The parameter preferences of acquired motor programs for rapid, discrete movements:

I. Transfer of training

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Sixty subjects made discrete movements to visual targets without concurrent visual feedback. After 160 acquisition trials with a single target/movement, subjects were divided into five groups for transfer. The major independent variable was the relationship between the acquisition and transfer movements. For three groups, extent, duration, or velocity was the same in acquisition and in transfer, with the other two parameters changing. For the remaining two groups, either all parameters were changed or no parameters were changed (i.e., subjects performed the same movement). It was found that, as long as one parameter remained the same, subjects performed as well as if nothing were changed. Only when all parameters were changed did performance deteriorate. The results are in direct contrast to those of Newell and Zelaznik (1980) and provide no support for their conclusion that velocity is a more important parameter than movement duration or extent.

Most contemporary theories of movement assume that many actions are controlled by motor programs or schemata (Keele, 1981; Schmidt, 1982). These representational structures are assumed to contain rules or functions that, given initial conditions and the desired consequences, can generate appropriate instructions to the musculature (Schmidt, 1975). Do these motor programs make equal use of various movement parameters such as extent, duration, and velocity, or are some parameters preferentially represented and employed?

One approach to this problem is to compare performance on a movement that is similar to a previously acquired movement in extent, duration, or velocity. Learning of the new movement should benefit to the extent that values of parameters that are represented by the program for the previously acquired movement remain the same. In this study, we used a transfer-of-training design to determine if extent, duration, or velocity is a preferred parameter of the motor program for rapid, discrete movements.¹

Since exactly this approach was adopted in a study by Newell and Zelaznik (1980), some discussion of their study is appropriate. Their experiment used four groups, each of which performed the same task of moving a slide on a trackway through 5 cm in 100 msec during the acquisition phase. The conditions during transfer were manipulated such that different parameters, average velocity, time, distance, or everything, remained the same as they were during acquisition. The instructions emphasized that the task was to move through the target distance, not to stop directly opposite the

finish marker. In transfer, the group with time constant performed worse than the other three groups. Newell and Zelaznik concluded:

The findings suggest that time is not a parameter of the motor program. Rather, the space-time demands of the task determine what response impulse is generated, leaving movement time as simply a consequence of the real time filled by the movement, rather than a parameter of the motor program. (p. 161)

Two problems with the design of the Newell and Zelaznik (1980) study make it improper to draw this conclusion from their data. First, in transfer, subjects in different groups (velocity, time, distance, and everything remaining the same as in acquisition) performed different movements. With this design, it is not possible to separate the effects that are due to the parameter held constant (group) from those that are due to transfer-movement difficulty, since transfer movement and group are confounded. Indeed, in Experiment 1 of Newell and Zelaznik, the group whose movement time remained constant was required to move more rapidly in transfer than any other group. The constant errors for this group suggest that this movement was difficult to achieve. Second, since subjects were instructed to move through the endpoint marker, the actual distances and durations of the subjects' movements were not under the experimenters' control. In fact, only the initial average velocities are under experimental control with this task.

If the Newell and Zelaznik (1980) study had not attracted the attention of influential workers in the field, it might not be appropriate to devote so much space to this discussion and critique. However, at least

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one important paper has drawn the same, unwarranted conclusion. Posner and McLeod (1982), in an *Annual Review of Psychology* chapter, state:

Newell and Zelaznik have shown that transfer performance in a task where the subject is trained on one movement and then learns another is not directly related to the similarity of the pretransfer/posttransfer movement times. Rather, what appears to be learned in the pretransfer phase is some property of the movement which controls its velocity. (p. 493)

The goal of the present study is to compare extent, duration, and velocity in a transfer paradigm that avoids the flaws of the Newell and Zelaznik (1980) study. To overcome the first problem, a completely balanced design was used in which the same set of six movements was encountered by an equal number of subjects in each group in both stages of the experiment (acquisition and transfer). With this design, group differences in transfer performance cannot be attributed to differences in transfer-movement difficulty. To avoid the second problem, the task was to terminate the movements within spatiotemporal targets. Thus, extent, duration, and velocity were under experimental control.

METHOD

Subjects

A total of 61 right-handed male and female students, staff, and faculty participated as subjects in the study.²

Apparatus

A 12-cm-wide handle was fitted to the center of a wooden box housing a variable potentiometer and associated circuitry. The handle was mounted so as to allow rotary wrist movements through 180 deg. Manipulation of the handle controlled the horizontal position of a cursor displayed on a Tektronics 604a oscilloscope, which was at eye level directly above the handle. The experimental manipulations were controlled by a PDP 11/34 computer.

Procedure

The subject was seated in front of and facing the oscilloscope, with the right hand manipulating the handle. The subject was asked to grasp the handle firmly with the palm of the hand in contact with the handle. All movements were made in a clockwise direction.

At the start of each trial, a startbox appeared in the lower left portion of the screen. A cursor also appeared at the same height. The subject was instructed to move the cursor into the startbox by rotating the handle. Five hundred milliseconds after this was accomplished, the startbox disappeared, sampling of the handle's position at 6-msec intervals was initiated, and a target appeared at one of seven locations above and to the right of the startbox. This indicated to the subject to begin his/her movement. When the subject moved the cursor out of the startbox, its vertical position was incremented at a fixed rate (about 1.25 mm every 6 msec). Leaving the startbox was considered the initiation of the movement for the computation of duration and velocity parameters. The position of the cursor was blanked from the screen until a near-zero angular/horizontal velocity (less than 30-deg/sec average velocity during any 18-msec period) was detected, at which time the cursor's terminal position was displayed along with the target for 500 msec. Thus, all movements were made without the benefit of visual feedback. Only terminal feedback on spatiotemporal accuracy was avail-

Figure 1. Layout of the display showing startbox (SB), cursor (C), practice (P), and experimental (1-6) targets. This figure is only illustrative; the subjects saw only one target at a time, and targets were not displayed until after the cursor was positioned in the startbox.

able. The layout of the stimulus display is shown in Figure 1. The subject's task was to stop the cursor in the middle of the target. If the subject failed to come within 50% of the duration or extent required to hit the target, the message "ERROR" was displayed, and the trial was considered a miss and was later repeated. Otherwise, the cursor appeared to explode. If the subject's movement was within 10% of the required extent and duration, the target appeared to explode, with the magnitude of the explosion proportional to overall accuracy. The purpose of the "exploding" feedback was to keep the subject motivated to perform and improve over a large number of trials with the same target.

It should be noted that this aiming task (which is similar to that used by Wright & Meyer, 1983) allows the experimenter to control the extent (horizontal position of the target) and duration (vertical position of the target), and therefore the average velocity of the required movements. These parameters are shown in Table 1 for the targets used in this experiment.³

To familiarize the subject with the task, the subject first received a set of instructions. He or she then watched the experimenter perform 5 trials, and then the subject performed 10 practice trials with the experimenter present. After this, the ex-

Table 1
Parameter Values for Each of the Targets
Used in the Experiment

Target	Extent*	Duration**	Velocity†
1	53	.120	444
2	53	.180	296
3	80	.120	666
4	80	.270	296
5	120	.180	666
6	120	.270	444
P	80	.180	444

*In degrees.

**In seconds.

†In degrees per second.

perimeter answered any questions and then left the room. The subject then received a further practice block of 20 trials.

The target used in this practice phase was common for all subjects, and was one that none would experience during the experiment proper. During acquisition, each subject received eight blocks of 20 trials on one of six targets (see Figure 1). During transfer, each subject received an additional three blocks of 20 trials. Subjects in all but the "All" group were informed prior to transfer that the task would remain the same, but that the target would change.

Design

The subjects were assigned randomly to one of five groups. The targets during acquisition and transfer were manipulated such that: (1) no parameters remained constant; (2) all parameters remained constant (same target in acquisition and transfer); (3) extent remained constant while duration and velocity were changed; (4) duration remained constant while extent and velocity were changed; and (5) velocity remained constant while extent and duration were changed. The assignments of targets to the acquisition and transfer stages of the experiment are shown in Table 2 for the subjects of each group. The attractive feature of this design is that each of the six different targets is used in acquisition and transfer by the same number of subjects in each of the groups.

Data Analysis

Only movements that were within 50% of the target extent and duration were analyzed for their accuracy. Since trials that did not meet this criterion (misses) were later replaced, there were exactly 20 nonmiss trials per block.

Nonmiss trials were analyzed for their accuracy in reproducing the extent, duration, and average velocity required to hit the target. For each of these three parameters, two dependent measures were used.

The first was mean absolute error divided by the mean value of the parameter, sometimes referred to as relative accuracy. The formula is: $AE/M = \sum (\text{abs}(X_i - C))/M$, where X_i is the value of a parameter for the subject's i th movement, C is the criterion value, $M = \sum (X_i)/N$, and N is the number of trials.

The second dependent measure was variable error divided by the mean value of the parameter, sometimes referred to as the coefficient of variability.⁴ The formula is $VE/M = \sqrt{((\sum (X_i - M)^2)/N)/M}$, where X_i , M , and N are as above.

These transformed or relative error scores were used for two reasons. First, recall that each group experienced six different targets in each phase of the experiment (see Table 2). Since error scores are highly correlated with the magnitude of the

parameter produced (all other things being equal), the use of untransformed scores would allow within-group variability due to different targets to overpower any between-group effects that were due to parameter similarity in transfer. Second, these transformed scores permitted a comparison of the relative accuracy and relative variability of the extent, duration, and velocity of the subjects' movements.

Thus, for each block of the experiment, values for each of these two dependent measures were calculated for each parameter (extent, duration, and velocity). The acquisition data were subjected to two $5 \times 8 \times 3$ mixed ANOVAs (on AE/M and VE/M), with groups as a between-subjects factor and blocks and parameters as within-subjects factors. It is understood that parameters are not really repeated measures and, in addition, are not independent. This means that, in these ANOVAs, terms involving parameters should be regarded somewhat cautiously. Primarily because of the lack of independence between the three parameters, we have reduced the degrees of freedom for these terms appropriately. The main reason for doing this analysis is to determine if the three parameters are behaving differently as a function of the independent variables groups and blocks, and whether subjects' relative accuracy differs for the three parameters.⁵ If the parameters behave similarly, then it is not necessary to analyze them separately. Terms in these ANOVAs that do not involve parameters are equivalent to those provided by an analysis of a combined error score that averages the error scores for the three parameters.

The transfer data were analyzed in a similar fashion, except that difference scores were used to assess the amount of performance disruption in transfer and to minimize the contribution of individual differences (sampling error). Each subject's error scores for the last three acquisition blocks were averaged, and these scores were subtracted from each of the corresponding scores for each of the transfer blocks. These difference scores were subjected to the same $5 \times 3 \times 3$ mixed ANOVAs as described for acquisition. Similar difference scores were computed for the number of misses and mean initiation time in transfer. These measures were analyzed by 5×3 mixed ANOVAs with groups as a between-subjects factor and blocks as a within-subjects factor.

RESULTS AND DISCUSSION

Acquisition

The ANOVAs on the absolute and variable errors from the nonmiss trials revealed a significant main effect of parameter [$F(1,55) = 25.5$, $p < .01$, for AE/M, and $F(1,55) = 106.36$, $p < .01$, for VE/M]. No interactions involving parameter were significant. In addition, the effect of blocks was significant for both dependent measures [$F(7,385) = 14.96$, $p < .001$, for AE/M, and $F(7,385) = 4.78$, $p < .001$, for VE/M], reflecting the learning over trials. The performance of all 60 subjects during acquisition is combined in Figure 2 to illustrate these effects. The fact that the relative inaccuracy and variability of the extent parameter is smallest and that that for velocity is largest might be taken to suggest that extent and/or location is more codable than duration or velocity. However, it should be borne in mind that these differences may be related to the nature of the task and not to the motor-program process per se. It is interesting that extent, duration, and velocity are acquired at the same rate, suggesting that no one of the parameters receives preference in the acquisition of a motor program. It is also interesting that, between

Table 2
Assignment of Subjects to Acquisition and Transfer Targets

Subject	Acquisition Target	Transfer Target for Each Group				
		All	None	Extent	Duration	Velocity
1	1	1	4	2	3	6
2	1	1	5	2	3	6
3	2	2	3	1	5	4
4	2	2	6	1	5	4
5	3	3	2	4	1	5
6	3	3	6	4	1	5
7	4	4	1	3	6	2
8	4	4	5	3	6	2
9	5	5	1	6	2	3
10	5	5	4	6	2	3
11	6	6	2	5	4	1
12	6	6	3	5	4	1

Note—Each row shows five subjects who were trained on the acquisition target and then transferred to one of the five transfer targets.

Figure 2. Relative accuracy (a) and variability (b) of performance during acquisition for all subjects. Each parameter is shown separately. (Standard error of the mean is shown for each data point in Appendix A.)

Blocks 1 and 2, AE/M is increasing and VE/M is decreasing. During this early learning stage, subjects may focus more on gaining control over the cursor (reducing variability) at the expense of hitting the target. After this initial stage, both dependent measures show a gradual decline to asymptote.

During acquisition, the five groups performed the same movements, and thus we did not expect to obtain any group effects. However, for AE/M there was a main effect of groups [$F(4,55) = 3.55, p < .05$] and a groups $\times$ blocks interaction [$F(28,385) = 2.17, p < .05$]. The group differences were due to the duration group's performing worse than the other groups during acquisition (AE/M was .230 for the duration group, and .151 for the others combined). These effects must be attributed to sampling error, since the groups were not treated differently until transfer.

Transfer

Analyses of the transfer-difference scores revealed no effect of parameter and no interactions involving parameter for either dependent measure; thus, the discussion will focus on the combined error scores that average the extent, duration, and velocity errors. The main effect of block was significant for both dependent measures [$F(2,110) = 11.3, p < .01$, for AE/M; $F(2,110) = 6.2, p < .01$, for VE/M], with performance during transfer improving over blocks. The main effect of groups was not significant in either analysis. For AE/M, the groups $\times$ blocks interaction was significant [$F(8,110) = 2.14, p < .05$], and the data from this interaction are shown in Figure 3a (Figure 3b shows the corresponding data for VE/M). It appears from the pattern of results in Figure 3a that the groups $\times$ blocks interaction is due to

Figure 3. Difference between the last three acquisition blocks and each transfer block collapsed across parameters for relative accuracy (a) and variability (b). (Standard error of the mean is shown for each data point in Appendix B.)

the "none" control group. This was confirmed by the absence of a groups $\times$ blocks interaction in a post hoc ANOVA with the "none" group excluded.

It was expected that, after 160 trials with a particular target, subjects transferring to a new target would show some disruption in performance. It is clear from Figure 3 that, if there are any groups showing significant performance deterioration, it is eliminated by Block 2 of transfer. In order to give the Block 1 data a closer look, t tests were used to determine whether any transfer-difference scores were significantly different from zero. For AE/M, only the "none" group showed significant disruption [$t(11) = 4.75$, $p < .01$, two-tail]. For VE/M, the "none" group was significantly disrupted [$t(11) = 2.94$, $p < .05$, two-tail], whereas disruption for the extent group was marginally significant [$t(11) = 2.59$, $p < .1$, two-tail]. However, since the ANOVA on VE/M showed no significant effect of groups or interactions with groups, these t values should be regarded cautiously.

The overall conclusion from these analyses is that, after 160 trials with a particular movement, performance on a new movement is as good as continuing on the original one as long as one parameter remains the same; only changing all three parameters produced significant deterioration.

Reaction times and number of misses in transfer were analyzed as described earlier. For reaction time there were no significant effects, and for number of misses there was only an effect of blocks.⁶

CONCLUSION

After learning to make a discrete aiming movement with relatively precise spatiotemporal requirements, transfer performance on a different target was not disrupted when duration, extent, or velocity was kept the same, with the remaining two parameters taking new values. Only when all three parameters were changed did performance show any evidence of deteriorating. It appears, then, that when the flaws of the Newell and Zelaznik (1980) study are avoided, their preference for velocity (impulse) over duration as an important motor-program parameter is not supported. Instead, we conclude that the motor program is eclectic with regard to the movement parameters varied in this study. It seems that our subjects acquired a motor program or schema that could be applied to new movements without decrement as long as one parameter remained constant.

The transfer-of-training paradigm that we employed in this study is only one of several approaches to the original question "Do motor programs make equal use of various movement parameters...or are some parameters preferentially represented and employed?" (p. 2). Studies in progress will use the same discrete aiming task, but will pose this question for different aspects of the motor program; in particular, we will examine

acquisition, repetition, and preparation. Our finding of an eclectic motor program when the influence of prior learning upon performance of a novel task was examined may or may not generalize to these other aspects of motor performance.

NOTES

1. It should be pointed out that, since velocity equals extent divided by duration, these three parameters are not mathematically independent. Although it is not possible to change one parameter while keeping the remaining two constant, it is possible to change two, keeping the third the same. This procedure will be used in the experiment that follows.

2. One subject's performance was anomalous. The pattern of errors produced by this subject suggested that she was aiming at the correct duration but not at the correct extent/location. It was as though this subject misinterpreted the instructions to mean "try to get the debris from the exploding cursor (see below) to hit the target with its horizontal vector." Since she was not aiming at the intended target, she was replaced.

3. It should be noted that extent of movement and final location are confounded in this task.

4. We recognize that absolute error and variable error are not completely independent. Nevertheless, they do get at different aspects of the accuracy of our subjects' performance. Constant error (which is often reported in studies of movement accuracy), although meaningful on a subject-by-subject basis, is of dubious value when (1) the data from subjects performing on different targets must be combined (as our design entails), (2) the errors for duration, extent, and velocity are combined (see below), and (3) difference scores are used to evaluate disruption of performance in transfer.

5. The method we have adopted met with the approval of several statistical consultants.

6. Since research based on an analysis of initiation times has supported the idea that movement time is an important motor-program parameter (Klapp, 1978), it is perhaps surprising that initiation time did not show any group effects during transfer. The most likely reason for this was that our subjects were under no pressure to initiate their movements rapidly, and thus the reaction time variable in our study was probably not as sensitive as those in previous work focusing on this measure.

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Appendix A
Standard Error of the Mean for Data in Figure 2

Block	Parameter		
	Extent	Time	Velocity
AE/M, Figure 2a			
1	.0175	.0131	.0234
2	.0159	.0109	.0217
3	.0137	.0064	.0194
4	.0168	.0083	.0241
5	.0156	.0072	.0208
6	.0135	.0089	.0164
7	.0103	.0112	.0126
8	.0108	.0098	.0138
VE/M, Figure 2b			
1	.00526	.00812	.00836
2	.00450	.00685	.00673
3	.00465	.00690	.00719
4	.00436	.00654	.00664
5	.00368	.00596	.00624
6	.00414	.00647	.00699
7	.00355	.00631	.00609
8	.00427	.00614	.00654

Appendix B
Standard Error of the Mean for Data in Figure 3

Block	Group				
	None	All	Extent	Duration	Velocity
AE/M, Figure 3a					
1	.0147	.0061	.0250	.0317	.0234
2	.0145	.0151	.0200	.0377	.0224
3	.0171	.0136	.0171	.0307	.0263
VE/M, Figure 3b					
1	.0145	.0053	.0144	.0121	.0098
2	.0124	.0098	.0103	.0107	.0104
3	.0100	.0103	.0107	.0273	.0163

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