Post-Knowledge of Results Delay:

Effects of Interpolated Activity on Learning and Performance

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Abstract

The present study investigated the theoretical assumption of Adams' (1971) closed-loop theory that KR processing during the early stage of acquisition is of a verbal-cognitive nature. This assumption was tested by requiring subjects to perform a verbal task during the post-KR delay interval. To overcome the shortcomings of previous studies, a ballistic response served as the criterion task and subjects performed on a paced interpolated activity. The design was 2 x 2 factorial with 5 or 10 second post-KR delay and interpolated activity present or absent. In contrast to many previous post-KR delay studies, interpolated activity interfered with subjects' ability to learn and perform the criterion movement time of 150 msec. Both memory and perceptual trace measures were similarly affected.

Post-Knowledge of Results Delay and Interpolated Activity

Experimental evidence strongly supports the theoretical assumption that knowledge of results (KR) is necessary for learning to occur (Adams, 1971; Bilodeau, 1969; Newell, 1974). The question of interest to the present study concerns the temporal locus of KR and the information processing requirements during the post-KR interval. According to Adams (1971), the post-KR delay is the time during which the learner processes KR information by comparing it to response-produced stimuli and decides on error correction for subsequent responses. Interfering activities during the post-KR interval would presumably interfere with KR processing. Generally, interpolated motor activities have not caused detrimental effects on performance during acquisition (e.g. Hardy, 1983) but this is not unexpected since theoretically the post-KR delay interval is of a verbal cognitive nature (Adams, 1971). An exception to this generalization is a recent study by Lee and Magill (1983). Verbal activities, however, should interfere with KR processing during the post-KR interval and cause poorer performance during acquisition.

Empirical evidence has not completely supported this theoretical assumption (Boucher, 1974; Magill, 1973, 1977). Studies interpolating verbal activity in the post-KR delay interval predicted decrements in performance based on the idea that the learner's information processing capacities were limited. That is, verbal activities interpolated in the post-KR delay supposedly compete with the ongoing processes of KR interpretation and utilization. To test this prediction, Magill (1973) had four experimental groups perform a slow angular positioning task using post-KR intervals filled with verbal activity, motor activity, or rest. Post-KR intervals for the two rest groups were 2 and 30 seconds, and the verbal and motor activity groups had 30-sec. post-KR delays. The treatment effects were non-significant, indicating that neither length of post-KR delay nor interpolated activity effected the rate of acquisition. In a subsequent study, Boucher (1974) employed a linear positioning task of 10 cm with post-KR delays of 3 or 10 sec which were filled with rest or verbal activity (reading difficult words). The results indicated that interpolated verbal activity interfered with performance during the first two blocks of trials only. Apparently, practice reduced the interfering effects of the verbal activity. A more recent study by Hardy (1983) similarly demonstrated the detrimental effect of interpolated activity on acquisition rate.

These studies did not provide strong evidence for the verbal nature of KR processing, but several methodological problems were evident which could account for the results. The use of a slow task could have allowed the subject to process KR information during the subsequent movement. Magill's task was extremely easy, and control of the post-KR delay may have been inadequate. Subjects were told the criterion movement was 75 degrees, and it seems reasonable to assume that the subjects were familiar with this distance, reducing the importance of the information contained in KR. Following incorrect responses, the subject's arm was moved to the correct position to provide KR for that trial, reducing processing requirements that would normally be associated with the quantitative verbal KR. Furthermore, subjects remained at the criterion position for 2 sec, then returned to the starting position in 2 sec before post-KR treatments were administered. Therefore, all groups had 4 sec of post-KR delay without any interpolated activity. This amount of time might have been sufficient for KR processing on such a simple positioning response. Subjects in both the Magill and Boucher studies were not required to estimate their movement distance prior to receiving KR. This would presumably reduce processing requirements also, perhaps resulting in the secondary activity effects lasting only over the first two blocks of trials as found by Boucher (1974).

In a subsequent study, Magill (1977) employed a serial-positioning task requiring three angular movements in a given order on each trial. Post-KR delays were 12 or 60 sec, with verbal, motor, or no interpolated activity. Once again, neither delay nor interpolated activity affected the rate of acquisition. The control of post-KR activity manipulations was better than the previous study

(Magill, 1973), and subjects received verbal KR in the form of degrees of error from the criterion, but the above criticisms about using a slow, relatively familiar, positioning response apply to this study as well. Also, KR consisted of three numbers corresponding to the three angular movements so some processing could have occurred during KR administration. Perhaps separate learning data on each movement within the serial-positioning task would have revealed this effect, with slower acquisition occurring on the third angular movement. Unlike previous studies, Magill reported data in terms of variable error instead of absolute error, making comparisons difficult between the two studies.

A more recent study by Lee and Magill (1983) examined the nature of the activity during the post-KR delay to determine possible differential effects on learning and performance. In contrast to previous studies, the motor and non-motor interpolated activities were presumed to be of a similar nature since both types of activities were goal-directed and required the subjects to process error information. Results indicated that both interpolated motor and verbal activity adversely affected performance of the primary task of knocking over barriers in a criterion time of 1050 msec. Results for the retention phase produced no group difference suggesting that learning was not affected by interpolated tasks during the post-KR delay.

Schendel and Newell (1976) had previously reviewed the early studies by Magill (1973) and Boucher (1974), and discussed several problems which needed to be corrected before conclusions about the effects of secondary activity in the post-KR interval could be made. Most importantly, it was suggested that a slow task may allow the subject to process KR during the movement, and uncontrolled and unmeasured interpolated tasks may permit subjects to regulate the difficulty of these tasks by switching attention from the interpolated task to KR processing.

The recent experiment by Lee and Magill described above failed to correct these problems. The task employed required subjects to knock over three barriers in 1050 msec and due to the rather slow nature of this task, subjects may have processed KR during this movement. The non-motor interpolated activity required subjects to guess a three digit number. Subjects were provided feedback in an attempt to require them to process cognitive information, but the rather lengthy 15 sec post-KR interval may well have left sufficient time to process KR from the primary task. The motor interpolated activity required subjects to knock over barriers in a similar fashion required by the primary task except the criterion time was extended to 1350 msec. This condition produced an effect on acquisition but not retention leading the authors to suggest that "post KR activity may not be a variable which adversely affects learning" (p. 343). However, constant error results suggested that the motor activity may have produced a biasing effect.

The present experiment attempted to correct some of the problems inherent in previous studies by using a ballistic timing task instead of a slow positioning response or a slow timing response. To eliminate the problem of subject regulation of the difficulty of the interpolated activity, a paced and measured interpolated task was used. Subjects were presented with addition problems at a fixed rate instead of counting or reading at their own pace.

Several hypotheses derived from Adams' (1971) theory were tested. First, verbal interpolated activity (IPA) in the post-KR delay interval should cause poorer performance than rest during both acquisition and KR withdrawal trials. Second, performance should worsen when KR is withdrawn because IPA during acquisition and the relatively moderate level of training will cause the development of relatively weak memory and perceptual traces. Third, since both the memory trace and perceptual trace depend on KR acquisition trials no differential effects would be expected during acquisition. However, IPA interference with the subject's ability to compare response-produced feedback and KR during acquisition might result in development of a weaker perceptual trace which would decrement more than the memory trace during KR withdrawal.

The use of a ballistic task, a paced and measured verbal interpolated activity, and constant interresponse interval should provide results which give a more definitive answer to the question of the nature of KR processing posed by Magill (1973, 1977), Lee and Magill (1983), and Boucher (1974). Secondarily, differential effects on the perceptual and memory trace measures would provide added support for the two-state mechanism proposed by Adams (1971).

Method

Subjects

Sixty right-handed volunteer subjects were selected from the female student and staff population of the University of California, Davis. The testing order was randomly determined, and upon arrival at the testing room subjects were assigned by order of appearance to one of the four treatment groups (N=15).

Apparatus

The hand-movement apparatus was a 30.5 cm. x 15.2 cm. x 6.4 cm wooden box on which two microswitches were mounted 24.03 cm apart. A 5.1 cm high barrier running the width of the box was located next to the right microswitch to serve as a guide for the subject when resting her hand on the apparatus. The other microswitch was located beneath a hinged 15.2 cm square wooden barrier.

The apparatus was fixed to a table and was covered by a cardboard box with a 31.8 cm x 20.3 cm opening. The subject sat in a chair with her right shoulder perpendicular to the apparatus and her hand resting on the starting button. A Lafayette digital timer started when the subject's hand left the microswitch and stopped when the hinged barrier was contacted.

In front of the subject on another table was a modified memory drum. The viewing area of the memory drum was covered by four 5.1 cm. wide plexiglass plates which could be raised individually by means of four solenoids mounted on top of the memory drum. A steel rod was attached to the drum-rotation control so the experimenter could start the drum at the proper time during each trial.

Four columns with 28 addition problems in each were typed on a sheet of paper and mounted on the memory drum. The numbers were chosen in pairs from a table of random numbers excluding zeroes and same-number pairs.

Just above and behind the memory drum was a 30.5 cm square panel on which a green light signalling movement initiation was located. This panel also served to shield the experimenter from the subject's view.

Procedure

The subject was seated in a chair facing the memory drum while the experimenter read the instructions. The task requirement of learning to move from the right microswitch to the hinged barrier in exactly 150 msec. was explained. For those subjects in the interpolated activity groups, the instructions included a description of the procedure for answering the problems on the memory drum. Subjects were told to answer the problem by announcing the sum of the two numbers and indicating whether this sum was odd or even.

The green light signalled the subject to make the hand movement. Following completion of the movement, the subject gave the experimenter an estimate of her movement time. After a 10 or 15 sec delay, depending on experimental group, the subject was told her actual movement time. Subjects in the No-IPA groups then rested until presentation of the next green light.

For those subjects in the IPA groups, simultaneous with the end of the presentation of KR, one of the four columns on the memory drum opened, presenting the subject with addition problems at a rate of one per second. Subjects were told to answer the problems by announcing the sum of the two numbers and then declaring whether the answer was odd or even. Performance was recorded on a tape recorder.

After the presentation of 5 or 10 problems, depending on experimental group, the column closed, and the green light came on signalling the subject to make the next hand movement. After Trial 30, the experimenter explained that during the remaining 20 trials the subject would continue to move in response to the green light and to give an estimate of her movement time but would not receive

KR. Subjects in the IPA groups were no longer presented with addition problems. The final 20 trials were then completed.

Design

Two levels of post-KR delay (5 and 10 sec) were factorially combined with two levels of interpolated activity (present or absent) to yield four experimental groups. Each subject completed 50 trials consisting of 30 KR trials followed by 20 no-KR trials. The interresponse interval was constant at 20 sec resulting in KR delays of 15 and 10 sec. This design was chosen because KR delay had not been shown to effect performance, but interresponse interval had (Bilodeau & Bilodeau, 1958; Denny, Allard, Hall & Rokeach, 1960; Macpherson, Dees, & Grindley, 1949).

Results

Absolute movement error, that is the absolute difference between actual movement time and 150 msec, was used to measure the strength of the memory trace. Figure 1 presents the block means of the four treatment groups.

Insert Figure 1 about here

Results of the 2 x 2 x 6 ANOVA for the KR acquisition trials indicated the main effect of IPA was significant, F (1, 56) = 8.07, $p < .01$, with the IPA groups (M = 41.28) exhibiting larger error than the No-IPA groups (M = 27.15). Therefore, IPA interfered with the subject's ability to perform the criterion movement of 150 msec. As expected, absolute error significantly decreased over blocks, F (5, 280) = 7.97, $p < .01$. Tukey's post hoc analysis (Kirk, 1968, p. 88) revealed that Block 1 error was significantly larger than Blocks 3, 4, 5, and 6 ($p < .01$). The main effect of post-KR delay and all interactions were not significant.

Results of the 2 x 2 x 4 ANOVA for phase two indiated that the significantly larger absolute error for the IPA groups (M = 40.97) as opposed to the No-IPA groups (M = 27.76) persisted in the KR withdrawal trials, F (1, 56) = 5.38, $p < .05$. None of the other main effects or interactions were significant over the no-KR trials.

All four experimental groups showed an increase in absolute error when KR was withdrawn, but paired t tests between the means of Block 6 and 7 indicated the decrement in performance was significant for the 5 and 10-sec No-IPA groups only, t (14) = 2.21, 2.83, $p < .05$, respectively.

The measure used to indicate perceptual trace strength was objective-subjective (O-S) difference, which is the absolute difference between the subject's estimated movement time and actual movement time. Figure 2 presents the block means for the four treatment groups.

Insert Figure 2 about here

Results of the 2 x 2 x 6 ANOVA for the KR acquisition phase revealed a significant main effect of IPA, F (1, 56) = 10.76, p < .01. Inspection of the means indicated that the interpolated task (M = 31.73) made the recognition of the subject's own movement time more difficult than when no interpolated activity was required (M = 22.77). Significant reduction in error occurred over blocks F (5, 280) = 11.32 , p < .01. *Post hoc* analysis by Tukey's test indicated that Block 1 had significantly larger error than all others (p < .01). The main effect of post-KR delay and all interactions were not significant.

The 2 x 2 x 4 ANOVA of the O-S difference error for the KR withdrawal trials revealed the persistence of a significantly larger error for the IPA groups (M = 36.95) than the No-IPA group (M = 27.73), F (1, 56) = 6.11, p < .05. None of the other main effects or interactions were significant.

Figure 2 indicates that all groups had a decrement in performance when KR was withdrawn. Paired t tests on the O-S difference between Blocks 6 and 7 revealed that the increases in error were significant for the 5-sec. No-IPA, 5-sec. IPA, and 10-sec. No-IPA groups, t (14) = 2.36, 2.54, 2.93, $p < .05$, respectively. In general, IPA caused poorer performance during acquisition and KR withdrawal. KR withdrawal however, tended to affect the No-IPA groups more than the IPA groups.

Discussion

The present experiment was designed to resolve the conflicting results reported by Magill (1973, 1977), Lee and Magill (1983), and Boucher (1974) in testing Adams' (1971) closed-loop theory. Several changes were incorporated in the design to alleviate the methodological problems of the previous studies (Schendel & Newell, 1976). The two primary differences were the use of a paced secondary activity and a ballistic criterion task.

The most significant finding was that a paced verbal interpolated activity in the post-KR delay causes poorer performance on a simple ballistic task. In this study performance on the interpolated task was measured by calculating the number of correct responses made on each trial. Performance for both groups is shown in Table 1 and indicates that subjects improved their performance over trial blocks. Since performance was less than 100 percent, it can probably be assumed that subjects were still using considerable capacity to respond to the numbers and had little if any time available for KR processing.

Subjects required to perform the interpolated activity reduced movement errors at the same rate as subjects who rested during the post-KR delay interval, but their overall level of error was higher. This result supported Adams' (1971) contention that performance and learning is dependent on the processing of KR.

Insert Table 1 about here

One of the generalizations from closed-loop theory (Adams, 1971) states that performance should worsen when KR is withdrawn if activity has been present in the post-KR delay interval during acquisition. Results from the memory trace measure indicated that performance for the IPA groups did not significantly worsen from the last KR trial block to the first no-KR trial block, whereas performance for the No-IPA groups did. It should be noted that interpolated activity performance was not required during KR withdrawal which perhaps made it easier for subjects to maintain their prior level of responding. Subjects in the IPA groups were not able to process KR as well as those in the No-IPA groups so they may not have been as dependent upon its presence to maintain performance. These conclusions must be considered speculative however, since those groups not showing significant performance decrements were also characterized by larger amounts of variability which may have obscured the effects of KR withdrawal.

In the present experiment interpolated activity affected the memory and perceptual traces similarly. An observation which indicated at least a difference in the function of KR for the two traces was the tendency for O-S difference to be less than absolute error. Similar to the findings of Newell (1974), KR seemed to provide information which was more useful for recognizing movement time than for changing the response to meet the desired criterion. An alternative explanation of this tendency is that subjects may become more concerned about making a correct estimate than reaching the criterion of 150 msec. This explanation is supported by the experimenter's observations during testing. Many subjects had to be reminded of the criterion response even though their estimates indicated they were aware of their actual movement time.

In conclusion, the present experiment has provided a more stringent test of the effect of the interpolated activity during the post-KR delay than previous studies. Although Salmoni, Schmidt and Walter (1984) suggested that the Lee and Magill (1983) task was "rapid" (p. 372), the barrier timing task they used with a criterion time of 1050 msec may have allowed subjects to process KR during the movement. Also, it appears as though both the verbal and motor interpolated activities did not completely fill the 15 sec post-KR delay interval thereby leaving sufficient time to process KR during this time. In agreement with Adams (1971, p. 136), this study demonstrated that "the proper choice of verbal-cognitive responses should be able to show an effect" and indeed this was illustrated in the present study. Further insight into the capacity requirements of KR processing could be gained by varying the difficulty of paced interpolated activities during the post-KR delay. In the present study, IPA was not shown to differentially affect the memory and perceptual traces. If we presume that comparison of KR with response-produced feedback and initiation of the next response occur sequentially, then it may be possible to show differential IPA effects on the two traces if the position of interpolated activity is varied during the post-KR delay. Activity at the beginning of the interval might be expected to cause decrements in the perceptual trace since subjects would presumably be comparing feedback to the KR at that time. Interpolated activity at the end of the interval might more likely interfere with response selection and initiation, a responsibility of the memory trace.

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Table 1

Interpolated Activity Performance

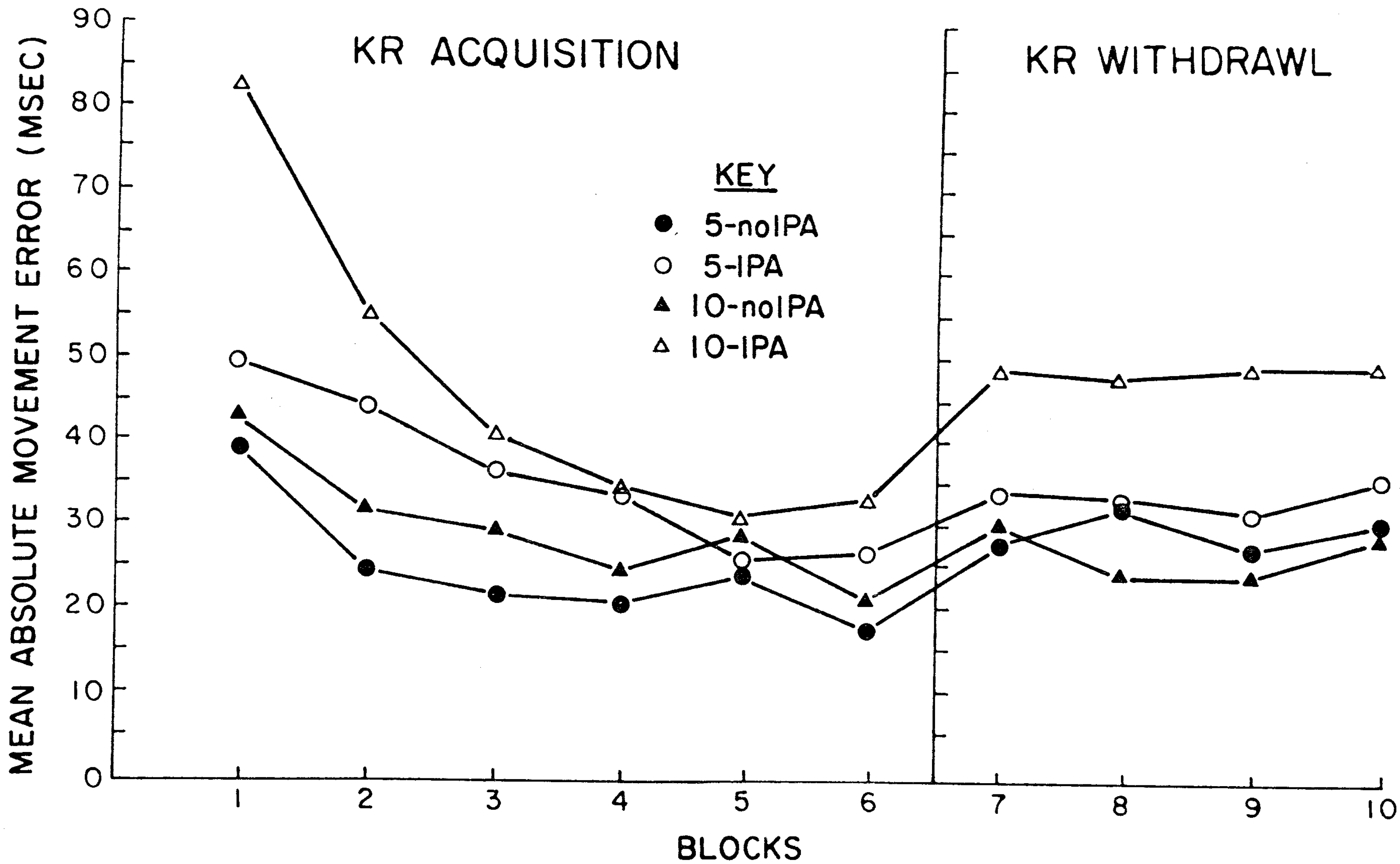
Group	Block 1	2	3	4	5	6
5 IPA	79.7	85.9	88.8	87.6	91.3	90.5
10 IPA	83.1	82.9	87.8	85.8	85.3	86.7

Note. Performance is given as percent correct.

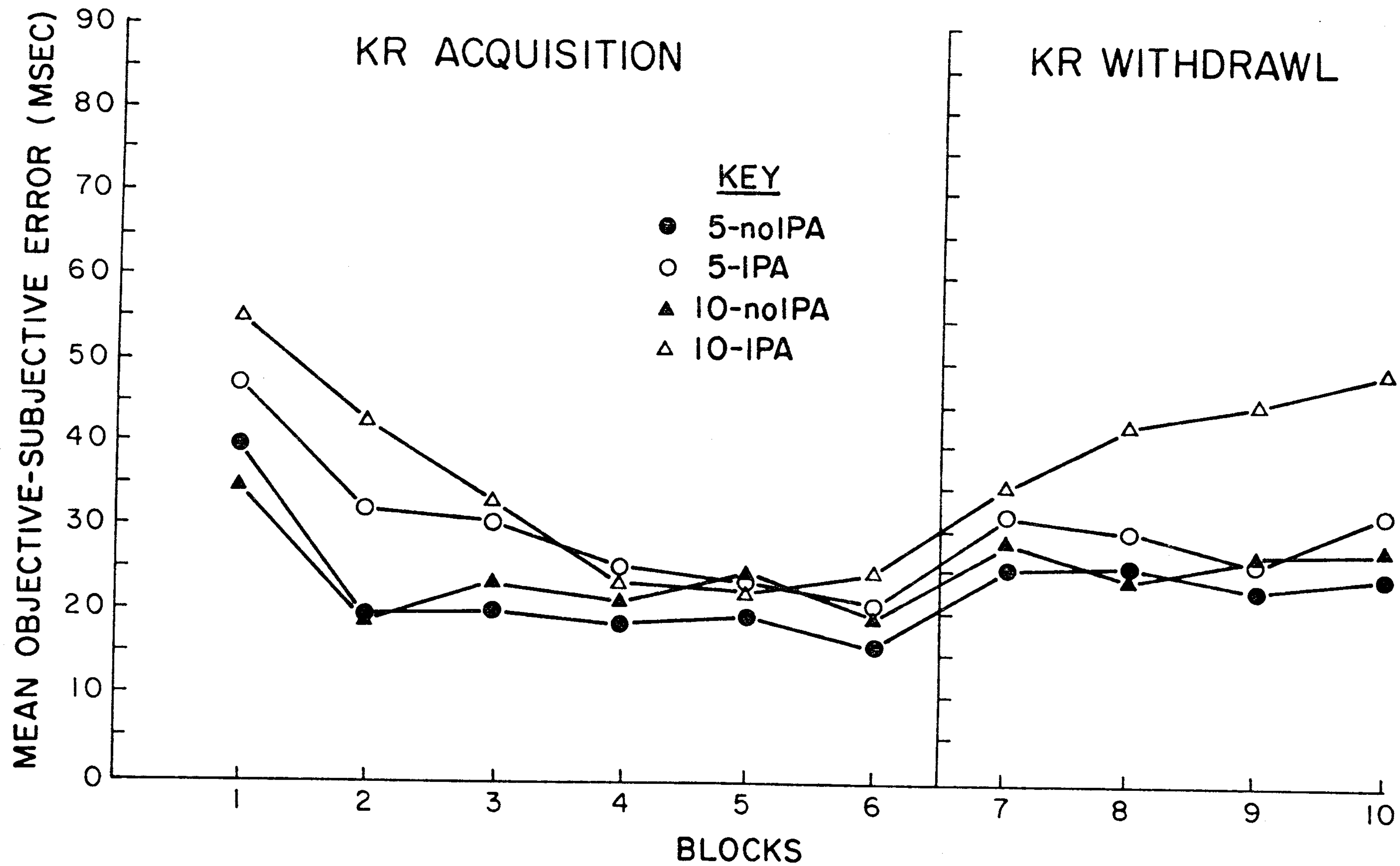
Figure Captions

Figure 1. Mean absolute movement error for all groups across trial blocks (MSEC).

Figure 2. Mean absolute estimated movement error for all groups across trial blocks (MSEC).



KR ACQUISITION
KR WITHDRAWL
KEY
5-noIPA
5-IPA
10-noIPA
10-IPA
MEAN ABSOLUTE MOVEMENT ERROR (MSEC)
0
10
20
30
40
50
60
70
80
90
1
2
3
4
5
6
7
8
9
10
BLOCKS



KR ACQUISITION
KR WITHDRAWL
KEY
5-noIPA
5-IPA
10-noIPA
10-IPA
MEAN OBJECTIVE-SUBJECTIVE ERROR (MSEC)
0
10
20
30
40
50
60
70
80
90
1
2
3
4
5
6
7
8
9
10
BLOCKS