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Complex movement patterns: Learning retention and sources of error in recall

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COMPLEX MOVEMENT PATTERNS: LEARNING RETENTION AND SOURCES OF ERROR IN RECALL*

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In this study of kinaesthesis, the learning, retention, and recall of complex patterns was examined. Subjects were blindfolded, held a stylus in the right hand, and moved around stencil patterns, either actively or passively. The patterns were recalled with a free active movement of the right hand, after various amounts of practice, immediately or after a 60-s interval, once or twice in succession, with and without visual guidance. The shape and size of the drawings was compared with the criterion patterns. The effect of practice varied depending on whether the criterion movement was active or passive, and on the measure of recall performance. Even when the criterion patterns were freely practised, the recall traces showed large errors in shape and systematic shrinkage in size, and there were large individual differences. Regardless of these errors, recall performance was reliable. The effect of an unfilled retention interval varied as a function of practice. When the patterns were recalled under visual guidance, there was no shrinkage in the size of the drawings.

Introduction

The present study addressed questions relating to the kinaesthetic perception and memory of complex movement patterns. The majority of work published on kinaesthetic perception relates to very simple stereotyped movements; movements that are much simpler than the two and three dimensional movements that we perform in everyday life. This study attempted to extend what is known about kinaesthetic perception to account for more complex two-dimensional movement patterns.

The accuracy of recall of simple criterion movements has been measured in a large number of studies, in which the criterion was given as movement along a straight runway or through an arc. The accuracy of recall tended to vary as a function of the amplitude of the criterion movement. Absolute error increased

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with amplitude in some studies (Posner, 1967; Posner and Konick, 1966; Woodworth, 1899) but not in others (Jones, 1972; Stelmach, 1970). Variable error (reflecting inconsistency) may increase with the amplitude of the criterion movement (Keele and Ells, 1972). The sign of the algebraic error also varied as a function of the amplitude of the criterion movement. After a minimally short retention interval (around 10 s), small amplitudes (10 to 30°) are overestimated when recalled (5 to 15%), while large amplitudes (30 to 120°) are underestimated (around 5%) (Keele and Ells, 1972; Laabs, 1973; Marteniuk, Shields and Campbell, 1972; Stelmach, 1970; Stelmach and Wilson, 1970).

The overt activity of a limb can be defined both in terms of momentary position, and also the amplitude through which the limb moves. A popularly held view is that positional information is more precise and codeable than information about movement amplitude (Diewert, 1975; Gundry, 1975; Marteniuk *et al.*, 1972), and that large amplitude movements are remembered and recalled on the basis of information about the terminal position of the limb (Gundry, 1975).

Memory for kinaesthetic information is subject to decay and interference. The accuracy of recall of the amplitude of a simple movement deteriorates even if there is an unfilled retention interval following the criterion movement (Adams and Dijkstra, 1966; Stelmach and Wilson, 1970), while the accuracy of recall of a kinaesthetically perceived limb position may be more resistant to forgetting so long as rehearsal is possible (Diewert, 1975; Laabs, 1973). Kinaesthetic memory for a particular movement is subject to interference by competing memory demands, with retroactive interference effects being more potent than proactive effects (Dickinson and Higgins, 1977).

One study on the accuracy of recall of complex movement patterns (Bairstow and Laszlo, 1978b), both confirmed and extended some of these findings. Subjects were blindfolded, and their right arm was guided around a curved, closed, two-dimensional stencil pattern in a single continuous movement. Their task was to memorise the spatial configuration of the pattern, and then reproduce it in shape and size with a free active movement of their arm. A stylus was used to guide the hand around the criterion patterns, preventing tactual exploration by the subject. Hence the task primarily involved the sense of kinaesthesis, as distinct from haptic sensibility associated with an active touch task (Gibson, 1962; Schwartz, Perey, and Azulay, 1975). While kinaesthetic acuity may well be high (Cleghorn and Darcus, 1952; Laszlo and Bairstow, 1980) gross errors were in fact made in the recall attempts, indicating considerable difficulties in the encoding, retention, and recall of kinaesthetic information relevant to complex movements. Consistent with studies of simple movements, the drawings were systematically and significantly smaller than the large amplitude criterion movements on three dependent variables: perimeter (10 to 15% smaller), area (19% smaller), and depth of individual features of the patterns (34 to 36% smaller). There were also large errors in recall of the shape of the criterion patterns with large distortions in the placement of individual features, though the correct amount of overall detail was present (as measured by the gross angle change in the perimeter of the patterns). While it could be predicted from a review of literature on simple movements that subjects would adopt the strategy of encoding, remembering, and recalling key positions along the criterion movement patterns (Russell, 1976), there was in fact no evidence of such a strategy. Finally, while data on decay and interference effects in kinaesthetic memory suggested that memory for a complex pattern would show a strong recency effect, the first sections of the complex patterns were more accurately reproduced.

Subsequent studies on complex movement patterns have shown that the large attenuation in the amplitude of recall movements is not a direct result of perceptual processes. It was shown that an unseen criterion movement is in fact perceived to be *larger* than visual reality (Bairstow and Laszlo, 1979a), so that the attenuation in recall reported by Bairstow and Laszlo (1978b) must have been a function of the process of translating a magnified percept of a criterion pattern into motor commands for reproduction. In another study it was shown that if one essentially bypasses the need to encode and remember a criterion pattern, the criterion movement can be accurately reproduced by having the contralateral limb concurrently shadow the criterion movement (Bairstow and Laszlo, 1979b).

The present study addressed the following specific questions. Firstly, what is the effect of practice of unseen criterion patterns on the accuracy of recall? In all of the studies on complex patterns so far reviewed, subjects were permitted only a single circuit of each pattern. In the following experiment, one group was permitted to move around the stencil as many times as was necessary to feel confident about the pattern, while in other groups, the amount of practice was controlled.

Secondly, what is the effect of an unfilled retention interval on recall performance? Forgetting was measured after various amounts of practice at the criterion patterns.

Thirdly, an attempt was made to investigate some of the sources of error in the reproduction of complex patterns. The reliability of recall performance was examined by having a group of subjects reproduce each criterion pattern twice in succession. The question was asked, to what extent are the errors in drawing a function of random inaccuracies in the programming of the recall movement? A close similarity between two successive recall attempts would suggest a capacity for accuracy in the programming of a complex movement. In addition to this measure of reliability, another group was included that recalled each criterion pattern under visual control. The question was asked, is there significant attenuation in the recall attempt even when subjects visually monitor their recall movements?

Fourthly, is there a difference between the reproduction of active and passive criterion movements? The recall of directed (constrained) active and passive criterion movements was examined, to gain behavioral indices of the known physiological differences between these movements. In an active movement, the functioning of muscle spindles (Matthews, 1972), joint receptors (Grigg, 1975), and tendon organs (Stauffer and Stephens, 1975) relevant to actively contracting muscles is modified, and efferent activity in the pyramidal tracts feeds into areas of the central nervous system involved with sensory processing and motor coordination (Wiesendanger, 1969). Studies of simple movements have failed to show a difference between the recall of directed active and passive criterion movements (Jones, 1972; Keele and Ells, 1972; Kelso, 1977). It is suggested that the failure to demonstrate a behaviourally significant difference between such movements may have been due to the lack of a sufficient perceptual demand in the criterion movements. Studies of more complex criterion movements have already highlighted differences between active and passive movements. Complex passive movements are perceived to be larger than active movements (Bairstow and Laszlo, 1979a), and active movements tend to be reproduced with greater detail compared to passive movements. Furthermore, there were significant interactions between the active and passive conditions, and the criterion patterns on most measures of recall performance (Bairstow and Laszlo, 1978b). In the present study, the effect of practice with active and passive criterion movements, and the effect of delay prior to recall was examined.

Method

Apparatus

A set of six arbitrary, curved, closed patterns was drawn in accordance with the criterion that they were difficult to label verbally. A set of stencils was made with the patterns being represented by a groove 1·8 cm wide and 2 cm deep in a board 50 × 50 cm. A counterweighted sling was used to secure the subject's arm. A plastic stylus 1·6 cm in diameter, a blindfold, a roll of "Gateway Natural Tracing" paper (extra smooth), 50 × 50 cm pinboards, pencils, and a chair were also part of the apparatus.

Subjects

Forty-two male and 42 female students of the University of Western Australia, who normally wrote with their right hand, were paid volunteers.

Experimental design and procedure

A "within subjects" design with respect to the active and passive movement conditions was adopted. That is, all subjects performed in both conditions. An alternating trial design was employed to minimise any possible effects of transfer of training between the two conditions (Laszlo and Pritchard, 1969, 1970).

There were seven groups of 12 subjects each; they were tested individually, and each had six trials. Features of the procedure that were common to all groups will be described first. Prior to, and during the criterion movements, subjects were blindfolded to prevent any visual experience of the criterion patterns. On active trials, the right arm was in the sling and the subjects held the stylus in the right hand. The sling was manipulated by the experimenter to place the stylus in the groove at a set starting position on the pattern. The subjects were instructed to find their own way around the groove in a continuous movement, and at a slow speed of their own choice. At the completion of the criterion movement, the right arm was lowered to the table. Tracing paper on a pinboard was then placed over the surface of the stencil. The subjects held a pencil in the right hand and attempted to freely locate the starting position, reproducing the criterion movement as best they could in position, shape, and size. The procedure on passive trials was similar, except that prior to the first trial the experimenter spent time teaching the subjects to relax with the aid of an additional counterweight to approximately balance the weight of the forearm. As they relaxed, the experimenter manipulated their right arm around the patterns at a slow speed within the range chosen by subjects on active trials. The counterweight was removed for the recall attempt. A different criterion pattern was given on each trial. Six of the subjects in any one group began with an active trial, alternating with a passive trial for the total of six trials. Six of the subjects began with a passive trial. In this way each of the 72 subjects in the six groups had three active and three passive trials with a different criterion pattern on each trial.

In group 1, subjects were permitted only one circuit of a given pattern before recalling it.

In group 2, subjects continuously moved around the criterion patterns as often as they wanted, until they felt they could accurately reproduce them. The experimenter told the subject when he/she was at the starting position of each circuit, and the number of the circuits were counted.

In group 3, the amount of practice was graded. Subjects were permitted only one circuit of the patterns on the first two trials, two circuits on the second two trials, and four circuits on the last two trials. By grading the amount of practice, proactive interference effects between patterns would be kept to a minimum.

In groups 1, 2 and 3, subjects recalled the patterns with the minimum of delay (5 to 10 s). In group 4, the amount of practice was graded as in group 3, but subjects were required to wait for a 60-s period between the end of each criterion movement, and the commencement of recall.

In group 5, subjects reproduced each criterion movement twice in succession without delay.

In groups 1 to 5, subjects were blindfolded throughout the experiment, and the criterion and recall movements were carried out in the subjects' midsagittal plane. In group 6, subjects were also blindfolded throughout, but movements were performed in the frontal plane. In group 7, movements were made in the frontal plane and subjects were blindfolded during the criterion movement. However, when the criterion pattern was covered with the pinboard and tracing paper, the blindfold was removed and subjects drew with visual guidance. They held a pointed stylus in their right hand and pressed against carbon paper. Hence, they could use vision to guide their hand but not see the outcome of their recall attempt.

In all seven groups of the present study, the subjects were given no information about the accuracy of their recall performance until the completion of the last trial.

Measurement

The measurement of the spatial configuration of patterns is difficult, and this may be one reason why the study of kinaesthetic memory and recall has been mostly limited to very simple movements. However, two classes of dependent variables can be considered as relevant; measures of shape and measures of size.

No single objective measure can adequately describe the shape of a complex pattern. Hence a ranking procedure was adopted, with two judges working separately and independently to rank a set of drawings along a complex scale from "best" to "worst". As a first step, all the traces were coded so that the judges did not know to what subject or what group a given trace belonged. The traces were grouped by the experimenter and were ranked by the judges in two ways. In one, the traces had been grouped together according to the criterion shape, and the judges ranked the patterns across subjects and movement conditions, with the overall shape of the drawings being the most important criterion. Secondary factors that were taken into account by the judges were the existence of crossed lines, the occurrence of additional or deleted features, and orientation. The mean rank of the two judges was given to each trace. This within-pattern, within-group ranking would show the difference between subjects in the accuracy of their recall performance. In the other method of ranking, the recall traces had been grouped according to subject, and the judges ranked the drawings across patterns and movement conditions. This within-subject, within-group ranking demonstrated whether there was any difference between the two movement conditions (active and passive) and whether there was any effect of practice. Spearman rank-correlation coefficients (Siegel, 1956) on judges' ranks, demonstrated that the two judges employed similar criteria (r_s ranged from 0·86 to 0·97).

Three partially related objective measures can describe the size of a complex pattern. A mechanical transducer incorporating a moveable stylus connected to two potentiometers, coupled with a Hewlett-Packard computer (Model 2100A) was used to digitise the drawings in terms of X/Y co-ordinates. From these co-ordinates, the perimeter or the length of the movement was computed. The perimeter by itself will adequately describe the size of a closed figure like a circle. It does not, however, adequately describe the size of the irregular curved patterns in the present study. The complex patterns had inward and outward deviations, so the space enclosed by the total movement is another relevant measure of size that is not perfectly correlated to perimeter. Area was calculated by a process of trapezoidal approximation. The third measure of pattern size related to the individual inward and outward features of a complex pattern. This measure of the amplitude of component features of a movement (fully described in Bairstow and Laszlo, 1979b) is a bridging variable between perimeter and area. That is, for a given perimeter the deeper the features the smaller the area; for a given area, the deeper the features, the larger the perimeter. These three measures, though partially related, are necessary to adequately describe the size of a pattern. The measurements were made on the criterion patterns, and on the drawings made by subjects on their recall attempts.

Various comparisons were made between the seven groups. For the ranking procedure, the traces relevant to a given pattern from one group were ranked with the related traces from the other group. This was done for each of the six patterns (within-pattern, across-groups ranking).

TABLE I

Mean number of circuits of the criterion patterns, together with the mean perimeter, area, and depth of features for the right hand criterion and the recall patterns

Dependent variable	Group	Overall	Active	Passive	Trials 1 and 2	Trials 3 and 4	Trials 5 and 6
Mean number of circuits of the criterion patterns	1	1	1	1	1	1	1
	2	5·1	4·9	5·3	5·3	5·0	5·0
	3, 4, 5, 6, 7	2·3	2·3	2·3	1	2	4
Mean perimeter of recall patterns (cm) Criterion = 166·2 cm	1	124·2	124·9	123·5	129·2	127·5	116·0
	2	143·3	143·2	143·3	137·0	144·8	147·9
	3	136·7	136·3	137·9	128·0	134·6	146·3
	4	116·3	116·3	116·3	111·4	116·3	119·7
	$5R_1$	132·7	134·6	131·3	123·0	136·3	138·0
	$5R_2$	135·6	133·0	138·0	126·0	138·0	142·9
	6	118·8	126·3	111·4	111·7	118·0	126·3
	7	171·2	172·9	169·5	172·9	171·2	169·5
Mean area of recall patterns (cm^2) Criterion = 550·9 cm^2	1	391·0	373·9	408·4	377·2	403·2	392·7
	2	493·5	460·9	526·0	480·6	457·8	542·1
	3	520·2	495·8	545·4	473·8	495·8	589·5
	4	380·1	380·1	380·1	391·1	363·6	385·6
	$5R_1$	458·8	446·2	473·8	369·1	469·3	534·4
	$5R_2$	473·8	457·3	490·3	363·6	490·3	567·4
	6	420·9	457·3	385·6	391·1	424·1	446·2
	7	685·4	694·1	677·6	694·1	710·6	650·1
Mean depth of features of recall patterns (cm) Criterion = 39·2	1	22·7	24·6	20·7	23·0	24·1	20·9
	2	28·4	29·6	27·2	27·3	29·2	28·8
	3	25·7	25·5	25·9	23·1	25·1	29·0
	4	20·7	21·9	20·8	16·9	23·1	20·0
	$5R_1$	24·8	25·1	24·3	22·3	26·7	25·5
	$5R_2$	25·8	25·1	25·9	23·5	26·3	26·7
	6	21·5	22·3	20·8	19·2	21·6	23·5
	7	35·0	35·3	34·9	34·9	33·9	36·1

Results

Table I presents the mean number of circuits that subjects made around the criterion patterns, together with the three objective measures of the size of the recall traces for each of the seven groups. Non-parametric tests were used when analysing ranking measures, because ranking is an ordinal scale.

The effect of free practice: Group 1 and Group 2

Results of group 1 confirmed those reported by Bairstow and Laszlo (1978b). The drawings were systematically and significantly smaller than the criterion patterns on all three dependent variables of movement amplitude: perimeter $t(11)=8{\cdot}07$, $P<0{\cdot}01$; area $t(11)=5{\cdot}23$, $P<0{\cdot}01$; depth of features $t(11)=14{\cdot}80$, $P<0{\cdot}01$.

Practice in group 2 led to improved reproduction. While the result for perimeter was not significant [$F\ (1,22)=4{\cdot}08$], the area [$F\ (1,22)=5{\cdot}96$, $P<0{\cdot}05$] and depth of features [$F\ (1,22)=5{\cdot}20$, $P<0{\cdot}05$] in the drawings were significantly larger in group 2 compared to group 1. The recall traces were closer to the size of the criterion patterns, but were still significantly smaller than the criterion in perimeter [$t\ (11)=2{\cdot}78$, $P<0{\cdot}02$] and depth of features [$t\ (11)=4{\cdot}14$, $P<0{\cdot}01$] but not in area [$t\ (11)=2{\cdot}05$]. The shape of the drawings also improved with practice. The mean within-pattern across-group ranks for group 2 (15·3) was significantly higher than for group 1 (9·7) (Mann Whitney U test; Siegel, 1956, $U=20{\cdot}5$, $n_1=n_2=12$, $P<0{\cdot}02$).

While the perimeter of the recall traces was nearly identical on active and passive trials, the area tended to be larger and depth of features shallower on passive trials. These trends missed being significant [area $F\ (1,22)=4{\cdot}28$; depth of features $F\ (1,22)=3{\cdot}85$]. The interactions between practice, and active and passive trials were not significant.

There were large individual differences both in the number of times that subjects chose to circuit the criterion patterns in group 2 (mean over the six trials, 2·5 to 10·3), and in the size and shape of the drawings (see Figure 1). Spearman rank-correlation coefficients showed negative though nonsignificant relationships between the number of times individual subjects chose to circuit the criterion patterns in group 2, and the accuracy of size and shape of the recall patterns. That is, subjects who circuited the patterns most frequently, tended to be those whose drawings were the smallest and least accurate in shape.

The effect of controlled practice: Group 3, Group 4 and first recall attempt of Group 5

The three groups were analysed together in a general assessment of the effects of controlled amounts of practice on recall performance. The size and shape of the recall traces improved as a function of practice [perimeter $F\ (2,70)=8{\cdot}33$, $P<0{\cdot}01$; area $F\ (2,70)=6{\cdot}31$, $P<0{\cdot}01$; depth of features $F\ (2,70)=12{\cdot}17$, $P<0{\cdot}01$; within-subject ranking of shapes, Friedman two-way analysis of variance, Siegal (1956), $\chi_r^2\ (2)=28{\cdot}76$, $P<0{\cdot}001$]. t tests showed there was a significant increase in

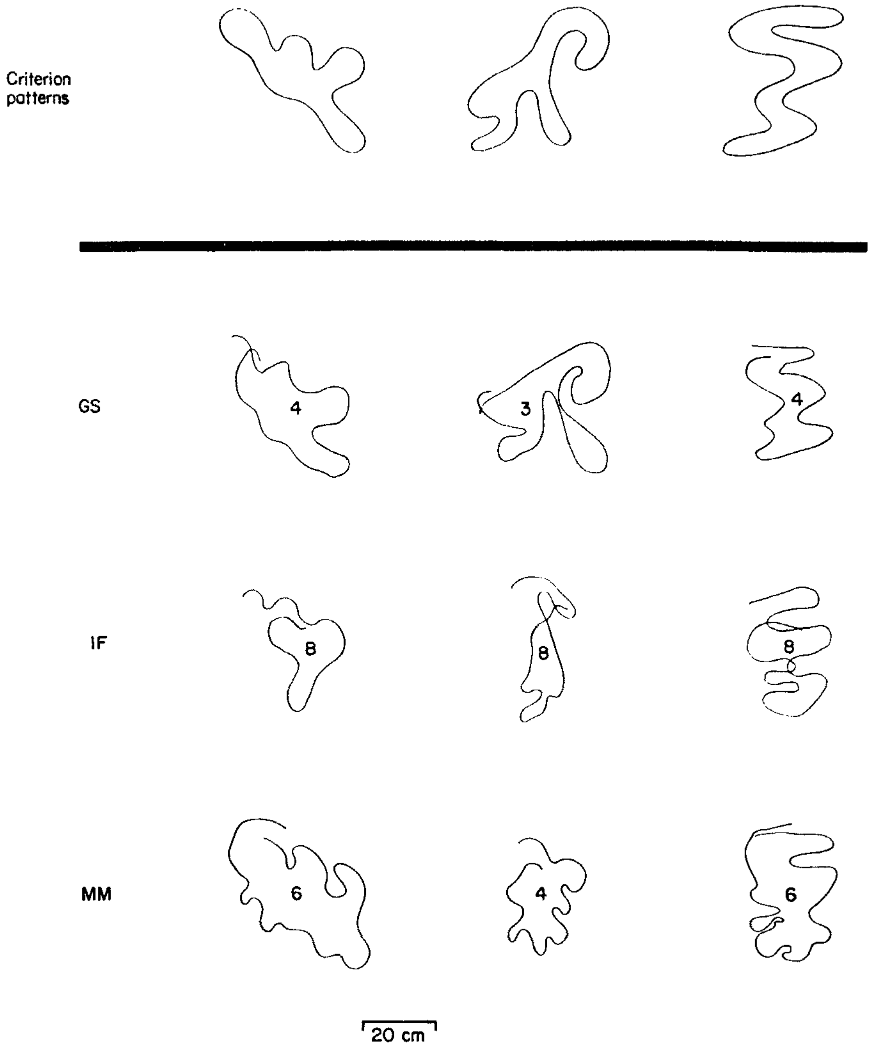

FIGURE 1. Three criterion patterns are shown. The recall traces of these patterns that were made by three subjects (GS, IF, MM) on their active trials, are presented. Subject GS was judged to be the best performer while subject MM was the worst performer. The numbers in the drawings denote the number of active circuits that the subjects chose to make around the criterion pattern until they felt confident that they could accurately recall it. The best subject chose to circuit the patterns least frequently.

perimeter [$t\,(35)=2{\cdot}44$, $P<0{\cdot}05$] and depth of features [$t\,(35)=3{\cdot}44$, $P<0{\cdot}01$] with low levels of practice (1x vs. 2x), followed by no further significant increase. The recall traces remained smaller than the criterion. For area [$t\,(35)=2{\cdot}62$, $P<0{\cdot}01$] a significant expansion occurred only following higher levels of practice (2x vs. 4x), to the extent that the drawings were not significantly smaller than the criterion. Practice led to a sequential increase in the accuracy of recall of shape: sum of ranks

1x=166, 2x=278, 4x=314 (Sign tests, Siegel, 1956; 1x vs. 2x, Z=4·057, P<0·001; 2x vs. 4x, Z=2·298, P<0·02).

There was no significant difference between active and passive trials, but the interactions with practice were significant for perimeter [F (1,35) 5·53, P<0·05] and depth of features [F (1,35) 4·14, P<0·05]. That is, there was a greater increase in size when comparing 4x with 1x trials for the active condition compared to the passive condition.

Immediate vs. delayed recall: Group 3 and Group 4

The 60 sec delay resulted in shrinkage of the perimeter [F (1,22)=7·09, P<0·05], area (F (1,22)=9·31, P<0·01] and depth of features [F (1,22)=5·19, P<0·05]. While the effect of delay tended to be greater on passive than on active trials, the interactions with retention interval were not significant. There tended to be smaller increases in size with practice when there was a delay prior to the recall attempt, but the interactions between practice and the retention interval were not significant. Delay led to a deterioration in the recall of the pattern's shape, as measured by the within-pattern across-group ranking procedure. Deterioration was significant on passive trials (521·5 vs. 380·0, Mann Whitney U test, U=26·0, n_1=n_2=12, P<0·02) but not on active trials (447·5 vs. 451·0), and the effect of delay was significant on trials involving one circuit of the criterion patterns (249·0 vs. 138·5, U=32·5, n_1=n_2=12, P<0·05) but was not significant on trials involving two and four circuits (2x, 319·0 vs. 317·0; 4x, 401·0 vs. 375·5).

First (R_1) vs. second (R_2) recall attempt: Group 5

The size and the shape of the two recall attempts of any given pattern were notably similar; subjects performed with great consistency, reproducing the distortions in the second attempt. Figure 2 shows four pairs of recall traces; two from subjects who recalled the criterion patterns fairly accurately, and two from subjects who recalled very inaccurately. The figure shows that whether or not a subject's recall of the criterion pattern was good, there was far greater similarity between the two recall attempts, than between the first recall trace and the criterion pattern.

TABLE II

Group 5: Mean absolute differences between the criterion patterns and the first recall pattern (C–R_1), and differences between the first and second recall patterns (R_1–R_2)

Dependent variable	Active	Passive	Trials 1 and 2	Trials 3 and 4	Trials 5 and 6
Perimeter C–R_1	34·9	35·1	42·3	30·9	32·2
(cm) R_1–R_2	9·9	11·2	11·3	10·9	9·5
Area C–R_1	172·5	159·4	200·0	139·7	158·2
(cm^2) R_1–R_2	73·2	65·5	57·1	57·6	93·5
Depth of features C–R_1	14·0	15·3	17·3	12·9	13·6
(cm) R_1–R_2	3·2	3·6	3·1	3·4	3·7

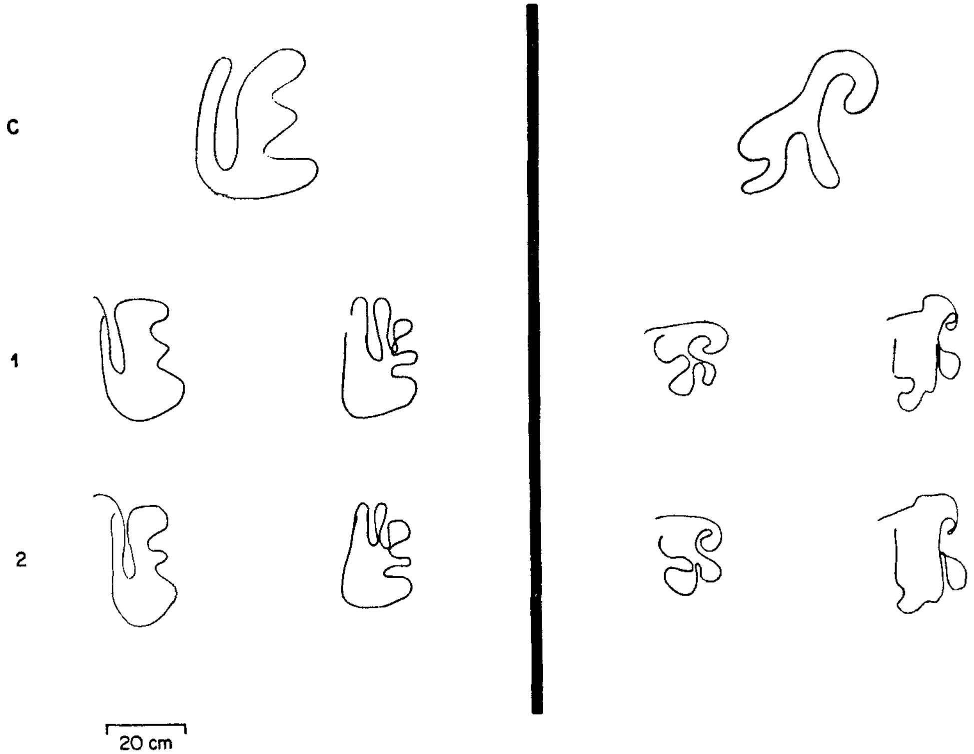

FIGURE 2. Two criterion patterns are shown and labelled C. The pairs of drawings labelled 1 and 2 were produced by four subjects. Regardless of whether a subject could accurately recall the criterion patterns, the two recall attempts were similar in shape and size.

Absolute differences between the size of the criterion patterns and the size of the first recall trace ($C–R_1$) and absolute differences between the size of the first and the second recall attempts ($R_1–R_2$) are presented in Table 2. The mean absolute error gives a measure of the gross discrepancy in the relative sizes of the patterns. Again, there was a far greater discrepancy between the criterion pattern and the first recall attempt, than between two successive recall attempts.

The effect of visual guidance: Group 6 and Group 7

On all measures of size, the recall traces were significantly larger under visual guidance compared to when the criterion movements were drawn in the absence of vision [perimeter F (1,22)=31·59, P<0·01; area F (1,22)=31·87, P<0·01; depth of features F (1,22)=26·67, P<0·01]. While the expansion in size tended to be greater on passive than on active trials, the interactions were not significant. The expansion in size was such that the perimeter [t (11)=0·74] and depth of features [t (11)=2·08] were not significantly different from the criterion, while the area [t (11)=4·39, P<0·01] was now significantly larger than the criterion.

Discussion

The inaccuracies in recall of complex patterns will first be discussed without reference to the separate active and passive conditions. It has been said that kinaesthesis is a gross sense especially compared to vision (Adams, Gopher and Lintern, 1977), so one could dismiss the errors in reproduction on this ground alone. However, studies on kinaesthetic discrimination (Cleghorn and Darcus, 1952; Laszlo and Bairstow, 1980) reveal sensory thresholds that are not gross, and in an earlier study on pattern perception (Bairstow and Laszlo, 1978a), there was no difference between analogous visual and kinaesthetic perceptual conditions. The present errors in recall need to be properly explained by processes involved in the encoding and retention of complex sensory stimuli.

When complex movement patterns were recalled after a single circuit of a criterion pattern, and in the absence of vision, large errors were apparent in the size and shape of the drawings. Consistent with studies of simple movements, the drawings were much smaller than the criterion. When subjects were permitted to freely practice the criterion patterns, they made a mean number of five circuits, with a range between two and 12 circuits around any one pattern. This amount of practice did not entirely eliminate the attenuation in the recall traces, though the area enclosed by the recall movements expanded to the point where it was not significantly smaller than the criterion. Practice also led to an improvement in the recall of the shape of the criterion patterns, though large distortions continued to be apparent (see Figure 1).

These findings were confirmed and extended when the amount of practice was controlled. While the perimeter and depth of features were expanded at low levels of practice, the area was increased toward the correct size only at higher levels of practice. The shape of the drawings improved with each level of practice.

The finding that the recall of shape improved with practice is consistent with the suggestion that on the basis of a kinaesthetic sense of good acuity, subjects developed a more complete percept of the criterion pattern's configuration by progressively building an overall impression of the shape, and by consolidating what was already encoded. The findings in regard to the size of the recall traces are not as easy to explain. The overall attenuation when large amplitude movements were recalled in the absence of vision was consistent with, though not explained by, studies of simple movements. What could be the basis for this attenuation? As reviewed earlier, it was not a direct function of perceptual processes during the criterion movement, since complex patterns are in fact perceived to be *larger* than the visual criterion (Bairstow and Laszlo, 1979a). Nor was the attenuation due to a lack of control over programming the recall movement. When subjects were asked to recall a given pattern twice in succession, there was some variability (see absolute errors in Table 2), but the two drawings were in fact closely similar in size. The overall attenuation was apparently intentional. When subjects attempted recall under visual guidance, the attenuation was eliminated at all levels of practice. Indeed, the area of the recall traces was now significantly *larger* than the criterion; a result consistent with the perceptual magnification reported by Bairstow and Laszlo (1979a).

The question arises, why did subjects recall a complex pattern smaller than they perceived it, when they didn't have vision to guide their movements? If one argues from the point of view that they were primarily concerned with recalling the *shape* of the pattern as accurately as possible, two related explanations can be proposed which account for the conservative programming of the recall movements. Firstly, taking the case of a subject recalling an individual loop of a pattern, if he sets out with a large amplitude movement and happens to overshoot his goal, he will need to make a reversal or a subtractive correction to bring the movement back to the goal. This would result in a distortion in smooth recall performance. A safer strategy is one in which a movement is programmed conservatively with successive additive corrections which bring the movement up to the required shape. Such a programming strategy would permit the realisation of the desired shape although at the risk of a constant attenuation in the amplitude of movement. Secondly, many movements in everyday life are made to external environmental goals whose locations are defined by vision. In programming a movement to such a destination, the result of overshooting may be collision with the goal. On the other hand, the safer strategy of conservative programming would permit additive corrections which would progressively bring the limb to the desired point. Movement without vision involves movement into an uncertain void, and hence motor behaviour is conservative. When vision was given to guide the programming of the recall movement, there was indeed no significant attenuation in the movements.

But why then did the size of the drawings increase toward the correct size with practice? As argued in the previous paragraph, the improvement may be an indirect result of an improvement in the subject's percept of the *shape* of the patterns, rather than any change in perceived size. When subjects had only a vaguely formed percept of the criterion shape, they may have tended to program their recall movement in a very tentative way, with frequent checks being made of the movement to ensure its shape conformed as closely as possible to their percept. After a subject practised a pattern he developed a spatially more explicit percept of its shape. The recall movement was programmed less conservatively, and its amplitude was brought up to the amplitude of the criterion pattern. However, the amplitude never actually reached the correct size, so long as vision was not available to guide the recall attempt.

Two other observations on the effect of practice require comment. Firstly, the three measures of size of the drawings did not increase in the same way with increases in practice. The depth of features, and therefore the perimeter, was significantly expanded even at low levels of practice, while the enclosed area was increased only with more extensive practice. It seems that the first concern of subjects was to bring the amplitude of the features of the patterns up toward the correct (or at least the perceived) size, and a "safe" strategy was to expand these features inwardly (sacrificing any significant increase in area) rather than outwardly. An outward expansion of features, and an increase in area, could have the attendant risk of reaching a physical limit to movement. The area was only expanded to the point where it was not significantly smaller than the criterion, when the configuration of a pattern was relatively well learned.

Secondly, the subjects who chose to circuit the criterion patterns most frequently, tended to recall the patterns least accurately. At the extremes it was quite clear that some subjects could grasp the configuration of an unseen complex pattern with apparent ease and good accuracy, while others had considerable difficulty, or were at least rather inaccurate.

Figure 2 shows, however, that regardless of the accuracy of the first recall attempt, two successive attempts were closely similar. It is apparent that adult subjects demonstrate a wide range in ability to veridically encode and remember a given complex pattern, while there is a comparatively good and uniform capacity for accurately programming a complex movement pattern.

The effect of a 60-s unfilled retention interval on recall performance varied as a function of practice. There was a significant deterioration in the shape of the drawings, with deterioration being significant on trials involving only a single circuit of the criterion patterns, but not significant following practice. This finding is consistent with the proposition that when a percept of the shape of a pattern is weak, it rapidly decays. However, practice reinforces the percept, making it more stable and less prone to being forgotten. A delay prior to recall tended to negate the increase in size with practice, though interactions between practice and the retention interval were not significant.

Turning now to the question of how a complex movement is encoded, it can be broadly assumed that it must be in terms of a representation of neural output and/or sensory input. Russell (1976) argued on the grounds of "parsimony" that it is unlikely that movements could be encoded and recalled in terms of the total pattern of afferent or efferent neural activity. Focusing on a representation of afferent information, he suggested that movements may be encoded in terms of relatively few spatial locations. For recall, a set of neural commands would be generated to reduce the discrepancy between the present location of the limb, and the desired location; the limb being effectively moved between key locations. Such a method or strategy of movement encoding and production would overcome the need for dealing with the total pattern of afferent or efferent neural activity. However, the difficulty that subjects had with the present task argues against such a strategy; or at least if such a strategy exists, argues against it being an efficient means of encoding and recalling movement patterns. The criterion patterns could be defined by relatively few (8 to 10) key positions; for example, the peaks and nadirs of features. Russell's (1976) proposition doesn't explain why some subjects produced over complicated recall traces after many circuits of a criterion pattern (e.g., subject MM, Figure 1) while believing that they had properly grasped the shape of the patterns; there may be some creative or elaborative process involved in the encoding of movement patterns. It doesn't explain the deterioration in performance over a short, unfilled retention interval. While subjects had the opportunity to rehearse the encoded key positions, the key position strategy doesn't account for the errors that may occur as a result of the subject having to allocate his attention to individually encoded key positions, the likely interaction (if not interference) between the memory for individual key positions, and the problem of what happens when a pattern is defined by more key positions than can be comfortably retained in memory. Russell's proposition also doesn't account for the gross discrepancy between the criterion and the first recall attempt when the subject may have been recalling from encoded sensory input, as opposed to the small discrepancy between two successive recall attempts when subjects may have been recalling neural output from the first recall attempt. In short, it is not known how the neural input and output interact in the encoding and recall of movement patterns. The present study doesn't advance the understanding of this issue beyond raising some of the factors that a general theory should be able to incorporate.

There was no direct significant difference between the recall of active and passive movements, though the conditions of recall tended to have a greater effect on passive than on active trials. Delay tended to lead to a greater deterioration in recall on passive trials indicating that active movements may be better consolidated in memory. Visual guidance of the recall attempt tended to give a greater expansion in the size of recall movements on passive trials, suggesting that subjects may be basically more confident in recalling an active movement in the absence of vision. The relevant interactions were not however significant.

Practice had a differential effect on the recall of active and passive movements, with a greater expansion of perimeter and depth of features in the recall traces on active trials. Bairstow and Laszlo (1980) presented evidence that efferent motor commands interact with the processing of kinaesthetic sensory information, so that a constrained active movement is perceived to be displaced in the direction of the constraint; that is, in the direction in which the movement is commanded. The following argument could account for the present effects of practice. Grooved stencils were employed in this study, and it is likely that as subjects actively found their way around the groove they would move at the outside of the groove at the peak of the features, and on the inside at the nadir of features. As they actively practised the patterns, they would learn the peaks and nadirs, and fall into a rhythm of moving on the outside and inside. The stylus fitted snugly in the groove, and the actual movement could not vary according to the side of the groove being followed. However such variations in commanding the movement around the groove would lead to a certain amount of distortion in the perception of the shape, such that the depth of features (and hence the perimeter) would be perceived and then recalled larger following practice, and proportionately larger than when the movements were made passively. This effect of actively commanding the criterion movements did not however persist when unlimited practice was given.

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