three of the below-elbow subjects reported tying a necktie daily, about three in four considered it important to be able to do so. Thus, some activities that occur frequently may be relatively unimportant; others may occur only infrequently but still have great personal significance.

Performance of Activities with the Prosthesis

Having considered the frequency of occurrence of the 20 selected activities and the relative importance of these activities in the lives of amputees, we come now to the frequency of use of the prosthesis in the performance of the tasks, the point being to evaluate both the extent of prosthetic use and the relationship between this utilization and the two factors previously presented *(i.e.,* frequency of occurrence and importance).

Data on use of the prosthesis in the 20 selected activities, obtained from all amputees in the study, were organized to show the percentage of amputees who always, regardless of frequency, used the prosthesis in the performance of a particular activity, the percentage who sometimes used the prosthesis, and the percentage who never used it, a small number of amputees who claimed that they never had occasion to perform a particular activity being excluded. Table 18 presents the incidence of use of the program prostheses as reported by the unilateral subjects.

Analysis of Table 18 shows that the prosthesis is used extensively by below-elbow sub-

Table 18

PERFORMANCE OF SELECTED ACTIVITIES BY UNILATERAL ARM AMPUTEES USING PROSTHESES

(Percentage of Amputees Responding)

Activity	Amputee Type								
	Below-Elbow (N = 168)			Above-Elbow (N = 158)			Shoulder Disarticulation (N = 23)		
	Always	Sometimes	Never	Always	Sometimes	Never	Always	Sometimes	Never
1. Cut food with knife and fork	52	18	30	20	13	67	9	4	87
2. Sharpen pencil	90	1	9	76	1	23	61	9	30
3. Sweep up dirt with brush and dustpan	79	0	21	54	7	39	61	17	22
4. File and clean fingernails	74	6	20	61	8	31	53	4	43
5. Tie necktie	67	2	31	47	1	52	17	4	79
6. Use telephone (particularly when taking notes)	40	9	51	27	10	63	26	9	65
7. Assist someone with coat	75	4	21	28	5	67	0	4	96
8. Take bills out of wallet	76	6	18	53	6	41	44	4	52
9. Unbutton shirt sleeve	61	3	36	25	7	68	4	4	92
10. Carry several packages	89	3	8	85	3	12	87	0	13
11. Use "Flit" gun	85	0	15	73	3	24	22	0	78
12. Open bottles, jars, and tubes	72	9	19	50	16	34	48	4	48
13. Put on glove	82	1	17	60	8	32	41	0	59
14. Use paper clip	83	2	15	67	6	27	70	4	26
15. Carry cafeteria tray	85	0	15	55	3	42	52	0	48
16. Use can or bottle opener	76	5	19	49	7	44	39	9	52
17. Tie shoelaces	73	5	22	38	4	58	9	9	82
18. Play cards	59	11	30	41	4	55	18	30	52
19. Rewire electric plug	83	2	15	73	0	27	52	0	48
20. Use hammer and nails	83	4	13	65	2	33	65	5	30

jecls in performing the 20 selected activities, all tasks save one being performed by more than 50 percent of the group every time the opportunity arose. With rare exceptions *(e.g.,* carrying packages), the utilization of the prosthesis in performing activities dropped off sharply and progressively from the below-elbow to the above-elbow to the shoulder-disarticulation groups. An intriguing and somewhat unexpected finding is the relatively small percentage of amputees reporting occasional use of the prosthesis. It would appear that amputee use of the prosthesis tends to be on an all-or-none basis. If an amputee uses his prosthesis to perform an activity at all, he tends always to use it for that activity. Even when this general tendency is violated, there are interesting areas for speculation. For example, cutting food with knife and fork has a relatively high incidence of "sometimes" responses. Since we know that cutting food is relatively difficult at all amputation levels, it seems probable that some amputees ignore the prosthesis under some circumstances *(e.g.,* eating at home) but use it on other occasions *(e.g.,* eating out or when they have company) in spite of the difficulty. The fairly general always-or-never use of the prosthesis in the performance of specific activities reinforces a conclusion presented earlier—that there is for each activity a certain threshold, or tolerance, level of difficulty associated with prosthetic performance, that this threshold varies from amputee to amputee and from activity to activity, that if the performance difficulty is within the individual's tolerance limits he will tend to use the prosthesis consistently, and that if the level of difficulty is above his limit he will tend not to use the prosthesis at all.

The data in Tables 15 through 18 may also be viewed as an index of the relative usefulness of the prosthesis in the performance of the 20 selected tasks and, conversely, as a measure of the relative difficulty of the several activities from the standpoint of accomplishment by means of a prosthesis. For instance, the activity "sharpen pencil" appears to be performed (with help from the prosthesis) by 90 percent of below-elbow, 76 percent of above-elbow, and 62 percent of shoulder-disarticulation amputees every time the occasion arises. It would appear, therefore, that sharpening a pencil is not too difficult an operation for any type of unilateral arm amputee. The corollary conclusion is that, in pencil-sharpening, the prosthesis is a highly useful assistive device. On the contrary, activities such as cutting food or holding a telephone with the prosthesis appear to be quite difficult for arm amputees at all levels, and the prosthesis is then obviously of less value.

If we extend this index-of-usefulness concept to the entire list of 20 activities, we obtain the results shown in Table 19, which presents the percentage of amputees reporting use of the prosthesis every time the occasion arose for performing the activities. If, further, it is assumed that those activities in which there is the highest degree of prosthetic utilization are activities for which prostheses are most useful (or, more simply stated, easiest to perform with a prosthesis), then Table 19 indicates that the below-elbow prosthesis is highly useful or well adapted to performance in most of the 20 activities. For above-elbow and shoulder-disarticulation subjects, the usefulness or adaptability of the prosthesis drops off sharply *(i.e.,* the prosthesis has a high level of usefulness for considerably fewer activities). Nevertheless, some consistency in pattern is evident for the three unilateral amputee types in that activities for which the prosthesis is most useful for the below-elbow group tend also to be easiest for the above-elbow and shoulder-disarticulation subjects. Similarly, the activities that are most difficult for below-elbow subjects also present the greatest difficulty for above-elbow and shoulder-disarticulation amputees. Not readily explained is the fact that the activities for which the prosthesis is apparently most useful generally rank low in frequency of occurrence or importance or both, while activities for which the prosthesis is least useful generally rank high in occurrence and importance.

Old Versus New

Table 20 compares reports by unilateral arm amputees as regards the extent of use of the old and the new prostheses. It reveals a consistent but by no means universal trend

Table 19

INDEX OF USEFULNESS OF PROSTHESES AMONG UNILATERAL ARM AMPUTEES[a]

(Percentage of Amputees Using Prosthesis Every Time Occasion Arose)

Activity	Amputee Type		
	Below-Elbow (N = 168)	Above-Elbow (N = 158)	Shoulder Disarticulation (N = 23)
1. Sharpen pencil	90	76 (2)	61 (4)
2. Carry several packages	89	85 (1)	87 (1)
3. Use "Flit" gun	85	73 (3)	22 (14)
4. Carry cafeteria tray	85	55 (9)	52 (6)
5. Rewire electric plug	83	73 (3)	52 (7)
6. Use paper clip	83	67 (5)	70 (2)
7. Use hammer and nails	83	65 (6)	65 (3)
8. Put on glove	82	60 (8)	39 (11)
9. Sweep up dirt with brush and dustpan	79	54 (10)	61 (4)
10. Take bills out of wallet	76	53 (11)	43 (10)
11. Use can or bottle opener	76	49 (13)	39 (12)
12. Assist someone with coat	75	28 (17)	0 (20)
13. File and clean fingernails	74	61 (7)	52 (7)
14. Tie shoelaces	73	38 (16)	9 (17)
15. Open bottles, jars, and tubes	72	50 (12)	48 (9)
16. Tie necktie	67	47 (14)	17 (15)
17. Unbutton shirt sleeve	61	25 (19)	4 (19)
18. Play cards	59	41 (15)	17 (15)
19. Cut food with knife and fork	52	20 (20)	9 (18)
20. Use telephone (particularly when taking notes)	40	27 (18)	26 (13)

[a] Activities are ranked in descending order of usefulness to below-elbow amputees. Numbers in parentheses give corresponding rank for above-elbow and shoulder-disarticulation subjects.

toward greater utilization of the new prosthesis as compared with the old. It is most apparent in the above-elbow subjects (increase for 17 of the 20 activities), less apparent in the below-elbow and shoulder-disarticulation amputees. As regards specific activities, however, there appears to be no systematic pattern of changes in degree of prosthetic utilization, and hence the general evidence here is rather inconclusive.

Reasons for Performing Activities Without Using the Prosthesis

In the foregoing material, consideration has been given to the matter of amputee utilization of prostheses in terms of their use always, sometimes, or never in performing each of the 20 activities under study. When an amputee always uses his prosthesis in the performance of a particular activity, some degree of adequacy of the limb for that task may be assumed. When, however, he "sometimes" performs a task without using his prosthesis, or when he "never" uses the artificial arm in the performance of that activity, prosthetic inadequacy to some degree would seem apparent. An understanding of the specific inadequacies of today's arm prostheses with respect to each of the 20 activities would be of great value in prescription and training as well as in planning research. Accordingly, each amputee who indicated less than full utilization of his prosthesis in a given activity was asked why he didn't use his prosthesis every time he had occasion to perform that task.

The most specific, although not the most frequent, reason given for not using the

Table 20

EXTENT OF PROSTHETIC USE, OLD *vs.* NEW ARMS

(Percentage of Unilateral Amputees Reporting That They Always Use the Prosthesis)

Activity	Amputee Type					
	Below-Elbow (N = 168)		Above-Elbow (N = 158)		Shoulder Disarticulation (N = 23)	
	Old Arm	New Arm	Old Arm	New Arm	Old Arm	New Arm
1. Cut food with knife and fork	43	52	9	20	13	9
2. Sharpen pencil	79	90	52	76	39	61
3. Sweep up dirt with brush and dustpan	84	79	44	54	13	61
4. File and clean fingernails	69	74	66	61	30	52
5. Tie necktie	62	67	40	47	74	17
6. Use telephone (particularly when taking notes)	24	40	12	27	30	26
7. Assist someone with coat	75	75	38	28	13	0
8. Take bills out of wallet	80	76	43	53	39	43
9. Unbutton shirt sleeve	64	61	13	25	0	4
10. Carry several packages	91	89	73	85	100	87
11. Use "Flit" gun	77	85	56	73	0	22
12. Open bottles, jars, and tubes	61	72	31	50	52	48
13. Put on glove	79	82	55	60	26	39
14. Use paper clip	89	83	60	67	70	70
15. Carry cafeteria tray	81	85	32	55	52	52
16. Use can or bottle opener	53	76	29	49	26	39
17. Tie shoelaces	58	73	42	38	22	9
18. Play cards	51	59	37	41	43	17
19. Rewire electric plug	90	83	68	73	57	52
20. Use hammer and nails	81	83	49	65	57	65
Mean	69.5	74.2	42.5	52.4	37.8	38.7

prosthesis in the performance of particular activities was that the terminal device was inadequate. For instance, a given terminal device might be capable of holding a wallet or taking out bills but be ill-suited for holding a fork; it might be suitable for holding a necktie but not for handling a telephone. It may therefore be concluded that one major reason for not using the prosthesis in performing certain activities relates to lack of versatility in the terminal device.

Another important reason advanced for failure to use the prosthesis was that the terminal device could not be brought to the appropriate functional position and operated there. Although the exact cause of this difficulty is not apparent from the data, it may be related directly to prosthetic inadequacies. As a matter of fact, not many amputees were able to give clear reasons for not using the prosthesis, so that it is possible only to speculate on the implications of the responses Some subjects stated simply that they "could not perform" the task in question. Since this kind of response may indicate either lack of training or genuine prosthetic deficiency or both, full interpretation requires further investigation. In the absence of a more complete examination, it may only be guessed that poor features in the available prosthetic equipment contributed in some way to its disuse.

That an activity was "easier to perform without the prosthesis" was the reason given most frequently for failure to use an artificial arm. Although not especially revealing, such

statements reaffirm the conclusion reached for other aspects—that for numerous amputees performance of certain activities presents such difficulty that it is "cheaper" in time, effort, and peace of mind to do without the prosthesis. A sharp rise in the number of "easier-without-prosthesis" responses was noted in the above-elbow amputees as compared with the below-elbow subjects—a result in keeping with earlier findings of decreasing prosthetic usefulness at the higher levels of amputation.

A number of amputees reported that the prosthesis was not worn at the time a particular activity was performed. This circumstance may be considered as indicating either that the activity was easier to perform without the prosthesis or that performance without the prosthesis presented no particular problems. Were the prosthesis indispensable, it would be worn on almost all occasions when opportunity to perform the listed activities arose. Since it evidently was not, it must be assumed that some amputees could dispense with their prostheses without (to them) significant functional loss.

Two other general observations can be made concerning the reasons for nonuse of the prosthesis. Both reinforce evidence presented earlier. One is that the number of "reasons" for nonuse of the prosthesis increased sharply for the above-elbow group as compared with the below-elbow subjects, which is only to say that more above-elbow amputees than below-elbow amputees report "sometimes" or "never" as regards use of the prosthesis. The other is that some "important" activities and some "occurring frequently" (such as cutting food, tying a necktie, using a telephone, taking bills out of a wallet, unbuttoning the shirt sleeve, tying shoelaces, and so on) are also reported by many amputees as being easier to perform without the prosthesis than with it.

In summary, it would appear that in general the statements made by all amputee groups point, either directly or by implication, to functional inadequacies of the prosthesis as the basic reason for failure to make full use of it. The specific inadequacies, and the means of correcting them, are of course not directly or fully revealed by the present data. Even the seemingly straightforward problem of inadequate prehension in terminal devices cannot be solved simply by adding rubber bands or by providing a device with a stronger grasp. Experience has shown that for numerous amputees a lightly loaded hook is adequate for most needs and that they therefore prefer it. They object to the necessity for overcoming heavy resistance in every operation just to accommodate needs occurring infrequently. Nor is the voluntary-closing hook always the answer. Evidence presented in Section V of this series shows that such voluntary-closing devices as are currently available also are not without objectionable features. The solution of such problems must await further research into the total area of prosthetic utilization.

Manner of Performing Activities Without the Prosthesis

When, in a particular activity, an amputee regards the use of the prosthesis as either impossible or too difficult, awkward, or time-consuming, he is faced with the choice of excluding the activity from his routine of living or of finding some substitute means of accomplishing it. In the NYU Field Studies, those subjects who did not use the prosthesis in one or more of the 20 selected activities were asked what they did when confronted with the task or tasks concerned. By far the most frequent response by all classes of unilateral arm amputees was to the effect that they used the remaining hand, either alone or in combination with some other part of the body or some external object. About 3/4 of all responses told of one-handed performance, and the activities which are normally bimanual but for which performance was actually one-handed were essentially the same ones for all three classes of unilateral amputees. Moreover, activities so performed were for the most part the same ones as those reported to be "easier to perform without using the prosthesis" and also the same as those said to be most difficult to perform with a prosthesis (*i.e.*, least facilitated by assistance from a prosthesis).

A second alternative to use of the prosthesis, occurring in about 10 percent of the responses,

was the use of substitute devices such as combination knife-forks, telephone holders, or playing-card holders—all simply aids to one-handed performance. As for other methods of accomplishing daily tasks without use of a prosthesis, some 15 percent of the subjects indicated that the services of another person were enlisted. Again, as in the case of one-handed performance, the activities most frequently cited were much the same ones for all three groups of unilateral amputees. Although there is no apparent reason behind the choice of activities for which outside help is to be sought, it is possible that the tasks selected are too difficult to perform alone, either with or without a prosthesis. But of course other factors—an overly solicitous wife, general dependency, lack of training—may well be involved.

Two important goals in upper-extremity prosthetics are to help the amputee be independent in the performance of the tasks of daily living and to permit him to function bimanually in as "normal" a fashion as possible. Obviously the final achievement level may be below that of a "normal" person, but nevertheless these goals remain the best standard of comparison. Prosthetic utilisation may be viewed as ranging from an optimum of complete independence and bimanual function to less independent performance with the sound arm alone, either with or without assistive devices, to a complete dependence on assistance from others. The employment of this scale of achievement along with additional measures of the *quality* or appearance of prosthetic performance should provide a useful basis for evaluating the degree of success obtained in amputee rehabilitation.

From the material here presented, we may conclude that, in the 20 selected tasks, the most common substitution for prosthetic use involves use of the remaining "good" hand, either alone or in combination with some other part of the body or some external object. One-handedness, with or without the use of substitute devices, avoids the necessity of dependence on others, but it also leaves much to be desired from the standpoint of simulating "normal" performance. Moreover, one-handed performance of such activities as tying a necktie, or unbuttoning shirt sleeves with the teeth, is not easy. If these methods really are "easier" without a prosthesis, then prosthetic use must indeed be unattractive to the individuals concerned. The general findings of the whole study lead, however, to the obvious conclusion that a prosthesis is at best only a partial replacement for a lost limb. In unilateral arm loss, increased usage of the remaining arm and hand has unavoidably to make up, to greater or lesser degree, for existing prosthetic inadequacies.

BILATERAL SUBJECTS

As already pointed out (page 49), the 10 bilateral subjects in the Upper-Extremity Field Studies included 7 bilateral below-elbow and 3 bilateral below-elbow/above-elbow cases. Undoubtedly, the general performance level of the group as a whole was higher than it would have been had the sample included bilateral above-elbow and bilateral shoulder-disarticulation subjects. The extent of prosthetic utilization exhibited must therefore be interpreted accordingly. The responses of the subjects concerning frequency of occasion to perform the 20 selected activities, importance of the selected tasks, and frequency of actual prosthetic performance are presented in Tables 21, 22, and 23.

Frequency of Occasion to Perform Activities

Table 21 presents the responses of the bilateral subjects as to the frequency of occasions for performing the 20 selected activities with prostheses. It will be apparent at once that the activities for which opportunity occurred to the majority of bilateral amputees daily were for the most part the same ones occurring most frequently for unilateral subjects.

Importance of the Activities

The ratings of the bilateral group as to the significance of the 20 activities are presented in Table 22. On the basis of a composite of the two ratings "very important" and "important," the activities most significant to the bilateral amputees were, with the single exception of sweeping up dirt, the same ones

Table 21

FREQUENCY OF NEED FOR BILATERAL ARM AMPUTEES TO PERFORM ACTIVITIES
PERCENTAGE OF AMPUTEES RESPONDING
(N = 10)

Activity	Frequency			
	At Least Once Daily	At Least Once Weekly	At Least Once Monthly	Less Than Once Monthly or Never
1. Cut food with knife and fork	90	0	0	10
2. Sharpen pencil	20	70	10	0
3. Sweep up dirt with brush and dustpan	10	70	10	10
4. File and clean fingernails	[a]	[a]	[a]	[a]
5. Tie necktie	40	20	10	30
6. Use telephone (particularly when taking notes)	60	10	30	0
7. Assist someone with coat	20	20	30	30
8. Take bills out of wallet	80	0	0	20
9. Unbutton shirt sleeve	50	10	0	40
10. Carry several packages	40	50	0	10
11. Use "Flit" gun	0	0	40	60
12. Open bottles, jars, and tubes	70	0	10	20
13. Put on gloves	[a]	[a]	[a]	[a]
14. Use paper clip	40	0	40	20
15. Carry cafeteria tray	10	0	40	50
16. Use can or bottle opener	70	10	0	20
17. Tie shoelaces	50	10	10	30
18. Play cards	10	20	20	50
19. Rewire electric plug	0	0	10	90
20. Use hammer and nails	10	10	20	60

[a] Not applicable.

that rated high in importance for the three unilateral groups, and more than half of these were among the ones occurring most frequently. Thus the general pattern of relationship between frequency and importance observed with the unilateral groups appears to apply to the bilaterals also. And again, as with the unilateral cases, the activities of bilaterals that apparently do not conform to this pattern give rise to speculation. A case in point is the matter of using the telephone. Ostensibly an activity which confronts bilateral arm amputees rather infrequently (Table 21), it is rated as significant by all of the ten subjects involved. Either the activity is considered important in spite of infrequent occurrence or, more likely, bilateral amputees avoid use of the telephone because of difficulty in handling it with their prostheses. Avoidance could explain infrequent occurrence.

Performance of Activities

Table 23 summarizes the responses of the 10 bilateral amputees as regards utilization of the program prostheses in the performance of the 20 selected activities. The always-or-never characteristic of prosthetic utilization, described earlier for unilateral amputees, is even more evident in the bilateral group. At Evaluation II, only one bilateral amputee reported "sometimes" use of the prostheses in any of the 20 activities. Judging from the proportion that never perform a given activity, the tasks that are the most difficult for bilateral amputees are also among those occurring most frequently for them, or rated most important by them, or both, so that the situation noted earlier for unilateral subjects again applies to bilaterals also. If we take as a basis of comparison the percentage of bilateral arm amputees who always use the prostheses to perform

Table 22

SIGNIFICANCE OF ACTIVITIES TO BILATERAL ARM AMPUTEES

PERCENTAGE OF AMPUTEES RESPONDING

(N = 10)

Activity	Importance		
	Very Important	Important	Little or No Importance
1. Cut food with knife and fork	70	20	10
2. Sharpen pencil	20	20	60
3. Sweep up dirt with brush and dustpan	10	40	50
4. File and clean fingernails	[a]	[a]	[a]
5. Tie necktie	20	30	50
6. Use telephone (particularly when taking notes)	60	20	20
7. Assist someone with coat	0	50	50
8. Take bills out of wallet	70	20	10
9. Unbutton shirt sleeves	30	10	60
10. Carry several packages	40	50	10
11. Use "Flit" gun	0	10	90
12. Open bottles, jars, and tubes	40	30	30
13. Put on gloves	[a]	[a]	[a]
14. Use paper clip	0	50	50
15. Carry cafeteria tray	20	20	60
16. Use can or bottle opener	50	20	30
17. Tie shoelaces	50	20	30
18. Play cards	0	40	60
19. Rewire electric plug	0	30	70
20. Use hammer and nails	20	30	50

[a] Not applicable.

an activity, then as a group bilaterals use their prostheses more extensively than do any of the unilateral groups. The comparative figures, including the apparent anomalies, lead to the logical supposition that, if they can, bilaterals will perform the most difficult tasks in order to be independent but that some tasks may be too complex for them to manage in spite of a strong desire to do so.

Reasons for Not Using the Prosthesis and Alternative Ways of Performing Activities

Because of the small number of cases involved, and because of the variety of body movements used by bilateral arm amputees to accomplish tasks without prostheses, a detailed analysis of substitution techniques is not warranted, but two general observations may be made nevertheless:

1. Prosthetic deficiencies related to nonperformance were concerned with inadequate grasp by the terminal device and inability to operate it at the appropriate level.
2. The chief remedy for such deficiencies was to have someone else perform the task. Use of substitute devices was confined largely to unbuttoning shirt sleeves, presumably by use of a special buttonhook held in a prosthesis.

DISCUSSION

The NYU Field Studies reveal a number of interesting highlights regarding the utilization of prostheses reported by upper-extremity amputees. With only minor exceptions, the 20 bimanual activities, chosen empirically, occurred in every case with sufficient frequency, and/or affected a large enough proportion of the amputee population, to be considered significant. Among the various amputee groups (unilateral below-elbow, above-elbow, and shoulder-disarticulation cases and bilateral arm cases) there was considerable agreement as to the relative frequency of occurrence of the activities. It must also be noted, however, that among the bilaterals the frequencies of occurrence were much lower than among the other groups. For example, only 10 percent of the bilaterals carried a cafeteria tray as often as once a week, and none of them used a "Flit" gun or rewired an electric plug as often as once a week. Finding such agreement supports the selection of these activities as being highly significant in the activity patterns of upper-extremity amputees.

As judged by amputee opinions concerning the importance of the 20 selected activities, the level of significance attached to the individual tasks varied considerably. For unilateral subjects, 10 of the activities were rated as important by 2/3 or more of the group, five were rated as important by 1/3 to 1/2, and five were significant to less than 1/3. For the bilateral group, 11 activities were rated as important by 2/3 or more of the sample. For all amputee types, even those activities rated as important by the least number of amputees could not be regarded as totally insignificant. On the basis of amputee judgments of frequency of occurrence and of importance,

Table 23

USE OF NEW PROSTHESES BY BILATERAL ARM AMPUTEES IN THE PERFORMANCE OF SELECTED ACTIVITIES
PERCENTAGE OF AMPUTEES RESPONDING
(N = 10)

Activity	Use of New Prostheses			
	Always	Sometimes	Never	No Occasion to Perform Activity
1. Cut food with knife and fork	60	10	20	10
2. Sharpen pencil	100	0	0	0
3. Sweep up dirt with brush and dustpan	90	0	0	10
4. File and clean fingernails	[a]	[a]	[a]	[a]
5. Tie necktie	40	0	30	30
6. Use telephone (particularly when taking notes)	100	0	0	0
7. Assist someone with coat	100	0	0	0
8. Take bills out of wallet	80	0	0	20
9. Unbutton shirt sleeve	10	0	40	50
10. Carry several packages	100	0	0	0
11. Use "Flit" gun	40	0	0	60
12. Open bottles, jars, and tubes	60	0	10	30
13. Put on gloves	[a]	[a]	[a]	[a]
14. Use paper clip	70	0	10	20
15. Carry cafeteria tray	70	0	10	20
16. Use can or bottle opener	70	0	10	20
17. Tie shoelaces	40	0	30	30
18. Play cards	50	0	0	50
19. Rewire electric plug	20	0	0	80
20. Use hammer and nails	50	0	20	30

[a] Not applicable.

therefore, the tasks selected appear to have constituted a sound basis for study of the patterns of prosthesis usage among arm amputees. Although significant exceptions were apparent, in general the activities occurring most frequently were also rated as the most important.

In sum, the data on amputee use of prostheses in performance of the 20 selected activities revealed a number of interesting, if occasionally unexpected, findings. Among these were:

1. *A sharp drop-off in prosthetic utilization from below-elbow to above-elbow to shoulder-disarliculalion amputees, found in an earlier investigation* (page 32), *was confirmed.* While over-all utilization of the prosthesis by all amputee types, including the above-elbow and shoulder-disarticulation cases, was quite remarkable, improved utilization was most striking among the below-elbow and bilateral amputees. More than 50 percent of all unilateral below-elbow subjects reported that they always used the prosthesis in the performance of 19 out of the 20 selected activities (Table 18), and at least half of the bilateral amputees reported 100-percent use in 13 out of 18 applicable activities (Table 23).

Because heretofore prostheses for above-elbow and for shoulder-disarticulation amputees have sometimes been regarded as comparatively useless, the data relating to these types of amputees are perhaps even more dramatic than are the corresponding results for the other two types. In the above-elbow group, 50 percent or more of the sample reported that for widely diverse tasks they always used the prosthesis. In a number of "important" activities, a smaller but still significant proportion of above-elbow subjects always used the prosthesis. If we focus attention on what was *done* rather than on what was *not* done, there is considerable evidence that the prostheses had real value even for the shoulder-disarticulation group. Some 50 percent or more of the sample reported that in performing 8 of the 20 tasks they always used the prosthesis. In almost none of the activities could the prosthesis be considered useless. Even for the shoulder-disarticulation amputee, to whom a prosthesis offers the least

functional replacement, the fitting and use of a modern artificial arm seems worth while. And a similar conclusion may be drawn from the data presented earlier concerning use of the prosthesis in eating, dressing, and vocational, recreational, and home activities by all classes of amputees, including above-elbow and shoulder-disarticulation cases.

There are, then, two sides to the coin of prosthetic usefulness. One points to the inadequacies of even the most up-to-date equipment and emphasizes the need for much improvement. The other shows that, despite prevailing inadequacies, present-day upper-extremity prostheses are quite useful devices, particularly in those cases once thought incapable of deriving much benefit from any arm substitute.

2. *An "all-or-none" type of phenomenon in amputee use of prostheses was noted.* In any given activity, an amputee tends either always to use his prosthesis or never to use it. While not absolute or universal, the inclination was considered strong enough to be viewed as a general characteristic of prosthetic utilization.

3. *Paradoxically, the prosthesis was most useful for many activities which occurred less frequently, or which amputees rated as less important.* Some of the more frequently occurring, and more important, of the 20 activities, such as "cut food with knife and fork" and "unbutton shirt sleeve," were less frequently performed with the prothesis. This may indicate that the difficulty of performing the task with prothesis influences frequency of prosthetic use more than does the frequency of occasion for use or the importance of the task.

4. *Although there were definite indications that the program prostheses were used more extensively than were their preprogram counterparts, the increase in utilization was neither universal nor particularly striking.* The reasons given by arm amputees for not using their prostheses in the performance of activities pointed generally to prosthetic inadequacies as the basic cause. While lack of a suitable all-purpose terminal device was the only specific item identifiable from the data, it appears that the whole area of amputee use or nonuse of an arm prosthesis calls for further and intensive study. Where arm amputees did not use their prostheses in activity performance, the most common substitution among unilateral subjects involved use of the remaining hand, either alone or in combination with some other part of the body or some external object. One-handedness replaced what would normally be bimanual performance. Among bilateral arm amputees, "someone else does it for me" was the most frequent compensation for failure to use prostheses.

In the final analysis, the value of any particular set of principles or procedures in upper-extremity prosthetics is reflected by the degree of acceptance and utilization afforded the wearer by the prosthesis after the novelty has worn off and routine operation is expected. As part of the NYU Field Studies, therefore, the opinions of a large and diversified group of arm amputees were obtained on widely separated occasions in response to a series of open-end and multiple-choice questions relating to five key areas of activity considered more or less common to all persons. These reactions, classified and analyzed in terms of amputation type, were augmented by interviewing the same group of subjects with regard to 20 bimanual activities selected empirically as being important and of frequent occurrence in the course of daily living.

These two inductive approaches were selected from many possibilities for investigation as being the most practical and appropriate for determining amputee opinions as regards the utility and general value of their prostheses. Though the answers obtained do not provide a completely definitive method for grading success or failure in the rehabilitation of arm amputees, they have nevertheless furnished much useful information on a number of the factors influencing acceptance of prostheses by their wearers.

As might have been anticipated, amputees with the more disabling conditions (that is, with higher levels of amputation) were able to employ their prostheses over a smaller range of activities. On the other hand, the greatest increases in prosthetic utilization were found among these very groups. Not anticipated, however, was the indication that, in general, amputees tend to use their prostheses every time they do a given activity or not at all. The frequency of occurrence and the importance of an activity to an amputee were not always indices of the utility of the prosthesis in the particular task. While there were definite improvements in the utilization of program prostheses, a great deal of room for improvement remains, particularly in the bilateral group. Although deficiencies in the prostheses may be responsible, other factors such as training and motivation may also be involved. New studies focused on these questions will be required to illuminate the specific relationships.

Since arm amputees, like most people, are not generally capable of a completely realistic self-appraisal, there is an inherent weakness in data which derive solely from verbal reports. For this reason, a second method of evaluation was devised with the purpose of assessing prosthetic use on the basis of more objective information. Based on the assumption that proficiency in use also reflects the value of the prosthesis to the amputee, two types of prosthetic proficiency tests were developed. The first was designed to measure the amputee's skill in prehension and accuracy in positioning the terminal device for prehension. The second was concerned with evaluating skill in performing a series of common daily activities.

TEST RATIONALE AND TEST DEVELOPMENT

Methods of evaluating human performance in physical activities vary from the simple, relatively objective timing of a footrace to the more subjective assessment of figure-skating or fancy diving. In the footrace, effectiveness of performance is determined solely by measuring time, since speed of performance is the main factor. In rating activities of the second type, consideration also is given to such subjective features as timing, rhythm, grace, and form because here both effectiveness and appearance are matters contributing equally to the overall result. Since the total value of performance with a prosthesis involves these two factors, efforts to analyze the quality of prosthetic use in the NYU Field Studies sought information not only on the effectiveness with which the amputee used his prosthesis in activities of daily living but also on his appearance while performing them. In this sense, "effectiveness" refers to the ability to complete a task in a reasonable time. "Appearance" has to do with the relationship between the performance of the amputee and that typical of a normal person.

ABSTRACT-FUNCTION TESTS

Considering the uses arm amputees make of the various functions provided by modern arm prostheses, it is clear that all artificial arms are employed primarily as prehensile tools. But the ability to grasp with a hook or artificial hand would be extremely limited were the terminal device restricted to one plane or to a single area of operation. The value of other prosthetic functions, whether passively or actively controlled, lies in their usefulness as a means of positioning the terminal device so that work can be performed throughout a large operating sphere. It may reasonably be said that all the motions that can be provided in an upper-extremity prosthesis are capable of classification into one of two functional categories—those involved in the act of prehension itself and those which are used to position the terminal device so that meaningful prehension may be performed. Recognition of these functional divisions led to the development of two tests of abstract function—the prehension test and the positioning test—designed to permit study of some of the factors involved in prehension and positioning. They are tests of "abstract function" in the sense that no purposeful activity is involved and that only the biomechanical functions of positioning and operating the terminal device are analyzed.

Tests of abstract function were, then, used to assess the amputee's ability to:

1. operate and control his terminal device in grasping, transporting, and releasing objects.
2. position his terminal device accurately and operate it effectively in various places in front and to the side of his body.

PRACTICAL-ACTIVITIES TESTS

Tests of practical activities, used in an evaluation of *how* the amputees performed meaningful activities of daily living, were designed to provide information concerning the facility and appearance of a total performance in order to measure the functional value of the appliance. Selection of the performance tests of practical function was based on three prime criteria—that the activities concerned should normally require

bimanual performance, that the activities concerned should be those performed frequently by the subjects being tested, and that performance of the activities should be important to the amputee.

Tests of practical function were, then, used to rate:

1. the effectiveness with which amputees perform common, everyday tasks.
2. the naturalness of appearance while amputees perform daily activities.

STANDARDS OF PERFORMANCE

In the choice of a yardstick with which to measure the quality of prosthetic performance, consideration was given to the purpose of fitting an amputee with an artificial arm. Since the obvious aim is to restore as much as possible of the function lost through amputation, the desired outcome is that the amputee accept and use his prosthesis as naturally and as "normally" as possible. For this reason, normal, two-handed performance of tasks appeared to be a valid criterion. Because, however, it is commonly recognized that an amputee can never attain a completely normal, two-handed pattern of performance, it may reasonably be objected that such a standard is to some degree unrealistic and that the rating of amputee performance in relation to that of other amputees would provide a more reliable comparison. Perhaps it would. But the absence of norms or standards of amputee performance at the time the NYU Field Studies were undertaken precluded any choice in the matter. Consequently, the normal performance pattern was selected as the standard.

SAMPLE

The numbers of below-elbow, above-elbow, and shoulder-disarticulation amputees available for these performance tests varied considerably. Participating in the pretreatment tests were 80 below-elbow amputees, 57 above-elbow amputees, and 4 shoulder-disarticulation amputees representing, respectively, 48 percent, 36 percent, and 17 percent of each amputation type in the sample. Attrition during the pretreatment evaluation was due to nonfunctioning or malfunctioning of arms, amputees appearing for evaluation without prostheses, and breakdown of prostheses during use with consequent inability to complete the test. Owing to the generally better functional condition of arms during the course of the program and to the increase in the number of shoulder-disarticulation and above-elbow amputees wearing arms, the number of subjects available for post-treatment testing was substantially higher: 115 (68 percent) below-elbow, 111 (70 percent) above-elbow, and 17 (74 percent) shoulder-disarticulation cases. To provide the most rigorous analysis that the data will permit, only the performances of the patients available for both pre- and post-treatment evaluations are presented. This restricts the total sample to 75 below-elbow, 51 above-elbow, and 4 shoulder-disarticulation cases. Because there are so few shoulder-disarticulation amputees, their performance ratings are not treated statistically but are described in terms of impressions and trends.

All of these amputees took the prehension test, the first to be administered, but somewhat fewer completed the positioning test and the practical-activities tests, either because of breakdown of prostheses during the course of the tests or because of indisposition on the part of the patients.

PROCEDURES

ABSTRACT-FUNCTION TESTS

Prehension Test

In utilizing his prosthesis in the activities of daily living, the amputee has occasion to grasp objects of various sizes, shapes, weights, textures, and degrees of fragility or hardness. This diversity was recognized by including, in the prehension test, objects which embody many of the variables normally encountered. Of the 12 objects used, six were of metal (five aluminum, one steel) and six of compressible rubber, and all were of one of four

basic shapes—cylinders, spheres, prisms, and right-angled forms—in various sizes.

In addition, the testing materials included a form board constructed of "Masonite" attached to a three-ply wooden board measuring 17 X 17 in. and into which were cut recesses corresponding to the shapes of the test objects but slightly (1/8 in.) larger. The test objects were arranged on a table near the board and in the same relative position as the recesses in the board so as to reduce the need to search for the proper recess. In the course of the test, the amputee transferred each of the objects from the table to the appropriate recess in the form board. Before the actual test, the amputee was given a trial run to familiarize himself with the objects and to give him an opportunity to decide upon the most efficient way to approach and grasp an object. The test was explained to the amputees as follows:

"You are to place each of these objects in the appropriate recess in the form board. Start with the top row and work from left to right. Do each row in the same way.

"Work as quickly as you can but also as accurately and neatly as you can; do not waste any time.

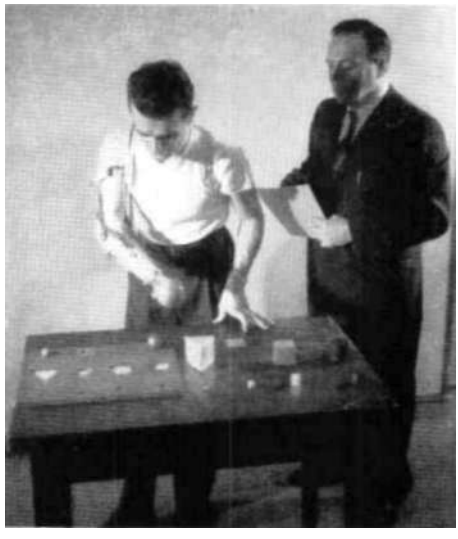
"If you cannot handle any object after trying for 1 minute, leave it and go on to the next. You will be notified when you have been on any object for 1 minute.

"Use only your prosthesis in handling the various objects.

"Avoid compressing or distorting the shape of the rubber objects as much as possible.

"You are being tested on your ability to grasp the objects and to release them into the recesses in the form board."

In the performance of these tasks, the terminal device is first brought into a position which allows for grasp of the object. The next step, concerned with the grasp itself, involves operation of the prehension mechanism, placement of the fingers to obtain a stable grasp, and control of finger pressures to provide appropriate prehensile forces. To complete the activity, the amputee must transport the object and then position the terminal device so that the object is released at the intended place. The general impression that an amputee's performance makes upon the observer depends upon the body move-



ments employed, the number of errors made, and the appearance of the control motion. In addition to these factors, the appearance of the total performance is related to the general ease, grace, and accuracy of movement.

In an attempt to appraise in each activity both the functional and the appearance value of the amputee's performance, the significant parts of the performance were rated with regard to positioning movements for grasp and release, appearance and effectiveness of control motion, and control of finger pressure. The ratings were then combined in an over-all score on the basis of the following 10-point scale:

Excellent (10). Graceful, rhythmic, fast, accurate performance closely approximating the cosmetic value of a performance by a normal person.

Good (8). Smooth, rapid performance involving one or two errors and some slight body and limb distortion in several positions.

Average (6). Uneven, somewhat inaccurate performance with occasional errors, some effort, and some body distortion.

Fair (4). Slow performance marred by errors and uncosmetic limb and body positions.

Poor (2). Awkward, strained, slow performance with fumbling, excessive movement, and many errors.

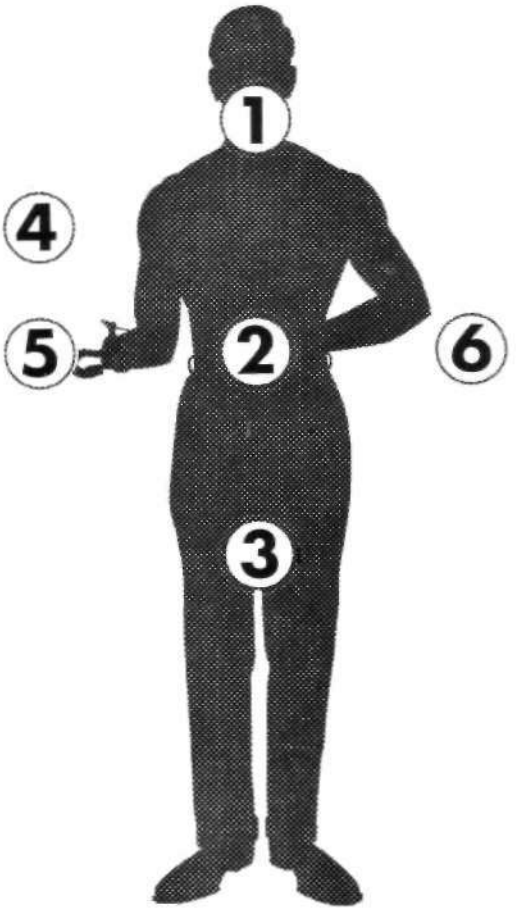
The observer interpolated ratings of 9, 7, 5, 3, and 1 when indicated.

The ability of the arm amputee to grasp and hold objects securely with a prosthesis is dependent partly upon the amount of power the man-machine combination can furnish and partly upon the structure, size, and shape of the terminal device. The number of errors made during the test was recorded, two kinds of errors being considered—grasp errors and compression errors. A grasp error was counted when the amputee regrasped an object in an attempt to obtain a more secure grasp, when the object, once grasped, fell from between the fingers of the terminal device, or when the object slipped within the fingers to the extent that the amputee had to reduce his speed or otherwise interrupt his performance to avoid dropping it. The ability to control finger pressure was appraised by tallying the number of compressible objects distorted and judging the extent of the distortion.

Considered alone, the time taken to perform a particular activity may not be a satisfactory indication of efficiency. When considered in relation to accuracy and appearance, however, it may be an important factor, particularly in view of frequent amputee complaints regarding inability to work rapidly. In the prehension test, the amputee stood at the table and began at his own volition, a stopwatch being started with his first movement. The watch was stopped as the last object was placed in the appropriate recess on the form board, and the elapsed time was recorded.

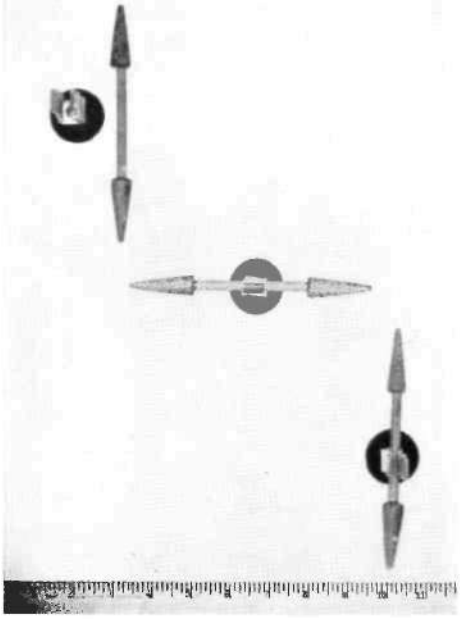
Positioning Test

Although prehension may be considered the primary function of both the normal hand and the prosthetic replacement, the ability to position the hand or its substitute in space is a key factor in utilization. The normal, two-handed person has occasion to reach for, grasp, and release objects in three planes. He commonly handles objects at the level of the mouth, the chest, and the mid-thigh, and objects at chest or waist level up to 1-1/2 feet on either side of him are usually within his reach. To study the ability of the amputees to employ their prostheses in these areas, use



was made of the positioning test, which involved six common hand positions. The six exercises devised to assess the ability of an amputee to operate his terminal device at different positions required the subject to place a 6- X 3/8-in. dowel into a clip positioned on the wall and so arranged that release of the dowel was required in both vertical and horizontal positions. Before the actual tests, each amputee was given a trial run to familiarize him with the procedures and to let him decide upon the best approach to each of the test situations.

In the performance of this test, the amputee was required to remain within a rectangle drawn on the floor 18 in. wide and extending 36 in. from a wall. He stood outside this re-



straining area until, on the signal to begin, he stepped into it. Although he was required to remain there while performing each of the tasks, he was permitted to reach over the restraining lines. The patient was told:

"Hold this stick in your sound hand and stand behind the restraining line.

"When I say 'go,' grasp the dowel in your prosthetic hand (hook), step into the restraining area, and place the dowel in the clip on the wall.

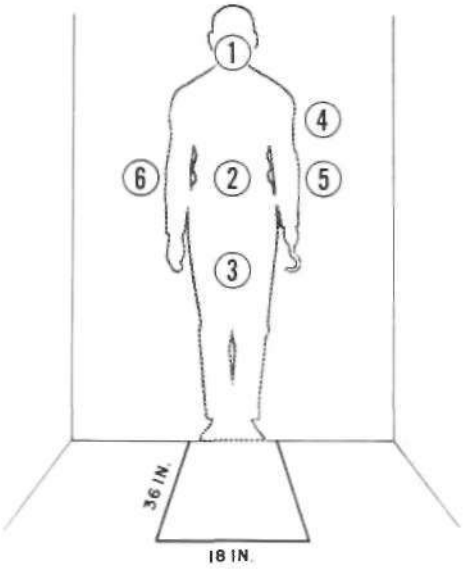
"Do this as quickly as you can after you receive the signal, but do it as smoothly and as accurately as you can.

"If you drop the stick while trying to place it in the clip, or at any other time, pick it up and continue the test.

"You are being tested on your ability to place the stick in the clip as quickly as possible with the least amount of excessive movement."

Proficiency in this test depended upon maintaining a relatively normal posture and appearance while operating the terminal device at varying distances and angles from the body. The cosmetic value of the performance was related to ease, grace, and smoothness of body movements and to associated characteristics in prosthetic control motions, while effectiveness was reflected in the speed and accuracy of positioning the dowel in the clip. Rated individually were

body- and limb-positioning movements, appearance of prehension control motion, and appearance of elbow-lock control motion. These were then consolidated into a rating of total performance by use of the same type of 10-point scale as in the prehension test: excellent, 10; good, 8; average, 6; fair, 4; poor, 2. Again, ratings of 9, 7, 5, 3, and 1 were interpolated as necessary. The time required to perform each positioning test was recorded by means of a stopwatch.



PRACTICAL-ACTIVITIES TESTS

The practical-activities tests called for each amputee to be tested in the performance of eight activities of daily living selected from the 20 common activities discussed heretofore. For each individual the activities varied in accordance with the criteria of frequency and importance previously mentioned *(i.e.,* each amputee was tested on the eight activities he reported as occurring most frequently in his routine of living). In choosing between activities of approximately equal frequency, those regarded by the subject as of greater importance were selected for test.

In the discussion of the temporal sequence of events during performance of the prehension test, it was pointed out that four phases of the performance could be isolated: the positioning movements for grasp, the grasp itself, the transporting of the object, and the positioning movements for release of the object. With one major exception, this breakdown served equally well as a guide to the more complex practical activities. Here, unlike the situation prevailing in the prehension test, the amputee must not only transport an object but must also make sure it arrives at a position where it can be used or manipulated purposefully. Moreover, the nature of the prehension test forced the amputee to pick up each object from the table without use of the sound hand, a feature that made it necessary to position the body and the prosthesis so that the object could be grasped with the terminal device. In routine practice, however, the amputee frequently picks up an object with his sound hand and places it in his terminal device, thus eliminating many of the positioning movements otherwise required for grasp.

With special reference to practical-activities tests, therefore, we may speak of "positioning movements for use," as distinct from "positioning movements for grasp or release," to mean the sequence of motions adopted by an amputee to bring an object into position for the performance of a useful task. Each activity was rated according to the normalcy of the pregrasp positioning movements, the security of the grasp, and the adequacy of positioning for use. The first two were scored on the same basis as in the prehension test; the degree of awkwardness in the positioning movements was rated and the number of errors tallied.

Positioning for use, however, refers to the manner in which an object is grasped as that relates to the intended manipulation or use of the object. For example, when the normal hand holds a telephone, both mouthpiece and receiver are positioned close to the face for ease and comfort in hearing and speaking. The artificial hand of an amputee may hold the telephone at some distance from the face, thus necessitating some undue amount of compensatory head-bending. Or the hearing end of the telephone may be held against the ear while the mouthpiece is at eye level rather

than mouth level. Errors such as these in positioning an object for use may be due either to faulty judgment on the part of the amputee or to limitations inherent in the prosthesis. Whatever the cause, the adequacy of positioning in relation to ultimate use was rated in terms of the deviation from normal position and of the degree of compensatory movement necessitated by the position of the object in the appliance. These scores were then combined in an over-all rating of the functional and cosmetic value of the amputee's performance in each activity. Rating was accomplished on a 10-point scale as follows:

Excellent (10). Object position does not deviate from position for normal use, nor are compensatory body and limb positions necessary.

Good (8). Object deviates slightly from position in which the normal hand would use it; slight deviations in body and limb positions may also be present.

Average (6). Object deviates somewhat from normal position, and some compensatory deviation in body or extremity position is necessary to use the object.

Fair (4). Object shows marked deviation from normal position for use and necessitates somewhat awkward body and limb positions to accomplish the task.

Poor (2). Object shows marked deviation from normal position for use, accompanied by strained, awkward, or obtrusive body and limb positions.

The observer interpolated ratings of 9, 7, 5, 3, and 1 whenever it was felt to be necessary.

In the accompanying annotated illustrations are depicted the materials, instructions, and procedures utilized in the administration of the 20 activities comprising the test series. Every time the amputee began one of the practical tests, he was first requested to perform the task in his customary way. He was told that the series of tests was a means of determining how he performed those tasks normally as part of his activity pattern. It was pointed out that he was being rated on how well he did the entire task regardless of the specific use he made of the prosthesis. The basis for rating the over-all appearance of the performance was the same as that for the prehension test, and the time taken to complete each test activity was recorded.

1. *Cut Food With Knife and Fork*
Subject was seated at small table set with fork on left and knife on right, regardless of side of amputation. Plate contained "meat and potatoes" of clay. Subject picked up knife and fork, cut three pieces of "meat," and replaced utensils on table.

2. *Sharpen Pencil*
Sharpener was mounted on wall at chest height. Pencil was placed on table to right of sharpener. Subject picked up pencil, sharpened it, and returned it to table.

3. *Use Can or Bottle Opener*
Can (or bottle) and opener were placed on table. Subject stood facing table. He opened can (or bottle) and returned opener to table.

4. *Sweep Up Dirt With Brush and Dustpan*
Subject stood facing table. Dustpan and brush were placed on table, "dirt" was put on floor about three feet from table, waste basket on floor next to "dirt pile." Subject grasped dustpan and brush, swept up dirt, put it into wastebasket, and returned props to table.

5. *Use Telephone*
Subject was seated at table. French phone was placed on table at right with pad and pencil. Subject removed phone, dialed number, wrote message, and returned phone to cradle.

6. *Use Nail File*
Subject was seated at table. Nail file was placed on table. Subject picked up file, filed both sides of nail on index finger, and returned nail file to table.

7. *Assist Someone With Coat*
Subject stood next to coat hung on hanger. He removed coat and held it up for another person to put on.

8. *Take Bills Out of Wallet*
Amputee stood near table on which was placed wallet containing paper currency. He picked up wallet, removed two bills, and, placing them on the table, closed the wallet and replaced it on the table.

9. *Unbutton Shirt Sleeve*
Amputee stood and unbuttoned shirt sleeve on his sound arm.

10. *Carry Several Packages*
Subject stood and picked up suitcase and prepared "packages." He carried them in both arms a distance of five steps and put them down.

11. *Use Spray Gun*
The amputee stood near a table upon which was placed a sprayer of the "Flit" variety. Amputee picked up sprayer and operated piston three times, once each toward the ceiling, straight ahead, and down at the floor. He then replaced gun on table.

12. *Open Bottle, Jar, or Tube*
Amputee was seated at table upon which was placed a jar. He picked up jar, unscrewed cap, and replaced both cap and jar on table.

13. *Put on Glove*
Subject stood at table, picked up glove lying upon it, and proceeded to don glove completely.

14. *Use Paper Clip*
Amputee was seated at desk upon which were placed three sheets of paper and a paper clip. He gathered up papers, clipped them together, and replaced sheaf on desk.

15. *Carry Cafeteria Tray*
Amputee stood at table upon which was placed tray loaded with two dishes, a cup, and a saucer. He picked up tray, walked five steps, and placed tray upon table.

16. *Tie Shoelaces*
Subject stood near chair and, on his own volition, remained standing and placed foot on chair or else sat in chair. He then tied bow in lace of one shoe.

17. *Play Cards*
Subject was dealt a hand of five cards while seated at table. He picked them up, fanned them out, and played three cards sequentially.

18. *Rewire Electric Plug*
Amputee was seated at table with screwdriver, plug, and short electric wire laid out before him. He picked up tool and connected wires to terminals.

19. *Use Hammer and Nails*
Amputee stood at table upon which were lying a block of wood, hammer, and a 2-in. nail. He picked up hammer and drove nail into block.

20. *Tie Necktie*
The patient started with a necktie tucked under his collar but untied. He tied the knot.

RESULTS

RELIABILITY AND VALIDITY

Fundamentally a test is an instrument for measuring the extent or absence of a trait or attribute. To be most meaningful, test results must be both reliable and valid.

The reliability of tests which are scored by means of judgmental ratings depends upon the use of consistent standards in rating performances, and ordinarily precautions are taken to ensure a comparable frame of reference among the raters. During the course of these studies, the reliability of the raters' judgments was evaluated periodically and found to be reasonably satisfactory. A stringent statistical analysis at the completion of the studies (Appendix I) confirmed the reliability of the ratings on the abstract-function tests. But because too few practical-activity tests were scored by each rater, the reliability of the practical-activities ratings could not be assessed in the same way.

The validity of a test rests upon the degree to which it actually measures what it is designed to measure. Selection of the abstract-function tests was based upon an analysis of the functional requirements of prosthetic utilization, the skills involved being those necessary to operate the prosthesis under *any* circumstances. Since these tests were designed to evaluate proficiency of prosthetic use by direct measurement of meaningful performance with prostheses, they have a certain amount of face validity. The validity of the practical-activities tests appears to be self-evident, since the amputee's ability to perform a given task was in this case determined by having him actually perform it in the presence of the raters.

ABSTRACT-FUNCTION TESTS

Prehension Test

As might have been anticipated, the ratings of below-elbow and above-elbow cases in the prehension test clearly indicated that performance was related to amputation level. That is to say, the average below-elbow performance level was consistently better than above-elbow performance in both pre- and post-treatment evaluations (Table 24). An important point reflected by these data is that the discrimination of differences by the prehension test may be regarded as evidence supporting the validity of the test. Experience indicates that the below-elbow amputee generally accomplishes more with a prosthesis and performs in a smoother and easier way than does the above-elbow amputee. Since it distinguishes these two groups clearly, the prehension test may be said to measure those qualities which distinguish the adequacy of performance.

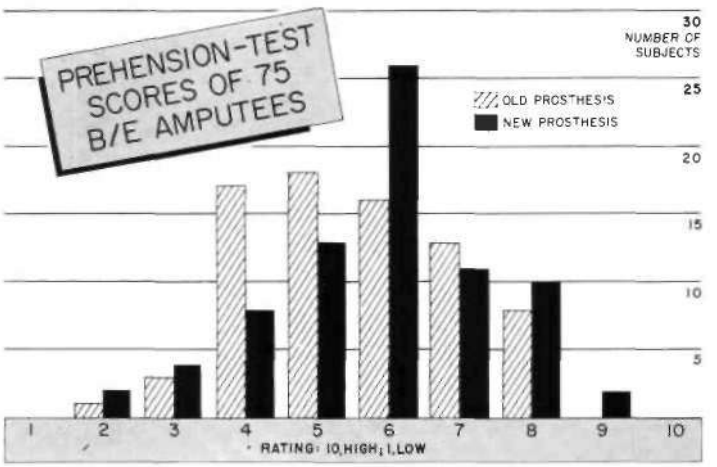
Table 24

MEAN PERFORMANCE RATINGS AND STANDARD DEVIATIONS IN PREHENSION TESTS

Amputation Level	Evaluation I		Evaluation II	
	MPR[a]	σ	MPR[a]	σ
Below-Elbow (N = 75)	5.5	1.5	5.8	1.6
Above-Elbow (N = 51)	4.0	2.0	4.9	1.5

[a] The significance of the differences between the mean ratings of below-elbow and above-elbow subjects at Evaluations I and II are given in Table 29 (page 80).

Comparison of performance ratings in the pre- and post-treatment evaluations, presented in Table 24, reveals a definite but not always statistically significant improvement in prosthetic function. For the 75 subjects comprising the below-elbow sample, the mean for the new arms was 5.8 as compared with 5.5 for the old. Although this difference is not significant statistically, closer study of the scores made at the two evaluations indicates a small but definite improvement in performance, especially through the middle of the score range, where there was a marked decrease in the number of amputees receiving ratings of 4 and 5 and a sharp increase in those receiving ratings of 6. It appears then that, although the treatment program had little effect on below-elbow amputees who exhibited very poor or very superior skills with their old

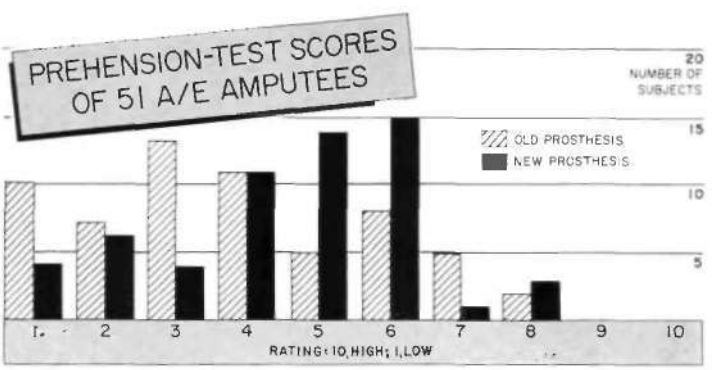


arms, it did improve the "low-average" performers.

As reported in Part 1 of this Section, the below-elbow group as a whole felt that their new arms were somewhat more useful and easier to operate than the old. But this improvement was less marked than that at other levels of amputation, and some below-elbow subjects even felt that the new prosthesis was inferior to the old. The data thus tend to corroborate an earlier conclusion that for the less severely handicapped below-elbow amputee the improvement in prehension skill was not outstanding. By contrast, the 51 above-elbow cases showed a decided improvement in prehension performance with the prostheses fitted in the Field Studies. Statistically, the 4.9 average achieved with the program prostheses was significantly higher than the 4.0 average attained with the old arms. A comparison of the scores at the two evaluations revealed a clear-cut and consistent shift in the direction of improvement of performance. There was a marked decrease in the number of amputees scoring below 5 and a sharp increase in those scoring above 5. It may therefore be concluded that there was a general elevation of the level of above-elbow performance, the greatest improvement being evidenced among those of low and low-average skills. With only four cases available for analysis, the findings for the shoulder-disarticulation amputees are of limited significance, although among the four there was also a definite trend toward improvement in post-treatment performance.

In general, the results obtained in the functional tests of the above-elbow and shoulder-disarticulation amputees correspond to the verbal reports, which strongly indicated that the program prostheses were more useful, easier to operate, and more extensively used. Improvement in these two groups was more marked than in the below-elbow group, and it may therefore be concluded that the more severely handicapped segments of the amputee population derived the most benefit from the program prostheses and that the benefits accrued principally to the poorer performers.

The speed with which amputees performed the prehension test was also related to level of amputation, the below-elbow subjects taking significantly less time than the above-elbow cases to complete the test at both pre- and post-treatment evaluations. For no group (below-elbow, above-elbow, or shoulder-disarticulation) did the average amount of time



taken to perform the prehension test decrease significantly after treatment. The data for the below-elbow and above-elbow subjects are presented in Table 25.

Table 25

MEAN PERFORMANCE TIMES AND STANDARD DEVIATIONS IN PREHENSION TESTS

Amputation Level	Evaluation I		Evaluation II	
	MPT[a]	σ	MPT[a]	σ
Below-Elbow (N = 75)	130	60	127	56
Above-Elbow (N = 51)	174	76	180	97

[a] To nearest second.

According to these findings, improvement in performance skill was not reflected in an appreciable increase in performance speed, but the reasons for this apparent inconsistency are not clear. One possibility has to do with the increase in the number of subjects using APRL terminal devices at Evaluation II as compared with Evaluation I (below-elbow, from 14 to 37; above-elbow, from 8 to 31). The "double-shuffle" control motion involved in this type of device, and the consequent increase in the time required to operate it, may account for the failure to increase speed along with skill and ease of operation. At the same time, however, there is a suggestion that slower operation with APRL devices is accompanied by smoother and easier prehension.

Two kinds of errors, grasp and compression, were recorded. Grasp errors were counted when an object slipped or fell from the terminal device or when it had to be regrasped. Compression errors were scored when the rubber objects were distorted by poor control of finger pressure. On both pre- and post-treatment evaluations, the below-elbow cases made fewer grasp errors than did the above-elbow amputees (Table 26). The shoulder-disarticulation cases made substantially more grasp errors than did either the below-elbow or the above-elbow subjects. The below-elbow subjects made fewer grasp errors after treatment (average: 8.0) than at Evaluation I (average: 9.2), but the difference was not significant statistically. There was little difference in the number of grasp errors made by above-elbow amputees before (10.0) and after (9.7) treatment. While the shoulder-disarticulation cases showed a stronger trend toward improvement in grasp security than did either of the other two groups, the result should be interpreted cautiously because of the small number of subjects involved.

Table 26

MEAN NUMBER OF GRASP ERRORS AND STANDARD DEVIATIONS IN PREHENSION TESTS

Amputation Level	Evaluation I		Evaluation II	
	MGE	σ	MGE	σ
Below-Elbow (N = 75)	9.2	6.0	8.0	5.5
Above-Elbow (N = 51)	10.0	5.9	9.7	6.4

Thus it would appear that, despite the changes made in terminal devices, harnessing, and control-system alignment, grasp security was not greatly influenced by the treatment process. Perhaps the principal limitation was the lack of "all-purpose" versatility in the hook, its rigid structure preventing it from being completely suitable for handling a variety of objects.

Unlike grasp errors, compression errors decreased in frequency among both below-elbow and above-elbow cases after fitting with program arms (Table 27), and the shoulder-disarticulation amputees appeared to follow the same trend. Below-elbow and above-elbow cases made the same number of compression errors (6.2) in the pretreatment evaluations. After the treatment procedure, there was again little difference between the scores of the two groups, the averages being 4.5 and

4.8 respectively. As one would expect, the shoulder-disarticulation cases made more compression errors than did either below-elbow or above-elbow subjects.

Table 27

MEAN NUMBER OF COMPRESSION ERRORS AND STANDARD DEVIATIONS IN PREHENSION TESTS

Amputation Level	Evaluation I		Evaluation II	
	MCE	σ	MCE	σ
Below-Elbow (N = 75)	6.2	4.1	4.5	3.9
Above-Elbow (N = 51)	6.2	3.9	4.8	3.2

Better control of finger pressure may be explained by the large proportion of APRL devices fitted in the treatment program and also by the contributions from improved harness and control systems. The apparent influence of APRL terminal devices in improving control of finger pressure without also improving grasp security suggests a deficiency in hook size or shape and perhaps also a general lack of emphasis on training for the proper approach in prehension activities.

Positioning Test

Skill in performance in the positioning test, as in the prehension test, was related to level of amputation, the below-elbow amputees making consistently higher scores, and the positions in which the below-elbow subjects performed best differed from those in which the above-elbow subjects were most effective (Table 28). The below-elbow amputees were most effective at mouth and waist levels in the centerline (Positions 1 and 2); at chest and waist levels toward the prosthetic side (Positions 4 and 5); somewhat less effective toward the sound side (Position 6); and poorest at mid-thigh level in the centerline (Position 3). Above-elbow subjects were most proficient at two waist-level positions (Positions 2 and 5); somewhat less effective at waist level on the sound side (Position 6), at chest level toward the prosthetic side (Position 4), and at mid-thigh in the centerline (Position 3); and poorest at mouth level in the mid-line (Position 1), all of which suggests that the most efficient use of the above-elbow prosthesis is to be had at 90 deg. of forearm flexion and that less efficient operation occurs when the forearm is flexed appreciably more or appreciably less than 90 deg. Shoulder-disarticulation subjects were most proficient in handling objects at waist level, either in the mid-line or toward the prosthetic side (Positions 2 and 5).

Table 28

MEAN PERFORMANCE RATINGS AND STANDARD DEVIATIONS IN POSITIONING TESTS

Position	Evaluation I				Evaluation II			
	Below-Elbow (N = 71)		Above-Elbow (N = 49)		Below-Elbow (N = 71)		Above-Elbow (N = 49)	
	MPR	σ	MPR	σ	MPR	σ	MPR	σ
1	6.9	1.3	4.1	2.4	7.2	1.3	4.9	1.6
2	7.1	1.4	5.2	1.7	7.3	1.2	5.9	1.5
3	6.0	1.4	4.3	1.8	6.3	1.4	5.1	1.7
4	6.7	1.3	4.6	1.9	7.1	1.4	5.1	1.7
5	6.8	1.2	4.9	1.6	6.9	1.3	5.8	1.6
6	6.3	1.6	4.5	1.7	6.8	1.3	5.3	1.8

Among both above- and below-elbow patients, skill in operating the terminal device in different positions improved significantly after treatment, a result more positive than that obtained from the corresponding prehension test, where improvement was statistically significant for above-elbow amputees only. Analysis of the pre- and post-treatment ratings of the below-elbow amputees revealed significant improvements (Table 29) in the ability to operate their terminal devices in three positions—at waist level in the mid-line (Position 2), at chest

Table 29

SIGNIFICANCE OF DIFFERENCE (P)[a] BETWEEN RATINGS OF ABSTRACT PERFORMANCE

Test	Significance of Difference (P)[a] Between Below-Elbow Cases and Above-Elbow Cases in Abstract-Performance Ratings		Significance of Difference (P)[a] Between Abstract-Performance Ratings at Evaluation I and at Evaluation II	
	Evaluation I	Evaluation II	Below-Elbow	Above-Elbow
Prehension	<0.01	<0.01	0.14	<0.01
Positioning				
1	<0.01	<0.01	0.06	0.03
2	<0.01	<0.01	0.16	0.02
3	<0.01	<0.01	0.12	<0.01
4	<0.01	<0.01	0.05	0.07
5	<0.01	<0.01	0.42	<0.01
6	<0.01	<0.01	0.02	0.01

[a] The letter P represents the probability that the difference obtained between the mean of each test occurred by chance. Any P value exceeding 5 chances in 100 (0.05 level) can be taken as indicating no substantial difference between the tests.

level toward the prosthetic side (Position 4), and at waist level toward the sound side (Position 6).

The time required by the amputees to complete each of the six tests did not appear to be related to the particular position involved, nor did performance time seem to be affected by the treatment process (Table 30). For the below-elbow cases, mean performance times for all six tests varied between 5 and 7 sec. in both pre- and post-treatment evaluations. Similarly, the above-elbow cases performed each of the six tests in approximately the same average time (10 to 16 sec. at Evaluation I, 9 to 14 sec. at Evaluation II).

Although by definition the positioning test is "abstract," the level of performance in the several positions bears a relationship to the ability that may be expected in the performance of practical activities in the same positions. Improved performance in the test should be reflected either in greater ease in use of the prosthesis or else in the ability to perform more activities with it. Since in all cases there was an improvement in test performance after treatment, there is strong indication that treatment resulted in improved skill in utilizing a prosthesis in the positions required for the pursuit of the normal pattern of daily activities. While the available evidence is not wholly definitive, the distinct shift toward higher scores after treatment must be taken as indicating a general improvement in achievement level.

Table 30

MEAN PERFORMANCE TIMES AND STANDARD DEVIATIONS IN POSITIONING TESTS

Position	Evaluation I				Evaluation II			
	Below-Elbow (N = 68)		Above-Elbow (N = 40)		Below-Elbow (N = 68)		Above-Elbow (N = 40)	
	MPT (sec.)	σ	MPT (sec.)	σ	MPT (sec.)	σ	MPT (sec.)	σ
1	5.9	4.3	12.0	8.5	5.2	2.5	13.6	11.3
2	6.0	3.7	10.3	6.5	5.4	3.2	11.0	7.8
3	6.1	4.4	11.2	10.8	5.6	2.9	9.9	4.8
4	5.8	2.9	16.1	17.5	5.9	4.4	11.0	7.1
5	5.7	3.7	10.7	6.4	6.0	4.8	9.1	4.3
6	6.5	8.1	11.1	8.7	5.3	2.9	11.0	6.6

PRACTICAL-ACTIVITIES TESTS

In contrast to the abstract tests of prehension and of positioning a prosthesis, the practical-activities tests were designed to evaluate the amputees' ability to integrate the mechanical operations of prehension and positioning into the efficient performance of a complete and meaningful task. From the list of 20 tasks there were selected for each amputee eight specific test activities which, according to the subject's own statements, occurred most frequently for him in his normal activity pattern and to which he himself attributed the most importance. By virtue of these criteria some tasks were tested less frequently than others. The present analysis involves only those activities performed by 10 or more subjects.

On this basis, the below-elbow subjects received substantially higher scores than did the above-elbow cases, a fact which only substantiates the superior ability of the below-elbow

amputee in coping with daily needs. The average, weighted, pretreatment performance rating was 6.4 in below-elbow cases, 5.0 in above-elbow cases. After the treatment program, the corresponding figures were 7.0 for the below-elbow and 6.2 for the above-elbow patients (Tables 31 and 32). The scores of the few shoulder-disarticulation cases tested were far below those of either below-elbow or above-elbow amputees.

If we consider that a score of 10 represents normal nonamputee performance, then the average score of 7.0 obtained by the below-elbow population for all 20 activities represents a creditable performance. For some tasks, of course, the average was higher than 7.0, and certain individual amputees consistently outperformed the average. It may thus be concluded that below-elbow subjects generally perform common daily tasks in a smooth, relatively unobtrusive, errorless manner. Although they never attain a level of skill equal to that of the nonamputee, they (and particularly the better performers in the group) tend to approach that level of performance.

The post-treatment skill of the above-elbow group, represented by an over-all weighted-average rating of 6.2, indicates a relatively high level of performance. While the need for an elbow-lock control motion, together with the greater body distortion that results from the lack of an anatomical elbow, reduces the functional level of the above-elbow amputee to less than that of the below-elbow group, the above-elbow patient is nevertheless capable of more or less skillful use of a prosthesis.

Table 31

PRACTICAL-ACTIVITIES TESTS

PERFORMANCE RATINGS AND TIME IN BELOW-ELBOW SUBJECTS

Activity	No of Cases	Evaluation I				Evaluation II				Difference Between Mean Ratings[a] (Evaluation II vs. Evaluation I)	Difference Between Mean Times[a] (Evaluation II vs. Evaluation I)
		Mean Rating	σ	Mean Time (sec.)	σ	Mean Rating	σ	Mean Time (sec.)	σ		
Assist someone with coat	12	7.1	0.9	8.4	3.4	7.2	1.9	9.8	7.6	+0.1	+1.4
Button shirt sleeve	37	6.6	1.4	6.6	4.4	6.9	1.9	6.7	4.1	+0.3	+0.1
Carry cafeteria tray	6	7.3	—	11.6	—	7.5	—	9.6	—	—	—
Carry several packages	32	7.3	1.2	13.5	6.7	7.4	1.4	14.3	6.1	+0.1	+0.8
Cut food with knife and fork	27	6.4	1.4	21.6	11.4	7.0	1.3	24.6	20.7	+0.6	+3.0
File fingernails	29	5.9	1.5	19.6	11.6	7.1	1.4	19.2	8.7	+1.2	−0.4
Hammer a nail	15	6.2	1.4	11.0	2.4	7.2	1.4	12.1	6.3	+1.0	+1.1
Hold telephone	9	5.9	—	27.0	—	6.6	—	22.3	—	—	—
Open jar	40	5.8	1.8	7.6	3.8	7.0	1.5	7.8	3.6	+1.2	+0.2
Play cards	2	7.5	—	14.0	—	6.0	—	25.0	—	—	—
Put on glove	12	6.3	2.4	17.2	15.7	7.4	1.6	10.3	18.3	+1.1	−6.9
Take bills from wallet	60	6.3	1.5	11.3	4.4	6.7	1.4	11.5	4.3	+0.4	+0.2
Tie necktie	22	6.0	1.8	34.7	23.2	6.5	1.9	30.5	12.5	+0.5	−4.2
Tie shoelaces	37	7.0	1.7	17.8	8.9	7.5	1.2	17.7	5.7	+0.5	−0.1
Use brush and dustpan	13	6.0	1.0	17.4	7.2	7.5	1.6	14.6	6.9	+1.5	−2.8
Use can opener	22	6.0	2.0	10.4	2.0	6.5	1.8	9.7	4.3	+0.5	−0.7
Use "Flit" gun	2	7.5	—	17.5	—	7.5	—	16.0	—	—	—
Use paper clip	43	6.4	1.9	12.6	7.0	6.9	1.3	11.4	3.5	+0.5	−1.2
Use pencil sharpener	32	6.7	2.8	14.0	9.2	7.1	1.9	13.4	7.4	+0.4	−0.6
Wire electric plug	1	9.0	—	82.0	—	6.0	—	115.0	—	—	—
Over-all mean rating		6.4				7.0					

[a] For activities performed by 10 or more subjects only.

Table 32

PRACTICAL-ACTIVITIES TESTS
PERFORMANCE RATINGS AND TIME IN ABOVE-ELBOW SUBJECTS

Activity	No. of Cases	Evaluation I				Evaluation II				Difference Between Mean Ratings[a] (Evaluation II *vs.* Evaluation I)	Difference Between Mean Times[a] (Evaluation II *vs.* Evaluation I)
		Mean Rating	σ	Mean Time (sec.)	σ	Mean Rating	σ	Mean Time (sec.)	σ		
Assist someone with coat	3	5.3	—	11.0	—	7.7	—	10.0	—	—	—
Button shirt sleeve	4	4.8	—	16.3	—	6.8	—	8.4	—	—	—
Carry cafeteria tray	3	3.7	—	19.3	—	6.5	—	14.7	—	—	—
Carry several packages	30	5.3	1.8	18.1	9.6	6.3	1.3	17.5	8.1	+1.0	−0.6
Cut food with knife and fork	6	4.2	—	37.3	—	6.5	—	29.3	—	—	—
File fingernails	20	5.1	1.4	29.8	19.6	6.1	1.1	21.4	10.7	+1.0	−8.4
Hammer a nail	11	5.0	1.0	13.0	5.5	6.6	1.4	15.3	5.5	+1.6	+2.3
Hold telephone	2	3.0	—	45.0	—	8.0	—	24.5	—	—	—
Open jar	18	4.6	1.9	16.1	14.2	6.5	1.3	10.8	7.5	+1.9	−5.3
Play cards	8	4.6	—	17.7	—	6.4	—	15.9	—	—	—
Put on glove	10	4.6	2.6	20.7	11.4	5.6	2.0	15.6	8.5	+1.0	−5.1
Take bills from wallet	23	4.9	1.8	14.3	7.8	5.7	1.6	15.4	7.7	+0.8	+1.1
Tie necktie	10	4.8	1.8	39.6	8.4	5.6	0.8	33.6	9.4	+0.8	−6.0
Tie shoelaces	14	5.7	1.3	23.6	13.4	6.4	1.2	18.4	9.7	+0.7	−5.2
Use brush and dustpan	4	3.5	—	27.0	—	5.3	—	17.8	—	—	—
Use can opener	13	5.0	1.8	14.1	8.7	6.8	1.4	11.1	6.8	+1.8	−3.0
Use "Flit" gun	1	2.0	—	20.0	—	6.0	—	18.0	—	—	—
Use paper clip	22	5.2	1.7	15.6	6.4	6.5	1.4	13.1	5.0	+1.3	−2.5
Use pencil sharpener	15	4.5	1.4	19.9	12.5	5.9	1.5	15.9	12.5	+1.4	−4.0
Wire electric plug	3	4.3	—	167.3	—	5.3	—	105.0	—	—	—
Over-all mean rating		5.0				6.2					

[a] For activities performed by 10 or more subjects only.

In the post-treatment evaluation, the below-elbow subjects generally performed better in all of the 15 activities studied. Increases in the ratings ranged from a low of 0.1 point to a relatively significant 1.5 points. Although the average increase (0.6 point) was not substantial, all of the changes were in the expected direction, an increase of a full point or more being achieved in five of the activities. A similar trend characterized the performance of the above-elbow subjects, where improvement (ranging from 0.1 point to 2.8 points) occurred in all 11 activities studied. In eight of the activities there was a gain of at least one full point, the average for all 11 being 1.2 points. The magnitude of the gains and the number of activities in which significant improvement occurred were both greater than in the case of the below-elbow subjects.

It should be noted that most of the 20 shoulder-disarticulation amputees taking the test at the post-treatment evaluation were capable of performing six to eight of the 20 activities. Apart from considerations of the quality of performance, this outcome represents a significant increase in the number of activities those subjects were capable of performing.

DISCUSSION

Proficiency in the use of arm prostheses is clearly related to level of amputation. The performance of the below-elbow amputees in the NYU Field Studies was found to be consistently better and faster than that of the above-

elbow amputees, who in turn performed better and faster than did the few shoulder-disarticulation amputees involved. Differentiation of performance was apparent in all tests, both before and after treatment.

The most important single reason for the superior performance of the below-elbow amputee lies in his retention of the natural elbow. The above-elbow amputee is required to operate a mechanical elbow scarcely designed to provide *all* the functions of the natural elbow. Coupled with this mechanical limitation is the relatively high degree of skill required to operate present-day mechanical elbows smoothly and unobtrusively. Together these two factors impose upon the level of above-elbow prosthetic performance an insurmountable upper limit. The difficulty is only magnified in the case of the shoulder-disarticulation amputee, who must operate both a terminal device and a mechanical elbow by scapular abduction, a motion more gross and yet more limited than the humeral flexion normally available to both above- and below-elbow amputees. Further development and refinement of existing elbows and an increased emphasis on amputee training could conceivably elevate the level of above-elbow and shoulder-disarticulation performance to some degree. But radical changes to bring the above-elbow or shoulder-disarticulation amputee functionally up to par with the below-elbow case must await new concepts and designs in the development of components and control systems.

As a result of the treatment program in the NYU Field Studies, the ability of all the amputee subjects to use their prostheses improved to varying extent. The superiority of the newer components and newer fabrication procedures, and the systematic training given to each patient as a routine matter, contrived to produce a general benefit differing only in degree from subject to subject and from amputation level to amputation level. That the improvement in performance among the below-elbow amputees was relatively small indicates that as a group they derived the least benefit from the new developments, for the obvious reason that their relatively high level of proficiency prior to the studies discounted their ability to profit greatly from the program. The more significant gains made by the above-elbow and shoulder-disarticulation amputees identified these groups as the major beneficiaries of the Field Studies. Although as a group the above-elbow subjects never quite attained the achievement level of the below-elbow amputees, the gap between them was significantly smaller after the treatment program, and as individuals the few shoulder-disarticulation cases improved markedly.

The prostheses prescribed in the program were designed to provide maximum comfort, freedom of movement, and optimal replacement of lost function. The more significant improvements included higher, better-fitting, and better-appearing sockets; more useful and more easily operating elbows; improved efficiency of force transmission through better cable alignment and use of more stable materials; lighter, freer, and more comfortable harnessing; and a marked increase in the use of terminal devices offering improved control of grasp force. The advantages offered by these features were apparent in the prehension test, in which the objects to be manipulated remained stationary and the amputee was required to place himself and his terminal device in the best position for grasp and release. The need for compensatory body movements, which tend to lower performance ratings, was clearly reduced by the increased freedom and mobility of the new arms. The increased control of finger pressure offered by the new devices was reflected in the general and significant decrease in the number of compression errors made at the second evaluation.

The value of the newer elbows seemed to be demonstrated by the improvement in performance of the above-elbow cases in the positioning test. The higher scores on the second test were based on more accurate positioning of the terminal device with lessened body contortion—a function of the elbow unit. It is interesting to note that, while performance ratings improved after treatment, speed of performance remained static. With the wider use of APRL devices on the second evaluation, an *increase* in the time required might have been expected. Since operating time did not increase, improved control of finger pressure was achieved without a concomitant slowing of performance.

The similarity in performance patterns in the abstract-function and practical-activities tests may have important clinical consequences. Further study is warranted to see whether proficiency in the practical utilization of a prosthesis is related to, and perhaps reflected by, performance in abstract-function tests. Should such a relationship be found, it would be possible to convert the easily administered abstract-function test from a research tool to a clinical instrument. A combination of the more sensitive and selective elements of the tests could provide the foundation for a reliable system of measuring achievement and proficiency in amputee training.

As a result of the Upper-Extremity Field Studies, it is now possible to establish a set of proficiency norms based upon amputee performance but retaining as its main criterion the skill patterns of nonamputees. The therapist who trains an arm amputee to use a prosthesis could thus have available a realistic and relatively objective standard against which to evaluate the progress and achievement of each patient, since she would be comparing his performance with that of hundreds of amputees of a similar type. The resulting improvement in the evaluation of training effectiveness should permit a judicious allocation of training time and services. Despite its inadequacies of crudeness and of administrative difficulty, the performance-evaluation system described here established for the first time a logical plan for ascertaining the degree of functional restoration offered amputees by modern prosthetics services, a problem heretofore frequently bypassed for lack of reliable and valid methods.

Concluding Remarks

Refinement of the existing research tools on the basis of past experience, reapplication of these methods in the light of present knowledge, and the further correlation of results may well make it possible to predict the anticipated outcome when specific prosthetic components are applied to a particular arm amputee. Such an eventuality may lead to major changes in the principles of arm prescription and fitting as currently embodied in the art-science of upper-extremity prosthetics.

The results of these studies, which have been analyzed and interpreted in the discussion sections on pages 54-61, 99-103, and 143-149, are not resummarized here by way of concluding this article. It is perhaps sufficient to close with the remark that there has been presented in this article a large volume of information providing new insights—some clear, some tentative—into the over-all problem of evaluating arm prostheses. The surface of this broad field has been partially mapped along with some scattered probings of the substrate; but certainly the way has been opened for those who may elect to pursue this problem a little further.

Appendix I

Reliability and Validity of the Test Methods

RELIABILITY

It is well known that test results are subject to a variety of influences and that therefore errors of measurement are to be expected under the best of experimental conditions. The tests used in the NYU Field Studies were at the time in a developmental stage, and in anticipation of errors tending to reduce reliability several precautionary steps were taken.

Three measures were employed in scoring the performance tests—performance rating, number of errors, and time. The reliability of the last two is not open to serious question, since such errors as are likely to occur in counting errors or in reading a stopwatch are not usually of significant magnitude or of a systematic nature and can be expected to vary randomly and "average themselves out." Performance ratings, being based on judgment, are more variable, so that errors tending to reduce reliability are to be expected. Some of the principal sources of bias in this study may have been:

1. *Errors of Leniency.* Judges tend to rate higher in the desirable traits the subject they actually know.
2. *Errors of Central Tendency.* Judges hesitate to give extreme ratings and so tend to displace subjects in the direction of the average for the entire group, thus misrepresenting the true variation in the group.
3. *Halo Effect.* We tend to judge in terms of the general mental attitude toward the test situation. Knowing, for example, that a subject is being tested for the second time, with an intervening period of fitting and training, a judge may tend to upgrade the performance unduly.
4. *Normal Variation in the Attitude of the Judge.* As individuals, we are continuously influenced by our physical environment and emotional status, and the net effect may produce variability in judgment.
5. *Variations in Judges' Values.* A judge's preconception about the relative difficulty of activities, or of the value to be placed upon efforts in relation to achievement, may bias his judgment.

During the course of the studies, 12 NYU Field Representatives conducted the performance tests over a 3-year period between 1953 and 1956. At no one time were all of the judges active in the work, and as a result they did not conduct equal numbers of tests. Nor was it always possible for the pre- and post-treatment evaluation of a patient to be judged by the same rater. Steps were therefore taken to maintain the reliability of the ratings by familiarizing judges with probable sources of error and by firmly establishing the judgment criteria. In addition, all judges were highly qualified members of the NYU staff, with previous research experience in testing and assessment. All were either graduates of the course in upper-extremity prosthetics at UCLA or else had been given similar instruction at New York University. Moreover, the criteria for evaluating performance were carefully studied in formal sessions by all the judges to aid in the development of consistent standards of judgment. The effectiveness of these steps in maintaining reasonable reliability was gauged by statistical analysis.

Evidence of reliability was obtained by comparing periodically the independent but simultaneous ratings of a single performance as arrived at by several judges. The ratings thus obtained were evaluated by means of a statistical procedure involving Kendall's Coefficient of Concordance,[1] which indicates the degree to which a number of raters are applying essentially the same standard. Kendall's coefficient *(W)* is used to evaluate the difference between the variability in a set of ratings actually obtained and the variability to be expected in a hypothetical set of ratings *if there were perfect agreement among all the raters.* The resulting single measure of the extent of agreement among several judges is usually expressed as a chi-square function [$x^2 = p(m - 1) W$, where m = number of judges and p = number of scores]. If the difference (in degree of variability) between the obtained and the hypothetical sets of ratings is significant (by statistical test), we may assume that not all of the raters were applying the same judgmental standard. Since of the original 12 raters in the Field Studies only eight rated enough cases for the results to

[1] Siegel, S., *Nonparametric Statistics for the Behavioral Sciences,* McGraw-Hill, New York, 1956.

be valid, only these eight were included in this and succeeding analyses of homogeneity. The statistical findings ($x^2 = 14.47$; $df = 7$; $P < 0.05$) indicated that a hypothesis of no relationship between the sets of ratings given by each rater is untenable. This may, therefore, be considered as indicative of a satisfactory degree of consistency in the judgments of the raters *at those times.* To test the reliability of the scores given by the judges during the *entire test period,* another technique, "analysis of variance," was used.

"Analysis of variance" is a statistical procedure by which a number of independent samples or sets of scores may be tested simultaneously to determine whether or not they are sufficiently similar to be pooled. It is an efficient method for evaluating inter-rater reliability when more than two raters are involved. The test is expressed in terms of a ratio, *F,* which describes the relationship between the variability of the scores among the several raters (between groups) and the variability of each rater's scores from the mean of all raters (within groups). Simply stated, it is a test of a hypothesis that the scores given by any one rater did not vary significantly from the average of the scores given by all the raters. As shown in the relationship

$$F = \frac{\text{variability between groups}}{\text{variability within groups}},$$

the larger the variance from one rater to another (between groups) as compared with a single rater's variance from the common mean (within groups), the larger the fraction *(F). A* large *F* signifies a great difference between the raters; an *F* of low value indicates homogeneity in the group. A low ratio therefore indicates that performances were consistently rated, that the raters are therefore interchangeable, and accordingly that all the ratings may be considered as having been given by the same rater.

Because of the small number of cases involved, this technique could not be applied to the data from the practical-activities tests or from the abstract-function tests for the above-elbow sample at the pretreatment evaluation. It was applied to the ratings given the below-elbow cases on administration of both the prehension and the positioning test and to the ratings given the above-elbow cases at the post-treatment evaluations (Table 1). There were thus 21 tests in which individual raters had scored enough cases for reliability studies to be made by this means. Used were only those ratings given to subjects evaluated on both pre- and post-treatment tests by the same group of raters. Which is to say that, although an individual rater may not have scored the same subject on both evaluations, he was a member of a group of raters who had given all the ratings.

Of the 21 tests, 17 were not significantly different (0.05 level). That is, the extent to which they varied is well within the relatively narrow limits of chance fluctuation, which indicates an acceptable degree of consistency and reliability among the raters. Four, footnoted in Table 1, were statistically significant beyond the 0.05 level of confidence *(i.e.,* there was enough variation in the ratings in these tests to raise a question about the consistency of rating standards).

Despite the significant *F* value obtained in the four questionable tests, all results were used in this report. While the lower statistical reliability of the four may indicate rater unreliability or instability due to smallness of the sample (which would suggest the possibility of eliminating either these tests or the extreme raters), they were retained because the results clearly followed the trend of those tests appearing more reliable statistically. Since, furthermore, all of the tests are, or were, in a developmental stage, no theoretical reason could be adduced for their low reliability. There seemed to be greater value in retaining all of the tests and analyzing the conditions affecting reliability than in discarding some tests on statistical grounds alone. Considering the implications of the findings from all 21 tests, the ratings seemed homogeneous enough to warrant pooling.

VALIDITY

To establish the validity of a test on empirical rather than logical grounds requires a previously established independent criterion with which to compare the test in question. The degree of correspondence between the two *(i.e.,* the extent to which the test measures the same variable as does the independent criterion) is

Table 1

MEASURES OF INTER-RATER RELIABILITY

Test	Evaluation I					Evaluation II							
	Below-Elbow				Above-Elbow	Below-Elbow				Above-Elbow			
	F	df	F Significant[a] 0.05 level	F Significant[a] 0.01 level		F	df	F Significant[a] 0.05 level	F Significant[a] 0.01 level	F	df	F Significant[a] 0.05 level	F Significant[a] 0.01 level
Prehension	1.96	4,48	2.56	3.74	Not Tested	2.32	3,35	2.78	4.16	2.21	3,36	2.86	4.38
Positioning 1	2.23	4,44	2.58	3.78	(Insufficient	1.72	4,60	2.52	3.65	2.34	3,34	2.88	4.42
Positioning 2	1.03	40,4	5.71	13.74	Number of	3.23	50,4	5.70	13.69	1.32	3,34	2.88	4.42
Positioning 3	1.65	4,44	2.58	3.78	Subjects)	1.08	4,60	2.52	3.65	1.24	3,34	2.88	4.42
Positioning 4	1.91	4,44	2.58	3.78		3.54[b]	4,60	2.52	3.65	3.97[b]	3,34	2.88	4.42
Positioning 5	1.58	4,44	2.58	3.78		5.27	50,4	5.70	13.69	7.51[b]	3,34	2.88	4.42
Positioning 6	1.38	30,3	8.62	26.50		1.52	4,55	2.54	3.68	10.06[b]	3,34	2.88	4.42

[a] The threshold value of F at which differences can be considered significant for a given number of raters and subjects.

[b] Unreliable. That is, it cannot be said, with an acceptable degree of confidence, that differences in this rating are due to chance rather than to bias on the part of the raters.

the extent of test validity. External criteria usually are: a specific outcome or product of an activity (as, for example, the number of words typed by a typist in a specific time is a criterion of typing speed), or the activity itself (as illustrated by the speed of a runner as a criterion of fleetness of foot), or the judgment of persons qualified in a given field. The abstract-function tests—the prehension test and the positioning test—require activities which correspond closely to the skills being measured *(i.e.,* to the ability to grasp a very wide variety of objects and to operate a terminal device in several useful planes). No other criteria appear more germane. The practical-activities tests derive their validity in the same fashion—each activity is a valid test since it is itself the skill being measured.

To go a step further and to determine whether all or none of these tests are also useful measures of "prosthetic utilization" or of "extent of functional restoration" or of "rehabilitation" requires broader study and the use of other criteria. The presently available judgment of qualified clinic personnel may be the most useful criterion with which the tests may be compared. If, for example, the way in which amputees were classified on the basis of the test results was closely related to qualified judgment about amputee achievement, it would tend to establish the validity of the test as a measure of prosthetic utilization. Such an analysis is beyond the scope of the present work but remains as an interesting avenue for further study.