EFFECTS OF REDUCED ATTENTION AND CHANGES IN DISPLAY MAGNIFICATION AND CONTROL SENSITIVITY ON TRACKING PERFORMANCE

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Effects of Reduced Attention and Changes in Display Magnification and Control Sensitivity on Tracking Performance

Previous studies of perceptual-motor skills suggest that the control of motor sequences shifts from visual cues to proprioceptive cues as the level of learning increases (Fleishman & Rich, 1963; Hartman & Fitts, 1955). This proposed shift from visual control to proprioceptive control has been the basis for one definition of the automation of motor activity (Bahrick & Shelly, 1958; Schmidt, 1968). According to this definition, as the pattern of responses becomes more stable and hence the pattern of response produced cues becomes more stable, reliance on external cues decreases. Motor activity can be maintained at relatively high levels of proficiency without reliance on external cues.

A second definition of automation states that it is the process of reducing the amount of a limited capacity central processor which is required to perform the primary task (Fitts & Posner, 1967). Posner (1969) agrees that both internalization of relevant cues and a reduced utilization of internal cues will necessarily demand less processing capacity than the utilization of external cues.

A recent study by Christ and Newton (1970) suggests a procedure which would allow for the simultaneous and independent investigation of the internalization of motor control and the reduction of processing capacity required by the primary motor task. These Es trained Ss on one of four tracking conditions resulting from the combination of two repeating input functions, step and ramp, and two display modes, pursuit and compensatory.

After extensive training, tracking conditions were interchanged between subgroups of Ss. The four conditions of transfer which resulted were: a control condition in which neither the display mode nor the input function changed, a changed display condition in which only the display mode changed, a changed input condition in which only the input function changed, and a condition in which both the display and the input were changed. The transfer conditions involving change were designed so that Ss in the changed display conditions were presented with a different type of visual cue after transfer, but were required to make exactly the same pattern of control movements both before and after transfer; Ss in the changed input conditions were presented with the same type of visual cue both before and after transfer, but were required to make a different pattern of movements after transfer. The results of this study showed that all three change conditions produced an increase in tracking error, but the changed display condition led to less disruption than the changed input function and both of these single change conditions were less disruptive than the condition in which both the display and the input were changed. Since the changed display condition required no change in the pattern of control movements, Christ and Newton concluded that proprioceptive cues were more important than visual cues for the maintenance of tracking proficiency.

A closer look at the procedures employed by Christ and Newton suggest, however, an alternative interpretation of their results. Specifically, the changed input condition in their study produced, at transfer, not only a changed pattern of movements, and hence a changed pattern of proprioceptive cues, but also a complete change in the pattern of visual cues, even though the same display mode was used. Hence, according to this interpretation of their procedure, the Christ and Newton findings show nothing relating to the relative importance of visual and proprioceptive cues. Instead, they show that changes in the pattern of both visual and proprioceptive cues produce more disruption in performance than changes in only the pattern of visual cues. In spite of this reinterpretation of results, it is still true that their study does show that proprioceptive cues were transferred to the new display condition.

In the present study, the relative influence of internal as opposed to external cues was assessed using a transfer-of-training design like that used by Christ and Newton, but without the confounding of visual and proprioceptive cues these _E_s had in their study. The gradual reduction with practice in the processing capacity required by the primary tracking task was assessed by determining the degree of interference produced by a secondary task. To avoid the possibility that the secondary task requirements would inhibit the learning of the primary task, as suggested by Noble, Trumbo, and Fowler (1967), the secondary task in this study was presented intermittently over the experimental session.

Method

Subjects

Ninety right-handed male students who demonstrated at least a minimal degree of tracking proficiency served as _S_s. Ages of _S_s varied between 18 and 25 years. All _S_s were paid for their participation.

Apparatus

The apparatus was a slightly modified version of the Versatile Electronic Tracking Apparatus (VETA) developed at Kansas State University. A complete technical description of the apparatus is available elsewhere (Trumbo, Eslinger, Noble, & Cross, 1963). Target inputs were punched on mylar tape, read by a Digitronics Model 2500 tape reader, converted to analog voltages by a digital-to-analog converter, and displayed on a cathode ray tube (CRT) as a 12 mm. vertical hairline which moved horizontally across the center of the CRT. An arm control, consisting of a horizontal arm rest pivoted at the elbow and a pistol type hand grip was attached to the right side of Ss chair. Movements of the control caused the position of a second vertical hairline, the cursor, to vary. The cursor was 12 mm. long and was located below the target. The two lines overlapped by 2 mm. when they were in the same horizontal position on the CRT.

Primary Task Conditions

Eighty-four Ss were randomly assigned, 12 each, to one of seven primary task conditions. All Ss were given the same pattern of step function inputs on a pursuit display. The pattern of successive positions was 7, 3, 4, 2, 1, 5, 6, with the position on the extreme left represented as 1 and the position on the extreme right as 7. The target remained in each position for 0.8 sec. and moved from position to position in discrete jumps. The movement of the target through all seven positions constituted one repetition of the pattern. A series of eight continuous repetitions constituted a trial lasting 44.8 sec.

Tracking conditions differed in terms of the magnification of the display and the sensitivity of the control. Two levels of display magnification were used to vary visual input. In the small display (level S) the distance between adjacent positions on the CRT was 5 mm.; in the large display (level L), the distance was 10 mm. Two levels of control seniti-vity were used to produce different response requirements. The low level of control sensitivity (level 1) required 6.50 degrees of control movement to move the cursor 10 mm.; the high level of control sensitivity (level 2) required 3.25 degrees of movement to move the cursor 10 mm.

Orthogonal combinations of the two levels of display magnification and the two levels of control sensitivity define the four constant tracking conditions which were given throughout the experiment to four corresponding groups of Ss. These groups and their constant tracking conditions were: Constant-Small 1 (CS1), where the smaller display was combined with the less sensitive of the two levels of control sensitivity; Constant-Small 2 (CS2), where the smaller display was combined with the more sensitive control; Constant-Large 1 (CL1), where the larger display was combined with the less sensitive control, and Constant-Large 2 (CL2), where the larger display was combined with the more sensitive control.

Three additional groups of Ss were also trained in the tracking condition having the small display and the less sensitive control, but Ss in each of these groups were subsequently transferred to one of the other three tracking conditions. These transfer groups were: S1-S2, where the display was always small but the control sensitivity was increased at the point of transfer; S1-L1, where the less sensitive control was always employed but the size of the display was increased; and S1-L2, where both the display size and the control sensitivity increased.

Secondary Task Conditions

Half of the Ss in each of the seven primary task conditions were periodically required to perform another, secondary task while tracking.

The secondary task was to count backwards by fours in a loud voice. One additional group of six Ss served as a secondary task control. The Ss in this counting control group were normally required to perform the same primary task as those Ss in constant condition CS1, but they did not track when they were performing the secondary task.

Performance Measures

The momentary absolute difference between target and cursor positions, measured in volts, was integrated over each trial to provide an overall measure of tracking performance for each S. This integrated error was read out on a digital voltmeter at the end of each trial.

Performance on the secondary counting task was measured by the number of times S correctly counted backwards by fours. The first number given during each counting trial was scored as a correct count. Each response after the first response was scored as correct if it was four less than the previous response regardless of whether the previous response was correct. A response which followed an error, and was not four less than the error response, was scored as a correct response only if that response was eight less than the response preceeding the error. This method of scoring penalized S only once for each error.

Procedure

On the first day of training Ss were instructed on how to optimize their tracking performance. They were told that the target moved through a fixed pattern of seven positions and that it would remain in each position briefly before jumping to the next position. They were instructed to learn the pattern of traget movements, to move simultaneously with the target, and to move as rapidly as possible to each new position. Each counting S was further instructed to begin counting backwards by fours when ever he was given the command "count" over the intercom, and to continue counting until the end of that trial. These counting Ss were told to begin counting at 1000 the first time they were given the signal to count, and to begin counting on subsequent counting trials at the number where they had previously ended their counting.

On the second day of training, all Ss were told that some aspect of the primary task could change at some point during the session. They were told that if a change did occur, it would involve only one aspect of the task and that the rest of the task would remain the same. They were reminded of the procedures to follow to optimize their performance and told to continue tracking as accurately as possible whether or not a change occurred in the task. Counting Ss were told to begin counting at 1000 on the first signal to count and to continue in the same manner as on Day 1.

Each S tracked for 25 trials on the first day and 30 trials on the second day. The two sessions each lasted about 50 min. and they were separated by about 48 hours. Counting Ss were given the signal to begin counting after one repetition of the pattern on Trials 7, 11, 18, and 23 of the first session and Trials 9, 13, 16, 22, and 29 of the second session. The changes in display size and/or control sensitivity were introduced at the beginning of the third repetition of the target pattern on Trial 16 of the second day for conditions S1-S2, S1-L1, and L1-L2. Counting Ss were counting at transfer.

Each trial of the primary task was followed by a 20 sec. rest interval. A small red lamp, located above the CRT, was lit during the last 5 sec. of each rest interval to serve as a ready signal. During the rest interval S was informed of his integrated error score on the previous trial except when he had counted during the previous trial; no feedback was given following a counting trial.

Subjects were generally run in pairs, one in each of two identical tracking booths. Both Ss of a pair were in the same primary task condition but only one counted during the counting trials; the two booths, and the intercom to each, were isolated from each other.

Results

Acquisition

Tracking performance on non-counting trials. The integrated error on non-counting trials was pooled within each successive five trials to form 11 blocks of non-counting trials for each S. This procedure produced 11 five-trial blocks for the non-counting Ss and 2 five-trial (the first five trials of each day) and 9 four-trial blocks for the counting Ss.

An analysis of variance was performed over all 11 blocks for the four constant conditions. This analysis showed that display size, $F\ (1, 40) = 96.72$, blocks, $F\ (10, 400) = 108.46$, and the Display Size x Blocks interaction, $F\ (10, 400) = 15.54$, were the only significant effects, all at $p < .01$. There were no differences between counting and non-counting groups nor any interaction involving the counting conditions for these non-counting blocks of trials. The significant effects are illustrated in Figure 1. It can be seen that the larger display produced more error than the smaller display.

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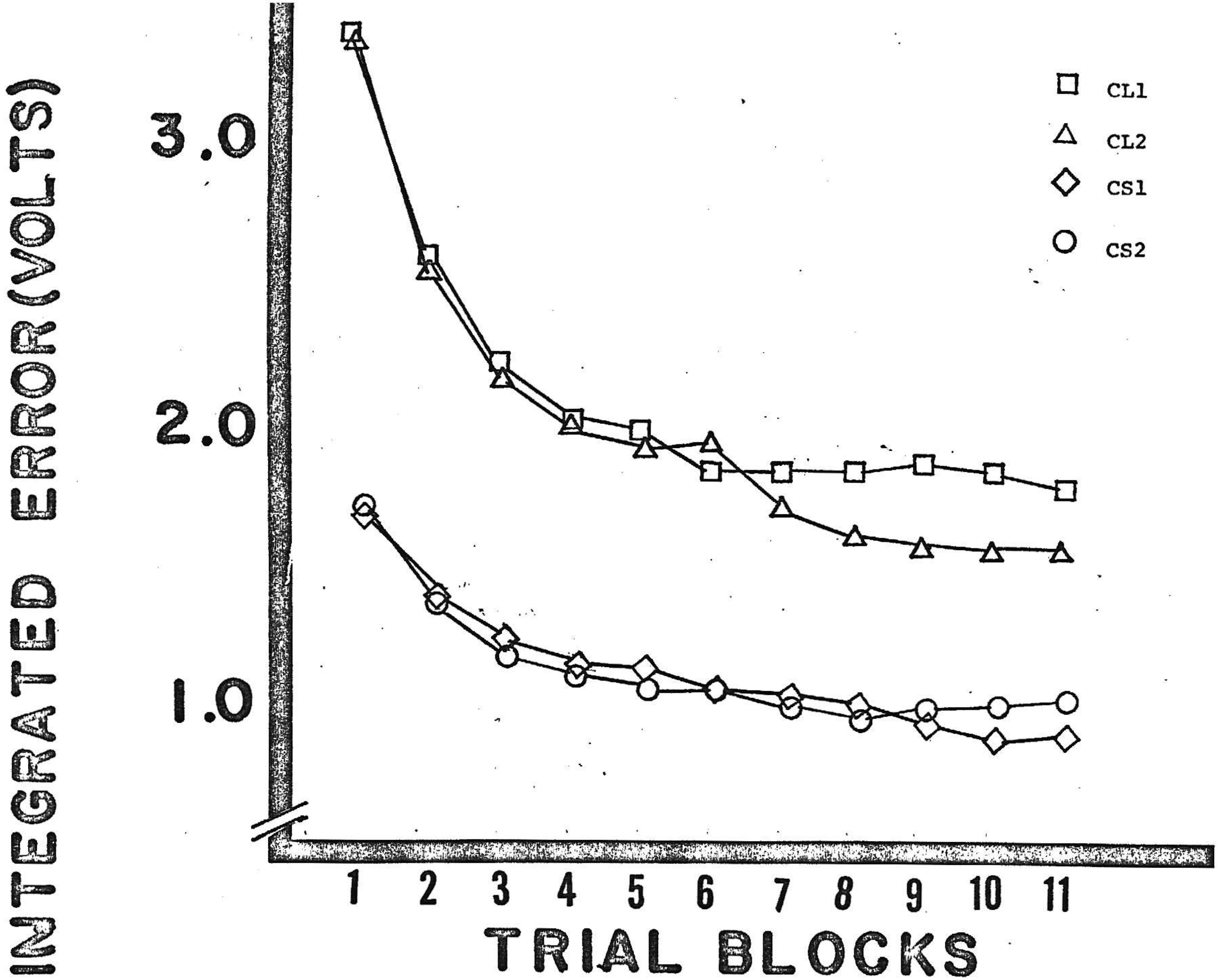

Fig. 1 Integrated error as a function of 11 five trial blocks for the four constant tracking conditions.

It can also be seen that while all four constant conditions showed decreasing error over blocks, more improvement was shown by the groups with the larger display.

A separate analysis of variance over just the pretransfer blocks for the four conditions employing the smaller display and the less sensitive control (Condition CS1 and the three transfer conditions) showed no significant effects attributable to condition or to the Condition x Block interaction. Another analysis of variance for just the Trial 15 data again showed no differences between these four primary task conditions before transfer.

Tracking performance on counting trials. The integrated error in each counting trial was separately compiled for only those _S_s who were periodically required to count while tracking. Analyses of these data over all 9 counting trials for the four constant conditions revealed essentially the same effects as were found for the non-counting blocks of trials (see Figure 1) except that integrated error was consistently higher on counting trials than on non-counting blocks of trials.

The decrease in primary task performance caused by the secondary task can be seen more directly by looking at the difference in integrated error between each counting trial and the immediately preceeding non-counting trial. These difference scores were computed separately for each _S_ who was required to count while tracking. The average difference score for each of the four constant conditions is shown as a function of trials in Figure 2. An analysis of variance of these difference scores for the four constant conditions showed that the only significant effects were for display size, $F\ (1,\ 20) = 19.72$, $p < .01$, trials, $F\ (8,\ 160) = 2.20$, $p < .05$, and the Display Size x Trials interaction, $F\ (8,\ 160) = 2.12$, $p < .05$. Figure 2

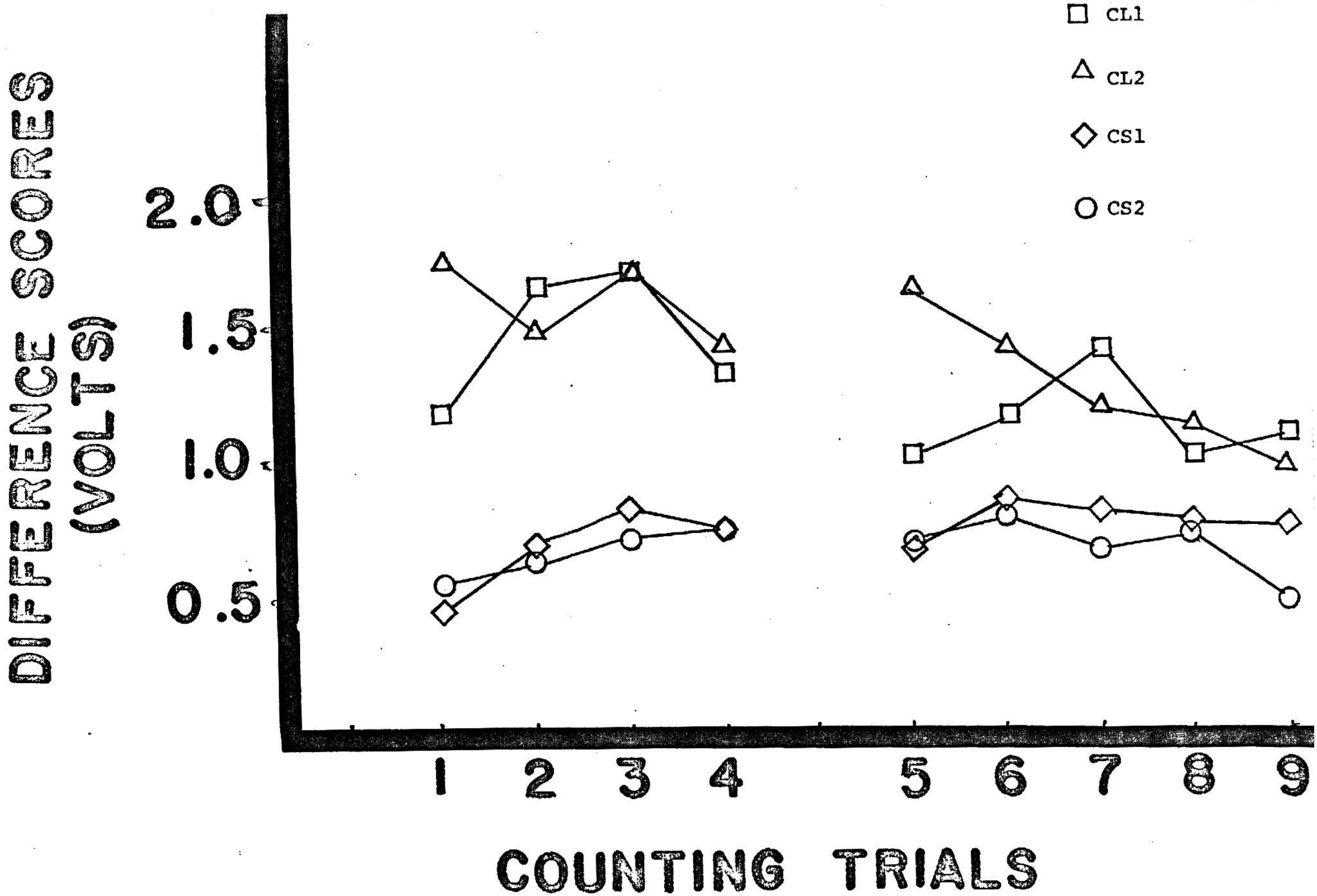

Fig. 2 Difference in integrated error between each counting trial and the preceding noncounting trial as a function of counting trials for the four constant tracking conditions.

shows that the secondary task caused a larger disruption in tracking performance for the large display conditions than for the small display conditions. Furthermore, it can be seen that while the amount of disruption was fairly stable over trials for the small display conditions, it decreased over trials for the large display condition.

A separate analysis of variance over only the pretransfer counting trials for the four conditions employing the small display and the less sensitive control showed no significant effects attributable to conditions or to the Conditions x Trials interaction.

Secondary task performance. Counting performance was quite variable both within and between Ss. An analysis of variance over the six pretransfer counting trials for all seven primary task conditions showed that the main effect for trials, $F\ (5, 175) = 6.52$, $p < .01$, was the only significant effect. The mean number of correct counts pooled over all dual task groups increased from 15.9 on the first counting trial to 18.8 on the sixth counting trial. However, the number of correct counts for the counting control group increased even more, going from 14.5 on the first counting trial to 21.5 on the last pretransfer counting trial. An analysis of variance of correct counts for all eight counting groups (the seven dual task groups and the counting control group) revealed a significant Groups x Trials interaction, $F\ (35, 200) = 1.99$, $p < .01$. This latter finding suggests that the greater improvement in counting for the counting control group relative to the seven dual task groups was reliable.

Transfer Effects

Figure 3 summaries the effects of changes in tracking conditions on

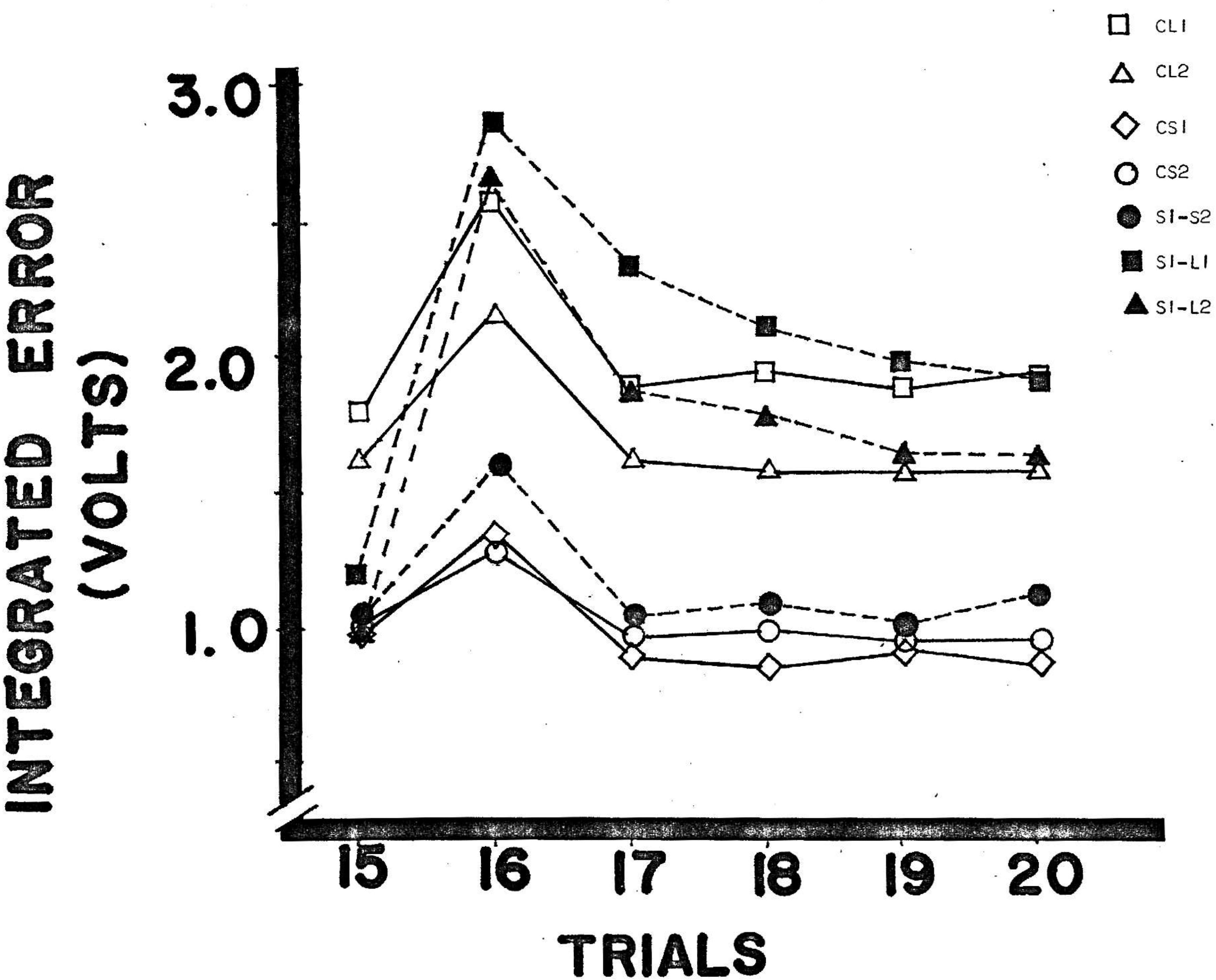

Fig. 3 Integrated error as a function of the last pretransfer trial and the first five post-transfer trials for all seven primary task conditions.

tracking performance. This figure shows integrated error as a function of the last pretransfer trial (Trial 15) and the first five trials after transfer (Trials 16-20) for each of the seven primary task conditions. It should be noted that the means shown in Figure 3 were obtained by pooling over the secondary task conditions; the relatively large levels of intergrated error on Trial 16 are therefore, in part, due to the fact that one-half the Ss in each primary task condition were counting on this trial.

An analysis of the absolute change in performance between Trials 15 and 16 showed that the primary task condition, F (6, 70) = 20.43, and the secondary task condition, F (1, 70) = 81.19, both significant at the .01 level, were the only significant effects. Overall, Ss who counted on Trial 16 showed a much larger absolute (1.31 volts) and relative (-117%) change in performance than Ss who did not count on Trial 16 (0.42 volts and -45%, respectively). Newman-Keuls' test on the primary task condition main effects showed that the changes in performance for Conditions S1-L1 and S1-L2 did not differ from one another but that both were greater than the changes found for the other five conditions; the latter five did not differ.

An analysis of tracking performance on only Trial 16 showed that the presence of a secondary task produced larger errors in tracking, F (1, 70) = 49.69, $p < .01$, and that the primary task conditions differed from one another, F (6, 70) = 17.06, $p < .01$, but again, there was no interaction between the primary and secondary task conditions. It may be seen in Figure 3 that all three transfer conditions tend to have more error on Trial 16 than their corresponding post-transfer constant condition controls. Newman-Keuls' test on the Trial 16 main effects, however, showed that Condition S1-L2 was the only transfer condition significantly different from its control. Separate analysis comparing each transfer condition to its pre- and post-transfer tracking control conditions showed that both Condition S1-S2 and Condition S1-L2 differed significantly from their post-transfer tracking control condition. Condition S1-L1 did not differ from its post-transfer control.

The post-transfer data illustrated in Figure 3 also suggest that the performance of the three transfer conditions recovered at different rates from Trial 16 to match the performance of their respective post-transfer constant control conditions. Specifically, while all four constant conditions and transfer condition S1-S2 returned to pretransfer levels of performance by Trial 17, transfer conditions S1-L2 and S1-L1 seemed to recover much more slowly.

Investigations of tracking performance for all conditions over all post-transfer non counting trials, and for just the counting Ss over the three post-transfer counting trials, showed no effects not revealed in the analyses of Trials 16-20. Performance on the secondary task during the post-transfer trials was so variable, both within and between groups, that no analyses of these data were attempted.

Discussion

The poorer tracking performance found with the larger display conditions was at least partially, if not primarily, an artifact of the procedures employed for magnifying the input function and for measuring performance. The size of the display was increased by doubling the input voltages to the CRT. As a result, integrated error would necessarily increase for all Ss except the ideal perfect tracker. Furthermore, since the rates of control movement would vary as a function of the amplitude of target displacement, there is no simple way to correct for this artifact in measurement.

The greater improvement over blocks of trials for the Ss tracking the larger display relative to those tracking the smaller display may also be an artifact. However, the greater improvement with the larger display may also be a real effect of display size. Helson (1964) showed that magnification of error in a tracking task requiring fine adjustive movements led to improved performance, presumably because Ss had a limit on how much error they would tolerate. Increasing the apparent size of the error through magnification caused them to try harder to reduce this perceived error.

One of the major pruposes for this study was to investigate the relative influence of internal and external cues for tracking efficiency. It was assumed that transfer condition S1-S2 could be associated with a constant external pattern of cues but a change in the pattern of response amplitude reouirements and hence a change in only internal cues. On the other hand, it was assumed that since both the display size and the control sensitivity was doubled for transfer condition S1-L2, this condition could be associated with a constant set of internal cues (required movements remained unchanged) and a change in only external cues. Condition S1-L1 was associated with a change in both the external and the internal cues.

The results of this study showed that all three transfer conditions tended to produce disruptions in performance which were approximately equal in magnitude relative to the three corresponding post-transfer control conditions. These results suggest that Ss were relying on both the external (visual) cues and the internal (response produced) cues at the moment of transfer. The finding that transfer condition S1-S2 recovered more quickly after transfer than the other two transfer groups suggest that if there were any differences due to the importance of external and internal cues, the constant external cues were more important than the constant internal cues.

This interpretation of the present findings disagrees with the conclusions of Christ and Newton (1970), but is in agreement with the alternate interpretation of their results suggested earlier. Specifically, it was suggested that the changed input condition in the Christ and Newton study produced not only a change in the pattern of response produced cues, but also a change in the pattern of visual cues. Hence, their conclusion concerning the relative importance of internal cues over external cues was not warranted. The present study, like theirs, varied proprioceptive cues and visual cues, but did not vary the pattern of either, just their magnitude.

One possible, and quite plausible, alternate interpretation of the present study could incorporate the original interpretation of the Christ and Newton study. This interpretation is based on the different levels of training achieved in the two studies. The Ss in the Christ and Newton study were trained for 830 repetitions on a 6 element pattern before transfer, while Ss in the present study were trained for only 322 repetitions on a 7 element pattern. Internalization of control is hypothesized to be a slow process developing after extended practice. Although performance in this study increased only slightly after about 200 pattern repetitions, it is possible that the process of internalization had not reached a final or a sufficiently high level when transfer began.

The second major purpose of this study was to attempt a clarification between the two definitions of automation discussed by Posner (1969). This was to be accomplished by independently measuring the extent of internalization of primary task control and the amount of disruption in the primary task caused by a secondary task. The large disruption in primary task performance caused by changing the amplitude of required responses indicated that performance in this task was, at least partially, controlled by internal, response-produced cues.

If the amount of processing capacity required by the primary task decreases as performance on the task becomes automatic, their performance on the secondary task should increase while the amount of disruption in primary task performance caused by the secondary task should decrease. The results show that secondary task performance increased with practice and that the disruption caused by the secondary task decreased slightly with practice. This pair of findings could be taken as an indication that automation is associated with a reduction in the amount of a central processor required by the task. However, it should be noted that the decrease in disruption caused by the secondary task was largely limited to the larger display condition. Furthermore, the increase in secondary task performance may only reflect the fact that Ss can learn to count backwards more rapidly and accurately, as suggested by the increased performance of the counting control group.

If reduced channel requirements result from a shift from dependence on external cues to a dependence on internal cues, the ability to perform a concurrent secondary task should decrease when the internal cues are suddenly varied. The results do not support this hypothesis. In fact, the findings of this study are consistent in not finding any interaction between secondary task performance and primary task performance either before or during transfer. Hence, to the extent that both internalization of control and reduced processing requirements are factors in automation of skill, they would seem to be independent factors.

Large disruptions in primary task performance resulted from the concurrent demands of the secondary counting task. These disruptions in tracking performance were limited, however, to only the trials on which counting occurred. There was no evidence that intermittent counting interferred with acquisition of skill on the primary task. This finding limits the conclusions made by Noble, Trumbo, and Fowler (1967). These investigators found that a secondary task inhibits primary task learning. However, they required their Ss to perform the secondary task during the major portion of every trial while Ss in the present study were required to perform the secondary task during less than one trial in five.

It would appear, in conclusion, that the procedures employed in this study are apporpriate for studying the factors governing the automation of skilled performance. Future applications of this procedure should strive to overcome two faults of the present study. The secondary task used was virtually self-paced and large differences in secondary task performance were the rule. A more controlled secondary task and the use of more training before transfer (to insure high levels of internalization) are recommended.

References

Bahrick, H.P. & Shelly, C. Time sharing as an index of automatization. *Journal of Experimental Psychology*, 1958, *56*, 288-293.

Christ, R.E. & Newton, R.R. The relative effects of display mode and input function on tracking performance. *Journal of Experimental Psychology*, 1970, *85*, 237-244.

Fitts, P.M. & Posner, M.I. *Human performance*. Blemont, Calif.: Wadsworth Publishing Company, 1967.

Fleishman, E.A. & Rich, S. Role of kinesthetic and spatial-visual abilities in perceptual-motor learning. *Journal of Experimental Psychology*. 1963, *66*, 6-11.

Hartman, B.O. & Fitts, P.M. Relation of stimulus and response amplitude to tracking performance. *Journal of Experimental Psychology*, 1955, *49*, 82-92.

Helson, H. *Adaptation-level* theory. New York: Harper & Row, 1964.

Noble, M., Trumbo, D., & Fowler, F. Futher evidence on secondary task interference in tracking. *Journal of Experimental Psychology*, 1967, *73*, 146-149.

Posner, M.I. Reduced attention and the performance of "automated" movements. *Journal of Motor Behavior*, 1969, *1*, 245-258.

Schmidt, R.A. Anticipation and timing in human motor performance. Psychological Bulletin, 1968, *70*, 631-646.

Trumbo, D., Eslinger, R., Noble, M., & Cross, K. A versatile electronic tracking apparatus (VETA). Perceptual and Motor Skills, 1963, *46*, 649-656.

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The study investigated the roles of visual and proprioceptive cues. 12 Ss were placed in each of 7 tracking conditions. All Ss tracked the same 7 element pattern 440 times. 4 conditions resulted from combinations of 2 levels of control sensitivity and 2 levels of display magnification. For the first 322 pattern repetitions, 3 other groups tracked the same pattern under 1 of the conditions of display aize and control sensitivity, then were required to track under 1 of the other conditions. Half the Ss in each condition were periodically required to perform a difficult counting task while tracking. Both changed control sensitivity and display magnification reduced tracking performance. The secondary task interfered with tracking only when Ss were counting and tracking simultaneously. The results are discussed in terms of theories of internalization and automation of skilled motor performance.