A Note on the Effect of Bandwidth Knowledge of Results on Movement Consistency

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Running Head: Movement Consistency and KR

Abstract

The effect of "bandwidth KR" (that is, knowledge of results given only if the subject's response is outside of a certain movement time bandwidth) on learning and performance of a rapid limb movement was examined in two experiments. In Experiment 1, two male and two female undergraduates moved a light, aluminum lever through 60 deg of elbow flexion in 200 msec in the horizontal plane, with a follow-through allowed. Subjects performed 200 trials in each of two conditions: the 15% bandwidth condition where KR was given only if the subject's response was outside of the goal movement time (MT) $\pm$ 15%, and a control condition where KR was presented after every trial. Subjects in the bandwidth condition showed less variable error (VE) than subjects in the control condition. A second experiment, using a between-subject design and the same task, showed that subjects in a 10% bandwidth group demonstrated more consistent performance and better overall accuracy than either a 5% bandwidth group or a control group during a no-KR retention test.

One aspect of skilled motor behavior is the ability of the performer to consistently repeat a particular response. But even the most skilled performers cannot produce exactly the same response on every attempt, and therefore show variability across trials. Among the causes for trial to trial response variability might be changes in the level of concentration, fatigue, anxiety, or even changes in what the subject intended. Recently, two "impulse" models of motor control (Schmidt, Zelaznik, & Frank, 1978; Meyer, Smith, & Wright, 1982) have suggested that variability in spatial and temporal aspects of rapid limb movements are due to random variability in the force- and time-production mechanisms. That is, the amount of force produced may vary randomly from trial to trial, although the mean force (over trials) may meet the criterion force for the particular movement condition. Both models assume that all other sources of trial to trial variability (e.g., motivation, fatigue, changes in what was intended) are constant within and between conditions, leaving force and time variability as the primary cause of response variability.

In most experiments investigating the impulse-variability models, an effort is usually made to reduce the effect of fatigue by giving the subject adequate time to rest between conditions. In addition, an effort is made to minimize changes in the subject's "intent" by presenting a constant goal movement time (MT) and distance (A) for one block of trials before moving to the next movement condition.

However, a method has been used in some experiments (Schmidt, Zelaznik, Hawkins, Frank, & Quinn, 1979; Sherwood & Schmidt, 1980) examining the impulse-variability model that possibly can encourage the subject to shift the intended response over trials. When KR (knowledge of results) is given on every trial (as it was in some of the experiments mentioned above) it may tend to make subjects change their response based on the outcome of the previous trial. If the subject moves too slowly on a particular trial, and is informed of that fact, the subject would make a systematic attempt to decrease the MT on the next trial. Although the goal set by the experimenter may be constant in terms of MT, the subject may alter the intended response based on previous responses, thereby adding a component of variability that is assumed to be minimal and inflating the response error.

One way to help the subject make the intended response more consistent and reduce the chance that variability due to the selection of alternative responses may appear, might be to reduce the number of KR trials given during acquisition of a particular skill. However, few experimental studies have conclusively shown that movement consistency (i.e., variable error, VE) can be influenced by a reduction in the number of KR trials. Seashore and Bavelas (1941) in a re-analysis of Thorndike's (1931) original line-drawing experiment (with no KR) showed that the variability of block means (around the subject's grand mean) tended to decrease with practice. But the within-subject SD about each of the block means, (i.e., the VE) showed no tendency to decrease. In another experiment, Bilodeau and Bilodeau (1958) gave subjects KR every tenth trial during acquisition of a linear-positioning response. On the no-KR trials, the subjects tended to repeat the previous response and only varied the movement distance significantly after the KR was given, suggesting that reducing the number of KR trials may enhance movement consistency.

The effect of reducing the number of KR trials on overall error (e.g., AE) is somewhat better understood. Bilodeau, Bilodeau, and Shumsky (1959) and Newell (1974) demonstrated that movement error is inversely related to the number of KR trials given during acquisition. But the effect on movement consistency could not be ascertained because VE was not reported. Other studies have reported a reduction in movement error during no-KR practice (Henderson, 1975; Solley, 1956; Wrisberg & Schmidt, 1975), but in each case subjects may have been able to form an error-detection mechanism through knowledge of the target location, thereby eliminating the need for KR.

In summary, reducing the number of KR trials tends to produce a "trade-off" between VE and AE. When KR is not given, subjects tend to produce consistent responses around their own mean, but they may show a relatively large constant error shift to either side of the criterion, enlarging the AE. Although the method of not giving KR appears to help the subject make the intended response more consistently, the method also encourages greater overall error. The no-KR method might actually add an additional source of variability which would detract from the force-variability hypothesis of the impulse-variability model as the major source of trial to trial response variability. Similarily, the normal method of giving KR (i.e., on every trial) does not appear to provide a valid test of the impulse models either, with KR acting to encourage the subject to change the present response based upon the previous response within a movement condition.

Therefore, the present paper explores a different method of giving KR which may help the subject maintain consistency in what is intended, while allowing the subject to maintain overall accuracy. In the following experiments, the usual method of giving KR (i.e., on every trial) is compared to a condition where KR is given only if the subject's response is outside of a certain acceptable MT bandwidth. This type of KR is referred to as "bandwidth" KR.

EXPERIMENT 1

The first experiment compares bandwidth KR with normal KR during performance of a rapid-timing movement, where the subject moves a certain distance in a certain time with a follow-through allowed.

Methods

Apparatus

The apparatus consisted of a horizontal aluminum lever (54.6 cm in length and 5.0 cm in width), mounted to a 24.1 cm-long vertical steel axle. The ball-bushings supporting the axle were bolted to the side of a standard metal desk, allowing lever movement in the horizontal plane, parallel to the desk top. The lever was fitted with a D-shaped handle located 33.6 cm from the pivot.

Movement away from a microswitch activated a millisecond timer. After 60 deg of movement, the timer was stopped when a second microswitch was actuated by the lever.

Subjects

Four right-handed students at the University of Maryland (two males and two females, aged 20 to 27 years) volunteered to serve as subjects. They were not paid for their services.

Task

The task for the subject was to move the lever through 60 deg in 200 msec with a rapid elbow-flexion. A follow-through past the target was allowed and encouraged. The task was self-paced.

Procedures

Each subject participated in two conditions, the KR condition and the bandwidth (BW) condition, each given on a separate day. In the KR condition, knowledge of results about MT was given after every trial in milliseconds by the experimenter. In the BW condition, knowledge of results about MT was given only if the subject's MT was outside of a bandwidth defined by the goal MT $\pm$ 15%. This is, if the subject's MT was between 170 and 230 msec, no knowledge of results was given. However, if the subject had an MT of less than 170 msec, or greater than 230 msec, knowledge of results was given in milliseconds about the actual MT.

Two subjects received the KR condition on the first test day and the BW condition on the second test day. The other two subjects received the experimental conditions in the opposite order. Each subject produced 200 trials per day in each experimental condition.

Data Analysis

The constant (CE), variable (VE), and overall error (E) in MT were computed for each block of 20 trials for each subject and each condition. The resulting values were entered into separate ANOVAs (subjects x blocks x conditions, with repeated measures) for each error measure.

Insert Table 1 about here

Results and Discussion

Amount of KR

The number of trials on which knowledge of results was given in the BW condition is shown in Table 1 for each subject and block. Out of 200 trials, each subject received an average of 12.5 verbal reports of their MT, indicating that they had moved outside of the acceptable bandwidth. Clearly the number of trials on which KR was given was markedly reduced in the BW condition compared to the control condition where KR was given after every trial.

Constant Error (CE)

The average within-subject constant error in MT is shown in the lower portion of Figure 1. The CEs for both KR and BW conditions were positive for all blocks of trials, indicating that the subjects, on average, moved slightly slower than the goal MT. There appeared to be almost no effect of blocks with CE declining only about 3 msec from the first to the tenth block. The effect of blocks was not significant, $F(9,27) = 1.1$, $p>.05$.

There appeared to be some effect of KR conditions, with the BW condition showing greater CEs than the KR condition in all blocks, but particularly in blocks 1 through 7. However, the effect of conditions was not significant, $F(1,3) = 1.2$ $p>.05$. The conditions x blocks interaction was also not significant, $F(9,27)<1$, $p>.05$.

Variable Error (VE)

The average within-subject variable error in MT for each block and condition is shown in the top portion of Figure 1. There appeared to be a gradual decline in VE for both KR conditions from the first to the seventh block, with little change in VE for the remaining blocks. The effect of blocks was significant, $F(9,27) = 14.1$, $p<.05$. Evidently, the subjects in both conditions became more consistent with practice.

Insert Figure 1 about here

There also appeared to be an effect of conditions, with the BW condition showing less VE than the KR condition for every block. The effect of conditions was significant, $F(1,3) = 28.1$, $p<.05$. Therefore the subjects were more consistent when "bandwidth" KR was given. The conditions x blocks interaction was not significant, $F(9,27) = 1.0$, $p>.05$.

Overall Error (E)

The average within-subject SD of the subjects responses about the target MT (i.e., the E) are shown in Figure 2 for each block and condition. E appeared to decline with practice in both conditions, the decrease being about 7 and 6 msec in the KR and BW conditions, respectively. The effect of blocks was significant, $\underline{F}(9,27) = 11.9$, $\underline{p}<.05$.

There also appeared to be a small effect of conditions, with the KR conditions showing a larger E than the BW condition for all blocks.

Insert Figure 2 about here

However, the effect of conditions was not significant, $\underline{F}(1,3)<1$, $\underline{p}>.05$). Although overall performance appeared to be better in the BW condition, it was not significantly so. The blocks x conditions interaction was also not significant, $\underline{F}(9,27)<1$, $\underline{p}>.05$.

Summary

There appeared to be some suggestion of a "trade-off" between CE and VE in this experiment. While performing in the BW condition, but with increased consistency as measured by a reduction in VE. Considering MT alone, one would have expected VE to be larger due to the slower average MT in the BW condition because VE and MT and thought to be proportional (Schmidt et al., 1979). The fact that VE was smaller in the BW condition, despite the increase in MT, argues for the effect of the KR manipulation in this experiment.

Although there was a systematic reduction in E in the BW condition compared to the KR condition, the differences between the conditions were not significant. This was probably due to the fact that the higher CEs in the BW condition were "cancelled out" by the lower VEs in the same condition, while the reverse was true for the KR condition. The result was for the Es to be about equal for both conditions because of $E^2 = CE^2 + VE^2$.

One drawback of the first experiment is that it cannot be known whether or not bandwidth KR is a learning variable, a performance variable or both. That is, does bandwidth KR have relatively long-term effects on the retention of motor skills (a learning variable) or, are the effects shown only when the bandwidth KR variable is present (a performance variable)? To help answer this question the first experiment was repeated but with a between-group transfer design, where the "long-term" effects of independent variables can be ascertained (Schmidt, 1982).

EXPERIMENT 2

Methods

The task and apparatus were exactly the same as in the first experiment, so only the differences in the method will be described.

Subjects

Thirty-three right-handed undergraduate and graduate students at the University of Maryland (aged 18 to 25) volunteered to serve as subjects for this experiment. None were paid for their services. Of the volunteers, 18 were males and 15 were females.

Procedures

Subjects were randomly assigned to one of three groups, the BW5 group (5% bandwidth), the BW10 group (10% bandwidth), or the KR group (control). During the acquisition phase of the experiment, subjects received knowledge of results about their MT depending upon their group assignment. Subjects in the BW5 group received KR only if their MT was faster than 190 msec or slower than 210 msec, a 5% bandwidth around the goal MT of 200 msec. Subjects in the BW10 group received KR only if their MT was faster than 180 msec or slower than 220 msec, a 10% bandwidth. The control group (KR) received knowledge of results after every trial during acquisition. KR was always given in milliseconds by the experimenter. Each subject was given 96 trials during acquisition.

Following the completion of the acquisition trials, and a 5-min rest, all subjects participated in the transfer phase of the experiment. The transfer phase consisted of 25 attempts at the goal response (200 msec, 60 deg) but with no KR given at any time, regardless of the MT.

Data Analysis

For each block of 8 trials in acquisition, constant error (CE), variable error (VE), and total error (E) were computed for each subject in each group. The resulting error scores were entered into separate ANOVAs (group x blocks) with repeated measures on the last factor. For the transfer phase, the first trial was not analyzed because it was not a "true" no-KR trial (KR may have been given on the last acquisition trial preceeding the first transfer trial). Therefore, on the remaining 24 trials, CE, VE, and E were computed for each block of 8 trials for each subject in each group. Separate ANOVAs (group x blocks) were made for each error score based on the transfer trials.

Insert Table 2 about here

Results and Discussion

Amount of KR

The mean number of trials on which knowledge of results was given (per block of 8 trials) in both bandwidth conditions is shown in Table 2 for the acquisition trials. For the BW5 group, the mean number of KR trials received ranged from 5.4 trials for block 1 to 3.6 trials for block 11. Across all acquisition trials, subjects in the BW5 group received an average of 4.5 KR trials per block of trials, or on an average of 56% of the trials. For the BW10 group, the mean number of KR trials received ranged from 3.2 trials on block 6 to 1/7 trials on block 10. For all acquisition trials, subjects in the BW10 group received an average of 2.6 KR trials per block of trials, or an average of 32% of the trials. Clearly, the KR manipulation in the present experiment was successful in varying the number of KR trials given each group with KR given on 32%, 56% and 100% of the trials for the BW10, BW5 and KR groups, respectively.

Insert Figure 3 about here

Constant Error

The mean within-subject CE in MT is shown in the lower portion of Figure 3 for each block and group for both the acquisition and transfer trials. For the acquisition trials, all the CEs were positive, indicating responses slower than the goal MT. There appeared to be a general increase in CE with practice, but the effect of block was not significant, $\underline{F}(11,330) = 1.5 \leq \underline{p} > .05$. The BW5 and BW10 groups tended to show higher CEs for blocks 8 through 12, compared to the KR group which showed higher CEs in blocks 3 and 4. However, the effect of KR condition, $\underline{F}(2,30) < (1$, and the condition by block interaction, $\underline{F}(22,330) = 1.2$, $\underline{p} > .05$, were not significant.

For the no-KR transfer trials, again all CEs were positive, with a slight increase in CE occurring as blocks increased. The effect of blocks, however, was not significant, $\underline{F}(2,60) < 1$. All groups tended to show increases in CE from the first to the third transfer block, but the effect of KR condition, $F(2,30)<1$, and the condition x block interaction, $F(4,60)<1$, were not significant.

Variable Error (VE)

The mean within-subject VE in MT is shown in the upper portion of Figure 3 for each block and group for both acquisition and transfer trials. Between the first and last block of the acquisition trials, VE tended to decrease with practice, the decrease being about 10, 9, and 7 msec, for the BW5, KR, and BW10 groups, respectively. The effect of blocks was significant, $F(11,330) = 6.1$, $p<.05$. There did not appear to be a large effect of KR with the VE for all groups showing a great deal of overlap, except for blocks 4 through 7 where the KR group appeared to have less VE than either of the two bandwidth groups. However, the effect of KR condition, $F(2,30)<1$, and the condition x blocks interaction, $F(22,330) = 1.0$, $p>.05$, were not significant. Unlike the first experiment, bandwidth KR did not reduce the VE compared to the control condition during acquisition.

For the no-KR transfer trials, however, there appeared to be some effect of KR, the mean VE being 11.3, 13.7, and 14.8 msec, for the BW10, BW5, and KR groups, respectively. The effect of KR condition was significant, $F(2,30) = 3.4$, $p<.05$, suggesting that subjects respond more consistently during transfer after practicing under KR bandwidth conditions. A post-hoc analysis using the "T-method" (Glass and Stanley, 1970), revealed that the mean VE of the BW10 group was significantly less than both the BW5 and the KR groups. There was no difference between the BW5 and the KR group. There also appeared to be some interaction between KR condition and block, with the BW10 and KR groups showing an inverted-U function with blocks while the BW5 group showed systematic decreases in VE with blocks. However, the effect of blocks, $F(2,60) = 1.1$, $p>.05$, and the KR condition x blocks interaction, $F(4,60)<1$, were not significant.

Total Variability (E)

The mean within-subject E about the goal MT is shown in Figure 4 for each block and group for both acquisition and transfer trials. During acquisition, E generally decreased between the first and last blocks, the decrease being 10, 10, and 6 msec for the BW5, KR, and BW10 groups, respectively. The effect of blocks was significant,

$F(11,330) = 5.6$, $p<.05$. There appeared to be almost no effect of KR condition, with a great deal of overlap shown between the E scores for all groups. The effect of KR condition, $F(2,30)<1$, and the condition x block interaction, $F(22,330) = 1.2$, $p>.05$, were both not significant.

Insert Figure 4 about here

For the transfer trials, there appeared to be an effect of KR condition with the BW10 group showing less E than the other two groups, the mean Es being 15.9, 19.0, and 19.9 msec for the BW10, KR, and BW5 groups, respectively. The effect of KR condition was significant, $F(2,30) = 3.2$, $p<.05$. A post-hoc analysis revealed that the BW10 group performed better (i.e., showed a lower E) than either the BW5 or the KR group. No difference in E was found between the BW5 and the KR group. Therefore, during transfer, the subjects in the BW10 group not only performed more consistently, but also showed better overall accuracy compared to the BW5 and KR groups. There also appeared to be an interaction between KR conditions and blocks with the BW10 and KR groups showing an increase in E with blocks while the BW5 group reduced E with blocks. However, the effect of blocks, $F(2,60) <1$, and the conditions x blocks interaction, $F(4,60)<1$, were both not significant.

Overall Discussion

The two experiments suggest that using the bandwidth KR method has both a temporary "performance" effect and a relatively permanent effect on the learning of a rapid limb movement. Experiment 1 showed that bandwidth KR resulted in more consistent performance than conditions where KR was given on every trial. In addition, constant errors tended to be larger and overall variability smaller in the BW condition compared to the KR condition, but the differences were small and not significant. The second experiment showed that bandwidth KR had a relatively long-term effect with the BW10 group showing more consistent performance during transfer than either the BW5 or the KR group. Experiment 2 failed to confirm the earlier finding that VE was reduced during acquisition in the BW groups. Perhaps the subjects in the second experiment, with more practice, would have shown the same pattern of results as the first experiment, as suggested by the VEs in the final 4 blocks of acquisition.

The experiments also suggest that better final performance is attained when fewer KR trials are given during acquisition. Although this finding is counter to early work on KR (Bilodeau, Bilodeau, & Shumsky, 1959; Adams, 1971) the present work agrees with the more recent work of Johnson, Wicks, and Ben-Sira (1980) who showed that final performance on a positioning task was inversely related to the percentage of trials on which KR was given during acquisition. This type of result where the group receiving the "more difficult" condition during acquisition performs better during transfer, has been interpreted in light of the "depth of processing" notion (Craik & Lockhart, 1972). Perhaps the subjects in the BW10 group, without KR on every trial, had to work harder to learn the task. They may have needed to process feedback from the limb more completely knowing that KR may not be given to help generate the correct response on the next trial. Because greater "depth" may have been required during acquisition, the BW10 group was better able to perform during the no-KR transfer trials.

However, the performance advantage of bandwidth KR appears to be limited to bandwidths greater than or equal to 10% of the goal MT. A 5% bandwidth did not result in more consistent or better overall performance than the KR group in Experiment 2. A 15% bandwidth in the first experiment was wide enough to produce advantageous effects over the KR condition. Whether or not performance advantages are a function of bandwidth size remains to be seen. The present research suggests that a bandwidth between 10% and 15% may be optimal for enhancing both short- and long-term performance.

Finally, if one can assume that the reduced VEs in the bandwidth conditions are due, in part, to the subject reducing the tendency to change the intended response from trial to trial, then the bandwidth KR method provides a valid technique for examining the assumptions and predictions of the "impulse" models where the subject's "intent" is assumed to be constant from trial to trial.

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Author's Notes

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Table 1

The Number of KR Trials in the Bandwidth

Condition in Experiment 1 for Each Block (20 Trials/Block)

Block

Subject	1	2	3	4	5	6	7	8	9	10	Sum
1	3	2	0	2	1	0	1	2	0	0	11
2	6	4	3	2	1	1	0	1	1	0	19
3	3	2	2	1	0	0	1	0	1	0	10
4	4	2	0	1	0	1	1	0	1	0	10
	16	10	5	6	2	2	3	3	3	0	50
										mean	12.5

Table 2

The Mean and SD sof the Number of KR Trials

for the Bandwidth Groups in Experiment 2

(per block of 8 trials)

Group	1	2	3	4	5	6	7	8	9	10	11	12	Mean
5% BW													
Mean	5.4	4.8	3.9	4.6	4.4	4.7	4.3	4.9	4.7	3.9	3.6	4.8	4.5
SD	1.2	1.1	1.4	1.2	1.4	1.7	1.6	1.7	2.3	1.4	1.8	2.1	
10% BW													
Mean	3.0	2.5	2.5	2.9	2.4	3.3	3.1	2.9	2.3	1.7	2.6	2.1	2.6
	1.4	2.4	1.5	1.6	1.3	1.4	1.4	1.7	1.7	0.8	2.1	1.1	

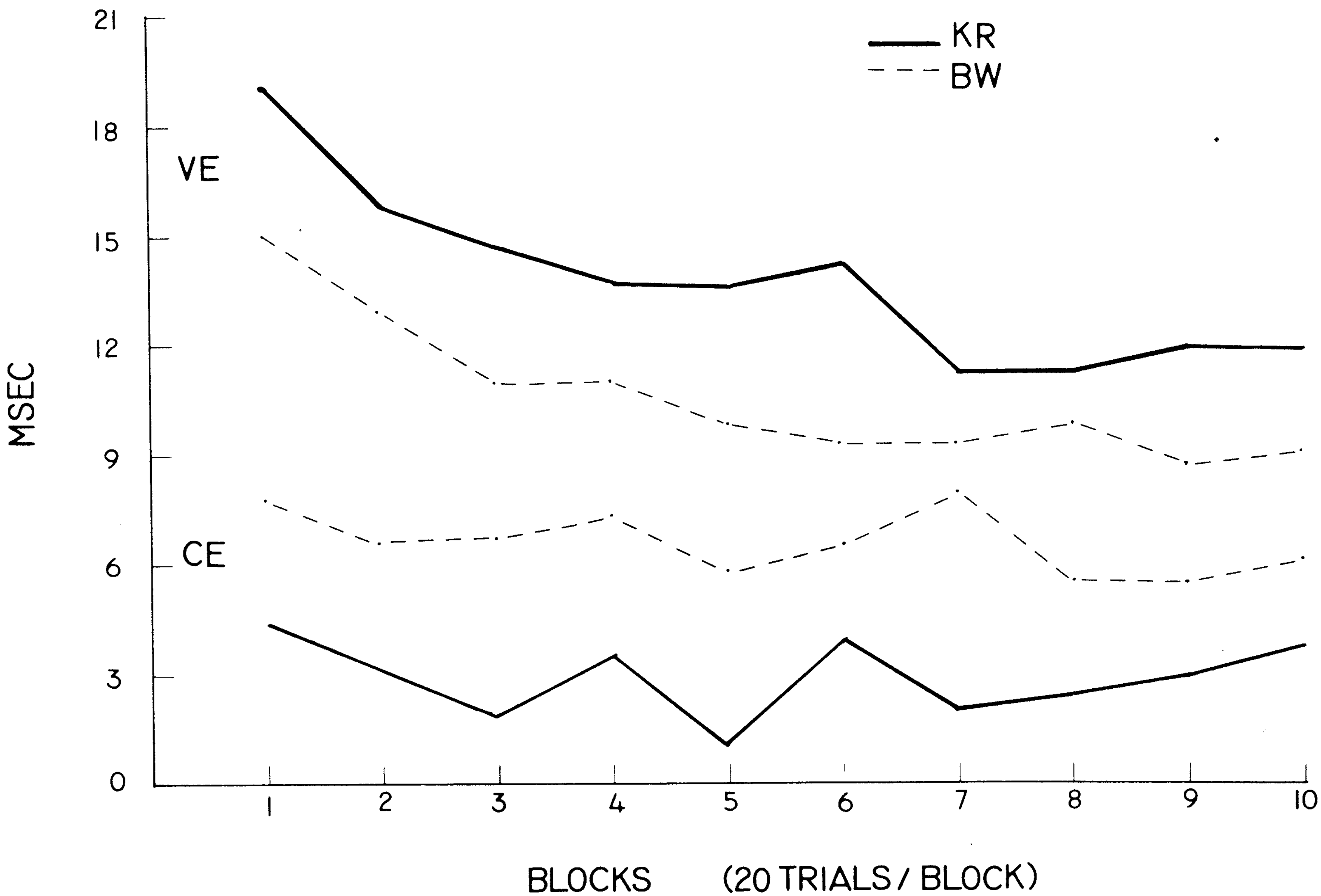
Figure Captions

Figure 1. Constant error (CE) and variable error (VE) in movement time as a function of practice and KR condition in Experiment 1.

Figure 2. Overall variability (E) in movement time as a function of practice and KR condition in Experiment 1.

Figure 3. Constant error (CE) and variable error (VE) in movement time as a function of practice and KR condition for acquisition and transfer trials, Experiment 2.

Figure 4. Overall variability (E) in movement time as a function of KR condition and practice for acquisition and transfer trials, Experiment 2.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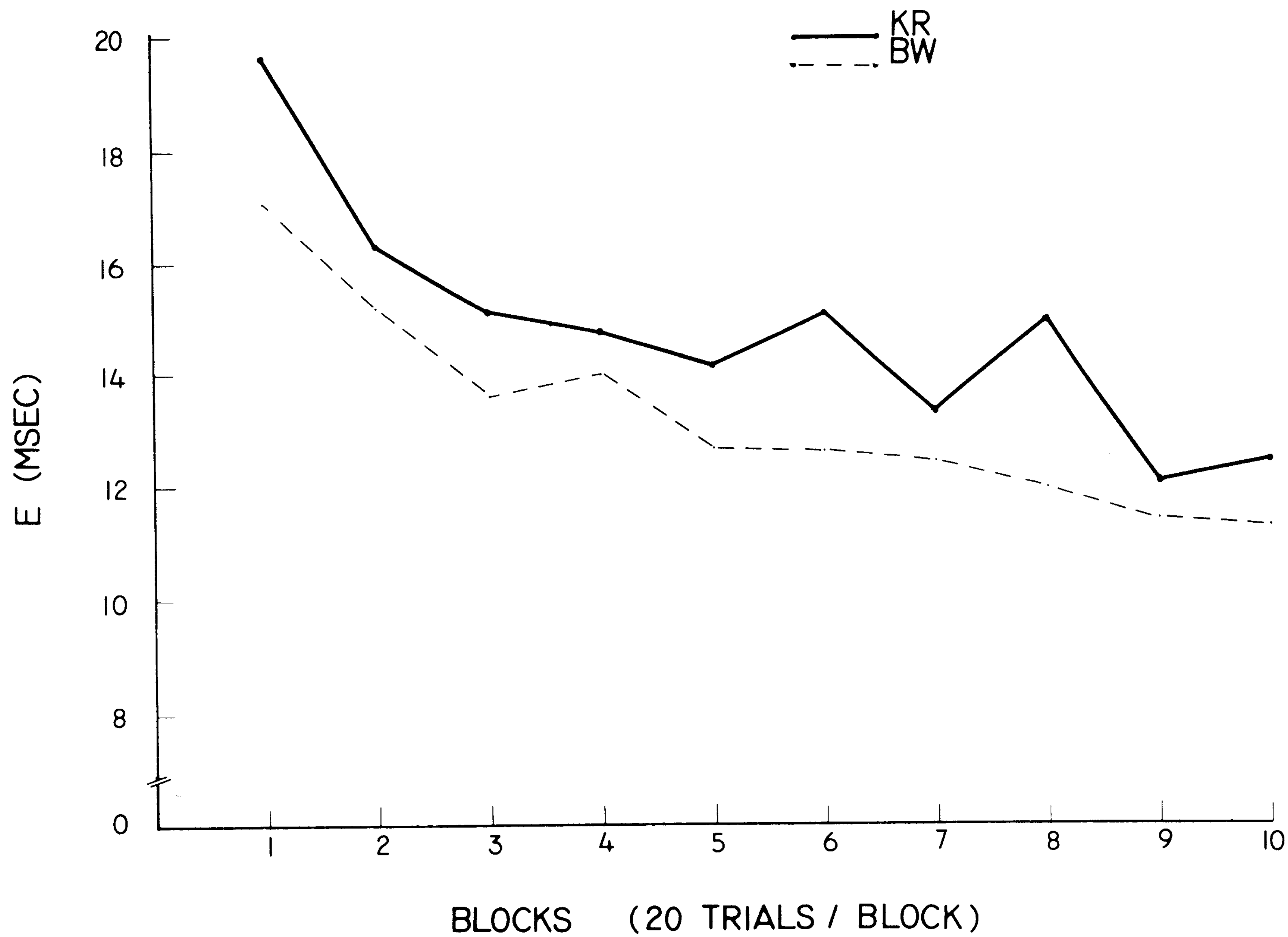
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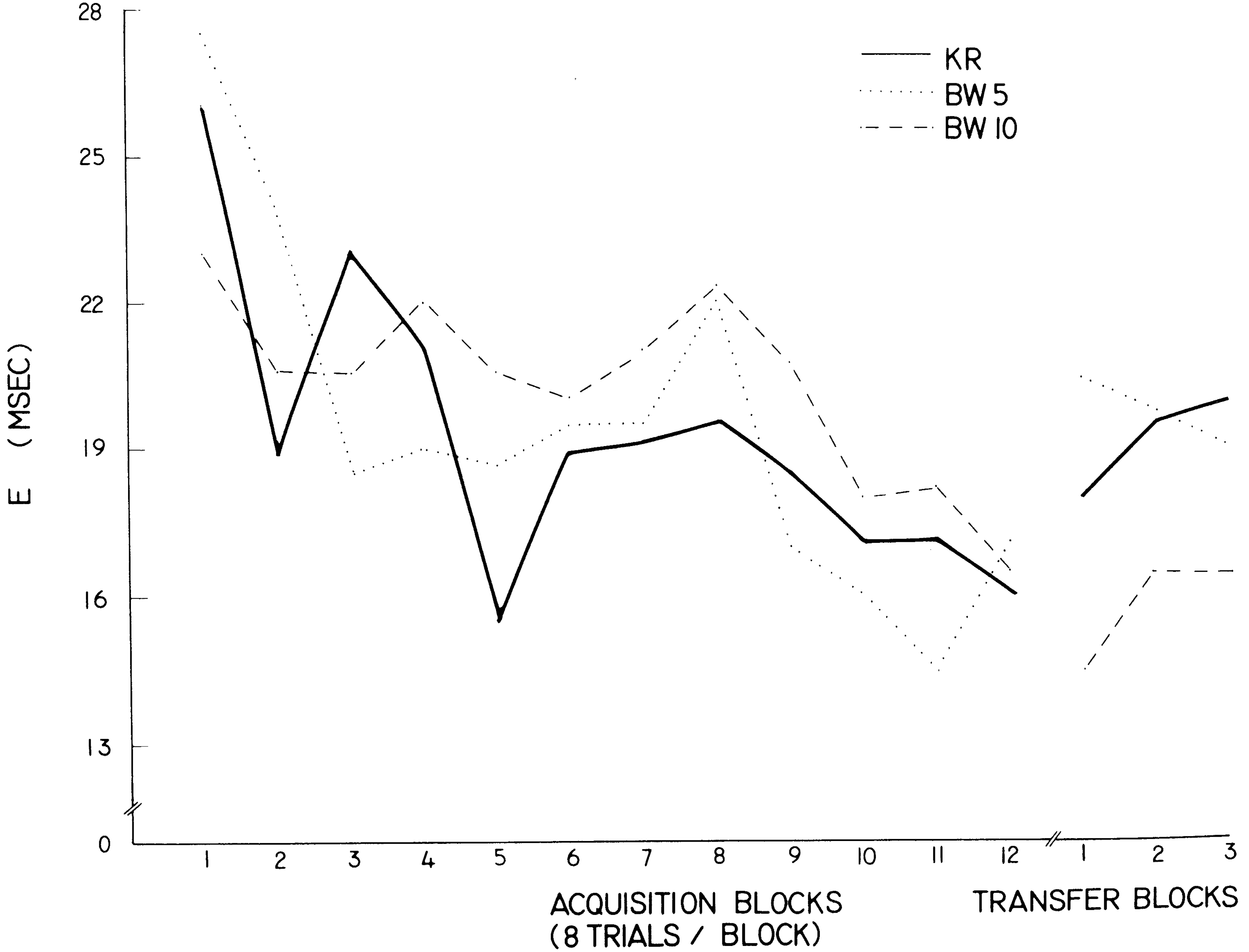
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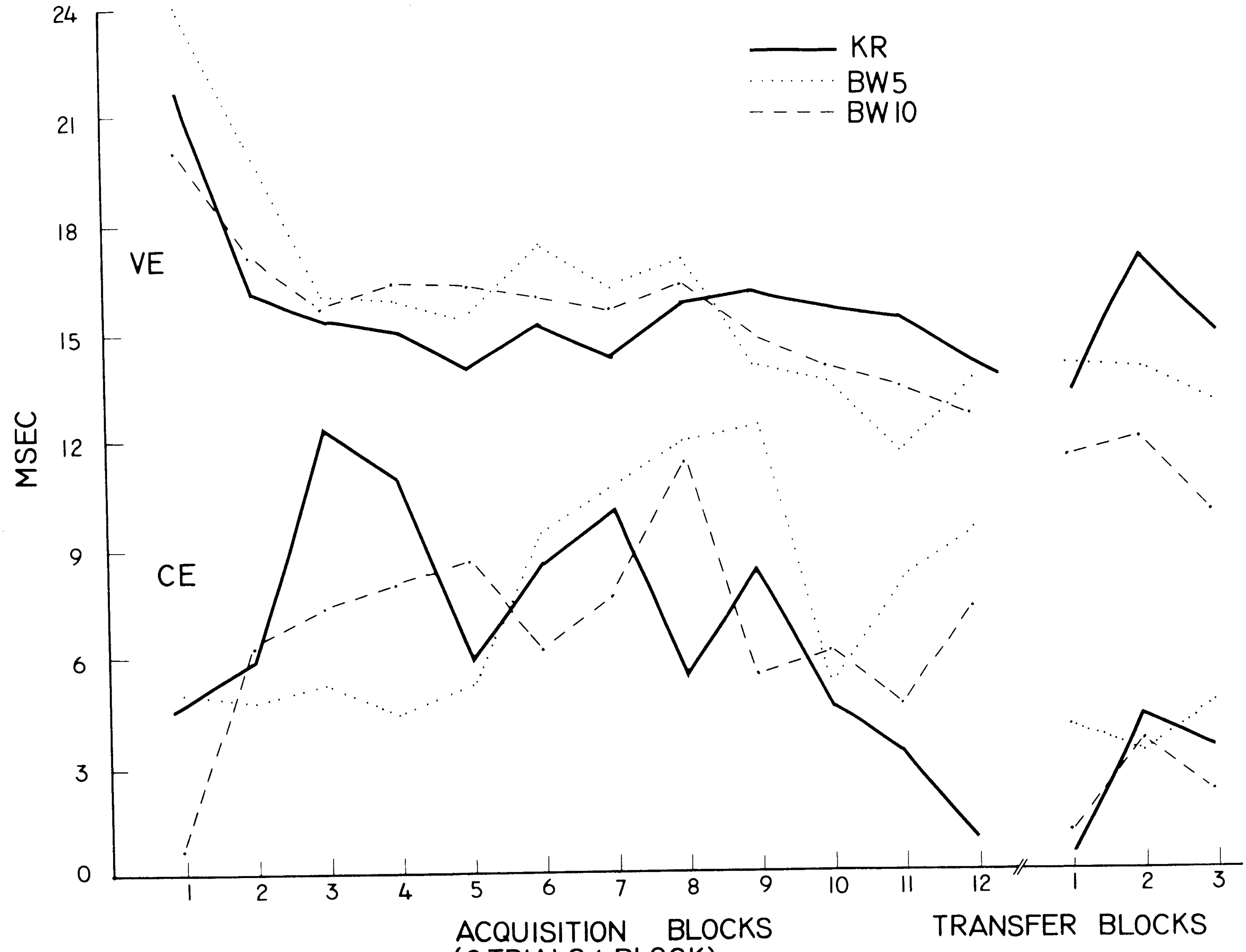

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