Prosthesis Training as a Context for Studying Occupational Forms and Motoric Adaptation

Hon Keung Yuen, David L. Nelson, Cindee Q. Peterson, Alyce Dickinson

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Objectives. Occupational therapy authors frequently emphasize the importance of the use of objects in the development of motor skill. This study investigated the use of object-produced visual input in learning control of flexion and extension of an above-elbow training prosthesis.

Method. Fifty-two male college students were randomly assigned to two training procedures: (a) two 15-min periods in which they used a flashlight attached to the hook of the prosthesis to connect dots on paper with light, or (b) the same time periods in which they had the opportunity to practice moving an equally weighted prosthesis, but without the light or dots. To assess motoric adaptation after training under one of the two conditions, each subject traced a continuous line through a maze with a pen attached to the hook. Deviations from the line were measured reliably.

Results. Data analysis with a Mann-Whitney test revealed that subjects in the group that trained with added materials traced with significantly more skill than subjects in the other group (one-tailed U = 225.5, p = .02).

Conclusion. As predicted by occupational therapy theory, the object-produced visual input enhanced the learning of a motor skill relevant to rehabilitation. Although there is a need for more study across different occupations and populations, clinicians are urged to consider the possible benefits of the use of objects in the development of motor skills, as opposed to object-less exercise. Prosthetic training provides a useful context for future research addressing theoretical issues in motor learning.

The occupational therapist facilitates adaptation by synthesizing an occupational form appropriate to the person's developmental structure (Nelson, 1988). To facilitate motoric adaptations, the careful synthesis of objects is particularly important. Trombly (1989) described how the size, shape, texture, density, and weight of objects must be considered when eliciting motoric adaptations. For example, increasingly heavy, dense, or coarse objects often facilitate the development of strength; in contrast, the grading of the materials is often in the "opposite direction" when the therapeutic goal is increased coordination (p. 314). Trombly's ideas concerning the relationships between objects and motoric adaptations are consistent with a line of thinking in the occupational therapy literature that stretches from the early days of occupational therapy to the present (Baldwin, 1919; Dunton, 1945; Green, 1922; Hopkins, Smith, & Tiffany, 1983; Licht, 1957; MacDonald, 1960; Mathiowetz, 1991; Slagle, 1938; Spackman, 1971).

This intellectual heritage is seldom submitted to systematic theory-building or to research. A review of the occupational therapy literature did not reveal any experi-
ment in which the independent variable involved a comparison between types of objects and in which the dependent variable involved some measured change (adaptation) in motor skill.

Not until 1984 did occupational therapy researchers begin to study occupationally embedded exercise (sometimes termed purposeful activity), but experimental interest in investigating this concept has risen substantially (Bakshi, Bhambhani, & Madill, 1991; Bloch, Smith, & Nelson, 1989; Kärcher, 1984; Lang, Nelson, & Bush, 1992; Licht & Nelson, 1990; Mathiowetz, 1991; Mullins, Nelson, & Smith, 1987; Sietsema, Nelson, Mulder, Mervau-Scheidel, & White, 1993; Steinbeck, 1986; Thibodeaux & Ludwig, 1988; Yoder, Nelson, & Smith, 1989). These 11 studies contrasted different occupational forms in terms of their immediate effects on participants' performance (movements). Occupational performance is important in its own right, but it must not be assumed that occupational forms that promote the most performance also promote the most adaptation (change in the doer's developmental structure, such as the development of a new motor skill). Schmidt and Bjork (1992) have summarized motor learning research documenting that, under certain experimental conditions, training procedures that are relatively effective for enhancing immediate performance are relatively ineffective in the promotion of learning of motor skill (adaptation). Because no study to date has actually tested motoric adaptation, there is a need for occupational therapy research in this area. Can it be shown that an object-based occupational form enhances not only immediate performance but, more important, the development of a new motor skill?

To operationalize this question, we judged an upper extremity prosthesis to provide an opportunity for developing a novel motor skill. It is noteworthy that both King (1978) and Gliner (1985) have suggested prosthesis training as an interesting context for the study of movement from an occupational therapy perspective. Traditionally, the initial phase of prosthetic training, known as control training, involves little reference to objects in the environment as the client learns to operate the control cable in different positions (Fisher, 1983). Aylsworth (1952) and Jampol and Leavy (1954) wrote that the person with amputation should be able to perform the control motions easily and gracefully with a minimum of awkwardness before proceeding to interaction with common objects. However, could the addition of objects in the early stages of prosthesis training enhance motor learning?

To have an adequate sample, we decided to use a training prosthesis that can be operated by persons who have not had an amputation (the mechanism of control is the same as for a person with amputation using a standard prosthesis). Another problem in the operationalization was to identify a control condition that offered the same opportunities for movement as the added-objects condition, so that a fair comparison could be made. The decision was made to synthesize materials so that the two conditions of the independent variable differed in terms of visual input only, not proprioceptive input. A third decision was to concentrate only on flexion and extension of the prosthesis elbow by keeping the prosthetic device in the closed-book position, so that relative skill in book opening and closing could not confound the study of elbow flexion and extension. Finally, to study motoric adaptation, as opposed to only motor performance, it was necessary to design a simple test that could be administered in an unbiased way to all subjects after training.

Authors in other fields have frequently described the importance of objects in the development of motor skill. Bilodeau (1966) summarized research showing how objects can provide the feedback necessary for learning a motor skill. Gibson (1966, 1982) coined the term affordance to describe the direct link between objects and movement (i.e., a doorknob affords grasp and rotation). Turvey (1977) suggested that perception of objects and their relationships to body parts could modulate coordinative structures, thereby leading to superior future motor performance. Newell (1978) stated that objects are important parts of the task constraints faced by a person in a motor learning situation, whereas Gentile (1987) considered objects to be regulatory conditions of the task to be learned. Arbib (1980) proposed an especially close relationship between visual schemata and motor schemata for reaching and grasping.

Gliner (1985) and Sabari (1991) discussed many of these ideas from the perspective of occupational therapy theory and practice. Given the importance of object–person interactions (termed events) in motor learning, Gliner questioned the use of objectless exercise as an effective therapeutic strategy. Sabari described the importance of “goal objects” (1991, p. 529) in influencing the movement patterns and postural adjustments of persons relearning motor skills.

In summary, several theoretical perspectives support the importance of material objects in the development of motor skill. Within occupational therapy, concepts about the use of objects as a means to promote motor skill have not been studied systematically; however, practice-oriented occupational therapy literature repeatedly has suggested that objects can provide the information patients need to develop motoric skill. Therefore, in this study it was hypothesized that subjects who received added, object-related visual input would develop greater skill in the use of a training prosthesis than control subjects lacking special object-related visual input.

**Method**

**Subjects**

Fifty-two right-handed healthy male college students from a Midwestern university, who were not occupational therapy students and who reported no previous experi-
ence in using any upper limb prosthetic device, volunteered to participate in the study. Ages ranged from 18 to 29 years with a mean of 21.5 years. Selection criteria included height and weight. To minimize variation in the height of the working level, each subject's height was between 1.7 m to 1.9 m with a mean of 1.8 m. To ensure proper fitting of the prosthesis, the each subject's weight was between 61.4 kg and 93.2 kg with a mean of 77 kg.

Apparatus

The prosthetic device was a standard above-elbow training arm equipped with a farmer's hook. The prosthesis has a sleeve attached to the arm piece so that it can be put on the arm of a person without amputation. The mechanism of the cable control of this training prosthesis is the same as that of the standard above-elbow prosthesis for persons with amputations. The locking mechanism of the cable, which permits opening of the terminal device, was kept unlocked. Therefore, the only possible movement of the training prosthesis was elbow flexion and extension through flexion and extension of the shoulder supporting the prosthesis. Stump socks were used as padding on subjects' arms, as necessary, to ensure proper fitting of the prosthesis.

Used in the added-objects condition was a piece of white paper, 43 cm x 28 cm, dotted with 30 glued-on blue paper discs 6 mm in diameter, made with a hole punch. The discs were dispersed on the white paper in no identifiable pattern.

The testing maze for the dependent variable (see Figure 1) was on white paper and taped to a blackboard inclined 10° forward from the vertical. The degree of deviation of the maze from the vertical and the inclination of the blackboard were determined by the following criteria: maximum range of contact between the ball-point pen and the maze; minimum trunk movement required; and maximum elbow flexion-extension of the prosthesis during tracing.

Procedure

Each subject was randomly preassigned to one of two types of training, the added-materials group or the control group. After entering the training room, each subject was given written instructions on the rules for manipulation of the prosthesis, posture, and duration. The added-materials group instructions were: "The purpose of this study is to see how well you can learn to control the movement of the mechanical arm at the elbow joint steadily and accurately by focusing on the movement of the mechanical arm."

After subjects read through the instructions, they were assisted in putting the training prosthesis on the dominant (right) arm. The forearm component of the prosthesis was internally rotated to 10° and placed next to the sound forearm rather than on top of it to prevent the subject from moving the prosthesis with his forearm. Subjects were instructed on how to lift and lower the prosthesis by flexing and extending the right shoulder. They practiced this movement for five successful trials. Then the principal investigator left the room. Each of the four research assistants administered the procedures to an equal number of subjects from the two groups (except in the case of an odd-numbered total). Each research assistant was trained to follow a carefully typewritten protocol. The use of research assistants permitted the principal investigator to be blind to group assignment when administering the test.

For the added-objects group, the research assistant attached the flashlight to the hook and taped dotted paper on a wall at a point 100 cm above the floor. For the control group, a flashlight was also attached to the hook but with the light source pointing in the nonfunctional direction toward the base of the hook (this set-up equated the two conditions in terms of weight). Subjects in the control group stood on a mat with two footprint cutouts on it; the mat was placed in the middle of the room measuring 4.3 m x 2.6 m with no objects immediately in front of the subject.
Training Phase

Subjects were verbally reminded to keep the body upright in standing position and to use the right shoulder action to operate the forearm component of the prosthesis. Subjects were also shown the limits of the range of movement at the elbow joint of the prosthesis. The experimental group was told, “Use the light beam from the flashlight to join the dots in your own way, but be as accurate as possible.” Touching the dotted paper was not allowed. The control group was told, “Practice lifting up and lowering down the forearm component of the mechanical arm in your own way, but be as steady as possible.” Each subject was allowed to have two 1.5-min training periods with a break of about 10 sec between periods. During the break, the research assistant corrected the subject if the instructions were not followed perfectly (for example, if too much movement other than flexion and extension of the shoulder was used).

After the two training periods, a break of about 30 sec between the training phase and the testing phase was allowed to provide sufficient time for the research assistant to remove the flashlight from the hook. During the break, the subjects were given instructions similar to the previous ones to remind them about the rules and posture that they had to observe. Moving the prosthesis during the break was discouraged. Once the research assistant restored the setting to its original state, the principal investigator (blind to the subject’s training condition) returned to the room to begin the testing phase of the experiment when the subject would be required to trace the maze.

Testing Phase

The distance from the floor to the elbow of the prosthesis was measured. This information was used for the adjustment of the height of the maze relative to the subjects. Subjects were told to stand on the footprint cutouts on a floor mat placed in front of the blackboard. A trial to trace over the first segment of the first row of the maze with the tip of the ball-point pen covered by its cap was used to make a minor adjustment (within 2°), if necessary, in the rotation of the prosthesis. Subjects were asked to make a continuous mark on the maze line (see Figure 1). They were told to start the tracing whenever they wanted, and they were timed covertly.

Measurements

Proficiency in controlling the movement of the prosthesis was measured by the lack of deviation from the maze line. A graph paper transparency with squares of approximately 3 mm² size was placed on top of the testing maze. Each square partially or completely between the tracing line and the original maze line was counted. A low score indicated motor skill. The principal investigator scored all mazes while being blind to the condition of each subject. Two research assistants each independently rescored half of the mazes (it should be noted that the scoring system involved no marking or alteration of the maze, which might detract from the objectivity of the second scorer). Interrater reliability was calculated by dividing each subject’s smaller score by his large score, and by taking the mean of these percentages. The intrarater reliability was 87.9%.

Data Analysis

A preliminary analysis showed that the dependent variable was positively skewed (mean deviation scores were well above median scores). Therefore, a nonparametric Mann-Whitney U test was used to test the research hypothesis.

Results

Results of the Mann-Whitney U test indicated that the added objects group scored significantly lower than the control group, \( U = 225.5, p = .02 \), one-tailed. This supported the directional hypothesis. The mean and median scores for the added-objects group were 662.23 and 624.00 respectively, with an SD of 158.44. The mean and median of the control group were 859.50 and 736.00 respectively, with an SD of 375.59.

The mean time spent tracing the testing maze was 90.92 seconds (SD = 41.2) for the added-objects group and 84.69 (SD = 38.6) for the other group. This difference was not statistically significant (\( p = .58 \)).

Discussion and Conclusion

Results indicated that subjects learned to control the flexion and extension of the prosthesis at the elbow joint better after engaging in training with added objects than after engaging in training without added objects. This study helps to reinforce the importance of the use of objects and the provision of added information in the development of a novel motor skill. Though future replication is necessary to confirm the principle, occupational therapists are urged to consider the use of objects in the training of motor skill rather than just practicing the required movement, as in no-object exercise. Objectless,rote exercise may not be the better method of training, even in the early stages.

This study also has implications for future occupational therapy research. Performance-oriented research, such as the recent studies in occupational therapy cited in the introduction, is important to continue, because in many cases immediate performance or movement is a reflection of typical occupational therapy goals, such as increased range of motion or the development of...
strength. However, if motor learning (a type of adaptation) is the occupational therapy goal, then occupational therapy research needs to explore adaptation as a dependent variable, not just immediate performance. As Schmidt and Bjork (1992) wrote, motor learning as a dependent variable requires a posttraining transfer test because there is much research to indicate that the best training for enhancing performance is different from the training that is best to enhance learning, or adaptation. In this study, the posttraining transfer test involved the manipulation of a pen to follow a maze. Future research should consider a longer interval between the training phase and the transfer testing phase, to assess long-term adaptation.

In this study the principal investigator was blind to training group assignment. This prevented the possibility of conscious or even unconscious bias. Another methodological feature of this study was the use of the training prosthesis as a context for studying human movement relevant to issues in rehabilitation. Although this study focused on a single pattern of movement, future investigations could explore coordinated, sequential movement patterns. These future investigations would be possible in a practical way with the use of training prostheses. Training prostheses also could be used in further research into the involvement of other sensory modalities (in addition to vision, as in this study) tapped in the purposeful use and manipulation of objects.

Though difficult to conduct because of sample size requirements, research on patients with amputations and patients with other disabilities that require the use of adaptive devices, such as mobile arm supports or permanent orthoses, are essential. Wheelchair mobility training, such as teaching persons to do a wheelie, is a specific area that might be explored.

Although most simple motor skills cannot be tested in college students who already possess a full repertoire of skills, it may be feasible to study such skills in patients with neuromuscular disorders. Another interesting issue related to clinical practice is discovering the optimal amount of information for a patient when learning a particular task. An occupational therapist needs to be able to assess or evaluate this optimal amount to give a patient who is learning or relearning a motor skill maximum facilitation without simultaneously distracting or confusing the patient. For example, in driver education for patients with neurological deficits, too much sensory stimulation from objects in the environment could distract the patient from concentrating on the visual or auditory cues that are essential to learn a particular skill. Structuring the environment and adjusting the amount of information provided to facilitate learning a motor skill is a special challenge for the occupational therapy clinician.

There are several theoretical perspectives that would predict the results found in this study, that objects can enhance the development of a motor skill. Perhaps the most straightforward explanation is that additional feedback helped subjects monitor, and thus learn, the motor skill. Although subjects in the control group had the opportunity to receive some feedback by observing the correlation between the shoulder movement and the prosthesis (they were not totally without feedback), subjects in the added-objects group had the opportunity for additional feedback. It is well known that feedback is an essential component in the development of many motor skills (Bilodeau, 1966). What is not always recognized is that objects frequently provide naturalistic, immediate feedback. As Wallace and Hagler wrote, it is "surprising" (1979, p. 266) that a great deal of motor learning research has focused on verbal feedback "in light of the fact that the learner readily can obtain information" from common objects in real-life settings. In future research it would be interesting to compare the use of objects with the use of verbal feedback in terms of the development of motor skill.

Another possible explanation of the results is the concept of specificity of learning (Henry, 1968). According to this point of view, motor skill tends not to generalize across tasks (e.g., an excellent football passer is often not an excellent baseball thrower). It might be argued that the training phase involving the flashlight and dotted paper was more similar to the testing phase involving the pen and maze than was the control condition. The concept of specificity of training would predict that a performance on a test would be enhanced by test-specific or test-related practice. However, although objects and targets were present in both the added-objects training and the testing phase, the objects were different from each other and the targets were different from each other. In addition, the testing phase involved not only visual input but also a proprioceptive input, as the pen met resistance (friction) on the paper. Therefore, the two occupations were quite different, and it could be argued that considerable transfer of training and generalization took place.

Another comment in regard to the specificity explanation is that the naturalistic world frequently requires the use of objects (skilled use of a pen is a highly naturalistic use of a prosthesis), and that the most useful indicator of motor skill might be naturalistic occupations (those involving objects). Still, it would be interesting for theoretical reasons to conduct a study with the same independent variable as in this study but with a dependent variable that involved skilled movement without added objects or targets, such as movement evaluated for smoothness by motion analysis technology.

A third explanation is the concept of affordance (Gibson, 1966, 1982). We can say that the flashlight and dotted paper used in the experimental condition afforded a pattern of movement that was not afforded in the control condition. The visual perception provided in the training phase might have fine-tuned relevant coordinative structures, and this could account for more accurate move-
ment in the subsequent testing phase. In evaluating this explanation, it should be pointed out that Gibson emphasized naturalistic objects as affordances. Connecting of dots by a flashlight might be considered unnaturalistic; it could also be argued that such an occupation is more naturalistic than is objectless movement. Another comment is that it is difficult to rule out the effects of feedback in any test of the effects of affordances on motor learning. Indeed, affordances characteristically leave traces that can be considered feedback. The concept of affordance is difficult to operationalize in a pure way, but Gibson’s theory is philosophically congruent with an important historical principle of occupational therapy, namely that the human being can only be understood within the person’s naturalistic context (i.e., occupational performance can only be understood through consideration of the occupational form).

Thus there are several competing explanations for the effects of the independent variable of this study: feedback, specificity of learning, and affordance. Common to all these explanations is the importance of objects in the development of motor skill. This fact is probably the most relevant to the profession of occupational therapy, which has historically emphasized the importance of the nonhuman environment. ▲

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