Reproducing Movement in the Lower Extremity Using Kinesthetic Cues of Distance and Location

SUSAN D. NEUFELD, MS

The purpose of this study was to determine if kinesthetic cues of distance or location serve as references in motor memory for reproducing movement in the lower extremity. Thirty normal subjects randomly reproduced criterion movements of 30, 60, and 90 degrees of knee flexion. Starting positions of the criterion and reproduction movements were varied. Reproducing distance required that subjects move the same amplitude as the criterion movement, while reproducing location involved moving to the end position of the criterion movement. Results showed that reproductions based on location were significantly (p < .05) more accurate than those based on distance cues. Reproductions of 30 and 60 degrees were found to be significantly (p < .05) less variable than 90-degree reproduction movements. The results were explained according to the theories that have been proposed for retention of kinesthetic distance and location cues in motor memory.

Key Words: Motor skills, Memory, Kinesthesis.

Physical therapists are often concerned with training patients who lack coordinated control of movement. The ability to position one's limb correctly depends on kinesthetic accuracy. Kinesthetic judgment requires integration of information on distance or extent of limb placement as well as the location or end position of the displaced limb.

When a movement is learned, engrams—traces of the pattern of movement—are left in the CNS. The stored data can then be used as a reference for reproducing future movements. Neurophysiologic evidence suggests that joint receptors are capable of monitoring the speed, direction, and acceleration of movement. Investigators have found that joint receptors and cortical neurons are capable of responding to specific joint positions. Kinesthetic information derived from joint receptors regarding the distance (amplitude) of movement and the location (end point) of a particular movement may be encoded and reliably retained in motor memory. In studies on upper extremity movement, limb placement was more accurate when kinesthetic location cues were given than when distance cues were used. Location cues seemed to provide more precise information over longer distances of movement; distance cues were more reliable for reproducing shorter movements. Few data are available on the usefulness of such cues for reproduction of lower extremity movements.

An individual's ability to make accurate kinesthetic judgments about limb displacement also depends on the sensitivity of the kinesthetic system to movement information throughout the range of motion. Although little information exists on kinesthetic sensitivity in the lower extremity in humans, evidence indicates that kinesthesia is relatively constant and precise throughout the full range of upper extremity movement.

Voluntary effort during movement is believed to elicit a motor program from higher centers in the CNS, in which information from joint receptors may be included. The motor program assists in control of movement by providing the basic plan for movement, which can be modified by peripheral feedback.

When feedback from muscles and joints is deficient or absent, as in the case of the hemiplegic patient or amputee, a central program from higher centers may be retrieved to assist in voluntary control of movement. These patients may also use visual or auditory feedback for awareness and coordination of movement. Therapists commonly use mirrors to provide augmented visual feedback, or they give verbal feedback to shape motor behavior toward more correct limb placement. The type of instructions given by the therapist may affect the movement outcome. Therefore, providing the patient with specific cues such as
distance or location may enable the individual to use these cues for accurate performance of a movement.

The purpose of this study was to determine whether distance or location cues given prior to the performance are more accurate in reproducing a standard angular displacement of the knee joint. Because verbal cueing is such an important part of treatment, results of this study may provide the clinician with valuable guidelines for the most effective type of instructions to be given to a patient with limited intrinsic feedback.

**METHOD**

**Subjects**

Thirty normal subjects, 26 women and 4 men, volunteered to participate in this study. Ages ranged from 20 to 35 years, with a mean age of 25.8 years. Participants were physical, occupational, or respiratory therapists.

**Experimental Apparatus**

The experimental apparatus (Figure) consisted of two wedge-shaped wooden boards each with a radius of 63.5 cm (25 in). They were separated by six dowels at a distance of 14.6 cm (5.7 in). The upper board held a padded "skate" (61 cm x 14 cm, or 24 in x 55 in), which pivoted freely on ball bearings. The skate movement described an arc from zero to 120 degrees, in half-degree increments, which was drawn on the surface of the board. A pointer attached to its distal end indicated the degree of movement. Three hinged stops were recessed into the board and could be raised to stop the movement of the skate at 55, 75, and 95 degrees of knee flexion within the arc of movement. At the apex of the upper board was a thigh support, which was elevated to the same height as the skate.

**Procedure**

Testing took place in an isolated treatment area. Following a standard explanation of the procedure, subjects were blindfolded and instructed to lie on their left side on an exercise plinth. The apparatus was placed on the plinth with the left leg positioned between the boards. The right thigh was positioned on the thigh support and stabilized with Velcro straps to allow movement only at the knee. The axis of the knee joint was located by palpation and placed on a center mark at the proximal end of the skate. The lower leg was strapped on the skate, with its long axis aligned with the midline of the skate. Following positioning, subjects freely flexed and extended their knees to various degrees in order to become familiar with the apparatus and to establish a moderate rate of motion that was subjectively determined by the examiner.

The experimental procedure began by presenting the subject with a standard or criterion movement by passively moving the subject's limb to a specific starting position. The subject was instructed to flex his knee until the skate was stopped by one of the hinges on the board. The subject was then repositioned to a new starting point and asked to reproduce either the end location of the criterion movement or the distance travelled during the criterion movement. A verbal cue for location or distance had been given at the beginning of the criterion movement so the subject would attend to the appropriate kinesthetic information for that movement.

The method of differentiating between the subject's use of location and distance cues by varying the starting position of the reproduction movement has been established in blind-lever positioning experiments of the upper extremity. When the subject is told to reproduce the distance of the criterion movement, position cues from the criterion become unreliable. Similarly, when the subject is told to reproduce the end location of the criterion movement, cues derived from the amplitude of the criterion become unreliable references for movement reproduction.

A trial consisted of presentation of a criterion movement followed by the appropriate reproduction movement. To approximate an immediate reproduction situation, and to eliminate the effects of varied time intervals, the experimenter allowed only three seconds before the subject was repositioned for the start of the reproduction movement. The rationale of the three-second time period was stated. This time period was believed to be within the range of what constitutes an immediate reproduction situation. It was also the least amount of time in which the subject could be repositioned at a new starting position.
Three standard amplitudes of 30, 60, and 90 degrees were used to constitute short, medium, and long movements, respectively, over the 120-degree range of motion for the knee joint. These three amplitudes were established so that kinesthetic accuracy could be tested over the entire range of knee flexion. The standard for the 30-degree movement began at 25 degrees and was always paired with the reproduction movement beginning at 45 degrees. Similarly, the standard for the 60-degree movement always began at 15 degrees and was paired with a reproduction beginning at 35 degrees; the standard for the 90-degree movement began at 5 degrees, with the reproduction starting at 20 degrees. This pairing procedure was designed to ensure that the reproductions for the medium (60-degree) and long (90-degree) movements could be included within the 120-degree arc of motion (Tab. 1). Reproduction of both location and distance was required from each of the three starting positions.

The experiment consisted of 18 randomized trials, with each reproduction movement performed three times. Three dependent measures were calculated. Constant error (CE) was the difference in degrees between the predicted end point and the end point of the reproduction movement. Minus and plus signs, respectively, were used to indicate direction of error either short of or greater than the predicted endpoint. Absolute error (AE) was the mean of the 18 error scores while ignoring the direction of error. The degree of variability within subjects (variable error, or VE) was calculated from the standard deviation of the 18 constant-error scores of each subject.

The three dependent variables of CE, AE, and VE were each analyzed by a two-way analysis of variance (ANOVA) with criterion amplitude and reference cue as repeated measures. Significance was accepted at a level of .05.

RESULTS

Constant error showed constant undershooting for both distance and location cues (Tab. 2). The ANOVA, however, did not demonstrate any significant differences. The ANOVA for AE revealed a significant difference (p < .05) in reference cue only, with location cues resulting in less error than distance cues (Tabs. 2, 3). Analysis of VE showed a high degree of significance (p < .05) for criterion amplitude (Tab. 4). To locate the source of these differences, Tukey's Highly Significant Difference Statistic was used. This test showed that variability was significantly greater for reproductions following the 90-degree criterion movement (q = 7.12) than for either the 30-degree (q = 0.49) or 60-degree (q = 6.63) criteria.

DISCUSSION

Location cues yielded significantly greater reproduction accuracy than did distance cues, as evidenced by the AE scores. The above findings concur with the results of several studies of the upper extremity and support the theory that location information may be more readily codable into short-term motor memory than distance information is. Based upon this theory, location cues would seem to be more useful than distance cues as references for accurate, immediate reproduction of a movement.

Skoglund's study of cats provided neurophysiologic evidence that a qualitative receptor mechanism un-
derlies kinesthesia.² This concept refers to a process whereby specific joint receptors are sensitive to specific joint positions. The sensitivity range for a joint receptor encompasses a 15- to 20-degree arc of movement within the joint range of motion. Movement over a large range of motion therefore activates overlapping populations of receptors.

Because there are no receptors in animals or humans for distance per se, several authors suggest that discrimination of movement amplitude may use this positional information.¹⁵, ¹⁶ Thus, the encoding of distance would involve an additive process, which would require a greater degree of processing than the encoding of location. Therefore, discrimination of long movements should require more processing than short movements would. The degree of processing may account for the greater VE found in reproducing movements over 90 degrees than of 30 or 60 degrees. Keele and Ells studied movements of 30, 60, 90, and 120 degrees at the elbow and also found that VE increased with the amplitude of the movement.¹⁰ In their study, this suggestion was true even though both distance and location cues were used as references for reproduction, whereas in the present study only one or the other cue was used at each trial.

Marteniuk and associates found no difference between the AE scores for movements of 45, 90, and 125 degrees at the shoulder.¹² These authors suggest their findings indicate that joint receptors respond with equal precision over the full range of movement studied. These results are similar to those found in this study and suggest that similar neurophysiologic mechanisms may underlie kinesthesia in both the upper and lower extremities.

According to Skoglund’s study,² one would expect the AE, which reflects accuracy without regard for direction, to vary with the amplitudes studied. However, this situation was not seen. The accuracy of reproduction demonstrated by the subjects might be attributed, in part, to the experimental population. As experienced therapists, these individuals would be familiar with estimating degrees of range of motion. This knowledge may have helped subjects formulate a mental image of the experimental task better than laymen could.

Constant error reflected accuracy, taking into account the degree of overshooting or undershooting. Constant-error scores did not differ between the three amplitudes studied. This finding could be attributed either to the large variability in performance, as evidenced by the high standard deviations, or to the subjects’ skill.

One limitation of this method was that kinesthetic input from joint receptors could not be isolated from proprioceptive input from muscle spindle receptors. Therefore, information from proprioceptors may have contributed to the accuracy of position sense, and the results cannot be considered conclusive evidence for sensitivity of joint receptors alone. In addition, the sound of the moving skate on the board provided auditory feedback, which may have contributed to the subjects’ ability to discriminate movement amplitude. A few subjects also reported that they had used a system of counting combined with the auditory

<table>
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<th>df</th>
<th>MS</th>
<th>F</th>
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<td>Cue X Amplitude</td>
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<td>58</td>
<td>14.26</td>
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TABLE 4
Summary of Two-Way Analysis of Variance of Variable Error for Comparing Two Reference Cues and Their Criterion Amplitudes

<table>
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</table>
feedback to reproduce the distance of the criterion movement.

The majority of subjects reported that they had less difficulty reproducing location than distance. Some subjects described a process for discriminating distance whereby they remembered the starting and end positions of the criterion and reproduction movement. These subjects mentally added or subtracted the difference, in degrees, between the starting positions of the criterion and reproduction movements to the end point of the criterion movement to reproduce distance. This complicated cognitive reasoning seems to support the notion that a greater degree of processing is involved in discrimination of distance than of location.

**CONCLUSIONS**

I believe that the process of motor learning inherent in most therapeutic techniques could be greatly enhanced if patients were given the most effective cues for reproducing a coordinated movement. My study suggests that information regarding location is more valuable than distance information in contributing to accuracy of reproducing angular movement in the lower extremity. From the present results one cannot definitively state if different neurophysiologic mechanisms underlie the discrimination of location and distance of limb displacement. The fact that the results agree with previous studies suggests that the underlying processes are similar for kinesthetic judgments involving distance and location for upper and lower extremities.

Further research is necessary to establish what other types of movement information are stored in motor memory and can serve as reliable references for reproducing movement. Similar experiments need to be conducted with subjects having dysfunctional movement.

**REFERENCES**