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Cleared: April 17th, 1980
Clearing Authority: Air Force Wright Aeronautical Laboratories

WADC TECHNICAL REPORT 55-366

THE EFFECT OF VARIATIONS IN CONTROL-DISPLAY DURING TRAINING ON TRANSFER TO A "HIGH" RATIO

MARTY R. ROCKWAY

AERO MEDICAL LABORATORY

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CONTRACT No. AF 18(600)-78
PROJECT No. 7197
TASK No. 71635

WRIGHT AIR DEVELOPMENT CENTER
AIR RESEARCH AND DEVELOPMENT COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

Carpenter Litho & Prtg. Co., Springfield, O.
400 - June 1956

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FOREWORD

This report was prepared by the Psychology Branch of the Aero Medical Laboratory, Directorate of Research, Wright Air Development Center, for a task under Project 7197, "Human Engineering Factors in the Design of Training Equipment" with Dr. Gordon A. Eckstrand acting as Project Scientist. The task was 71635, "Simulation Requirements of Training Equipment" with Dr. Marty R. Rockway acting as Task Scientist. The experimental data were collected at the Ohio State University, Columbus, Ohio under Contract No. AF 18(600)-78 and under the direction of Dr. Delos D. Wickens. Mr. Delmar L. Landen supervised the collection and analysis of data.

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ABSTRACT

One of the parameters of continuous control systems that appears to have relevance for transfer of training is control-display (C/D) ratio. The present study was designed to investigate the relationship between amount of transfer of a two dimensional tracking skill and degree of physical similarity between training and test ratios.

Each of three groups of subjects received training using either a low, medium, or high C/D ratio. Following training, all groups were tested while using the high (i.e., least sensitive) ratio. The experimental results were as follows: (a) During training, tracking performance was a function of the C/D ratio employed. (b) All of the training ratios produced significant positive transfer to the test ratio. (c) Amount of transfer to the initial test trial was a function of the training ratio employed. However, differential transfer effects were very transitory, and by the second test trial differences among groups were no longer significant.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

JACK BOLLERUD
Colonel, USAF (MC)
Chief, Aero Medical Laboratory
Directorate of Research

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THE EFFECT OF VARIATIONS IN CONTROL-DISPLAY RATIO DURING TRAINING ON TRANSFER TO A "HIGH" RATIO[1]

INTRODUCTION

A major responsibility of the human engineer with respect to the design of synthetic training devices is the specification of the extent to which the operational situation must be simulated in order to achieve adequate transfer of learning from training to operational tasks. If the recommendations of the human factors specialist are to be of optimal value to the design engineer they must be both comprehensive and specific. Recommendations must be comprehensive to insure that all aspects of the operational situation that may be relevant for transfer have at least been considered. And, recommendations must be specific (where possible) to permit their unambiguous translation into training device hardware.

The selection of operational characteristics that may be relevant for transfer is often a matter of common sense, experience, or intuition. However, the ultimate determination of relevance and the specification of the extent to which the selected characteristics must be simulated in a training device is almost always a matter for research.

For those operational systems that require some form of manual tracking, one of the parameters that appears to have relevance for transfer is C/D ratio; i.e., the magnitude of display change produced by a given control input. Experimental variations in C/D ratio have been effected in a number of ways (1). The techniques employed include optical magnification of the display, the addition of derivatives to the control output, variation in the shape of the function relating control movement and display movement, and "mechanical" alteration of the C/D gear ratio. It is the latter type of variation with which the present study is concerned. In this situation the problem amplitude remains constant, but the magnitude of control input required to eliminate it is varied.

The present study. There is considerable experimental evidence (e.g., 3, 4, 6) which indicates that variations in C/D ratio affect tracking proficiency per se. However, very little is known concerning the effects of training with one ratio on subsequent performance with another, different ratio. The present study was designed to investigate the relationship between amount of transfer of a two-dimensional compensatory tracking skill and degree of similarity--in terms of C/D ratio--between training and final tasks.

1. This is the first of two related studies which for convenience were run separately. The second is concerned with transfer to a "low" C/D ratio.

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Although there is little experimental precedence for the type of transfer variation effected in the present study, an investigation reported by Baker, Wylie, and Gagne (2) has obvious relevance. In this study, operators were trained on a pursuit tracking task using a handwheel control which required either 1/4, 1/2, 2, or 4 control revolutions per 12.5° of cursor movement. The results indicated that the amount of transfer from training to test tasks was directly related to the degree of similarity between training and test C/D ratios. However, the relative amount of transfer was also a function of the direction of change, with training on the "highest" ratio producing more transfer to the "lowest" ratio than vice versa.[2]

A pair of transfer experiments by Levine (5) also have some relevance to the present study--if one is willing to assume that variations in C/D exponential time delay produce changes in control "sensitivity" (6) which are similar, although obviously not identical, to those produced by variations in C/D ratio. Using a one-dimensional compensatory tracking task with a position control, Levine investigated transfer as a function of changes in exponential delay between control and display. In the first experiment, operators transferred to a task containing a 3.000-sec. exponential delay following training with either a .015, .150, .900, 2.100, or 3.000-sec. delay. In the second experiment, operators transferred to a .015-sec. delay following training with either a .015, .900, or 3.000-sec. delay. It was found that when transfer was to the longest delay, differences in performance among groups were significant for the first block of transfer trials only. The relationship between amount of transfer and similarity between training and final task delays was somewhat unique, since the transfer exhibited by the groups which trained with the 2.100 and .900-sec. delays was greater than that of the group which trained with the final (3.000-sec.) delay. On the other hand, when transfer was to the shortest delay, the amount of transfer was directly related to the similarity between training and final tasks.

METHOD

Apparatus. The experimental apparatus was a two-dimensional compensatory tracking device mounted in a rough simulation of an aircraft cockpit. The device can be considered to consist of the following major components: (a) the display, (b) the control, (c) the problem generator, and (d) the scoring mechanism.

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2. The reader is cautioned to note that control-display ratio is conventionally expressed as a numerical fraction (C/D). Thus, the "higher" (i.e., larger) the ratio the greater the magnitude of control input required to produce a given display change and--other things being equal--the less sensitive the control.

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The tracking display was a fluorescent spot on the face of a 5-in. cathode-ray tube (CRT). The CRT was mounted behind an aperature in a vertical instrument panel perpendicular to the subject's (S's) line of sight and at a viewing distance of about 28 in.

The tracking control was a lightly loaded aircraft joystick with which the S could position the display spot on the face of the CRT in two dimensions.[3] Fore-aft motions of the stick moved the spot vertically, and right-left motions moved it horizontally.[4] (The position of the spot on the scope face was always the vectorial sum of the two dimensions of control input.) Control-display ratio was varied by means of two rheostats in the control circuit. The settings of the rheostats determined the amount of spot movement which resulted from a given control deflection. The control stick protruded thru a rectangular opening in a metal plate bolted to the deck of the cockpit. The dimensions of the opening were such as to restrict the range of stick movement to $\pm$ 11° from the vertical in both dimensions. Since the length of the stick, as measured from the fulcrum, was 28 1/2 in., the total range of movement of the top of the stick in each dimension was 10.9 in.

The problem signals to the display were generated by two low torque potentiometers driven by Masonite cams rotating at 1 rpm. The cam contours were smoothed approximations of the sum of three equal amplitude sine waves whose frequencies were 3, 5, and 11 cycle per min. (The addition of the sinusoids was made with the 3 cycle wave displaced 180° in phase. This produced cams with a few extremely abrupt changes in slope which were smoothed out to reduce the complexity of the problem and to allow the cam followers to ride freely.) The cams for both dimensions were identical but were mounted so that their inputs were 15 sec. (i.e., 90° of cam) out of phase. The maximum excursion of the display spot when driven by the problem cams was 33/16 in. from the center of the CRT in each dimension.

While tracking, the S's task was to compensate for the inputs of the problem generator by moving the control stick so as to maintain the display spot within a 3/8 in. square target area outlined in India ink around the center of the CRT. Three .001-min. Standard Electric Timers were used to record time-on-target data. One clock recorded the time the spot was within a scoring band 3/8 in. wide and symmetrical about the vertical axis of the CRT.

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3. Practically all of the loading resulted from the mass and friction of the mechanical portions of the control linkage.
4. In order to eliminate 60 cycle pickup, which distorted the display spot at high control gains, it was necessary to employ an R-C filter which effected an exponential time delay of .15 sec. between control and display. The filter was interposed in the link between the control and the differential (where the S's input was compared to the problem input and the difference presented on the display).

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A second clock recorded the time the spot was within a 3/8 in. band about the horizontal axis. The third clock recorded the time the spot was within both scoring bands simultaneously, i.e., within the 3/8 in. square target area.

Subjects. A total of 45 right-handed male Ss, 15 per group, were employed in this study. All Ss were inexperienced with respect to the experimental apparatus and none served in more than one condition.

Conditions. The experimental conditions are shown in Table I. It will be noted that the three levels of C/D ratio employed in this study were, in the order of increasing control sensitivity, 1:3, 1:9, and 1:27.

The notation of C/D ratio in the form 1:X should be read as "1° of control deflection produced X/16 in. of spot movement."[5] The relationship between control deflection and spot movement was essentially linear. Therefore, in the case of the 1:3 ratio, a 1° control deflection moved the spot 3/16 in.; a 2° deflection moved the spot 6/16 in. (i.e., 2 x 3/16); a 3° deflection, 9/16 in......; and an 11° deflection, 33/16 in.

It will be recalled that the maximum displacement of the display spot produced by the problem generator was 33/16 in. from the central axes of the CRT. Thus, with the 1:3 ratio, it required the maximum control deflection to compensate completely for the maximum spot displacement.[6] On the other hand, with the 1:27 ratio, it required only about 1.2° of control deflection to nullify completely the maximum problem input.

Procedure. Each S served in two experimental sessions, one on each of two successive days. On the first (training) day, S received 25 trials of practice using one of the three C/D ratios. On the second (transfer) day, all Ss practiced for an additional 25 trials using the 1:3 ratio. Trials were 1 min. in length and the inter-trial rest interval 30 sec.

The S performed the tracking task while seated in a simulated cockpit housed in a semi sound-proofed cubicle. A low level of glare-free illumination was provided by a shielded 60-watt bulb placed behind the S. A few seconds prior to the start of each trial the experimenter would say "Ready." This was the signal for the S to center the spot within the target area and to prepare to track.

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5. For those readers who prefer another form of notation, a 1° deflection corresponded to about a .54 in. movement of the top of the control stick.
6. Since the scoring bands extended 3/16 in. on each side of the central axes, it actually required less than full stick deflection to activate the scoring clocks.

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TABLE I

The Conditions of the Experiment

Cond.	n	Day 1 (Training) C/D Ratio	Day 1 (Training) Trials	Day 2 (Transfer) C/D Ratio	Day 2 (Transfer) Trials
A	15	1:3	25	1:3	25
B	15	1:9	25	1:3	25
C	15	1:27	25	1:3	25

During the interval between trials the experimenter reported to S his simultaneous time-on-target score for the immediately preceding trial.

RESULTS

It will be recalled that three different time clocks were operative during each 1-min. trial throughout practice. One clock cumulated the time the display spot was within the vertical scoring band, the second clock cumulated the time within the horizontal band, and the third clock cumulated the time within both bands simultaneously (i.e., within the 3/8 in. square target area). In this report, however, only the analysis of the simultaneous time-on-target (TOT) scores will be described. The mean TOT scores for all training and transfer trials are plotted in Fig. 1, and tabled in the Appendix.

Training data. Prior to discussing the effects of variations in C/D ratio on transfer, the effects during training will be considered briefly.

From the data plotted in Fig. 1, it appears that performance during training was a function of the particular C/D ratio employed. It will be noted that although the curves for the 1:3 and 1:9 ratios do not differ greatly, they are both considerably higher than the curve for the 1:27 ratio.

Only the TOT scores on training trial 25 were subjected to statistical analyses. The statistical tests confirm what seems apparent from inspection. That is, both the 1:3 and 1:9 groups

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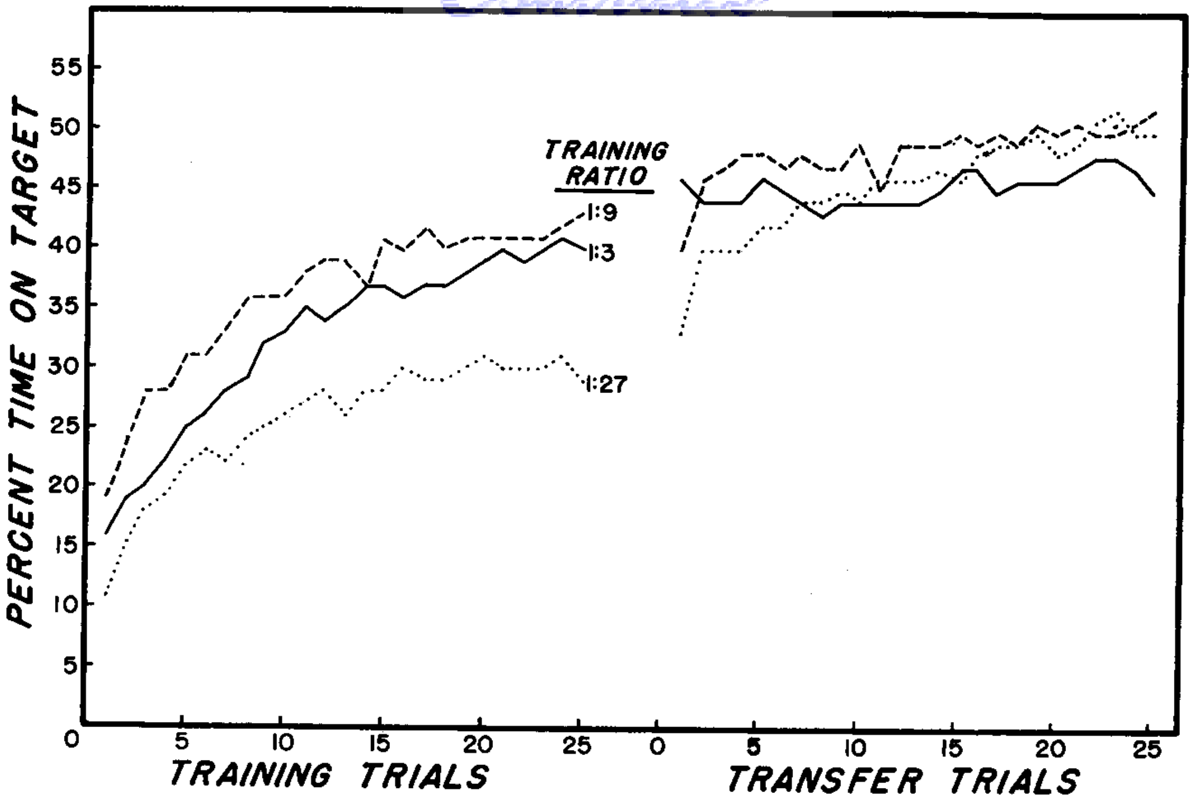

Figure 1. Mean percent simultaneous time-on-target scores during training and transfer trials. (All scores were rounded to the nearest one percent.)

achieved significantly larger mean TOT scores on training trial 25 than did the 1:27 group, but they did not differ significantly from each other. Summaries of the analysis of variance and t-tests of the training scores are presented in Tables II and III.

Transfer data. A comparison of the performance of all three groups on the first transfer trial with the performance of the 1:3 group on the first training trial reveals that practice with each of the training ratios effected a sizable amount of positive transfer to the test (1:3) ratio. An inspection of the transfer curves in Fig. 1 indicates that the trial 1 means are ordered in a manner which suggests that the amount of transfer is directly related to the similarity between training and transfer ratios. However, because of the very rapid improvement in the performance of the groups which trained with the 1:9 and 1:27 ratios, appreciable differences among groups are largely confined to the initial transfer trials.

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TABLE II

Analysis of Variance of the Time-on-Target Scores on Training Trial 25

Source of Variance	df	Mean Square	F	p
Between Ratios	2	.0825	9.59	<.01
Within Groups	42	.0086		
Total	44			

TABLE III

t-Ratios Resulting from Inter-group Comparisons of Mean Time-on-Target Scores on Training Trial 25

Comparison	df[7]	t	p
1:3 vs 1:9	42	.59	n.s.
1:3 vs 1:27	42	3.44	<.01
1:9 vs 1:27	42	4.02	<.01

To verify the statistical significance of the positive transfer revealed by the plotted data, the difference between the mean TOT scores of the 1:27 group on transfer trial 1 and the 1:3 (control) group on training trial 1 was subjected to a t-test. The obtained t-ratio of 6.38, with 28 df, has an associated probability of less than .01. (The preceding test was the only one performed, since it was assumed that if the smallest mean difference was significant the other two larger differences also were.)

7. The degrees of freedom are those associated with the within-groups mean square in Table II which was used as the estimate of population variance.

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TABLE IV

Analysis of Variance of the Time-on-Target Scores on Transfer Trial 1

Source of Variance	df	Mean Square	F	p
Between Ratios	2	.060	7.69	<.01
Within Groups	42	.0078		
Total	44			

TABLE V

t-Ratios Resulting from Inter-group Comparisons of Mean Time-on-Target Scores on Transfer Trial 1

Comparison	df[8]	t	p
1:3 vs 1:9	42	1.72	n.s.
1:3 vs 1:27	42	3.96	<.01
1:9 vs 1:27	42	2.23	<.05

To test the significance of the differences among the groups during the transfer trials, analyses of variance were performed on the TOT scores for transfer trials 1, 2, 4, 25, and the sum of the scores of trials 1 to 25. Of the many transfer differences tested, only those on trial 1 were found to be statistically significant. Here again the 1:3 and 1:9 groups were found to perform at a significantly higher level than the 1:27 group, but they were not significantly different from each other. The analysis of variance and the t-tests of the trial 1 data are summarized in Tables IV and V, respectively.

8. The degrees of freedom are those associated with the within-groups mean square in Table IV which was used as the estimate of population variance.

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Additional remarks. It is interesting to note the improvement in TOT scores between the final training trial and first transfer trial exhibited by the 1:3 group. This "reminiscence" phenomenon following an interpolated rest is a common finding in motor performance studies where practice occurs under relatively "massed" conditions.

DISCUSSION

The results of this study indicated that on the first transfer trial, amount of transfer was directly related to the similarity between the C/D ratios of the training and final tasks. However, these differential transfer effects were very transitory, and by the second transfer trial, differences among groups were no longer statistically significant.

The initial transfer effects demonstrated are consistant with predictions based simply on a consideration of the physical similarity between training and final tasks. On the other hand, there is considerable experimental evidence which indicates that when physically unidimensional task variations effect differences in measured performance during training, relative transfer depends upon the order in which the tasks are experienced.[9,10] For example, in the present study, the 1:3 group achieved significantly higher TOT scores during training than did the 1:27 group. Thus, the fact that transfer from the 1:27 ratio to the 1:3 ratio was proportionately less than transfer from the 1:3 ratio to itself does not mean that transfer from the 1:3 ratio to the 1:27 ratio would be less than transfer from the 1:27 ratio to itself by the same proportion.

Some of the difficulties encountered when attempting to make transfer predictions when experimental variations effect performance differences during training are illustrated by the results of the two studies summarized in the Introduction. For example, in the study by Baker, et al, performance scores during training decreased with an increase in C/D ratio; and transfer from the high (low score) ratio to the low (high score) ratio was relatively greater than transfer from the low ratio to the high ratio. In Levine's study,

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9. This is not the case, obviously, where differences in scores merely reflect differences in the unit of measurement employed rather than differences in system functioning--as might occur, for example, where target size is varied and time-on-target is used as the measure of system performance.
10. The writer has elected to confine his comments to differences in performance scores in order to avoid the superfluity of meaning associated with the term "difficulty." Some of the problems encountered in the use of "difficulty" as a task dimension for predicting transfer effects will be considered at length in a subsequent report.

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on the other hand, performance scores during training decreased with increasing delay; and transfer from the shortest (high score) delay to the longest (low score) delay was relatively greater than transfer in the reverse direction.

Obviously, differences in performance scores per se, even when coupled with a knowledge of some of the physical similarity relationships involved, are not sufficient to permit accurate predictions of transfer effects. For, while differences in performance scores may suggest the presence of differences in the psychological requirements of tasks, they do not indicate the nature of such differences. Therefore, prior to making differential transfer predictions it would seem necessary to analyze and compare the similarities and differences in the response (behavioral) demands of the tasks involved. Unfortunately, at the present time anything but the grossest kind of analysis is often "beyond the state of the art."

Future research. In view of the probable interactions between several variables of manual tracking systems (6), it seems apparent that the results of this one experiment are not sufficiently general to permit the deduction of principles likely to be of great value to the designer of training devices. On the other hand, so little is known concerning the effects investigated that almost any reliable empirical evidence may be considered to be a useful contribution to psychological knowledge. As was pointed out in footnote 1, another study similar to the present one will be performed to investigate transfer to the low C/D ratio. A consideration of the results of these two complementary studies may lead to some fruitful hypotheses concerning the factors involved in complex transfer situations.

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SUMMARY

Three groups of Ss received training on a two-dimensional compensatory tracking task using one of three different control-display ratios. The three ratios were such that 1^{o} of control deflection produced either 3-, 9-, or 27-sixteenths in. of display movement. Following training, all groups were tested on the task using the 1:3 ratio.

The experimental findings were as follows:

1. During training the groups using the 1:3 and 1:9 ratios performed at a significantly higher level than the group using the 1:27 ratio.

2. All groups displayed a significant amount of positive transfer to the test task.

3. On the first test trial, the groups were ordered in a manner which suggested that the amount of transfer was directly related to the similarity between training and test ratios. However, differential transfer effects were very transitory and by the second test trial the order of the groups had changed and the differences among them were no longer significant.

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APPENDIX

TABLE VI

Mean Time-on-Target Scores
(Units _ .001 min.)

Trial	Training Day Group 1:3	1:9	1:27	Transfer Day Group 1:3	1:9	1:27
1	164	186	108	457	401	330
2	190	245	149	443	456	398
3	205	276	180	436	468	401
4	224	283	186	444	478	403
5	248	208	218	456	479	415
6	256	314	227	453	471	424
7	277	326	217	441	482	441
8	294	356	243	431	474	441
9	315	360	253	444	466	446
10	331	361	257	439	489	439
11	349	381	270	442	451	455
12	345	386	275	435	491	456
13	347	390	261	441	494	464
14	368	372	277	452	490	467
15	367	413	284	468	502	461
16	362	403	295	467	494	476
17	367	420	290	454	502	485
18	374	402	291	455	494	487
19	383	408	301	465	513	501
20	389	412	311	462	502	475
21	404	411	299	466	506	494
22	392	407	295	477	503	510
23	401	409	302	479	501	518
24	409	415	311	469	509	503
25	404	426	287	449	516	496

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