UNIVERSITY OF ALBERTA

THE EFFECT OF REPETITION ON THE ACQUISITION AND LEARNING OF A MOTOR SKILL

BY

© JAMES (JAY) PRATT

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE

DEPARTMENT OF PHYSICAL EDUCATION AND SPORT STUDIES

EDMONTON, ALBERTA

FALL, 1991

ISBN 0-315-70199-4

UNIVERSITY OF ALBERTA

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NAME OF AUTHOR: JAMES (JAY) PRATT

TITLE OF THESIS: THE EFFECT OF REPETITION ON THE ACQUISITION AND LEARNING OF A MOTOR SKILL

DEGREE: MASTER OF SCIENCE

YEAR THIS DEGREE GRANTED: 1991

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ABSTRACT

Two experiments were developed to test for the effects of repetition in motor skill acquisition and learning. A line drawing task was used, with the following factors controlled for: a) the amount of movement supplied feedback available to the subject, b) the distinction between performance effects and learning, and c) the total-time hypothesis. The overall effect of repetition on both acquisition and retention performance was found to be negligible. The lack of a repetitions effect in the no-KR acquisition trials is thought to be due to the subjects inability to form a mental representation of the motor act. In retention, the null effect of repetition may be due to the following: a) the inability of the subjects to form a mental representation of the motor act, b) insufficient number of acquisition trials, and c) not sufficient task difficulty. The results from the two experiments highlight the need for future research concerning the role of repetition in skill acquisition.

ACKNOWLEDGEMENT

I would like to thank Dr. R.B. Wilberg, my advisor and my friend, for constantly inspiring and challenging me over the course of my time in "the Lab". Through the seminars, the countless discussions, runs, and even mountain bike rides, it is hard to conceive of a more resourceful and thought provoking advisor than Bob.

I would also like to thank my parents, who waited a long time for their son to grow up and leave town to go to school.

Finally, I would like to thank Cam, Jim, Tina, Adonis, Jos, and Ian, who made working and learning in "the Lab" as pleasurable as it was profitable (and just a little bit strange).

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Introduction

The old adage of 'practice makes perfect' has long been a general rule of thumb for practitioners and motor learning researchers alike. An example of this 'rule' can be found in Salmoni, Schmidt, & Walter's (1984) review of knowledge of results (KR) literature in which they state that KR "is generally viewed as the most important variable for determining learning, except possibly for practice per se" (p. 355). Schmidt (1982) describes the importance of practice being "so obvious that it need hardly be mentioned at all" (p. 481). Despite the clear indications as to the importance of practice, relatively little is known regarding the principles of its operation.

In its simplest form, practice may be regarded as repetition. That is to say, repeated instances of a trial may be said to constitute the simplest form of practice. Examples of simple repetition leading to improved performance can readily be seen in hundreds of skilled activities; from shooting free throws in basketball, to video games, to the studying of various terms for an exam. However, despite masses of anecdotal evidence, the effect of repetition on the learning of motor tasks has often been overlooked by motor learning researchers.

The effect of repetition on motor skill acquisition has not been totally ignored. The behaviourists (e.g., Thorndike, 1927) suggested the repetition of the motor act strengthened the bond that connected a specific stimulus with a specific response. As the stimulus-response bond was strengthened, the subject's performance improved (to some asymptotic value, at which point the stimulus-response pair was thought to be 'learned'). The behaviourist doctrine of bond strengthening often required the use of a reinforcer, and the emphasis was subtly shifted from a repetition effect to a reinforcement or feedback effect. While the strengthening of the stimulus-response bond was adequate to handle relatively simple learning situations (i.e., one stimulus - one response), the complexity of human motor learning could not be accounted for within the behaviourist framework.

Coinciding with the decline of behaviourism was the growth and eventual domination of the information processing approach in mainstream experimental psychology. The information processing explanation for the improvement of performance due to practice centres on the concept of a mental image or a representation of a specific motor act in the mind. As practice progresses, the performer is able to produce a clearer and more complete image of the motor act. Feedback from each response is compared to the mental image of the motor act and appropriate changes are made so that the response will resemble the image of the motor act as closely as is possible.

The concept of an internal mental representation of the motor act is central to the learning theories of Schmidt (schema theory, 1975) and Adams (closed-loop theory, 1971).

Knowledge of Results

Despite the central position of practice in the information processing approach to motor skill learning, the bulk of human research regarding skill learning has been concerned with various manipulations of knowledge of results (KR) (see Appendix A). KR is the movement related information arising from the result of the movement provided to a subject by an external source. Researchers have typically manipulated KR in various forms while assuming that the effect of movement repetition would remain constant across experimental conditions. Even in his pioneering work on line drawing, Woodworth (1899) supplied his subjects with various sorts of KR (for details of Woodworth's work, see Appendix B).

The Learning - Performance Distinction

The distinction between performance effects and learning effects are crucial to the understanding of any motor learning experiment involving repetition. Salmoni et al. (1984) suggest that the "most common and widely accepted definition is that learning is a relatively permanent change, resulting from practice or experience, in the capability to respond" (p.357). In addition to the relatively permanent effects of learning, there may also be performance effects (temporary or local effects altering the capability to respond).

In order to distinguish between learning and performance effects in the following experiments, the two phase experimental paradigm described by Schmidt (1982, Chapter 13) will be used. The paradigm begins with an acquisition phase in which repeated trials of the KR manipulation of choice is administered to a subject. The trials continue until either a certain number of trials or a certain level of performance has been obtained. The acquisition phase is used to measure performance effects. Following the acquisition phase, a delayed retention phase (the same task but delayed in time from the last acquisition trial) or a transfer phase (different but related task) is given. These trials are used to measure the amount of learning that occurs during the acquisition phase.

The Total-Time Hypothesis

While the effect of repeated trials has remained largely unexplored in the KR literature, there is a repetition effect in the verbal learning literature that is relevant to motor learning studies. The relevant studies use the nomenclature of the total-time hypothesis (see Appendix C for details). The total-time hypothesis refers to the experimental finding that a "fixed amount of time is necessary to learn a fixed amount of material regardless of the number of individual trials into which that time is divided" (Cooper & Pantle, 1967, p. 221). Thus, if it takes a subject 30 seconds to learn a certain list of nonsense syllables, it should make no difference to the amount learned if the 30 seconds was divided into 2 blocks of 15 seconds each or 5 blocks of 6 seconds each. As long as the total time is approximately equal, the total amount learned should also be approximately equal (Baddley, 1976).

<u>Summary</u>

Based on the literature presented above, the following factors are of interest seem apparent. These are: a) the movement supplied feedback available to the subject, b) the distinction between performance effects and learning, and c) the total-time hypothesis. In order to test the effect of repetition on the acquisition of a motor skill, several factors must be accounted for. First, the amount of movement response information (i.e., feedback) must be held constant so that comparisons can be made across conditions. This procedure isolates the effect of the repetition factor. Second, in order to test for performance and learning effects, a two phase experimental paradigm is envisaged. Third, the total-time of the acquisition phases between conditions of varying numbers of trials should be as close as possible to avoid potential total-time hypothesis effects. The following experiments were developed to test for the effects of repetition in motor skill learning while controlling for the potential confounds listed above.

EXPERIMENT 1

Problem

The object of this experiment is to establish the effect of repeated acquisition trials on the performance and learning of a line drawing task. Its purpose is to determine in what manner repetitions supplied during the acquisition phase alter both acquisition and learning performance. Given the purpose of the experiment, two specific questions can be asked (along with their respective predictions).

Question one and predictions

When holding the amount of movement related information equal, does increasing the number of repetitions during acquisition phase produce a complimentary improvement in either acquisition and/or retention performance? The literature suggests that no matter what level of movement related information is supplied to the subject, more training trials should produce better results than fewer training trials. A qualification to this prediction is that an asymptote may occur, beyond which more trials will not improve task performance.

<u>Question two and predictions</u>

If the number of repetitions is held constant, will increases in the amount of movement related information supplied during each trial of the acquisition phase produce increases in acquisition and learning performance? The KR literature predicts that greater or more useful movement related information supplied to the subject during acquisition should result in superior acquisition and learning performance.

Method

The paradigm used in Experiment 1 is a variant of the two phase paradigm mentioned earlier (Schmidt, 1982). Subjects first learn the length of a criterion line during the acquisition phase, then replicate that line length during the retention phase. The experimental conditions consist of two levels of repetition (1 or 15 trials) and three levels of movement related information (stimulus, stimulus plus response, stimulus plus response plus KR) during the acquisition trials.

The stimulus criterion line length is viewed by all the subjects in each condition during the acquisition phase. In order to control for the effects found in the total-time hypothesis literature, each subject views the stimulus ensemble for the same time duration. Performance effects are obtained by measuring the subjects responses during the acquisition trials.

Learning levels are obtained by transferring the subjects to the delayed retention phase. The retention phase requires a delay interval of three minutes following completion of the acquisition trials. Once the delay period expires, subjects from all conditions replicate the length of the criterion line without the benefit of any experimenter supplied stimulus information.

<u>Subjects</u>

Twenty volunteer subjects, both male and female, aged from 18 to 35 years, participated in this experiment. All subjects were free from any physical disabilities. Handedness was not an issue, as the task and apparatus served equally well for both left and right handed subjects.

Apparatus and Task

The task required the subjects to view a criterion line length on a CRT screen and then replicate that line length by moving a stylus along the surface of a digitizing pad. A special desk (termed the apparatus desk) was constructed with two levels, so that to a seated subject, the lower level was at a standard desk height, and the upper level was at approximately head height. A digitizing pad (Summagraphics Professional II) was placed on the lower level and a computer monitor was placed on the upper level of the desk. A wooden cover was placed 30 cm directly above the digitizing pad, completely obscuring the digitizing pad from the seated subject's view. The wooden cover did not interfere with the movement of the stylus on the pad. With the subject seated, the monitor was approximately 45 cm in front of the subject.

Foam blocks were placed around the perimeter of the pad, forcing the subjects to keep the stylus on the active area of the pad. The active area of the pad was unobstructed, allowing the subjects an unimpeded movement anywhere on the 18 inch by 12 inch surface area.

A computer with associated keyboard was placed on a table situated adjacent to the apparatus desk. The experimenter used this arrangement to control the experiment without interfering or distracting the subject. Data collected from the digitizing pad was stored in a computer for further processing.

Stimulus

The stimulus ensemble for this experiment consists of two intersecting lines. A 15 cm horizontal line centred both vertically and horizontally, is attached by its left most end to a vertical line that runs the full vertical height of the CRT (see Figure 1). In essence, the two intersecting lines form a "T" rotated by 90 degrees. The horizontal line is used as the

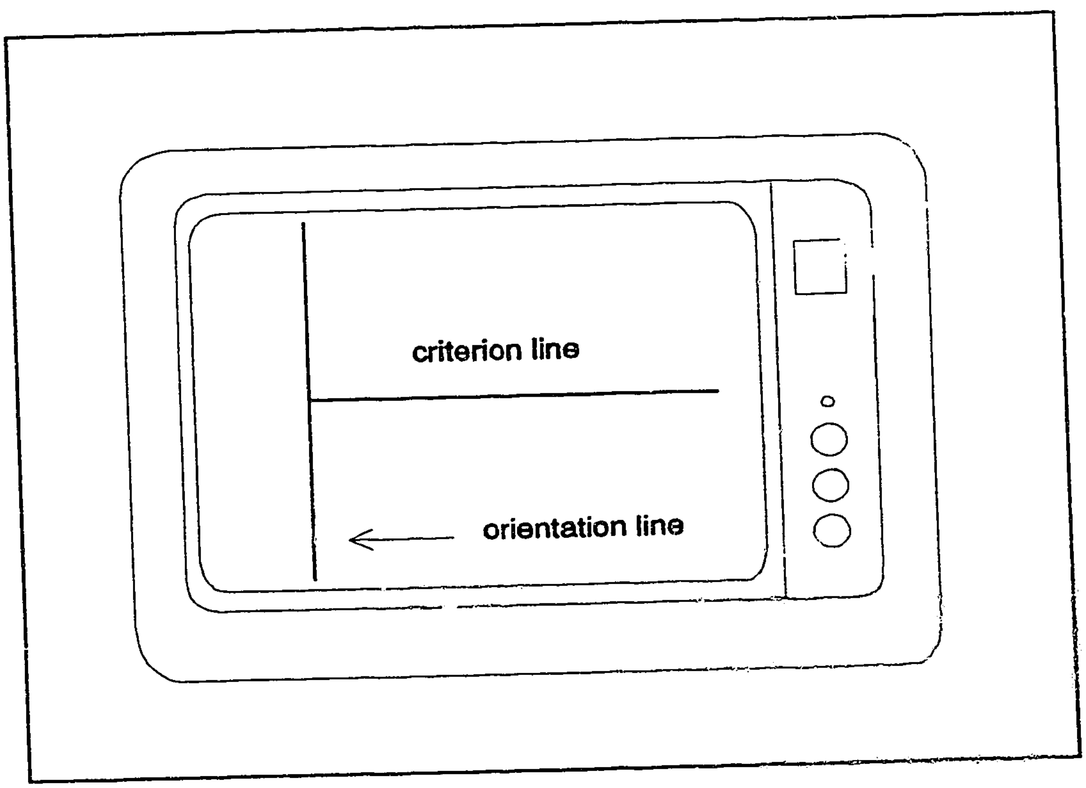

Figure 1. Stimulus ensemble for Experiment 1

criterion line, i.e. the line that the subjects are asked to replicate. The vertical line is used as an orientation line or benchmark for the uniform delivery of KR. The KR ensemble was presented for 500 msec.

Conditions

The subjects were randomly assigned to one of six conditions. The six conditions appear in Table 1.

Table 1

Conditions used in Experiment 1

	type of information		
number of repetitions	stimulus	stimulus with response	stimulus with response with KR
1	condition 1	condition 3	condition 5
15	condition 2	condition 4	condition 6

Subjects in conditions 1 and 2 receive only stimulus information. Subjects in these conditions do not make a response during the acquisition trials. Subjects in conditions 3 and 4 receive both stimulus information and make a response during acquisition (thus receiving whatever kinaesthetic information was available through the making of a response). In conditions 5 and 6, subjects receive stimulus information, make a response, then receive KR about that response. KR is presented by adding an additional line to the original stimulus ensemble. This new line represents the exact length of the subject's movement. It starts at the vertical line, and is placed approximately 1 degree of visual angle below the criterion line. Condition 1 and 2 subjects receive the least amount of information about the motor task, condition 5 and 6 subjects receive the most amount of information with condition 3 and 4 subjects falling somewhere in between.

Subjects in conditions 1, 3, and 5 receive a single trial during acquisition. The stimulus appears for a total time of 30 seconds. Subjects in conditions 2, 4, and 6 receive 15 trials during acquisition, with the stimulus appearing for a time of 2 seconds on each trial. The total time of stimulus presentation was constant across all conditions (i.e., 30 seconds of total stimulus time). The KR for condition 5 and 6 subjects is presented for a duration of 500 msec following each response during acquisition.

Procedure

The experiment was conducted in two phases: (a) an acquisition phase and (b) a retention phase (with a delay of three minutes between the two phases). A delay period separated the two experimental phases.

Acquisition phase. The subjects sit at the apparatus desk so that they can easily use the stylus on the digitizing pad but cannot view any portion of either the digitizing pad or their drawing hand. The monitor is adjusted so that it is at a comfortable viewing height, centred along the body midline.

The acquisition phase commences by informing the subjects that the stimulus ensemble will appear on the CRT. Subjects are instructed to view the stimulus, paying particular attention to the horizontal line. The stimulus is then 'blanked' from the CRT and a tone is sounded. The subjects then attempt to replicate the horizontal line length as accurately as is possible. The time interval between the tone and the next stimulus presentation is 5 seconds for conditions 1, 2, 3, and 4. Due to the 500 msec KR presentation, subjects in conditions 5 and 6 have 4.5 seconds to make their response. In order to insure response completion in time, subjects are instructed to make the response immediately following the tone.

Delay period. Following completion of the acquisition phase, subjects from all conditions are administered a three minute distracter task. Subjects are provided with a passage to read for three minutes, with instructions that they should concentrate on comprehension, rather than speed. The delay period and distracter task are designed to remove the criterion line length from memory and to stop the subjects from mentally rehearsing the line length.

Retention phase. Following the delay period, subjects from all conditions are transferred to an identical retention task. The subjects sit in front of the apparatus desk exactly as in the acquisition phase. Subjects attempt to replicate the criterion line length they had previously viewed during the acquisition trials. Each subject completes five line length replications, during which the CRT remains 'blanked'. Similar to the acquisition phase, a tone signals to the subject that a response is to be made. In the retention phase, there are no time constraints on the response time (i.e., no predetermined intertrial interval).

Results

Displayed in Table 2 are the absolute error[1] (AE) and variable error (VE) scores obtained from Experiment

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1. The scores are in digital values, with 19.6 digital values equalling 1 millimetre (mm). The criterion line length (15 cm) in digital values equalled 2940 digital values on the Summagraphics Pad.

1. The AE results are graphically displayed in Figure 2.

A two-way (6 condition by 7 block) univariate analysis of variance (UANOVA) was calculated using the

Table 2

AE and VE scores for Experiment 1 (digital values).

Condition		Block						
		TR 1	BL1	BL2	BL3	BL4	BL5	RET
1	AE							1012
	VE							57
2	AE							1041
	VE							50
3	AE	589						659
	VE	74						52
4	AE	746	805	728	758	726	723	920
	VE	206	66	74	77	62	69	40
5	AE	698						520
	VE	113						29
6	AE	508	356	199	160	223	172	302
	VE	137	55	30	26	19	28	23

19.6 digital values equals 1 mm. TR 1 = first trial, BL1-BL5 = block 1 - block 5, RET = retention

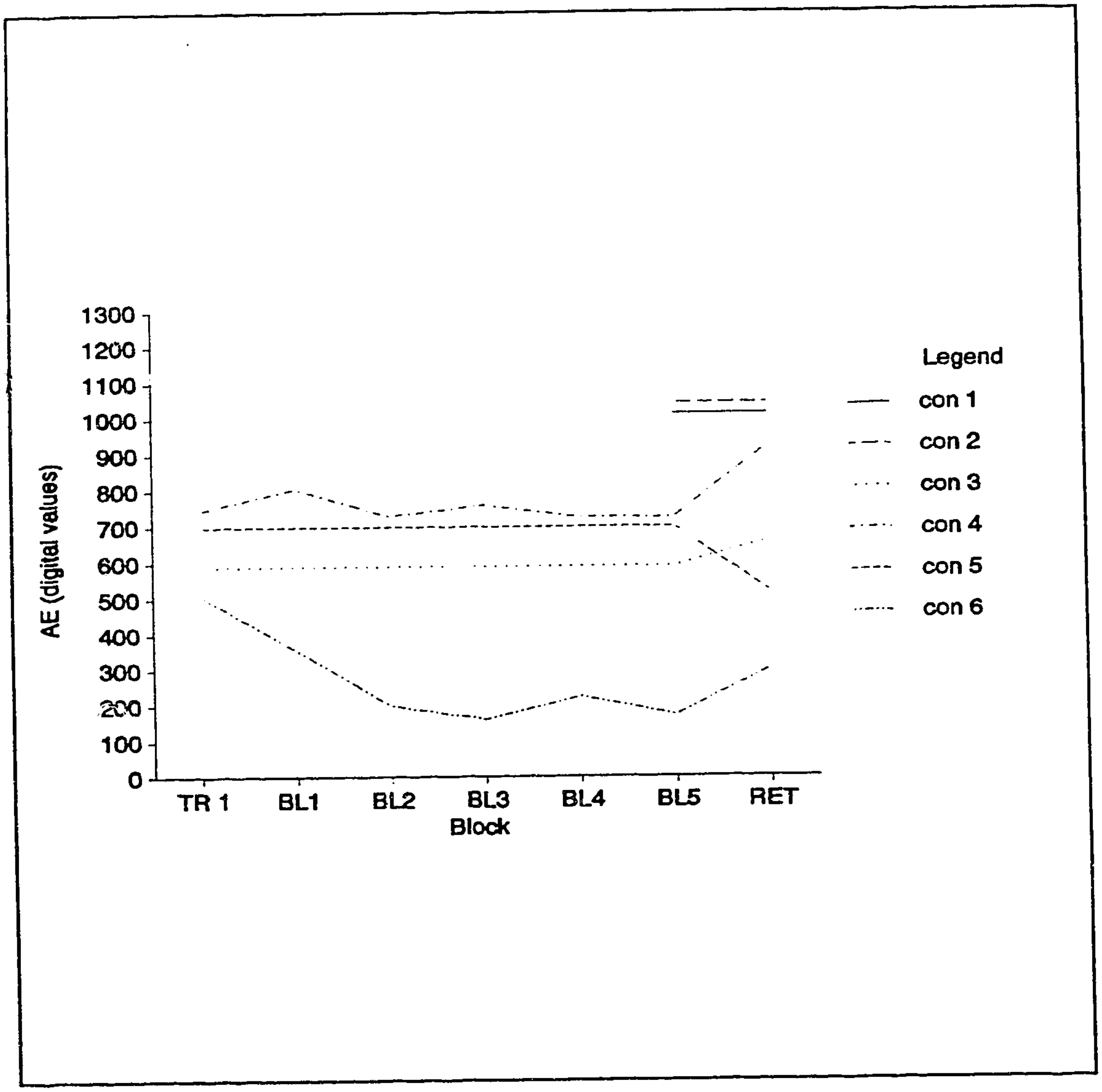

Figure 2. AE scores for all conditions in Experiment 1. TR 1= first trial, BL1-BL5 = block 1-block 5, RET = retention.

AE scores, followed by a post-hoc Student Neumann-Keuls (SNK, alpha set at $p<.05$) test on all means. Theonly main effect to reach significance was that of condition type ($p<.001$, $F=201$, $df=5,942$). The interaction between condition and block was significant at the $p<.05$ level ($F=1.52$, $df=30, 942$).

Acquisition Phase

Condition 1 and 2 subjects made no responses during the acquisition phase of the experiment and so did not contribute to the acquisition data. Condition 3 and 5 subjects, having single trial acquisition phases, contributed only 1 response to the acquisition data. Subjects in conditions 4 and 6 contributed 15 responses to the acquisition data. These 15 responses were divided into 5 blocks of 3 responses each for the data analysis. SNK comparisons revealed that there were no differences between the first trial acquisition responses of the subjects from any condition. Sign tests (Anderson, 1971) on the first trial data revealed that all first trial responses were chance in nature. The SNK comparisons between acquisition AE scores of the single trial condition subjects and the last block responses of the multiple trial subjects are presented in Table 3.

Retention Phase

Subjects from all conditions contributed data to the retention phase. The retention score SNK comparisons are presented in Table 4. Because the level of retention performance is dependent on the level of initial trial performance, delta retention

Table 3

SNK comparisons between conditions 3, 5 (first trial) and conditions 4, 6 (last block trials).

	Condition			
Condition	3	4	5	6
6	3.57*	3.82*	3.75*	-
5	3.22	2.86	-	3.75*
4	3.43	-	2.86	3.82*
3	-	3.43	3.22	3.57*

* $p<0.05$

scores were calculated (the mean retention AE score minus the first-trial acquisition AE score). The delta retention scores appear in Table 5 and are graphically presented in Figure 3. A two-way (4 conditions by 2 blocks) UANOVA was calculated on the delta retention data set, followed by SNK comparisons on the cell means. The SNK comparisons appear in Table 6.

Table 4

SNK comparisons between retention blocks of conditions 1, 2, 3, 4, 5, and 6.

	Condition					
Condition	1	2	3	4	5	6
6	3.91*	3.98*	3.59*	3.82*	3.04*	-
5	3.82*	3.91*	3.39	3.71*	-	3.04*
4	3.04	3.39	3.35*	-	3.71*	3.82*
3	3.57*	3.71*	-	3.35*	3.39	3.59*
2	3.04	-	3.71*	3.39	3.91*	3.98*
1	-	3.04	3.57*	3.04	3.82*	3.91*

* $p<0.05$

Table 5

Delta AE scores for Experiment 1 (in digital values).

	Block	
Condition	TR 1	RET
con 3 AE	0	70
con 4 AE	0	174
con 5 A	0	-178
con 6 AE	0	-206

19.6 digital values equals 1 mm. TR 1 = first trial, RET = retention

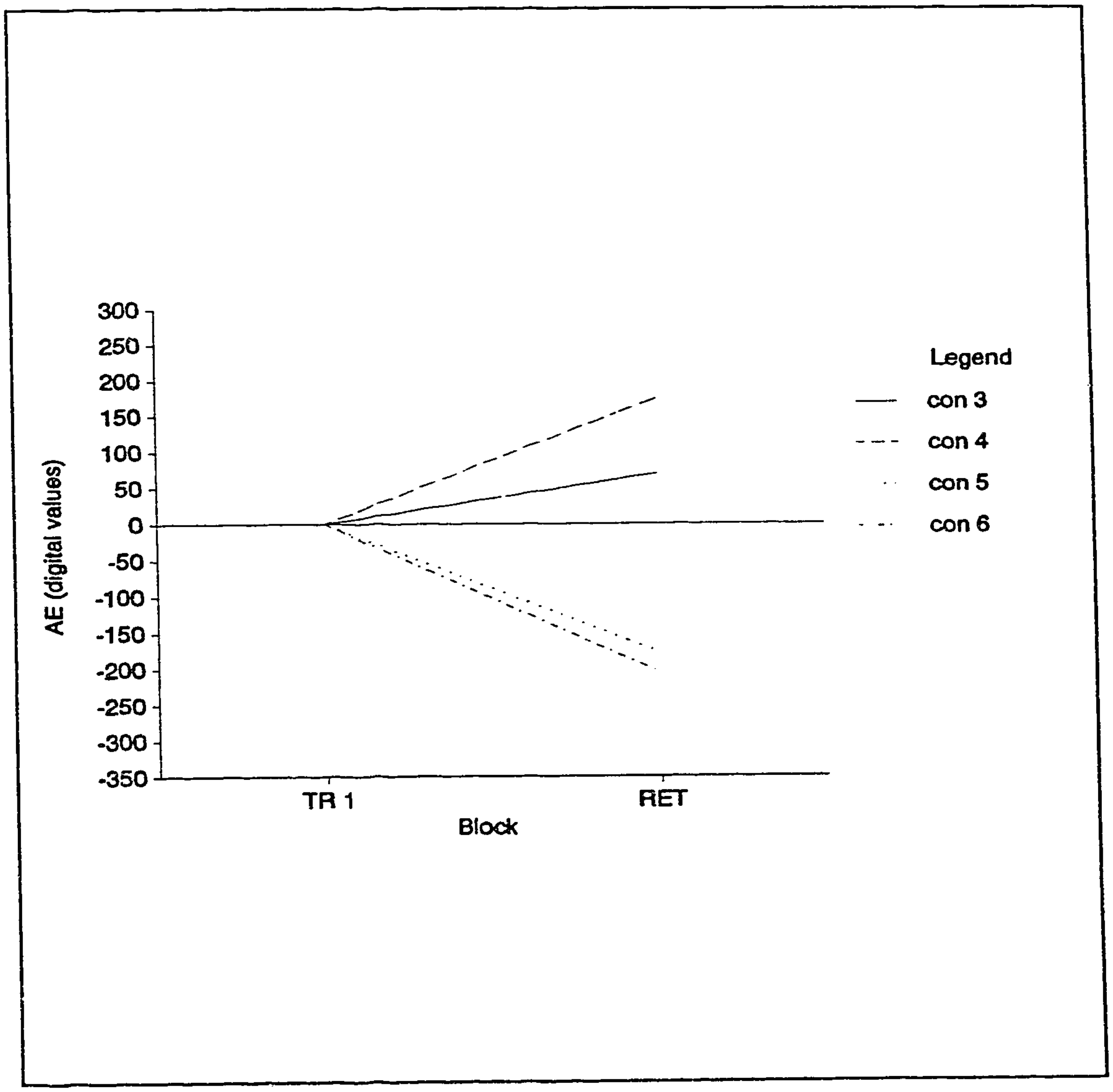

Figure 3. Delta AE retention scores for conditions 3, 4, 5, 6. TR 1 = first trial, RET = retention.

Table 6

SNK comparisons between delta retention scores of conditions 3, 4, 5, 6.

	Condition			
Condition	3	4	5	6
6	2.99*	3.07*	1.99	-
5	2.88*	2.99*	-	1.99
4	1.99	-	2.99*	3.07*
3	-	1.99	2.88*	2.99*

* $p<0.05$

Discussion

Results Relative to Question One: Acquisition

When holding the amount of movement related information equal, increasing the number of repetitions during acquisition phase may or may not produce improvements in acquisition performance. The last block performance of the subjects in condition 4 did not differ significantly from the single trial performance of the subjects in condition 3. Therefore, when stimulus and response information is supplied to subjects during acquisition, performance does not improve when repetition is increased. On the other hand, subjects in condition 6 were able to significantly lower their AE scores by the last block of acquisition trials over the subjects in condition 5. Thus, when KR is added to stimulus and response information during acquisition, increasing the amount of repetition facilitates improved performance. It follows from the above that the type of movement related information supplied to subjects in a motor learning task is the critical factor in determining whether or not increased repetition will improve acquisition performance.

Results Relative to Question One: Retention

Increasing the number of repetitions during acquisition does not facilitate superior learning performance. The SNK comparisons on the delta retention data set revealed that none of the subjects in the 15 trial acquisition conditions performed significantly better in retention than did subjects in any of the single trial acquisition conditions. Subjects in conditions 1 and 2 (for which delta retention scores could not be calculated) also failed to show any effect of increasing repetition. The finding that repetition does not effect retention performance (i.e., learning) contradicts one of the most common assumptions in the motor learning literature.

Results Relative to Question Two: Acquisition

Higher levels of movement related information supplied to subjects during repeated acquisition trials leads to superior acquisition performance. The answer is consistent with the bulk of the KR literature.

Results Relative to Question Two: Retention

When the amount of repetition in acquisition is held constant, increasing the amount of movement related information supplied to subjects during acquisition does, generally, result in superior retention performance.

Of the six SNK comparisons that were used to answer question two (including delta retention set SNKs), five comparisons revealed that higher levels of information result in better learning. However, no significant differences were found between the retention scores of subjects in conditions 2 and 4. The one anomalous finding was most likely due to a repetition effect, and not an information effect. It appears that during acquisition, repetition of stimulus and response information not only results in poor acquisition performance, but poor retention performance as well.

The amount of information supplied by the KR in Experiment 1 appeared to be somewhat of an overpowering factor, potentially overwhelming any effect of repetition. Consequently, to interpret the results more clearly, the following experiment was developed.

EXPERIMENT 2

Problem

The object of this experiment is to examine the effect of increasing the physical distance between the criterion line and the response line in the KR ensemble. Woodworth (1899) found that the physical separation between the viewed criterion line and the response line affected the accuracy of the response. The purpose of this experiment is to determine how varying the distance between the criterion line and the response in the KR ensemble alters acquisition and retention performance. Following the purpose of the experiment, a single specific question (and its predication) can be asked.

Question One and Prediction

When the amount of repetition is held constant, will increasing the distance between the criterion line and the response line in the KR display reduce the accuracy of acquisition and retention performance? Woodworth's data suggests that larger separations between the criterion and response line should result in poorer acquisition and retention performance.

METHOD

The methods developed for Experiment 1 were also used in 2.

Subjects

Twenty volunteer subjects, both male and female, aged from 18 to 35 years, were used in this experiment. All subjects were free from any physical disabilities. Handedness was not an issue, as the task and apparatus served equally well for both left and right handed subjects.

Apparatus and Task

Experiment 2 used the same apparatus and task as Experiment 1.

Stimulus

The stimulus ensemble for this experiment was identical with that used in the first experiment. The presentation of the KR in Experiment 2 differed from Experiment 1 in that the separation between the criterion line and the KR response line in Experiment 2 was increased from 1 degree of visual angle to 10 degrees of visual angle.

Conditions and Procedures

The procedures designed for Experiment 1, were used in this experiment as well.

The subjects were randomly assigned into two treatment conditions (termed condition 7 and 8 to avoid confusion with the Experiment 1 conditions). Subjects in both conditions received stimulus information, plus response information, plus KR. Condition 7 subjects performed 1 acquisition trial, whereas condition 8 subjects performed 15 acquisition trials. The two conditions used in Experiment 2 appear in Table 7.

Table 7

Conditions used in Experiment 2

	type of information
number of repetitions	stimulus with response with KR
1	condition 7
15	condition 8

Results

Acquisition Phase

The AE and VE scores obtained from the subjects in conditions 7 and 8 are presented in Table 8. Also presented in Table 8 are the AE and VE scores from the subjects in the 1 degree visual angle KR conditions in

Experiment 1 (conditions 5 and 6) . Figure 4 displays the AE scores from the subjects of the conditions listed in Table 8. The data from Experiment 2 was analyzed with the KR conditions from Experiment 1 with

Table 8

AE and VE scores for Experiment 2 (digital values).

		Block						
condition		TR 1	BL1	BL2	BL3	BL4	BL5	RET
5	AE	698						520
	VE	113						29
6	AE	508	356	199	160	223	172	302
	VE	137	55	30	26	19	28	23
7	AE	614						472
	VE	151						56
8	AE	581	515	345	223	287	209	308
	VE	76	67	43	46	38	29	35

19.6 digital values equal 1 mm. TR 1 = first trial, BL1-BL5 = block 1 - block 5, RET = retention.

a two-way (4 conditions by 7 blocks) UANOVA, followed by SNK comparisons on all cell means. No main effects or interaction effects were found. No significant

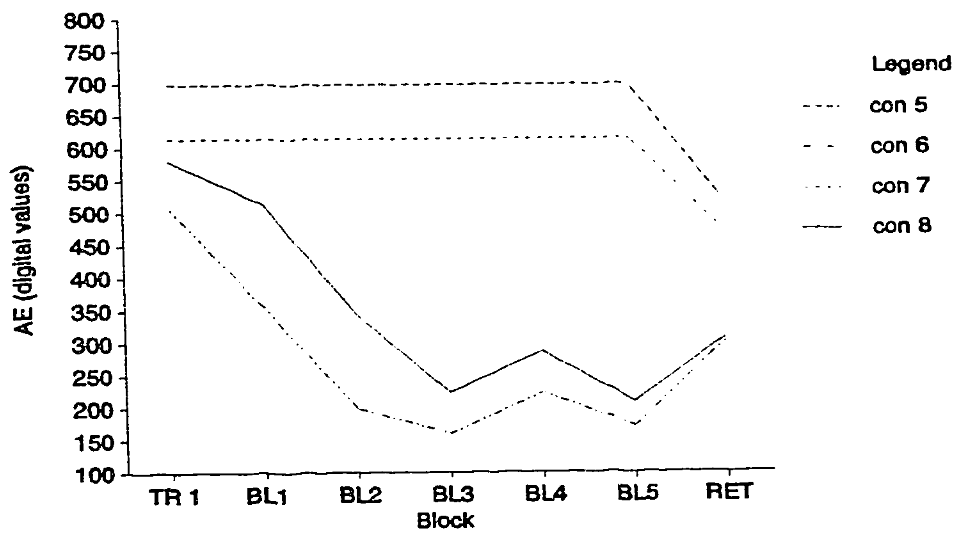

Figure 4. AE scores for conditions 5, 6, 7,and 8. TR 1 = first trial, BL1-BL5 = block 1 - block 5, RET = retention.

differences were found between the AE scores from the first trial of acquisition among the subjects of the 4 conditions. Sign tests (Anderson, 1971) on the first trial data revealed that all first trial responses were chance in nature. The comparisons between the AE scores from the subjects in the single trial acquisition conditions (conditions 5 and 7) and the AE scores from the last block of the multiple trial acquisition condition subjects (conditions 6 and 8) are presented in Table 9.

Table 9

SNK comparisons between the last block acquisition trials of conditions 5, 6, 7, and 8.

	Condition			
Condition	5	6	7	8
8	3.71*	2.36	3.59*	-
7	2.95	3.64*	-	3.59*
6	3.75*	-	3.64*	2.36
5	-	3.75*	2.95	3.71*

* $p<0.05$

Retention Phase

The results from the SNK post-hoc comparisons on the retention trials are presented in Table 10. Delta

Table 10

SNK comparisons between retention conditions of conditions 5, 6, 7, and 8.

	Condition			
Condition	5	6	7	8
8	2.95*	1.98	2.58*	-
7	2.58	2.74	-	2.58*
6	3.04*	-	2.74	1.98
5	-	3.04*	2.58	2.95*

* $p<0.05$

retention scores were calculated by subtracting the first trial response from the mean retention score. The delta retention set data appears in Table 11 and is graphically represented in Figure 5. The delta retention set was analyzed using a two way (4 conditions by 7 blocks) UANOVA, followed by SNK comparisons on all cell means. No main or interaction effects were found to be significant. The SNK

Table 11

Delta AE scores for Experiment 1 (digital values).

	Block	
Condition	TR 1	RET
con 5 AE	0	-178
con 6 AE	0	-206
con 7 AE	0	-142
con 8 AE	0	-273

19.6 digital values equals 1 mm. TR 1 = first trial, RET = retention.

comparisons between conditions of the delta retention data is presented in Table 12.

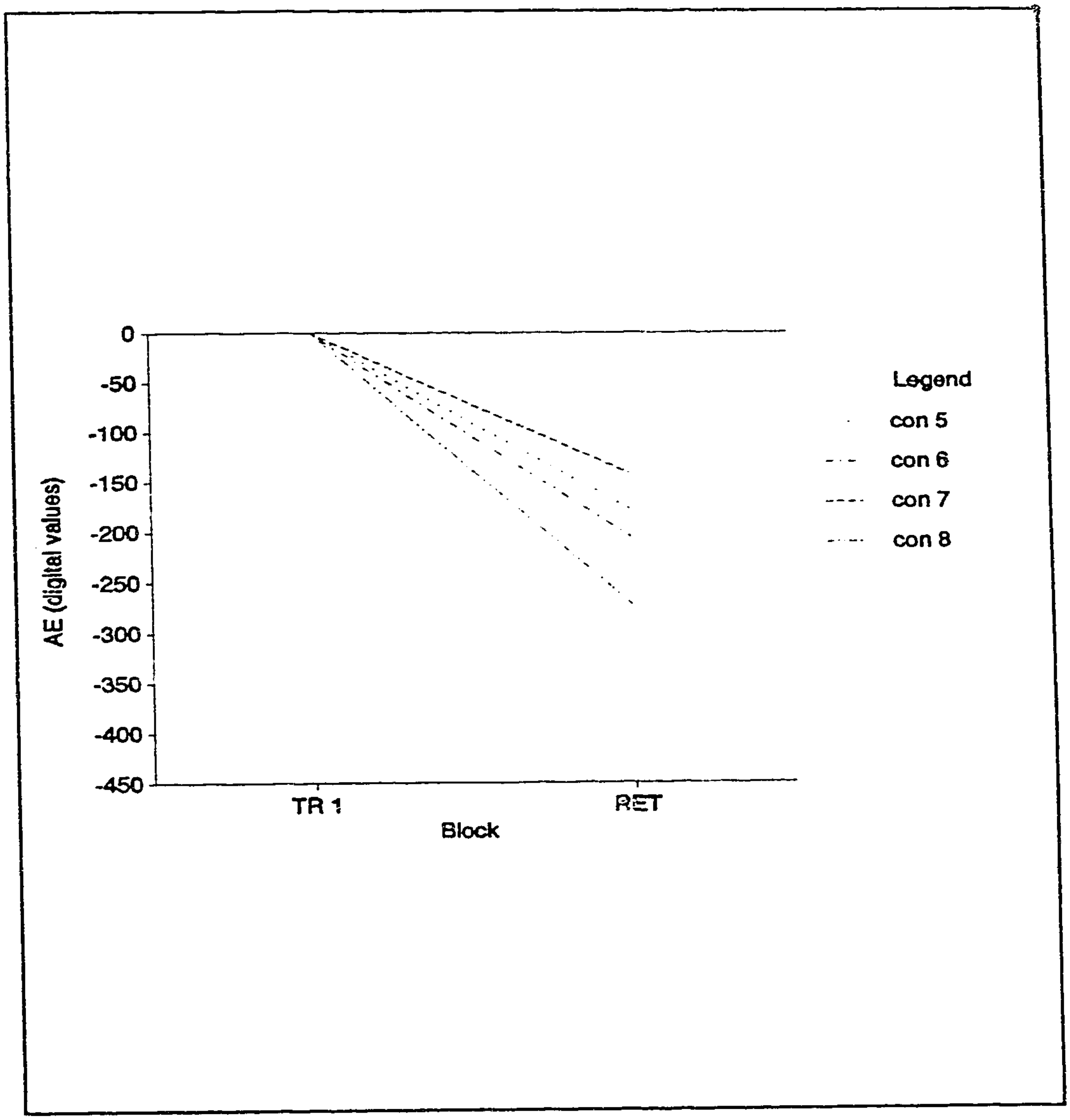

Figure 5. Delta AE retention scores for conditions 5, 6, 7, and 8. TR 1 = first trial, RET = retention.

Table 12

SNK comparisons between the delta retention data from conditions 5, 6, 7, and 8.

	Condition			
Condition	5	6	7	8
8	1.99	1.76	2.21	-
7	1.59	2.14	-	2.21
6	1.66	-	2.14	1.76
5	-	1.66	1.59	1.99

* $p<0.05$

Discussion

Results Relative to Question One: Acquisition

When the amount of repetition is held constant, increasing the distance between the criterion line and the response line in the KR display does not affect acquisition performance. It is possible that the difference between 1 degree of visual angle and 10 degrees of visual angle in a KR ensemble is not sufficient to effect acquisition performance. Whether the visual angle must exceed some critical value or if the nature of the KR ensemble may render the amount of visual angle irrelevant, is not understood at this time.

Results Relative to Question One: Retention

When the amount or repetition is held constant, increasing the distance between the criterion line and the response line in the KR display has no effect on retention performance. Much like the acquisition result, there appears to be no functional difference between the KR ensemble of 1 degree visual angle and 10 degrees of visual angle. The possible explanations for the retention result is the same as the explanations presented above for the acquisition result.

General Discussion

Acquisition

The results from Experiments 1 and 2 suggest that increasing repetition during acquisition trials does not always result in improved performance. When KR is available to subjects during acquisition trials, it appears that increasing the number of repetitions results in improved performance over trials. The result of this is the typical 'learning' curve commonly found in the KR literature (e.g., Bilodeau, Bilodeau, & Schumsky, 1959).

The finding that increased repetitions may not produce improvements in acquisition performance, when KR is absent, has both support and opposition in the motor learning literature. Several studies have shown that subjects in multiple no-KR acquisition trials are unable to improve their performance as a function of trials (e.g., Bilodeau et al., 1959; Newell, 1974). On the other hand, a number of studies have found that subjects that receive no KR during acquisition can significantly improve their performance over trials (Stelmach, 1970; Zelaznik, Shaprio, & Newell, 1978).

An explanation for the results regarding the effect of repetition on no-KR acquisition trials rests with the concept of an internal mental representation of the motor act (see Adams' closed-loop theory, 1971 and/or Schmidt's schema theory 1975). In order to form a mental image of the motor act, enough information about the task and the correct response needed must be available to the subjects. If enough information is available, subjects may form a mental representation of the motor act over trials and presumably use the mental image to improve their performance. Should not enough information for a mental representation be present during acquisition, subjects will be unable to correctly alter their performance without some sort of external referent being used (i.e., KR). The division in the motor literature on whether or not no-KR trials can result in learning therefore seems dependent on the amount of information inherent in the task situation. The findings from Experiment 1 indicate that given the experimental procedures used, stimulus and response information are insufficient to allow subjects to form an internal mental representation of the required motor act.

Retention

The finding that subjects in the stimulus and stimulus with response information conditions did not show improved retention with increased repetition, may also be explained with the concept of a mental image of the motor act. If the subjects were not able to construct a mental representation of the motor act during acquisition, it follows that retention performance should not vary as a function of acquisition trials.

Contrary to the KR literature (e.g., Newell, 1974), the results from Experiments 1 and 2 indicate that increasing repetition during acquisition trials with KR does not effect performance on retention trials. A possible explanation for the null effect of repetition on retention performance concerns the guidance function of KR. In conditions with KR supplied to the subjects during multiple acquisition trials, the KR may act like a 'crutch' (Schmidt, Young, Swinnen, & Shaprio; 1989) during acquisition, guiding subjects to improve their movement accuracy without actually learning (i.e., developing a mental representation of) the criterion line length (or the associated motor act). When KR is withdrawn in retention, the KR 'crutch' disappears and because no internal representation was created in acquisition, performance deteriorates. The use of summary KR (which appears not to have a 'crutch' like effect, Schmidt et al., 1989) may be the proper tool with which to further explore the relationship of KR, repetition, and retention performance.

Another possible explanation for the null effect of repetition in retention is that the difference between a single acquisition trial condition and a 15 trial acquisition condition is not sufficient to produce significantly different retention scores (regardless of the amount of information provided to the subject per trial). As demonstrated in Experiments 1 and 2, 15 acquisition trials are adequate to produce changes during the acquisition phase. Because acquisition and retention are two distinct phases (see the learning-performance distinction above), there is no reason to assume that enough repetitions to produce an acquisition effect is also enough repetitions to produce a retention effect. No method currently exists to determine how many trials, given a specific set of experimental parameters, are sufficient for learning to occur.

A final alternative explanation is that the replication of a straight horizontal line might be so simple a motor task that it requires no more than one acquisition trial to learn. While this explanation might be applicable to subjects who are supplied KR, subjects in no-KR conditions are not likely to find the task simple. Because increased repetition does not effect the retention scores at any level of movement related feedback, the 'simplicity' of the task alone does not seem to be an adequate explanation for the data. In order to test this possibility, future research might focus on manipulations of task difficultly (e.g., modify the criterion stimulus to a more or less difficult stimulus).

Total-Time Hypothesis

The findings of Experiments 1 and 2 generally support the total-time hypothesis. In acquisition, subjects that receive no-KR trials demonstrate total-time effects (equivalent performance with equivalent stimulus presentation total time). When KR was supplied to the subjects, the total-time hypothesis does not hold. Subjects who receive 2 second stimulus displays for 15 trials show greater improvement over subjects who receive a single 30 second stimulus display. In retention, the total-time hypothesis seems valid, merely increasing the number of repetitions alone does not improve retention scores.

Summary

The experiments presented in this paper were developed to test for the effects of repetition in motor skill learning while controlling for the following factors: a) the amount of movement supplied feedback available to the subject, b) the distinction between performance effects and learning effects, and c) the total-time hypothesis. With the above factors controlled for, the overall effect of repetition on both acquisition and retention performance was negligible. Under the conditions used in Experiments 1 and 2, repetition appears to have little or no effect on the acquisition and learning of a simple motor task. The lack of a repetitions effect in the no-KR acquisition trials is hypothesised to be due to an inability of the subjects to form an internal mental representation of the motor act. Possible explanations for the null effect of repetition in retention include: a) the inability of the subjects to form a mental image of the required motor act (due to either insufficient information or the guidance function of KR), b) insufficient number of acquisition trials, and c) insufficient task difficulty.

The often quoted saying 'practice makes perfect' appears to be less of a rule of thumb than is generally considered. The results from Experiments 1 and 2 underscore the need for future research concerning the role of repetition in skill acquisition.

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Appendix A

Definitions of Knowledge of Results

KR is most commonly thought of as movement related feedback that stems from a source external to the person making the response (eg. Adams, 1968; Salmoni et al., 1984). Displayed in Table 13 are definitions of KR that have been put forward by various researchers, as well as definitions of terms commonly found in the KR literature. The term "feedback" used in the various definitions presented in Table 13 refers to the feedback to the subject of movement related information.

For purposes of this review, KR is defined as any movement related information available to the performer about the relationship between the response and the response goal that arises from an external source. The definition allows for a great deal of latitude, thus permitting the widest range of studies to be reviewed.

In addition to the various conceptual definitions of KR, another set of definitions exist that includes the various manipulations of KR. Definitions concerning manipulations of KR are presented in Table 14.

Learning versus Performance

Despite the critical distinction between learning and performance (see page 3), only recently have

Table 13

Definitions of KR and terms associated with KR

Term	Definition and Author
intrinsic feedback	information arising as a natural consequence of the movement itself (Fitts & Posner, 1967)
augmented feedback	information arising from a source extrinsic to the performer (Fitts & Posner, 1967)
information feedback	stimuli presented to the subject, contingent upon the response according to a function determined by the experimenter (Bilodeau, 1969)
knowledge of performance	extrinsic feedback concerning the performers movement pattern (Gentile, 1972)
knowledge of results	feedback data from effector action and its results on the external world (Welford, 1976)
knowledge of results	augmented feedback (Singer, 1980)
knowledge of results	verbal, augmented, terminal feedback (Salmoni, Schmidt, & Walter; 1984)
knowledge of results	verbal and terminal feedback of a movement in relation to the goal (Schmidt, 1988)
knowledge of results	response information obtainable only from an external source (Magill, 1989)

Table 14

Definitions of the terms regarding the various manipulations of KR used in the literature

TERM	DEFINITION
No-KR	KR is unavailable to the subject
Temporal Locus	the point in time when KR is delivered in the learning sequence
KR-delay	interval between the completion of the task and the delivery of the KR
post-KR-delay	interval between the delivery of the KR and the initiation of the next movement
intertrial interval	sum of the KR-delay and the post-KR-delay
trials delay	KR for trial n delivered n_x trials later
summary	KR for trials n to n_x summarized and delivered on trial n_x
interpolated tasks	secondary task (motor or verbal) applied during either the KR-delay or post-KR-delay period
frequency	the schedule of KR delivery
absolute frequency	the absolute number of KR's given in a learning sequence
relative frequency	percentage of trials on which KR is given, absolute frequency divided by number of trials
precision	the level of accuracy about the result
modelling	a learning task in which the subject gains KR through the viewing of a demonstration of the task

delayed retention and transfer test been used extensively. Thus, while many researchers ostensibly tested learning effects, they did not use retention or transfer tasks and so may have only tested performance effects (e.g., Elwell & Grindley, 1938). For purposes of this review, studies that did not require a retention test or a transfer test are considered as studies testing for performance effects only.

Temporal Locus of KR

The temporal locus of KR may be defined as: the point in time at which KR is delivered to the subject during a learning sequence. A learning sequence is the experimenter controlled temporal order of events during the acquisition phase of a motor learning experiment. There are five major types of temporal locus of KR manipulations; KR-delay, post-KR-delay, intertrial interval, trials delay, and summary KR (Schmidt, 1988). A time line representation of trials during a learning sequence and the various temporal locus of KR manipulations is shown in Figure 6.

KR-delay

Many of the earlier studies (pre-WW II) concerning KR were conducted by researchers who manipulated the amount of time between the subjects response and the delivery of the KR. Among the earliest researchers

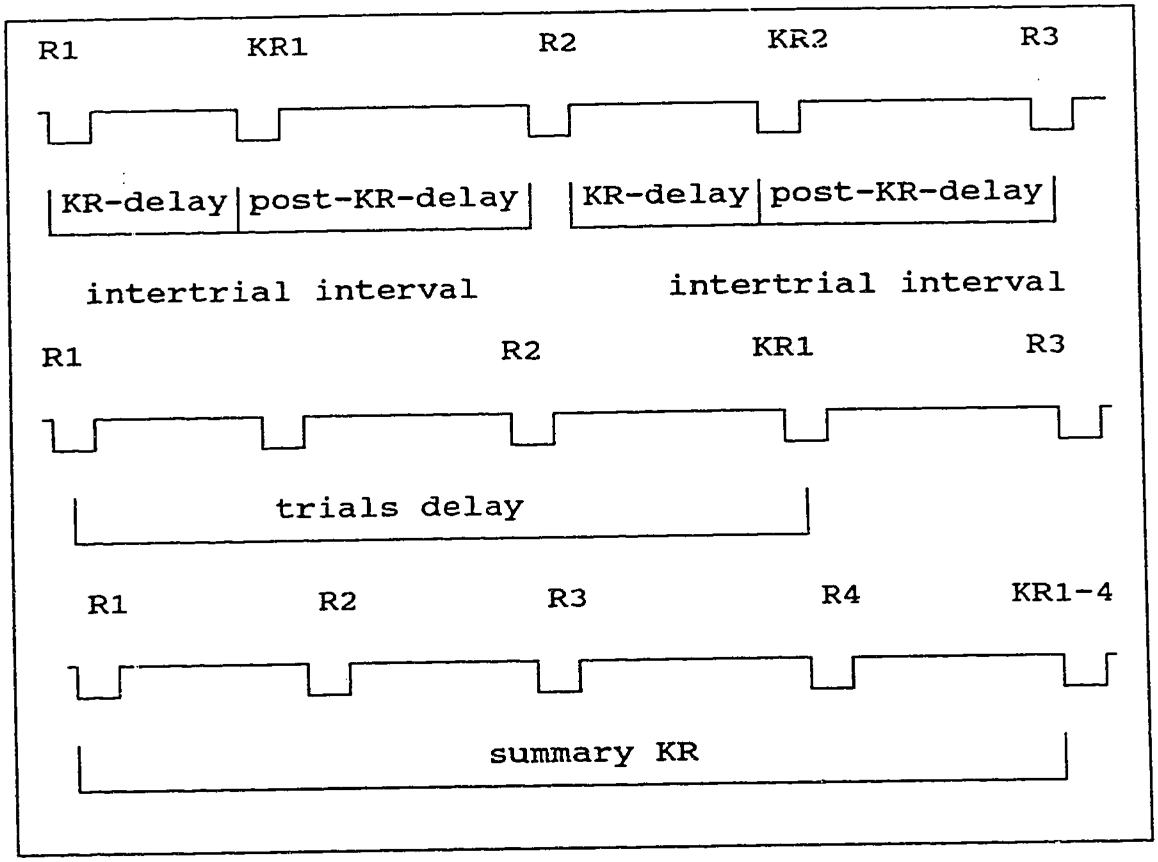

Figure 6. Time lines of the temporal locus of KR manipulations (KR-delay, post-KR-delay, intertrial interval, trials delay and summary KR). R = response, KR = delivery of the knowledge of results.

were Lorge & Thorndike (1935), who noted that delays between response and reinforcement were detrimental to performance in small animals. They attempted to discover if similar effects could be elicited in humans. The paradigm used by Lorge & Thorndike (1935) was a ball throwing task in which the subjects were blindfolded and the experimenters supplied KR after delays of between 1 and 6 seconds following each response. Lorge & Thorndike (1935) were unable to replicate the findings of the animal studies, concluding that "on the whole, no proof that delays up to 6 seconds weaken the influence of after-effects [the effect of KR on the next response]" (p. 191).

In 1956, Ammons published the first comprehensive review of the KR literature. Ammons (1956) presents eleven generalizations concerning KR in his review. The sixth generalization states that "the longer the delay in giving KR, the less effect the given information has" (p.324). Hypothesising further, Ammons (1956) suggests that for every task, and for every stage of the learning of the task, there probably exists an optimum delay time for the delivery of KR.

The majority of the studies reviewed by Salmoni et al (1984) showed no significant effects on learning or performance due to any manipulation in the KR-delay.

Effects of Performance. One of the most replicated studies concerning the effect of KR-delay on performance continues to be the 1956 work of Greenspoon & Foremen. They used the 3-inch line drawing task of Thorndike (1927), and withheld KR for periods of either 0, 10, 20, or 30 seconds. Greenspoon & Foremen found that subjects who had KR withheld for periods of 10, 20, and 30 seconds always produced poorer performances (on visually occluded line replications) when compared to subjects in a 0 second KR delay condition. The robust impairment of performance elicited by the KR-delay of Greenspoon & Foremen has never been equalled in the KR literature (e.g., Bilodeau, 1966).

Other researchers have found small detrimental effects on performance due to KR-delay (Abbey & Cowen 1960; Denny, Allard, Hall, & Rokeach 1960; Macpherson, Dees & Grindely 1948b; McGuigan, Crockett, & Boulton 1956; and Wargo, 1967), but none were able to demonstrate the detrimental effects on performance reported by Greenspoon & Foremen (1956).

A much larger body of evidence exists supporting the finding that manipulating the KR-delay interval does not effect movement task performance. Koch & Dorfman (1979) is typical of the studies finding no effect of KR-delay on performance. Utilizing a linear-slide task, Koch & Dorfman delayed KR either 5 or 45 seconds after the subjects response had been completed. No significant differences were found between the 5 second condition and the 45 second condition on any of the performance scores (absolute, constant and variable error). Support for the non-significant effects of KR-delay on performance is extensive: Becker, Mussina, & Persons (1963); Bilodeau (1966); Bilodeau & Ryan (1960); Boucher (1974); Dyal (1964, 1966); Dyal, Wilson

& Berry (1965); Noble & Alcock (1958); Saltzman, Kanfer, & Greenspoon (1955); Schmidt & Shea (1976); Schmidt, Christenson, & Rogers (1975).

Effects on Learning. There is very little evidence to support the idea that longer KR-delay intervals detrimentally effect learning. Koch & Dorfman (1979) trained subjects with either 5 or 45 second KR-delay acquisition trials. While they found "moderate performance decrements ... when KR was withdrawn" (p. 28), Koch & Dorfman did not find any significant differences in learning between the two KR-delay conditions. Additionally, McGuigan (1959) discovered that a 30 second KR-delay condition produced greater errors in transfer than did either a 0 or 15 second KR-delay conditions.

On the whole most of the evidence suggests there is no effect of manipulating the KR-delay interval during acquisition trials on learning. For example, Schmidt & Shea (1976), using an angular positioning task, transferred subjects in KR delay acquisition conditions of 2 and 30 seconds to a no-KR transfer test. While the 30 second KR-delay condition displayed slightly smaller absolute and variable error rates in transfer, Schmidt & Shea conclude that "there was no evidence that KR-delay degrades learning" (p. 130). Evidence supporting the Schmidt & Shea finding are :

Boulter (1964); Dyal (1964, 1966); Dyal et al., (1965); McGuigan, Hutchens, Eason, & Reynolds, (1964); and Schmidt et al., (1975).

In a recent KR-delay study, Swinnen, Schmidt, Nicholson, & Shapiro (1990) found that subjects that received instantaneous KR in acquisition displayed greater decrements in learning than did subjects that received a KR-delay of 8 seconds during acquisition. Two tasks were used by Swinnen et al., (1990), one a complex linear slide task (two reversal movements with a time criterion) and the other a "ball and bat" interception task. Using a retention and a delayed retention transfer task, Swinnen et al., established that the subjects in the instantaneous KR conditions from both tasks performed with higher error rates than did subjects in the KR-delay conditions. Swinnen et al., postulated that the subjects' motivation to 'subjectively analyze' the "response-produced feedback [was] reduced" (p. 713) in the instantaneous KR conditions.

Post-KR-delay

The post-KR-delay interval is the period of time between the delivery of the KR and the initiation of the next response in the learning sequence. Bilodeau & Bilodeau (1958a), after a series of experiments, suggested that the post-KR delay interval was a more important factor in determining performance and learning than the KR-delay interval.

Effects on Performance. Relatively few researchers have found improvements in performance due to increased post-KR-delay intervals. Both Greenspoon & Foremen (1956) and Gallagher & Thomas (1980) found significant improvements in performance as a result of longer post-KR-delays. Denny et al., (1960) reported that increased post-KR-delay improved performance, however the difference between post-KR-delay and baseline conditions were not significant.

Much like the literature on KR-delay, the bulk of researchers exploring the effect of post-KR-delay on performance have not found significant effects due to post-KR-delay manipulations. Magill (1977) used a serial order lever positioning task and gave subjects post-KR-delay intervals of either 12 or 60 seconds during acquisition trials. No performance detriments caused by the post-KR-delay were found by Magill, who noted that his results "are in line with the majority of other research studies concerning post-KR interval effects and the acquisition of motor skills" (p. 117). Studies supporting Magill's (1977) finding include Archer & Namikas (1958); Becker et al., (1963); Bilodeau & Bilodeau (1958a); Bilodeau & Ryan (1960); Bole (1976); Boucher (1974); Noble & Alcock (1958);

Ryan & Bilodeau (1962); Schmidt et al., (1975); Schmidt & Shea (1976); and Weinberg, Guy & Tupper (1964).

Effects on Learning. There is some evidence to suggest that learning is enhanced with longer post-KR-delays. Dees & Grindely (1951) found that longer post-KR-delay intervals resulted in improved learning scores, as tested on a knob turning transfer task. Similarly, Schmidt et al., (1975) used a linear slide positioning task and found greater accuracy in retention when longer post-KR-delays were administered during acquisition. Bilodeau & Bilodeau (1958a), in their extensive testing of KR-delay and post-KR-delay intervals, concluded that the "data suggests that the value of post-KR-delay has more influence than KR-delay" (p.611).

Not all the learning data supports the conclusion reached by Bilodeau & Bilodeau (1958a). When retention or transfer scores were tested, Archer & Namikas (1958), Becker et al., (1963), and Schmidt & Shea (1976) all found that various temporal manipulations of post-KR-delay during acquisition had no effect on learning.

Intertrial Interval

The intertrial interval has been indirectly (and at times accidentally) tested in numerous studies. The reason for the indirect (or accidental) manipulation of the intertrial interval is because if either of the KR-delay interval or post-KR-delay interval is held constant and the other is varied, the intertrial interval must also vary accordingly. To date, no researcher has explicitly designed a KR experiment to explore the effect of the intertrial interval length in isolation.

Interpolated Tasks

Several researchers have used interpolated tasks (a motor or verbal secondary task during either the KR-delay or post-KR-delay interval). When an interpolated task is added to the KR-delay or post-KR-delay interval, the complexity of the interpolated task is critical to the effect on the primary task. The effect of the interpolated task is measured by comparing the performance and learning scores of subjects that had an unfilled interval against subjects that had an interpolated task during the same interval. By comparing primary task scores with interpolated tasks and primary task scores without interpolated tasks, researchers have attempted to ascertain what interpolated tasks may be classified as detrimental to either the performance or learning process.

Interpolated Tasks during KR-Delay. Both Ryan & Bilodeau (1962) and Boulter (1964) have used very simple interpolated tasks (having the subject remove their hands from the response lever to their lap) and found no performance decrements on the primary task (linear slide positioning). However, Shea & Upton (1976) did find detrimental effects on a primary linear slide positioning task when the interpolated task was to learn a second positioning during the KR-delay interval. The detrimental effect of learning a second position carried over to the transfer condition, which resulted in significantly decreased learning. Shea & Upton (1976) attributed the detrimental effect on performance and learning caused by the interpolated task due to the "[interference] with the stored feedback representation of the previous response in a sequence of learning trials" (p. 281).

Interpolated Task during Post-KR-Delay. Much like the literature concerning interpolated tasks and KR-delay, the complexity of the interpolated task during the post-KR-delay interval largely determines the effect on the primary task. Boucher (1974), Blick & Bilodeau (1963), McGuigan, Crockett & Boulton (1964), and Magill (1973, 1977) all found slight (non-significant) decrements or no decrements on performance when relatively simple interpolated tasks were used (e.g., having the subjects move their hands).

Lee & Magill (1983) found significant detriments to performance when subjects were required to perform both a verbal and a motor interpolated task during the post-KR-delay interval that followed a rapid movement task. However, the detrimental effects did not carry over to the transfer condition and no learning effects were found.

Following their 1983 work, Lee & Magill (1987) used a primary timing task where subjects were required to complete a single-reversal arm swing in 750 msec. Two post-KR-delays were used (15 and 45 seconds) with one interpolated timing task performed every 15 seconds. The subjects in the 45 second post-KR-delay condition were required to perform 3 interpolated timing tasks. The results from both groups, on both acquisition and retention trials, supported Lee & Magill's (1983) earlier finding that post-KR activity had either non-significant or no effects on the primary task.

In contrast to the findings of previous researchers, Swinnen (1990) reported significant detriments to performance and learning when an interpolated task was applied to the post-KR-delay interval. Swinnen (1990) used a complex linear slide task (two movement reversals and a time criterion) as the primary task. The interpolated task consisted of requiring the subjects to observe an experimenter perform the same primary task. The subject was then to estimate the experimenters performance in relation to the time criterion. When compared to subjects who had an empty post-KR-delay interval, subjects who received the interpolated task showed significantly higher frequencies of errors on acquisition, retention and delayed retention (24 hour delay) scores. The effect of the interpolated task was not altered by the speed at which the experimenter performed the task.

<u>Trials Delay</u>

The trials delay procedure is an extension of the KR-delay procedure. In the KR-delay procedure, KR for a given response is delivered before the initiation of the response. In the trials delay procedure the KR for a given response may be delayed up to several responses later. The KR for $response_1$ may not be delivered until $response_4$ has been completed.

Lorge & Thorndike (1935) were the first to report the use of a trials delay procedure. When a condition of 1 trial delay was compared to a condition of 0 trial delay, Lorge and Thorndike (1935) found no differences in performance.

Bilodeau (1956) expanded on Lorge & Thorndike's (1935) procedure by varying the number of trials over which the KR was to be delayed. On both performance and learning scores, Bilodeau (1956) found that the 0 trials delay condition produced significantly fewer errors than did any of the other trial delay conditions. Additionally, as the number of trials the KR was delayed increased, so did the number of errors committed by the subjects.

In a series of experiments, Lavery (1962, 1964; Lavery & Suddon, 1962, Suddon & Lavery, 1962) extensively tested the effect of delaying KR over a period of trials. Typical of the studies conducted by Lavery was Suddon & Lavery's 1962 experiment using a "Hunter Force Gauge". Subjects were required to produce a pressure of 55 non-metric units, as calibrated by the force gauge. KR was supplied in the form of single unit increments and was delayed either 0 or 5 trials. On the transfer task, the 5 trial delay condition subjects displayed greater accuracy than did the 0 trial delay condition subjects, although this difference did not reach significance. Suddon & Lavery also discovered that better retention accuracy could be arrived at by having no-KR trials in between the KR delay trials. Thus, a subject would do a trial, be given 5 trials of no-KR and then receive KR about the first trial. The idea of interspersing KR with no-KR trials eventually led to the concept of summary KR.

<u>Summary KR</u>

Summary KR is a term coined by Schmidt, Young, Swinnen & Shapiro (1989) for a modification of Lavery's trial delay procedure. Schmidt et al., (1989) used a "complicated ballistic timing task" (two movement reversals and a time criterion) while delaying the delivery of the KR 1, 5, 10, or 15 trials. Once the appropriate trial delay had been completed, subjects received their KR in the form of a graph representing their performance on all of the no-KR intervening trials. For example, the 10 trial delay condition subjects would receive a graph, every 10th trial, on their performance of the previous 10 trials. Thus, the 10 trial delay condition subjects would receive a summary of their performance every 10 trials. Schmidt et al., (1989) found that the 10 and 15 trial delay conditions performed with significantly more errors than did the 1 and 5 trial delay conditions. However, on a delayed retention test, the increased summary length resulted in significantly fewer error scores. Schmidt et al., (1989) hypothesized that the long summaries lack strong guidance properties, thus forcing subjects into "alternative information processing activities" (p. 358), which, in turn, results in greater learning.

Frequency of KR

Frequency of KR refers to how often during a learning sequence KR is provided to the subject. Two types of KR frequencies have been studied, absolute frequency and relative frequency.

Absolute Frequency of KR. Absolute frequency is the "absolute number of times in a learning sequence that KR is provided to the learner" (Salmoni et al., 1984, p. 362). If there are 100 trials and KR is provided on half of them, the absolute frequency of KR is 50. The effect of absolute frequency on performance is one of the most robust findings in motor learning. Higher absolute frequencies of KR result in improved performances on motor tasks. Salmoni et al., (1984) note the they "know of no important contradictions" (p. 362) concerning the improved performance due to higher rates of KR. A lack of research does exist, however, concerning the effect of absolute frequency of KR on learning. To date, no study has been conducted that has manipulated the absolute frequency of KR during acquisition trials and then tested learning through either a transfer or a retention trials. Despite the lack of research, Salmoni et al., (1984) offer incidental evidence and evidence from animal learning studies to suggest that "more reinforcement or KR, other things being equal, leads to more learning" (p. 363).

Relative Frequency of KR. Relative frequency of KR is the "absolute frequency of KR divided by the total number of trials given" (Salmoni et al., 1984, p.

362). If 100 trials are in a learning sequence and KR is presented on 50 of those trials, the relative frequency would be 0.5.

Several researchers have shown that improved performance results from higher relative frequency rates, including; Annett (1959), Bilodeau & Bilodeau (1958b), McGuigan (1959), Stockbridge & Chambers (1958), and Taylor & Noble (1962). However, Baird & Hughes (1972) and Ho & Shea (1978) kept absolute frequency of KR constant while relative frequency of KR was varied and found non-significant differences between conditions.

In contradiction to performance results, decreased rates of the relative frequency of KR has been shown to produce improved learning scores. Bilodeau & Bilodeau (1958b) used a knob turning task with various levels of the relative frequency of KR. Learning was tested by a no-KR transfer condition, and they found that the lowest relative frequency rates of KR in acquisition resulted in the lowest error scores on the transfer task. Evidence supporting the finding of Bilodeau & Bilodeau comes from McGuigan (1959), Taylor & Noble (1962) and Wulf & Schmidt (1989).

The effect of improved learning due to reduced frequency of KR is not universal. Ho & Shea (1978), in their second experiment, found no effect on retention due to different relative frequencies of KR, and also failed to find significant retention effects when absolute frequency of KR was varied. Stockbridge & Chambers (1958) also found no differences in retention between groups that received different relative frequencies.

Recently, Winstein & Schmidt (1990) performed three experiments involving the manipulation of the relative frequency of KR. The first experiment of Winstein & Schmidt (1990) compared a 100 % KR group (KR on all trials) against a 33 % KR group (KR on every third trial) on a movement reversal to time criterion task. No differences between groups were found during acquisition, prompting Winstein & Schmidt (1990) to note that "less frequent KR may not be as detrimental to the acquisition process as previously thought" (p. 681). On the retention task, the 33 % KR group performed with fewer errors that did the 100 % KR group, although the difference was not statistically significant.

Experiment 2 of Winstein & Schmidt (1990) also used a movement reversal to time criterion task and a 100 % KR condition. Additionally, a 50 % graded KR condition was used, where subjects received KR on a variable schedule (more KR early in acquisition, less KR in later stages and producing a 50 % average). No significant differences were found in acquisition. Subjects in the 50 % KR condition significantly outperformed the subjects in the 100 % KR condition on retention trials. Experiment 3 replicated Experiment 2 with the addition of a 1 day delayed retention test. Once again, the subjects in 50 % KR condition performed with significantly fewer errors on retention trials than did the subjects in the 100% KR condition. Winstein & Schmidt (1990) conclude that no-KR trials are not detrimental to learning and may "contribute to enhanced learning if they are systematically distributed throughout practice" (p. 686).

Precision of KR

Precision of KR refers to the level of accuracy of the KR which is provided to a subject. Precision ranges from relatively imprecise (generally qualitative information such as "too long" or "too fast") through various levels of quantitative information (1 dm long, 10 cm long, 100 mm long, etc). While the information given as KR may contain both direction and magnitude scores, the magnitude scores alone are typically manipulated.

Effects on Performance. Several researchers have been unable to elicit any effects on performance with various precision manipulations of KR. Gill (1975) used a linear slide task and gave two levels of KR precision, one to the nearest centimetre and the other to the nearest millimetre. While "extremely precise KR had no apparent effect on actual performance" (p. 197), subjects did report more negative self-evaluations with the more precise KR. Supporting Gill's (1975) finding of no performance effects with manipulations of KR precision are: Newell & Kennedy (1978), Shapiro (1977), Smoll (1972) and Thomas, Mitchell & Solomon (1979).

On the other hand, a large number of investigators have been able to elicit reliable performance effects with KR precision. Bilodeau (1954), Hunt (1961), McGuigan (1959), Newell & Carleton (1980), Noble & Broussard (1955), Rogers (1974), and Salmoni, Ross, Dill, & Zoeller (1983) all found that the more precise the KR, the better the performance during acquisition. The lone piece of contradictory evidence comes from a study by Lincoln (1954), who found that increased precision resulted in degraded performance on a hand cranking test.

Effects on Learning. When testing the effects of precision on learning, relatively few investigators have failed to find any significant precision effects (Gill, 1975; Lincoln, 1954). The majority of researchers have found increased precision during acquisition has resulted in improved learning (Lavery, 1964; Thomas et al., 1979; McGuigan, 1959; Rogers, 1974; and Salmoni et al., 1983).

Salmoni et al., (1983) conducted two experiments to determine if improvements on both performance and learning measures continued as long as the precision of the KR continued to be increased. Using a knob turning task in Experiment 1, Salmoni et al. found that improvements in performance continued until the accuracy of the KR reached 3 significant digits. In fact, additional significant digits beyond 3 began to impair performance. In Experiment 2, they explicitly told the subjects before hand what the goal of the task was and what the KR meant in terms of performing the task. With these instructions, the various levels of precision (the number of significant digits) produced no significant differences between the conditions.

An unusual twist to the standard KR precision experiment was performed by Bilodeau (1955), where invalid KR (erroneous in direction and/or magnitude) was given to one group of subjects. Bilodeau (1955) found that using a simple knob turning task, small erroneous deviations in KR did not significantly affect performance.

Functions of Knowledge of Results

KR is widely thought to have three distinct functions (Magill, 1989; Salmoni et al., 1984; Schmidt, 1988). The three functions are: error correction and guidance, reinforcement, and motivation (Magill, 198

Error Correction and Guidance. Perhaps the mc obvious function of supplying a performer with KR is supplying error correcting and movement guidance information. Much of the previous review of KR has supplied ample evidence that KR may (but not in all cases) supply subjects with enough information to guide their performance toward the task goal.

The view of KR as one part of an information feedback loop is vital in Adams' (1971) closed loop theory. In closed loop theory, a reference of correctness is formed by the subject, and all consequent movements are compared against the reference (Adams, 1971). KR is thought to improve the fidelity of the internal reference with each additional trial, allowing the subject to identify errors between the response and the reference of correctness. In this manner, KR is thought to indirectly guide the responses made by the subject (Schmidt, 1988).

Reinforcement. The view that KR may act to help reinforce the connection between a stimulus and a response has its roots in behaviourist psychology. One of the earliest exponents of KR as reinforcement came from Thorndike and his 1927 Law of Effect. Thorndike suggested that following a satisfying after-effect (ie. knowledge of a correct response) there occurs a "confirming reaction" which is a physiological reinforcement that strengthens the connection between the stimulus and the response. The provision of KR to the subject provides the satisfying after-effect. Salmoni et al., (1984) point out that the suggestion is that "no learning can occur unless KR is provided (or unless subjects can generate their own subjective reinforcement)" (p. 380).

While associationist terminology may be considerable out of vogue, the ideas of Thorndike and other behaviourists do find modern counterparts, in Adams' (1971) closed-loop theory and in Schmidt's (1975) schema theory. Closed-loop theory hypothesises that two traces exist, a perceptual trace and memory trace. The perceptual trace recognizes the appropriate response and the memory trace activates the response chosen by the perceptual trace. Learning, in closed-loop theory, is viewed as the product of the association between the perceptual and the memory trace (Newell, 1974). Feedback in general, and KR in particular, are used in relation with the perceptual trace in order to increase the accuracy of the movement (Adams, Goetz, & Marshall, 1972).

In his schema theory, Schmidt (1975) hypothesises that a subject associates the KR on a given trial to the parameters of the motor program used to respond to the task. A schema is developed between the motor command and the actual movement response. In this manner KR is thought to provide a "rule about the relationship between the internal command and the outcomes that were produced in the environment" (Schmidt, 1988, p. 453).

Motivation. The idea that KR may have a motivation function arises from the study of industrial psychology. As production lines and mass production become more prevalent in the 1920's, many researchers became interested in methods to maximize workers production and minimize worker errors. A common tool for the industrial psychologists was the Bergstrom Ergograph, a device which required subjects to lift various loads with their fingers until exhaustion. Arps (1920) demonstrated that with KR, a subject would work at a higher rate (more lifts per minute) and would have a higher absolute value of lifts until exhaustion. However, Arps (1920) did not attribute this to the motivating function of the KR but to the notion that "the lifting response functions more efficiently when the afferent channels from the eye are open" (p, 34).

Numerous other studies from the industrial era of experimental psychology support Arps' (1920) finding that subjects work longer and harder when supplied with KR (Brown, 1966; Crawley, 1926; Elwell & Grindley, 1938; Macpherson, Dees & Grindley, 1948a; Mace, 1931; Manzer, 1935). Given the relative simplicity and repetitive nature of the industrial tasks used, the effectiveness of supplying KR may have resulted from boredom alleviation.

More recently, vigilance tasks (where a subject watches a monitor for extended periods of time looking for stimulus anomalies) appear to support the notion that KR motivates (i.e. reduces boredom). Several investigators using radar detection tasks (where subjects were required to spot the radar blip on the radar screen) have reported fewer misses, fewer false alarms and faster reaction times during the vigilance period when KR was supplied to the subjects (eg. Antonelli & Karas, 1967; Hardesty, Trumbo, & Beven, 1963; McCormack, 1959; McCormack & McElheran, 1963; McCormack, Binding & McElheran, 1963).

Specifically testing the motivational function of KR, Reynolds & Adams (1953) made use of a pursuit rotor task. KR was provided to the experimental groups on different time-on-target schedules. Each of the five experimental groups received a motivating audio click for every .1, .2, .5, 1.0, and 2.0 seconds on the target, respectively. A no-KR control condition was also used. While subjects in all the experimental groups outperformed the no-KR control group subjects, no significant differences existed between the groups. Reynolds & Adams (1953) concluded that the "superiority of the experimental groups is moreso due to learning, rather than motivational, variables" (p.319). However, both Sackett (1947) and Smode (1958) used similar task to that of Reynolds & Adams (1953) and concluded that any differences between groups were due to the motivational effects of KR.

Appendix B

Woodworth (1899) was the first experimental psychologist to undertake research in the accuracy of movements. His main interest was the relation of speed and accuracy, which he tested using a task that required subjects to replicate a criterion line length. The subjects were paced by a metronome and were required to replicate line lengths under a variety of conditions (left hand, right hand, viewing the criterion line during the replications, not viewing the criterion line during the replications, and replicating the line previously drawn).

One finding of Woodworth's from speed-accuracy work is of direct relevance to the discussion of repetition. Woodworth found that subjects averaged 7 percent error when attempting to replicate a given line length in full view to them (in an unspeeded situation). Also discovered by Woodworth was that as the amount of physical separation between the criterion line and the subjects response line increased, the accuracy of the replication decreased.

Woodworth also experimented specifically on the effects of repetition. However, he was more concerned with the fatiguing effects of practice, rather than of the effect of practice (in and of itself). Two types of tasks were used by Woodworth for testing the effects of practice. One was the criterion line drawing tasks that had been used in the speed-accuracy experiments. The other was a targeting task where a subject was to hit, with the tip of a pencil, a series of small squares on coordinate paper. As in the speed-accuracy experiments, handedness and eyes open or closed were experimental manipulations. Because Woodworth let the subjects view the criterion line and the response line (except in the eyes closed condition, which was designed to test memory for movement) there was always some form of KR available to the subject.

While the experiments on the amount of practice focused on task fatigue, Woodworth did make several conclusions on the effect of repetition. One of the major conclusions Woodworth reached was "the continued repetition of an accurate movement produces but a slow and slight decrease in its accuracy" (1899, p. 96). Woodworth qualifies the above statement with; "this decrease, though slight, is after a sufficiently long series unavoidable, and is not the result of mere failure of attention" (1899, p. 96). In other words, Woodworth felt that after a certain large number of trials, the central mechanism that directs accurate movements fatigues.

Appendix C

The body of support for the total-time hypothesis from the verbal learning researchers has been impressive. The findings of Bugelski (1962), Bugelski & Rickwood (1963), Jung (1964), Postman & Goggin (1964, 1966), Newman (1964), Goss, Moragan, & Golin (1959), Hovland (1949), Wilcoxon, Wilson & Wise (1961) all support the total-time hypothesis. Only two verbal learning studies (Carroll & Burke, 1965; Nodine, 1965) contradict the total-time hypothesis.

Baddley (1976) notes that the total-time hypothesis is more of a "rule of thumb than a law of nature" (p. 17). For example, the total-time hypothesis not does appear to hold for extremely long total-time durations. The failure of the total-time hypothesis at long durations is thought to occur due to the separation between the nominal duration and the effective duration (Cooper & Pantle, 1967). The nominal duration is the length of learning time set by the experimenter and the effective duration is the amount of learning time actually used by the subject. The two may be radically different. For instance, at very long durations, the subject may have extracted all the information possible from the to-be-learned set by the half time point, and then merely rehearse the set until the time limit is finished (Cooper & Pantle, 1969).

Cooper & Pantle (1969), in their review of the total-time literature, conclude that the underlying process of the total-time relationship may be repetition of the representational response (RR) evocation. In a paired associate learning paradigm, the RR "would be the perception of Response A contiguous with Stimulus B" (Cooper & Pantle, 1969). In other words, the underlying mechanism proposed of the total-time hypothesis by Cooper & Pantle (1969) is the subjects rehearsal of the RR. Tasks which involve more that simple rehearsal or study for mastery do not elicit results compatible with the total-time hypothesis. The effective time duration in which a given RR may be rehearsed is the crucial determinant in how long a learning set may be mastered. According to the total-time hypothesis put forward by Cooper & Pantle (1969), equal learning will occur no matter what division of trials are used if the effective time to rehearse RR's is held constant.