THE RELATIVE EFFECTS OF INTERNAL AND EXTERNAL CUES ON TRACKING PERFORMANCE

by

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In the learning of a perceptual-motor skill, two sets of cues are usually available for utilization by the subject. One set of cues comes from the display and other external sources while the second set of cues comes from the internal neuromuscular processes associated with control movements (Trumbo, Ulrich, & Noble, 1965).

Although the internal cues arising from movements of the human operator are regarded as fundamental to his proficiency in a man-machine system, they are inaccessible to direct manipulation (Adams & Creamer, 1962). Generally, in attempts to investigate these internal cues, external cues were held constant while the internal cues were indirectly manipulated by varying the physical features of the control mechanism; e.g., spring loading, viscous damping, or inertia were varied to manipulate force requirements, amplitude was varied to manipulate travel distance. If performance varied as a function of these manipulations, it was assumed that the performance relied at least in part on internal cues. Studies using this design showed that internal cues served as regulatory or feedback mechanisms which helped the operator discriminate correct from incorrect movements in positioning tasks (Weiss, 1954,1955; Bahrick, Bennett, & Fitts, 1955) and tracking tasks (Briggs, Fitts, & Bahrick, 1957). Adams & Creamer (1962), also using this type of design, found that internal cues served to facilitate the correct anticipation of temporal regularities in stimulus events.

A different approach was used by Andreas, Green, and Spragg (1954), who employed a transfer of training design in which internal cues were held constant while visual cues were varied. Subjects in this experiment were given eight trials on a pursuit tracking task and then given eight trials on a compensatory tracking task, or vice versa. The two tasks were designed so that even though the visual cues were different, the same control movements and hence internal cues were utilized in both tasks. Little or no transfer was found in going from pursuit to compensatory tracking or from compensatory to pursuit tracking. If, however, as Fitts (1951) and Fleishman & Rich (1963) suggest, internal cues are most important only after extended practice on the given task, the absence of an internal cue effect in transfer was probably the result of inadequate training prior to transfer.

The purpose of this study was to further investigate the effects of both internal and external cues. As in the Andreas et al. (1954) study, a transfer of training paradigm was used, but Ss underwent considerable training on an initial tracking task before transfer to a new task. Two considerably different tracking functions were orthogonally compared to two different types of displays yielding four tracking conditions during both initial acquisition and subsequent transfer trials.

Specifically, the two types of tracking modes (displays) were pursuit and compensatory. A pursuit display contains two moving elements; one representing the target (input) and the other representing the _S_'s output (e.g., control movement). The _S_'s task was to keep the two elements aligned. A compensatory display contains only one moving element, representing error, the difference between the target and the _S_'s output. The _S_'s task was to keep the moving element centered on the display at the zero error mark. Most studies to date have shown pursuit tracking to be superior to compensatory tracking (Hartman & Fitts, 1955; Chernikoff, Birmingham, & Taylor, 1955; Poulton, 1967). Thus, it was hypothesized that performance on the pursuit tracking task should be superior to that on the compensatory tracking task in both acquisition and transfer.

The two types of tracking functions were step and ramp. In a ramp function, the target continuously moves across the display at some constant rate and reverses directions at predetermined positions. In a step function, the target moves in discrete jumps from one position to the next position. These two tracking functions were selected in order to maximize differences in both internal and external cues. No predictions were made concerning tracking performance with these tracking functions.

The various combinations of acquisition conditions and transfer conditions resulted in four experimental conditions based on changes in cues between acquisition and transfer. Condition EVCON was a control condition in which both visual and internal cues remained constant throughout the experiment.

Condition VISCON had the type of visual cues held constant while internal cues were changed between training and transfer. In this condition, holding the type of visual cues constant meant that the mode of presentation (pursuit or compensatory display) was held constant; changing internal cues was accomplished by changing the input function (step or ramp input). In condition INCON, internal cues remained constant while the type of visual cues was changed. In condition NOCON, both visual and internal cues were changed.

It can be predicted that condition EVCON should show no significant change between acquisition and transfer stages and that condition NOCON should show the greatest amount of change. If internal cues are more important in later tracking performance than visual cues, as shown by Fleishman & Rich (1963), it can be predicted that condition INCON should show less change than condition VISCON.

Method

Subjects. The Ss were 96 right-handed males enrolled in the summer session at Kansas State University. Ages of the Ss varied between 17 and 25 years. All Ss were paid $7.00 for the five sessions needed to complete the experiment.

Apparatus. The Kansas State University Versatile Electronic Tracking Apparatus (VETA), with necessary modifications, was used. Only a general description of this apparatus will be presented here as a detailed technical description is presented elsewhere (Trumbo, Eslinger, Noble, & Cross, 1963).

This apparatus was used to present either of the two tracking functions in either of the two tracking modes. The target functions were punched on mylar tape, read out by a Digitronics Model 2500 tape reader, converted to analog voltages by means of a digital-to-analog converter, and displayed on a cathode ray tube (CRT).

Since both the target and the control positions were represented as voltages within the system, the absolute difference between these two voltages was integrated over each trial by an operational amplifier manifold. This integrated error was read out on a digital voltmeter at the end of each trial.

Two S's were run simultaneously in two identical experimental booths. The S's were seated approximately 71 cm. from the CRT.

Tracking mode. In the pursuit (P) mode, two vertical lines appeared on the CRT. Each line was 16 mm. long and they overlapped by 2 mm. The upper line was the target line, which moved along the horizontal axis of the CRT in either a step or ramp function. The lower line was the control line. The position of this line was continuously adjustable by means of an arm control attached to S's chair in a position for easy manipulation by S's right arm. This arm control consisted of a horizontal arm rest, pivoted at the elbow on a vertical shaft, and an adjustable hand grip. A potentiometer attached to the lower end of the rotating shaft converted the arm control position into a continuously varying voltage which, in turn, drove the control line on the CRT. A movement of 5.6 degrees of the arm control caused the control line to move 1 cm.

In compensatory (C) tracking, there were also two lines displayed on the CRT. One line, the standard, extended vertically across the center of the CRT display. This line remained stationary while another line, 16 mm. long, did all the moving. The difference between the two lines represented momentary error, the difference between the target and control voltages. Perfect alignment of the standard and moving lines represented zero error; and to maintain zero error, S had to move the arm control in the direction opposite to that in which the variable line was moving on the CRT. The pattern of variable line movements presented in the compensatory mode was the reverse of the pattern of target movements presented for the same input function in the pursuit mode. However, movements necessary to keep the two lines of either mode superimposed were exactly the same.

Tracking function. In the step (S) function, the target moved from position to position in discrete jumps and remained at each position for 1.6 secs. The target moved to each of the six different positions used in a given pattern which was repeated 10 times per trial. This resulted in a trial lasting 96 secs. The pattern was 1, 4, 6, 5, 2, 3, with 1 being the extreme left position and 6 the extreme right position. The center of the CRT was midway between positions 3 and 4. The distance between adjacent positions was 1.2 cm.

In the ramp (R) function, the target moved between successive positions at a constant rate of 1 2/3 cm/sec, paused at each position for .4 secs., and reversed direction after each pause. A pattern of six reversal positions was repeated 10 times per trial, resulting in a trial lasting 145 secs. The pattern for the ramp function was 2, 6, 4, 5, 1, 3, with the distance between adjacent reversal points being 1.4 cm.

Procedure. The Ss were assigned, generally in pairs, to 16 experimental groups for a total of six Ss per group. The 16 groups represented the four conditions of acquisition (PS-, PR-, CS-, CR-) crossed orthogonally with the four conditions of transfer (-PS, -PR, -CS, -CR). Note that the abbreviation used for each tracking mode by tracking function combination is followed by a dash when reference is made to the acquisition stage and preceded by a dash when reference is made to the transfer stage.

Upon arrival for the first experimental session, S was led to the experimental booth, seated at the controls, and given the instructions appropriate for his assigned group. The instructions informed S of the nature of the task he was to perform, the way in which his performance was to be evaluated, and strategies he could use to improve his performance. The Ss were then run through 20 acquisition trials. Each trial was preceded by a 2 sec. warning light and followed by a 15 sec. rest interval. Error score feedback was presented during 10 randomly selected rest intervals.

On each of Days 2, 3, and 4, each S was given 20 more acquisition trials. Each day, Ss were reminded of the appropriate methods for reducing their error scores.

On Day 5, _S_s were told that the first few trials would be the same as the earlier trials and that then something different would be tried. Three trials under the acquisition condition were then run.

After the final acquisition trial, each _S_ was given a reproduction trial. On this trial, the _S_'s task was to reproduce the pattern of movements he had learned to the best of his ability. The _E_ entered the experimental booth and told _S_ to center the control line on the CRT. The intensity of the CRT was then reduced until the scope face was blank. The _S_ was instructed to reproduce both the timing and the positioning necessary to duplicate his previously learned control movements. One complete trial was then run under these conditions. Subsequent examination of these data, however, revealed that some of the _S_s had apparently not understood the instructions completely. Therefore, these data were not analyzed further.

Upon completion of the reproduction trial, _E_ entered the experimental booth, made appropriate adjustments to the CRT, and gave _S_ the instructions appropriate for the transfer condition. If there was no change, _S_ was told that the new task would be similar to the previous task in that the tracking mode and tracking function would be the same. If there was any change involved, _S_ was given that section of the Day 1 instructions which told him about his new task. These _S_s were told that the new pattern would be similar to the old pattern in that it would be six units long, but none were told anything else about this new pattern. The _S_ was then given 15 trials under the transfer condition.

Performance measure. The primary measure of performance was integrated absolute error. Using this measure, the results were examined separately for acquisition, first trial after transfer, percent change between acquisition and transfer, and subsequent changes in performance after transfer. Also, performance early in acquisition was compared to performance early in the transfer task.

Results

Tracking Conditions

Acquisition. The data from Days 1-4 were pooled into 16 successive blocks of five trials each. The first three trials of Day 5 were also pooled to form a seventeenth block of acquisition for each group. The data over the first 16 blocks were subjected to an analysis of variance which showed acquisition condition, $F(3,80)=46.47$, blocks, $F(15,1200)=146.10$, and the Acquisition Condition X Blocks interaction, $F(45,1200)=8.81$, to be the only effects significant beyond the .05 level, the minimum criterion for all analyses reported herein.

Figure 1 shows integrated error as a function of blocks with acquisition condition as a parameter. Block 17 is also included in this Fig. Figure 1 shows that all acquisition conditions showed decreases in error over blocks. It can also be seen that during the first 16 blocks of acquisition there was a consistent difference among the acquisition conditions; the order of conditions from least to most error was PR-, PS-, CR-, CS-. It appears, however, that the Ss in these four

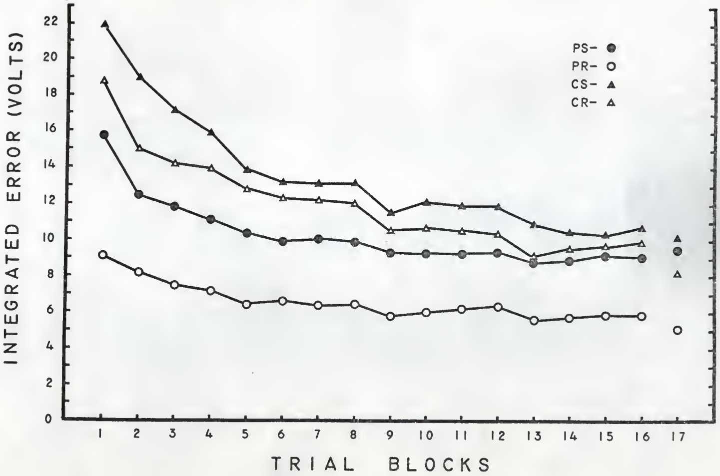

Fig. 1. Integrated absolute error as a function of acquisition conditions and trial blocks.

conditions start the experiment with widely differing levels of performance, but that by Block 16 their performance is much more uniform. Newman-Keuls tests performed separately on Block 1 and Block 16 confirmed this conclusion. On Block 1 all acquisition conditions differed significantly from each other; while on Block 16, condition PR- differed from each of the other three conditions, but they did not differ from one another.

As a further check on performance before transfer, the data from acquisition Block 17 (Day 5) were also subjected to an analysis of variance. Again, acquisition condition was significant, $F(3,80)=16.63$, and there were still no effects for transfer condition nor the Acquisition Condition X Transfer Condition interaction. It can be seen in Fig. 1 that there was a reversal between conditions CR- and PS-, but condition CS- was still the worst and condition PR- was still the best. Newman-Keuls tests were applied to these Block 17 main effects and again condition PR- was different from conditions PS-, CR-, and CS-, and the latter three did not differ from each other.

Figure 1 also shows that pursuit tracking was always better than compensatory tracking and that, within tracking modes, ramp function tracking was always better than step function tracking.

Transfer. To examine the importance of different tracking conditions in acquisition upon subsequent performance during the transfer tasks, the first trial after transfer was analyzed. The percent change within Ss between the last trial block of acquisition (Day 5) and the first trial in the transfer task was also analyzed. However, since the results of these two measures were quite similar, as indicated by an overall correlation coefficient of .79, only the first trial after transfer data will be reported in detail.

An analysis of variance performed on the data from the first trial after transfer revealed that all effects were significant; for acquisition condition, $F(3,80)=2.99$, for transfer condition, $F(3,80)=40.80$, and for the Acquisition Condition X Transfer Condition interaction, $F(9,80)=6.80$. These effects are illustrated in Fig. 2, which shows error during the last block in acquisition (open bars) and the first trial in transfer (solid bars) as a function of tracking conditions in acquisition and in transfer. Looking at just the solid bars, it can be seen that the hardest task in acquisition (CS-) led, overall, to performance in transfer which was equal to or better than that found for any other acquisition condition. It can also be seen from Fig. 2 that the overall means of the tracking conditions in transfer are aligned in the same order as were obtained during acquisition; tracking condition -PR was always the best and tracking condition -CS was generally the worst, regardless of acquisition condition. These latter conclusions were supported by Newman-Keuls tests.

Detailed inspection of Fig. 2 also suggests that, within tracking functions, transferring from compensatory tasks to pursuit tasks (CR-PR and CS-PS) was better than transferring from pursuit to compensatory (PR-CR and PS-CS). Furthermore, within tracking mode, transferring from step to ramp (PS-PR and CS-CR) was better than transferring from ramp to step (PR-PS and CR-CS).

The heights of the open bars relative to the heights of the

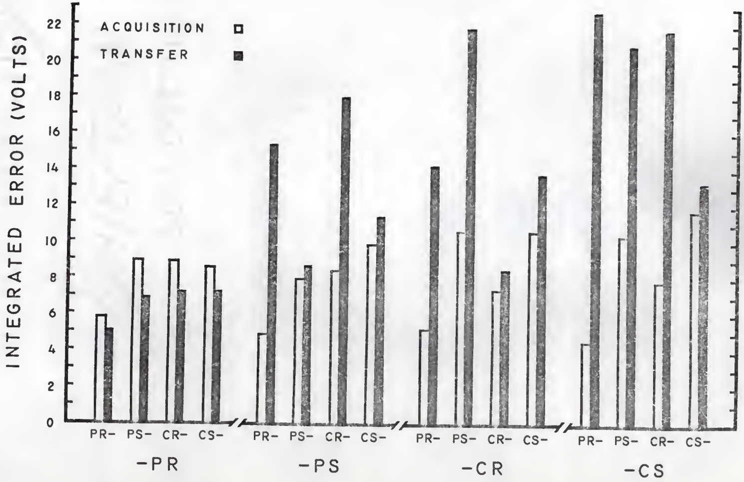

Fig. 2. Integrated absolute error during the last block in acquisition and the first trial in transfer as a function of tracking conditions in acquisition and in transfer.

solid bars in Fig. 2 yields an estimate of the amount of change which occurred between acquisition and transfer conditions for each of the 16 groups of _Ss_. Expressed in terms of percentage change scores, the main effects of tracking conditions in transfer were such that condition -PR had the least change and always a positive change (+20 percent) compared to increasingly greater amounts of negative change going from -PS to -CR to -CS. The percent change score for the latter main effect was -200.

To assess the overall effects of tracking conditions in transfer, the 15 transfer trials were pooled into three blocks of five trials each. An analysis of variance over these blocks showed that transfer condition, $F(3,80)=26.79$, Acquisition Condition X Transfer Condition, $F(9,80)=3.48$, blocks, $F(2,160)=12.54$, Transfer Condition X Blocks, $F(6,160)=2.74$, and Acquisition Condition X Transfer Condition X Blocks, $F(18,160)=2.40$, were all significant. Generally, error decreased over blocks, but not at the same rate for all 16 groups. The order of the tracking condition main effects in transfer was the same as that obtained in acquisition. The form of the Acquisition Condition X Transfer Condition interaction was essentially identical to that found on the first trial after transfer and illustrated by the solid bars in Fig. 2.

Cue Change Conditions

To investigate the relative effects of internal and external cues, the data from the 16 groups were rearranged to reflect changes in cues between acquisition and transfer. Figure 3 shows error as a function of tracking conditions within cue change conditions

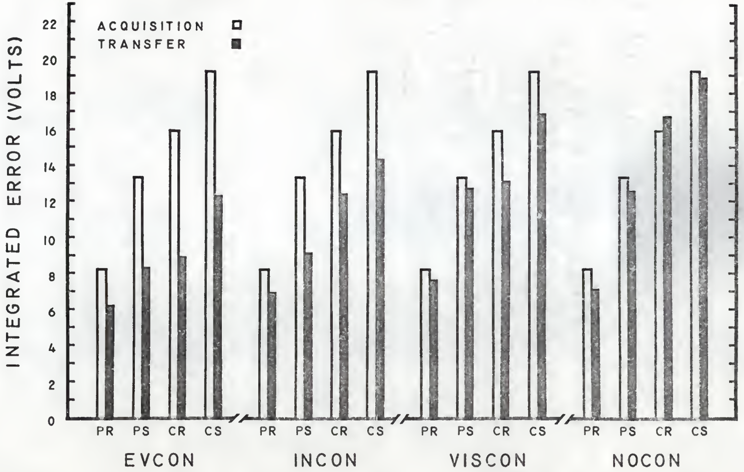

Fig. 3. Integrated absolute error as a function of tracking conditions within cue change conditions for the mean of the first three trial blocks in acquisition and the mean of the three trial blocks in transfer.

separately for the mean of the first three trial blocks in acquisition (open bars) and the mean of the three trial blocks in transfer (solid bars). It should be noted that in order to obtain the most stable estimates of tracking efficiency during acquisition, the means in acquisition were based on an N of 24, and the same means are shown within each cue change condition.

Figure 3 clearly shows that the effects of the different tracking conditions were the same for both the early acquisition trials and the transfer trials. More importantly, however, this Fig. reveals that tracking performance in the transfer trials was best over all tracking conditions for cue change condition EVCON, and that performance became progressively worse going from INCON to VISCON to NOCON. Newman-Keuls tests on the cue change condition main effects showed that condition EVCON differed from each of the other three conditions and that INCON differed from VISCON and NOCON, but the latter two did not differ from each other. Essentially identical effects were found for cue change conditions when the first trial after transfer and the percent change data were analyzed.

For each cue change condition, performance early in initial acquisition (N=24) was compared to performance after transfer (N=6) to determine if any savings had occurred. Specifically, the first block in acquisition and the first block in transfer were compared by an analysis of variance which used the cell means as data and the interaction between stage of learning (acquisition vs. transfer) and tracking condition (PR, PS, CR, CS) as an error term. This analysis showed that error in transfer was significantly less than error in acquisition for all cue change conditions except NOCON. This relation between acquisition performance and transfer performance can also be seen in Fig. 3 by comparing the heights of the open (acquisition) bars and the closed (transfer) bars.

Discussion

Tracking mode. The first hypothesis of this study, that pursuit tracking should be better than compensatory tracking in both acquisition and transfer, was confirmed. It can be seen in Fig. 1 that, during acquisition, tracking an input function with a pursuit display was always associated with less error than tracking that same function with a compensatory display. Examination of Figs. 2 and 3 makes it clear that this superiority of pursuit over compensatory tracking is also found during transfer trials. In general, then, performance in CS is always worse than performance in PS, and performance in CR is always worse than performance in PR.

The finding that transfer from compensatory to pursuit tracking was better than transfer from pursuit to compensatory provides further support for this conclusion.

Tracking function. It was uncertain at the beginning of this experiment whether tracking the step function or the ramp function would be easier, but examination of Fig. 1 revealed that within any given tracking mode, performance in tracking the ramp function was better than performance on the step function. The same was also found for performance after transfer (see Figs. 2 and 3). It was also found that transfer from step to ramp was better than transfer from ramp to step.

<u>Internal cues vs. external cues</u>. The major hypothesis of this study was that, after extended practice, internal cues would be more important for tracking efficiency than visual cues. If this were true, condition INCON would yield better performance in transfer than condition VISCON. In any case, condition NOCON would yield the worst performance. The blocks after transfer data (solid bars in Fig. 3) clearly support these predictions. Specifically, condition INCON led to performance which was significantly better than performance in conditions VISCON and NOCON while the latter two did not differ from each other.

Likewise, comparisons between early acquisition and subsequent transfer, performed separately for each of the cue change conditions, clearly show that something has been transferred in the INCON and VISCON conditions besides the general and nonspecific mechanics of tracking per se. That is, Ss in the NOCON condition learned no more or no less than Ss in the other two cue change conditions about the mechanics of the task, but INCON and VISCON were much better in transfer than in acquisition while NOCON showed no overall change. Therefore, some transfer of cues occurred for both INCON and VISCON.

It has been suggested that after extended practice, internal cues have become more important than visual cues in a perceptual-motor task. The fact that condition EVCON differs from condition INCON in the transfer trials suggests that changing any aspect of the task leads to a regression to an earlier level of performance wherein the visual cues once again become important. This means, in particular, that the INCON condition would have been adversely affected because the internal cues would not have been attended to as they may otherwise have been. Hence, the differences in cue change conditions may have been attenuated by the regression to the use of visual cues.

Another problem encountered in this study is the difference in difficulty among the four acquisition conditions. These differences in difficulty probably accounted in large part for the significant Acquisition Condition X Transfer Condition interactions found in the data for the first trial after transfer, percent change, and blocks after transfer. It would have been better had the acquisition conditions been of equal difficulty. It is doubtful that this could be accomplished with the present conditions because of the extreme ease of condition PR. By using the pursuit and compensatory modes with two different but equally difficult step patterns, all the cue change conditions of the present study could be duplicated without the problem of differences in difficulty. These conditions could also be duplicated by changing the control/display ratio.

In conclusion, it is apparent that internal cues were present and effective in later tracking performance and transfer, but this could have been better demonstrated and more clear cut had there not been the problem of unequal task difficulty and the possibility of regression to the use of visual cues after transfer.

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This study investigated the roles of internal and external cues in a tracking task with both spatial and temporal regularity. Subjects were trained on one of the four acquisition conditions which consisted of all combinations of two tracking functions, step and ramp, and two tracking modes, pursuit and compensatory. After four days of training, the subjects in each acquisition condition were transferred to one of four transfer conditions, again consisting of all combinations of tracking mode and tracking finction.

Integrated error data indicated that there was less error associated with the pursuit tracking mode than with the compensatory tracking mode both during acquisition and during transfer. It was also found that there was less error in the ramp function than in the step function during both acquisition and transfer. Most importantly, however, both internal cues and display mode (visual) cues were shown to be present and effective at transfer. The data, furthermore, shows that constant internal cues were more important at transfer than constant visual cues.