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# Do artificial limbs become part of the user? New evidence

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**Abstract**—This paper provides evidence that limb-deficient subjects who wear artificial arms tend to overestimate the perceived length of their residual limb. It is proposed that this "perceptual error" may provide a useful and possibly more valid alternative to existing methods of determining prosthetic acceptance. The degree of overestimation is substantial for most subjects with amputations, and typically represents 20 percent of the length of the prosthetic arm. The effect is considerably reduced when the prosthetic limb is removed. Comparisons are made with normal-limbed subjects of various ages. For the most part, their errors are small and typically are underestimates of actual limb length. This research is compared with the work of Fraser (1984), who found similarities in reaching trajectories for normal and artificial arms. Further investigation is required to determine if this effect may serve as an index of adjustment to a prosthesis and, additionally, if prosthetics training programs might benefit from including techniques for enhancing perceptual adaptations to artificial limbs.

**Key words:** *index of adjustment, perceived limb length, perceptual adaptation, prosthetic arm, upper limb amputations.*

## INTRODUCTION

One of the problems with existing measures of upper-limb prosthetic acceptance is that they all have questionable construct validity. That is, it is not at all clear that the measures used assess the client's acceptance as opposed to other variables. For example, some researchers have used movement counters to determine the frequency of opening and closing the hand unit. This measure may be ambiguous, because poor users may inadvertently open and close often in an attempt to control the hand operation. Time and speed tests have also been employed, but they tend to indicate performance under conditions in which the client has knowledge of the test, and can hardly be considered to reflect spontaneous performance under normal living conditions (10). Others have developed functional tests which are intended to observe performance of functional skills in spontaneous situations (1,3,8). These tests have the best chance of accurately assessing a client's acceptance, but so far, they have been developed only for children. Also, these tests use subjective rating scales, and so may be prone to error.

In this article, we report on a perceptual phenomenon arising as a result of wearing a myoelectric prosthesis. Clients apparently overestimate the length of their residual arm while wearing the prosthesis. This error appears to arise as a result of a gradual perceptual adaptation process. The effect seems to be very robust, to be easily measured objectively, and to reflect an intimate, personal adjustment to the prosthetic arm. The purpose of this paper is to document our observations, and to provide some idea of the size of the effect. Subse-

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quent research will investigate its value for assessing prosthetic acceptance.

Fraser (4) demonstrated that movements of an artificial limb were similar to movements of a normal limb in a 13-year-old girl with a congenital below-elbow absence on her left arm. This client was described as a proficient user who had worn a split-hook prosthesis for about 10 years, and a manually-operated Otto Bock prosthesis for approximately one year. Fraser used a sophisticated system for digitizing filmed episodes of reaching trajectories. The results of this case study demonstrated that the normal and artificial limbs were very similar in the early stages of a reach, but differed somewhat in the later stages.

In the early stages, the control of movements is ballistic in character in that, once initiated, the reach trajectory is not influenced by environmental information (open-loop). In the later stages, the control may be described as visually-guided (or closed-loop), in that the trajectory is continuously modified by visual information about a target's location (6,7). Fraser demonstrated that the ballistic control of movements in her client's artificial arm were similar to the control exhibited by her sound limb. Fraser contends that this similarity suggests that the underlying motor commands are the same, and in this sense, the artificial limb can be said to be "part of the user."

Although Fraser's demonstration is convincing, the strength of her conclusions would be increased if the effect could be demonstrated with a larger number of subjects, and if a comparison had been made between experienced and inexperienced artificial limb users. An alternative way to confirm that artificial limbs become "part of the user" is to find different experimental procedures that converge on this concept. One such procedure would be to determine if some perceptual adaptation occurs as a result of wearing an artificial limb.

Gibson (5) has proposed that tools become "part of the user," and it may be possible to extend his perspective to an artificial limb. "When in use, a tool is a sort of extension of the hand, almost an attachment to it or a part of the user's body, and thus is no longer a part of the environment of the user . . . This capacity to attach something to the body suggests that the boundary between the animal and the environment is not fixed at the surface of the skin, but can shift"(p. 41). From another perspective, adjustment to an artificial arm is similar, in some ways, to adaptation phenomena observed in optical rearrangement studies (12). In these studies, subjects used various kinds of optical devices (e.g., prisms, inverting lenses) to produce visual information discordant with kinesthetic-proprioceptive information. Following an exposure period, subjects showed significant adaptation, and when the distortion was removed, they showed after-effect errors compensatory to the direction of distortion. There is a similarity between these phenomena and adjustment to a prosthetic arm in the sense that there is a discordance between the "seen" location of the terminus of the arm and the "felt" location of the residual limb. Consequently, it might be reasonable to look for adaptation effects and after-effects.

Craske, Kenney, and Keith (2) have pointed out that the literature has failed to recognize that a sense of limb length is essential to achievement of motor coordination. These authors have demonstrated a significant adjustment in perceived limb length

**Table 1.**
Summary of essential biographical data on the 12 limb-deficient subjects participating in this study.

| Subject Number | Sex | Age (Years) | Conditions | Prosthesis Length (cm) |
|---|---|---|---|---|
| 1 | M | 5 | Congenital,<br>Below-elbow,<br>Right side | 12.7 |
| 2 | M | 6 | Congenital,<br>Below-elbow,<br>Left side | 20.0 |
| 3 | F | 6 | Congenital,<br>Below-elbow,<br>Left side | 16.5 |
| 4 | M | 9 | Congenital | 26.0 |
| 5 | M | 9 | Congenital | 20.3 |
| 6 | F | 12 | Congenital | 19.5 |
| 7 | M | 13 | Acquired | 26.5 |
| 8 | M | 14 | Acquired | 33.5 |
| 9 | M | 16 | Congenital | 12.0 |
| 10 | F | 16 | Congenital | 26.7 |
| 11 | M | 20 | Congenital | 31.8 |
| 12 | M | 21 | Acquired | 27.0 |

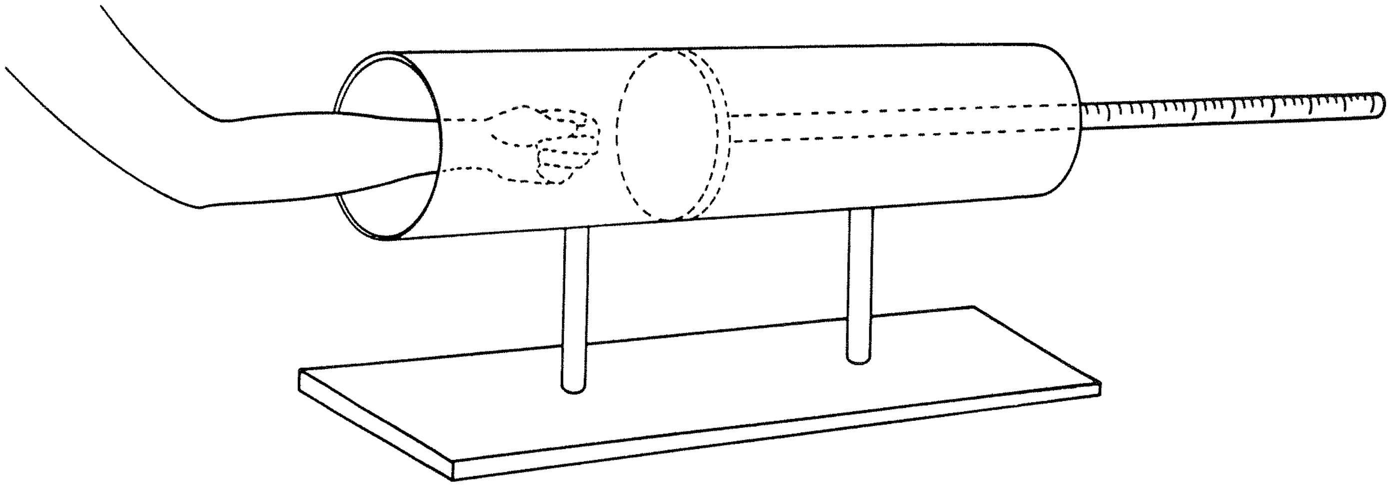

**Figure 1.**
A schematic view of the tube apparatus used to test arm localization.

following exposure to discordant sensory information. In the case of acquired amputation, a person should experience discordance whenever the terminus of the amputated limb is used to contact the environment following recovery. The discordance probably differs for persons with congenital limb deficiency. For both types, the discordance would be altered when an artificial limb is worn, necessitating a new adaptation.

Occupational therapist Elizabeth Sanderson* reported a clinical observation that a number of clients with upper limb amputation overestimated the length of their residual arm when asked to point to its terminus while wearing a myoelectric prosthesis. The purpose of the study reported here is to confirm that observation, and measure the magnitude of the effect.

## METHODS

### Subjects

Twelve subjects with unilateral upper limb deficiency were included in the following study. Their ages ranged from 5 years to 21 years. Three subjects had an acquired limb deficiency and the remaining nine had a congenital condition. **Table 1** summarizes biographical data on each subject. The performance of these subjects was compared to the performance of 39 normal-limbed subjects ranging in age from 3 years to 22 years. The normal-limbed subjects consisted of 16 children in the age range of 2.5 to 4.5 years, eight children from 4.5 to 6.5 years, seven children from 6.5 to 8.5 years, and eight adults ranging from 18 to 22 years. These people were contacted through subject pools made available by the University of New Brunswick Department of Psychology.

### Apparatus and procedures

The subjects with amputations, and the comparison group, were asked to align the index finger of one hand (pointer) with a designated spot on the other arm (target). This task was to be performed with only kinesthetic and proprioceptive information. To meet this requirement, all subjects were asked to place their target arm inside an opaque plastic cylindrical tube that was 96.5 cm in length and 15.2 cm in diameter. For each trial, the experimenters positioned a circular plate made of styrofoam and wood at a predetermined location in the tube. Subjects were asked to slide their target arm into the tube until it lightly contacted the plate. Then they were asked to point to the spot on the outside of the tube that they judged to be the position at which their target arm was touching the plate. The experimenters recorded the position of the plate and the pointer finger to the nearest millimeter. **Figure 1** depicts the essential features of the "test tube."

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* Personal communication, October, 1983.

The subjects with amputations were tested with their prosthesis on, and also with it removed. With the prosthesis removed, they were asked to insert their residual limb into the tube as far as possible to determine their maximum reach length. They then were asked to place their arm at the shortest tube position at which they were comfortable and yet were unable to see its terminus. The procedure for testing subjects while wearing their prosthesis was similar, except that they were asked to point to the end of their prosthetic hand, as well as to the end of their residual limb. For all measurements, it was decided that the tip of the residual limb had to extend at least 5 cm into the tube.

Once the longest and shortest reaches were determined, a microcomputer was used to generate, randomly, two sets of test positions between the shortest and longest values, one for each condition. The number of trials was varied between 10 and 25 depending on the age of the subject. In a preliminary study of eight children aged 3 to 8 years, it was found that both the mean error (ME) score and the standard error of the mean increased significantly in the second of two sets of 10 trials. Similar results were not found for adult subjects. These results, and our observations, indicated that the task became tedious for the children after several trials. Since maintaining subject motivation was felt to be essential to ensuring the validity of the data, it was decided that the number of trials would be reduced for the younger subjects.

Test trials were administered by positioning the plate at the computer-generated settings. With their prosthesis removed, subjects were asked to align their pointer finger with the end of their residual limb. The procedure for testing subjects while wearing their prosthesis was similar, except that they were asked to point to the end of their prosthetic hand as well as the end of their residual limb. Aside from interest in the subjects' ability to locate the terminus of their prosthesis, the requirement of pointing to the tip of both the residual and artificial limbs was useful, because it seemed to eliminate confusion about which tip was the target, especially for the younger subjects.

Normal-limbed subjects were tested in a very similar manner. Subjects were requested to make a fist, then the longest and shortest reaches were determined for both right and left arms. The number of trials for each arm varied between 10 and 25 depending on the subject's age. The settings for each subject were randomly generated and administered for each arm.

The instructions were modified for the younger subjects to ensure that they understood the task. The verbal instructions were simplified as much as possible. Also, a plexiglass model of the test tube was constructed so that the procedure could be explained in concrete terms. A cartoon character was drawn on the end of each child's residual limb or knuckles. The children were encouraged to name the character, and then the task became one of finding their "new friend" hidden in the tube. A special sticker page was used to record the trials, and stickers were awarded following each judgment. This technique helped the children keep track of the number of trials completed. It also successfully served as a way of motivating the children to continue with the task, even though it became tedious after several judgments were made.

## RESULTS

The average error and standard deviation (SD) for each set of trials was determined for each subject. Usually the average error could be calculated by simply subtracting the setting of the plate and the position of the pointer finger. When the subjects with amputations wore a prosthesis, it was necessary to determine the position of the end of their residual limb within the prosthesis by subtracting the extra length provided by the prosthetic limb. To determine the length added by the prosthetic arm, the length of the arm was measured without the prosthesis, and then while wearing it. In each case, one end of a tape measure was placed on the acromion tip of the subject's shoulder, and the length of the residual limb, or the limb plus the artificial arm, was determined. These measurements were repeated several times until the experimenters were confident that an accurate measure had been recorded. For all measurements, the prosthetic hand was closed. It was also closed when placed in the test tube during testing. The difference between the two measures represented the added length of the artificial limb.

The average errors and SDs for each condition used to test the subjects with amputations are shown in **Table 2**. Positive values indicate an overestima-

**Table 2.**
Mean error (ME) scores and standard deviations (SD) in cm for 12 limb-deficient subjects and three test conditions.

| Subject Number | Age (Years) | Pointing at end of residual limb with prosthesis | | | | Difference scores | Pointing at prosthesis tip | |
|---|---|---|---|---|---|---|---|---|
| | | OFF | | ON | | (ON - OFF) | | |
| | | ME | SD | ME | SD | ME | ME | SD |
| 1 | M 5 | −1.8 | 1.8 | 10.4 | 3.7 | 12.2 | 1.3 | 3.1 |
| 2 | M 6 | 4.4 | 3.7 | 7.3 | 1.8 | 2.9 | −0.8 | 2.2 |
| 3 | F 6 | 0.4 | 1.4 | 9.8 | 1.8 | 9.4 | −2.9 | 1.8 |
| 4 | M 9 | −1.3 | 1.3 | 3.2 | 4.8 | 4.5 | −1.0 | 3.8 |
| 5 | M 9 | 3.9 | 3.1 | 14.0 | 3.0 | 10.1 | −0.5 | 3.6 |
| 6 | F 12 | 0.9 | 2.0 | 4.5 | 3.2 | 3.6 | NA* | NA |
| 7 | M 13 | 1.8 | 2.1 | 14.2 | 1.8 | 12.4 | 2.3 | 1.9 |
| 8 | M 14 | −3.8 | 1.8 | 0.6 | 2.9 | 4.4 | NA | NA |
| 9 | M 16 | 0.0 | 2.6 | 2.0 | 3.4 | 2.0 | 0.4 | 3.7 |
| 10 | F 16 | 2.0 | 3.1 | 7.0 | 2.5 | 5.0 | −5.4 | 2.2 |
| 11 | M 20 | 1.0 | 2.3 | 14.8 | 2.2 | 13.8 | −5.5 | 3.7 |
| 12 | M 21 | 1.8 | 3.7 | 6.6 | 2.4 | 4.8 | −0.9 | 3.0 |
| Group Means: | | 0.8 | | 7.9 | | 7.1 | −1.2 | |

*NA: data were not recorded for these subjects.

tion and negative values indicate underestimations. With the prosthesis off, the average error was +0.80 cm. When the prosthesis was being worn, the average error was +7.9 cm. All 12 subjects overestimated, although Subject #8 scored close to zero. **Table 2** also shows the differences in average error obtained by subtracting the prosthesis-off scores from the prosthesis-on scores. These scores give a clearer picture of the magnitude of adjustment to the prosthesis. Clearly, Subject #8 (see **Table 2**) underestimated limb position with the prosthesis removed, but showed an increase of 4.38 cm when the prosthesis was worn. The average error in pointing to the end of the artificial limb was only −1.2 cm, and is closely comparable to the performance of normal-limbed subjects. **Table 3** and **Figure 2** summarize the results for each of the four age groups of normal-limbed subjects. The average error across all 39 normal-limbed subjects was −1.75 cm.

The average absolute error was also determined because it reflects the degree of accuracy in pointing. This measure showed similar results to the previous measure. For subjects with amputations, with the prosthesis off, the average absolute error was 1.93 cm, but with the prosthesis on, it was 7.85 cm. The average absolute error in pointing to the

**Table 3.**
Mean error (ME) scores and the range of scores in cm for four age groups of normal-limbed subjects (NL).

| Age Group | Age Range (Years) | N | ME | Score Range |
|---|---|---|---|---|
| NL1 | 2.5 - 4.5 | 16 | −3.0 | −9.0 to +1.4 |
| NL2 | 4.5 - 6.5 | 8 | −1.4 | −4.1 to +1.2 |
| NL3 | 6.5 - 8.5 | 7 | −0.7 | −2.4 to +0.4 |
| NL4 | 18.0 - 22.0 | 8 | −0.6 | −4.6 to +2.11 |

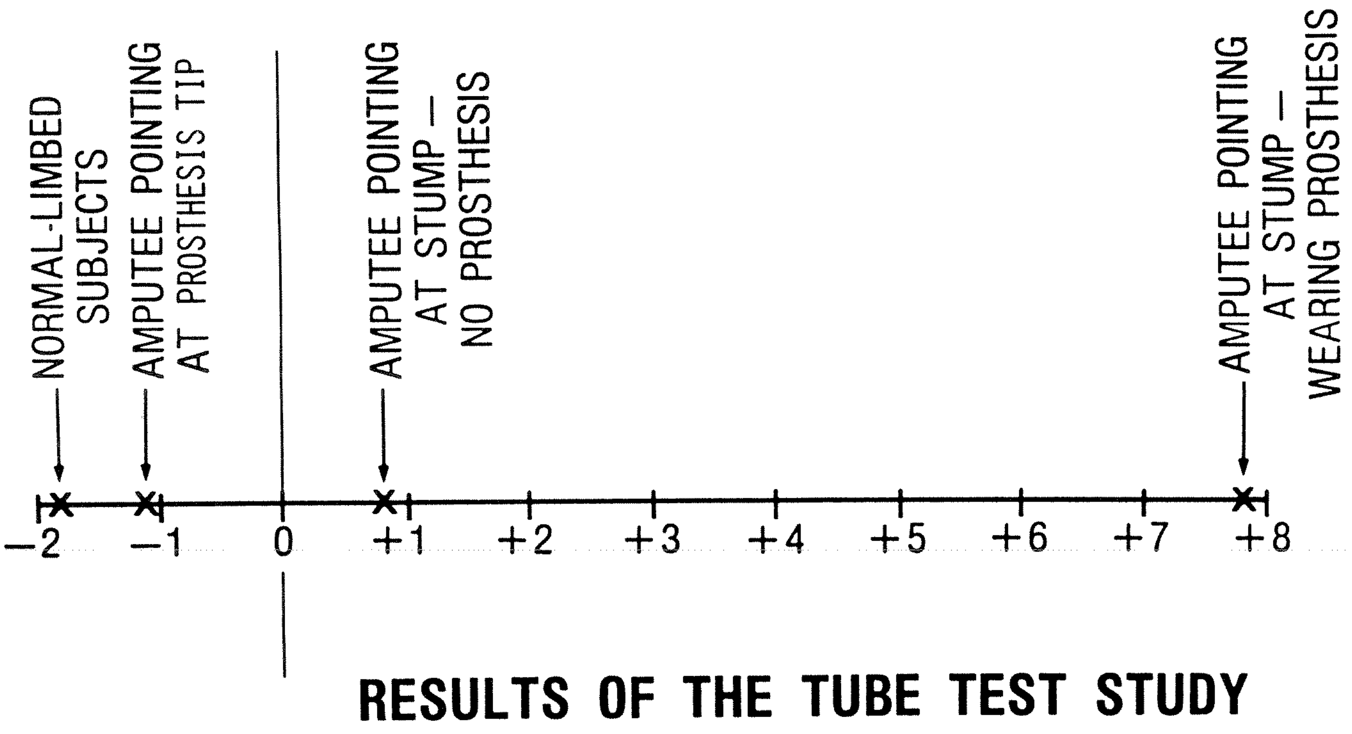

**Figure 2.**
The limb localization errors in cm shown for subjects with and without a prosthesis; normally-limbed subjects and subjects with amputations pointing at their prosthesis tip.

end of the prosthesis was 1.92 cm. The average absolute error for normal-limbed subjects was 2.16 cm. There is a remarkable similarity in the ability of the subjects with amputations to point to the tip of either the residual limb or the artificial limb.

All possible pair-wise combinations of the conditions shown in **Table 2** were compared with t-tests for correlated data. Also, the four age groups of normal-limbed subjects were compared with each other, and with each of the three limb-impaired subject test conditions using t-tests for uncorrelated data. The alpha level was set at 0.05, assuming a two-tailed test. **Table 4** gives the results of these tests. It can be seen that all t-tests were highly significant when one of the conditions was the subjects pointing at their residual limb with the prosthesis on (APL-on). Only two other comparisons reached significance, and these were between the two youngest age groups and the subjects with amputations judging their limb position with the prosthesis removed. When compared to the youngest normal-limbed subjects, there seems to be some evidence for a reduced, but statistically significant, adaptation.

Since there were only three clients with acquired amputations, it was not possible to make a meaningful statistical comparison between acquired and congenital cases. Finally, a Spearman rank correlation was used to determine if there was any relationship between age and magnitude of error score for the subjects with amputation. No relationship was found ($r_s = 0.042$, $N = 12$). Similarly, a rank correlation of age and test score was performed for a sample of 31 of the normal-limbed subjects. No relationship was found ($r_s = 0.37$, $N = 39$). Average error scores seem to be related to ages for the normal-limbed subjects, and it is certainly possible that a larger sample of subjects with amputations might reveal a similar correlation.

## DISCUSSION

The overestimation effect obtained in this study is very large and consistent across the 12 limb-deficient subjects. The percentage of average error to prosthesis length varied from 13.1 to 96.1 percent with a median overestimation error of 18.6 percent.

**Table 4.**
The results of t-tests used to compare ME scores across three testing conditions for limb-deficient subjects and to compare the performances of different age groups of normal-limbed and limb-deficient subjects.

**A. Comparison of Limb-deficient Conditions:**

Pointing at Limb Without Prosthesis (APL-off) vs Pointing at Limb With Prosthesis (APL-On).

| ME | ME | t | df | p |
|---|---|---|---|---|
| 0.8 | 7.85 | 5.85 | 11 | <0.001 |

Pointing at Limb Without Prosthesis (APL-off) vs Pointing at Prosthesis Tip (APP).

| ME | ME | t | df | p |
|---|---|---|---|---|
| 0.8 | −1.2 | 1.95 | 11 | NS |

Pointing at Limb with Prosthesis (APL-on) vs Pointing at Prosthesis Tip (APP).

| ME | ME | t | df | p |
|---|---|---|---|---|
| 7.85 | −1.2 | 5.61 | 11 | <0.001 |

**B. Comparisons Among Normal-limbed (NL) Groups and Limb-deficient Group and Each Normal-limbed Group:**

| | ME | ME | df | t | p |
|---|---|---|---|---|---|
| NL1 vs APL-on: | −2.96 | 7.85 | 26 | 7.00 | <0.001 |
| NL1 vs APL-off: | −2.96 | 0.8 | 26 | 3.32 | <0.01 |
| NL1 vs APP: | −2.96 | −1.2 | 26 | 1.55 | NS |
| NL1 vs NL2: | −2.96 | −1.39 | 22 | 1.24 | NS |
| NL1 vs NL3: | −2.96 | −0.73 | 21 | 1.76 | NS |
| NL1 vs NL4: | −2.96 | 0.60 | 22 | 1.77 | NS |
| NL2 vs APL-On: | −1.39 | 7.85 | 18 | 5.11 | <0.001 |
| NL2 vs APL-Off: | −1.39 | 0.8 | 18 | 2.22 | <0.05 |
| NL2 vs APP: | −1.39 | −1.2 | 18 | 0.18 | NS |
| NL2 vs NL3: | −1.39 | −0.73 | 13 | 0.84 | NS |
| NL2 vs NL4: | −1.39 | −0.60 | 14 | 0.86 | NS |
| NL3 vs APL-On: | −0.73 | 7.85 | 17 | 4.56 | <0.001 |
| NL3 vs APL-Off: | −0.73 | 0.8 | 17 | 1.61 | NS |
| NL3 vs APP: | −0.73 | −1.2 | 17 | 0.50 | NS |
| NL3 vs NL4: | −0.73 | −0.6 | 13 | 0.13 | NS |
| NL4 vs APL-On: | −0.60 | 7.85 | 18 | 4.52 | <0.001 |
| NL4 vs APL-Off: | −0.60 | 0.8 | 18 | 1.27 | NS |
| NL4 vs APP: | −0.60 | −1.2 | 18 | 0.56 | NS |

*Degrees-of-freedom are calculated for t-tests for correlated means in Section A and uncorrelated means for Section B.

These results clearly show that the subjects in this study perceive the terminus of their amputated limb to be more distal to the body than it actually is. Long-term use of a prosthetic arm has resulted in a significant and positive adaptive shift in the perceived extent of the residual limb. The size of this overestimation effect is perhaps more impressive when compared to the performances of normal-limbed subjects. Across all four age groups, the ME scores indicate a tendency to underestimate true arm length, with the larger underestimations occurring at the youngest age levels. At this point, we have tested only clients with myoelectric prostheses. It would be of interest to extend this paradigm to conventional prosthesis users. We were able to test only one client to date, and no overestimation effect was found. Additional research is clearly needed.

There are other studies on the estimation of size of body parts that have not found any particular tendency of subjects to overestimate. For example, Shontz (11) found some tendency for normal-limbed, adult subjects to underestimate foot size and overestimate hip size. Although there were some sex differences (for the hands, neck, and waist), judgments of leg, arms, lips, back, and face were quite accurate. When errors were made, underestimation was more common than overestimation. Robinson, Lippold, and Land (8) compared estimates of body part sizes by 12 children with spina bifida and controls matched for age, sex, and IQ. Their purpose was to discover any distortion of perceived body size in those limbs that lacked endogenously-derived sensations. (An artificial limb is similar in this respect.) Their results suggest that children with spina bifida were as accurate as nonhandicapped children in judging the lengths of inanimate objects, other person's body parts, and their own body parts.

These authors also reported a tendency for both groups of children in their study to overestimate short extents and underestimate long extents. This effect could be called regression-to-the-mean and could be used to account for the results of the present study. Such an explanation is unlikely to be valid, however, since it is not clear why the residual limb was not overestimated when the prosthesis was removed. Obviously, the effect is evoked by the presence of the prosthetic arm. People with an amputation develop selective adaptations suited to the presence or absence of the arm. Adaptations to optical distortions are typically followed by transient negative after-effects. In this case, subjects should have underestimated arm length when the artificial limb was removed. The average error for all normal-limbed subjects was −1.8, while the average error for limb-deficient subjects was +0.80. This difference could be construed as a positive after-effect. Indeed, the two youngest normal-limbed groups differed significantly from subjects with amputations when the prosthesis was removed. It is conceivable that positive after-effects could result from chronic, long-term exposure, but more research is needed to confirm this result. A positive after-effect is consistent with the notion that the artificial limb has altered the user's perception of limb length. It seems that the boundary between the body and the artificial arm is not "fixed at the surface of the skin but can shift" (5). In this sense, the results of this study converge with Fraser's conclusion that the artificial limb becomes part of the user.

As mentioned at the beginning of this article, it would be interesting from a clinical point of view to know if this effect is related to the degree of success of a person's adjustment to a prosthesis. If so, this technique might provide a simple and objective method of monitoring such adjustment. For example, it is possible that the degree of overestimation may depend on such predictor variables as age of fitting, length of time wearing a prosthesis, type of prosthesis, and type of amputation. It would also be of interest to determine if there is a correlation with certain criterion variables, such as attitudes to wearing a prosthesis, and skill and spontaneity of functional use. We are currently investigating some of these issues.

The success of a person's acceptance and use of a prosthesis will be determined by many factors aside from perceptual adjustments, and there are other ways to assess it. In order to determine the clinical validity of this measure, research would first have to determine if improved perceptual adjustment leads to better compliance and/or functional skills. If there are benefits, training might include procedures designed to increase perceived limb length. Such a perceptual adaptation would be fostered by training ballistic movements in tasks or games in which limb length is important for accuracy. This form of training is similar to suggestions made by Fraser (4).

The overestimation effect demonstrated here is a major phenomenon associated with the experience of prosthetic arms. To date, it has been unnoticed or, at least, unreported. Validation of this measure as a clinical tool is important, but the next step must be to determine the variables associated with the magnitude of this phenomenon, and to determine if the effect is demonstrable in other forms of prostheses.

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## REFERENCES

1. **Brooks M, Shaperman J:** Infant prosthetic fitting. *Am J Occup Ther* 35:329-334, 1965.
2. **Craske B, Kenney F, Keith D:** Modifying an underlying component of perceived arm length: Adaptation of tactile location induced by spatial discordance. *J Exp Psychol [Hum Percept]* 10:307-317, 1984.
3. **Crone N:** A comparison of myoelectric and standard prostheses: A case study of a pre-school-aged congenital amputee. *Can J Occup Ther* 53:217-222, 1986.
4. **Fraser C:** Does an artificial limb become part of the user? *Brit J Occup Ther* 43-45, February, 1984.
5. **Gibson J:** *The Ecological Approach to Visual Perception.* Boston: Houghton Mifflin Company, 1979.
6. **McDonnell P:** The development of visually guided reaching. *Percept Psychophys* 18:181-185, 1975.
7. **McDonnell P:** Patterns of eye-hand coordination in the first year of life. *Can J Psychol* 33:253-267, 1979.
8. **Robinson R, Lippold T, Land R:** Body schema: Does it depend on bodily-derived sensations? *Dev Med Child Neurol* 28:49-52, 1986.
9. **Sanderson ER, Scott RN:** *UNB Test of Prosthetics Function.* Fredericton, NB, Canada: The Bio-Engineering Institute, 1985.
10. **Scott RN, Sanderson ER, Parker P:** The fallacy of timed functional tests. *J Rehabil Res Dev* 22(3):104-106, 1985.
11. **Shontz F:** Some characteristics of body size estimation. *Percept Mot Skills* 16:665-671, 1963.
12. **Welch R:** *Perceptual Modification: Adapting to Altered Sensory Environments.* New York: Academic Press, 1978.