Journal of Motor Behavior, 2005, Vol. 37, No. 3, 231–238

Support for an Explanation of the Guidance Effect in Motor Skill Learning

David I. Anderson
Department of Kinesiology
San Francisco State University

Richard A. Magill
Department of Kinesiology
Louisiana State University
Baton Rouge

Hiroshi Sekiya
Faculty of Integrated Arts and Science
Hiroshima University
Higashi-Hiroshima City, Japan

Greg Ryan
Department of Kinesiology
San Francisco State University

ABSTRACT. The authors investigated whether the knowledge of results (KR) schedule influences the extent to which intrinsic feedback is noticed and used. Fifty-six participants received KR that was either delayed over 2 trials (Delay-2) or provided directly after each trial (Delay-0) during 160 trials of an unfamiliar aiming task. No-KR retention tests were given after 80 trials and 1 min and 24 hr after the end of acquisition. After retention, all participants were questioned about their use of intrinsic feedback during practice and whether those sources changed as a function of practice. The Delay-2 group performed significantly less accurately on the 1st and last blocks of acquisition trials but showed a significantly smaller performance decline from acquisition to retention. Moreover, the Delay-2 group noticed and used a greater variety of intrinsic feedback sources and its members were more likely to report that their usage changed with practice.

Key words: augmented feedback, intrinsic feedback, knowledge of results, trials delay

According to the guidance hypothesis, augmented information can have negative effects on motor skill learning if it is provided too frequently or in a form that is too easy to use (Salmoni, Schmidt, & Walter, 1984; Schmidt & Lee, 1999). The hypothesis has been tested most frequently in experiments on knowledge of results (KR). In such experiments, the provision of KR is manipulated during acquisition and the effects of the manipulations are assessed on delayed no-KR retention or transfer tests. Those effects are presumed to be a measure of the relatively permanent changes in behavioral capabilities that are associated with practice on the task (Schmidt & Lee). Any decrements in performance on the no-KR tests are assumed to reflect the negative consequences of guidance during acquisition.

Investigators have advanced three primary explanations for the negative effects of guidance on motor learning (Schmidt, 1991; Young & Schmidt, 1992). The prevailing view is that the learner becomes dependent on KR when it is presented too frequently or in a form that is too easy to use because the KR is processed as an essential part of the task (Proteau, Marteniuk, Girouard, & Dugas, 1987; Proteau, Marteniuk, & Lévesque, 1992). As such, the learner performs effectively when KR is available but not when it is removed. However, Winstein and Schmidt (1990) have shown that, compared with less frequent provision of KR, provision of KR on every trial in acquisition can also lead to inferior performance on a retention test in which KR is available. That finding implies that dependence on KR cannot fully account for the detrimental effects of frequent KR on learning.

A second explanation for the negative effects of guidance is that frequent KR encourages the learner to make too many corrections during practice (referred to by Schmidt, 1991, as *maladaptive short-term corrections*), which leads to an inability to recognize and produce stable behavior in retention. Contrary to that explanation, however, Anderson, Magill, and Sekiya (1994) have shown that delaying KR over trials can lead both to more variable acquisition performance and to more accurate no-KR retention performance than does providing KR directly after each trial.

A third explanation for the negative effects of guidance on learning is related closely to the first. The explanation put forward by Schmidt and his colleagues (e.g., Salmoni et al., 1984; Schmidt, 1991) is that frequent and useful KR can encourage learners to ignore important sources of sensory feedback (e.g., kinesthetic) intrinsic to the task. One

Correspondence address: David I. Anderson, Department of Kinesiology, San Francisco State University, 1600 Holloway Avenue, San Francisco, CA 94132-4161, USA. E-mail address: danders@sfsu.edu

consequence of failing to process intrinsic feedback is the inability to establish an internally generated error-detection mechanism (Schmidt & White, 1972) that can be used to support performance in the absence of KR. In support of that account, Swinnen, Schmidt, Nicholson, and Shapiro (1990) have shown that instantaneous KR, designed to block the immediate postmovement processing of task-intrinsic feedback, degrades performance on both immediate and delayed no-KR retention tests. In addition, Schmidt, Lange, and Young (1990) have shown that a manipulation of summary KR that led to optimal learning was also associated with superior ability to estimate errors in the absence of KR and thus on the basis of intrinsic feedback.

Recently, Anderson, Magill, and Sekiya (2001) used a different approach to obtain support for the notion that frequent and useful KR may discourage the processing of task-intrinsic feedback compared with manipulations in which KR is more difficult to use. They reasoned that delaying KR over trials could be rendered ineffective if the intrinsic feedback available in the task was unfamiliar to the learner. The rationale was that learners would prefer to use KR, even when it was difficult to use, if the intrinsic feedback associated with the task was either unfamiliar or difficult to use. Consistent with expectations, delaying KR by two trials facilitated delayed no-KR retention performance on an aiming task only when the intrinsic feedback from the moving limb was unaltered (and therefore familiar) but not when spring tension was added to the movement, thus modifying the task.

The main problem with the evidence provided by Anderson et al. (2001), Schmidt et al. (1990), and Swinnen et al. (1990) is that it is indirect. Those authors have not provided data to verify that learners were encouraged or discouraged to process intrinsic feedback because of the KR schedule to which they were exposed. Hence, our primary purpose in the present experiment was to seek such verification by delaying KR over trials or presenting it directly after each trial and simply asking participants to indicate which sources of intrinsic feedback they had used and whether those sources changed as a function of practice. We chose delaying KR over trials in preference to other methods of KR scheduling because previous research has shown that delaying KR consistently degrades performance in acquisition yet facilitates performance in retention in comparison with providing KR directly after each trial (Anderson et al., 1994, 2001; Lavery, 1964; Lavery & Suddon, 1962; Suddon & Lavery, 1962). Delaying KR over trials appears to be a particularly effective way to draw the learner's attention to intrinsic feedback because the learner must pay close attention to every trial to use the subsequent KR to improve on the task. In contrast, when other scheduling methods are used (e.g., when KR is provided less frequently or in summary form), KR always directly follows some trials and the learner can thus pay attention only to those trials and still improve on the task.

The experiment was a replication and extension of the experiment by Anderson et al. (2001), except that only the spring version of the task was used. Two factors influenced our decision to use the spring version of the task. First, the spring tension (force) added an additional source of information that the participant could potentially attend to and use, thus increasing our chances of differentiating those participants who did process intrinsic feedback from those who did not on the basis of the number of information sources reported. Second, we were able to address an additional question—whether the beneficial effects of delaying KR over trials would reemerge on this task with a doubling of the amount of practice provided by Anderson et al. Several researchers have suggested that considerable practice with KR may be required before participants can effectively use the intrinsic feedback associated with spring loading (Anderson, 1999; Bahrick, Bennett, & Fitts, 1955; Bahrick, Fitts, & Schneider, 1955; Williams, 1974).

Moreover, the amount of practice given to participants has been shown to interact with many variables in affecting motor skill learning. Those variables include the scheduling of KR (Guadagnoli, Dornier, & Tandy, 1996), KR precision (Magill & Wood, 1986), erroneous KR (Buekers & Magill, 1995), concurrent versus terminal augmented feedback (Patrick & Mutlusoy, 1982), and the scheduling of practice (Shea, Kohl, & Indermill, 1990). Most relevant to the present question is an experiment by Lavery and Suddon (1962) in which participants practiced a force-production task for either 30 or 90 trials and were provided with KR either directly after each trial or after a delay of 5 trials. The manipulation failed to produce group differences in retention after 30 trials, but reliable differences in favor of the groups that practiced with delayed KR emerged after 90 trials. Furthermore, only the groups trained with delayed KR showed any reliable improvements from the first retention test to the second, which suggested that during the additional practice trials, the participants in those groups had learned something about the sources of intrinsic feedback that would support performance in the absence of KR.

Given the aforementioned claim that KR provided directly after each trial in acquisition discourages the processing of task-intrinsic feedback, we hypothesized that the group that received KR delayed over trials would notice and use more sources of intrinsic feedback than would the group that received KR after each trial. With respect to our secondary purpose, we expected that delaying KR over trials would degrade performance during acquisition (consistent with previous work on the trials delay of KR), although it was not clear whether the amount of practice provided on the task would be sufficient to allow the group that experienced delayed KR to demonstrate superior performance in retention.

Method

Participants

Fifty-six undergraduate university students (mean age = 21.6 years, *SD* = 1.8 years) participated in the experiment in exchange for course credit. Participants were quasi-randomly assigned to one of two groups (Delay-0 or Delay-2) on the basis of a five-trial pretest without KR. That procedure ensured that the groups had equivalent accuracy and variability scores at the start of practice. Each group contained 16 women and 12 men. Four participants in each group were left-hand dominant. All participants provided written informed consent before participating in the study.

Task and Apparatus

The task involved a self-paced, blind aiming movement to a target that was located 80 mm from a predefined start location. The movement direction was away from the midline of the body (sternum) in the sagittal plane. Participants used their nondominant hand to perform the movement, and they were told to complete the movement with one smooth, continuous motion. All movements were made with a pen-shaped stylus that could be moved freely to the target location on an electronic CalComp (GTCO CalComp, Inc., Columbia, MD) Drawing Board II, Model 33180. A thin piece of rubber tubing (spring) that was attached to the table on which the drawing board was located was fixed to the stylus. The spring had a pull of approximately 0 g at the start location and 575 g at the target location. The spring was linear within the range of movements made by participants, and repeated testing revealed that its characteristics did not change across the experiment. The endpoint location of each movement was recorded by the drawing board and relayed directly to an IBM PC computer. A 30-cm-high table was placed above the drawing board, and the participant was positioned such that the table was directly below his or her chin. The table served two purposes: It occluded vision of the whole arm and the drawing board, and it supported an IBM color monitor that was placed directly in front of the participants' field of vision, approximately 1 m away. The computer controlled the entire experiment.

Procedure

The participant pressed the stylus down on the drawing board at a predefined start location (visible as a circle centered just above the lower edge of the computer screen) to initiate each trial. The start location and the participant's cursor disappeared from the screen and a target circle appeared on the center of the computer monitor. The distances between the stylus position and the start and target locations displayed on the screen were the same as the distances on the drawing board (i.e., the gain of the display was 1:1). The participant then attempted to move to the target, press down, and return to the start location. Note that although the target circle had a diameter of 5 mm, we told participants that their goal was to hit the center of the target because all error measures were taken from the center. Thus, the target was essentially a point.

We provided KR on the monitor by showing the terminal stylus position (a dot) relative to the target location (a circle) and a number that indicated the number of millimeters from the target center that the movement terminated. The Delay-0 group received KR directly after each trial, whereas the Delay-2 group received KR after a delay of two trials; that is, KR for Trial 1 was provided after Trial 3, KR for Trial 2 was provided after Trial 4, and so on. Participants performed 80 trials on each of 2 days for a total of 160 acquisition trials. On the 2nd day, participants performed a 5-trial retention test before the acquisition trials. Two 40-trial, no-KR retention tests were performed 1 min and 24 hr, respectively, after acquisition. Participants were not informed that KR would be withdrawn on the retention trials until after the acquisition trials had been completed. After the 24-hr retention test, participants were presented with a list of intrinsic feedback sources (hand position, movement time, movement distance, and spring tension) and were asked to indicate which sources they had used during practice. Second, they were asked to indicate whether the sources they used changed with practice and, if so, to briefly describe the nature of the change.

The intrinsic feedback sources were identified from semistructured post hoc interviews of participants who had performed the same task in the Anderson et al. (2001) experiment. In the present experiment, the participants checked the sources of intrinsic feedback on a sheet of paper and then wrote their answer to the second question on the same sheet. That procedure usually took less than 5 min. It must be acknowledged that one cannot determine the reliability of participants' answers when the questions are asked only at the end of the experiment. However, that limitation was deemed acceptable relative to the more serious threat to the validity of the study that would have occurred had we also asked the learners about their intrinsic feedback usage during acquisition or before the retention trials. In other words, there was a high probability of biasing the learner's attention to certain sources of intrinsic feedback or modifying the way in which they used intrinsic feedback, once we had asked our questions. With respect to internal validity, it must also be acknowledged that there was no way to independently verify that participants actually noticed and used the sources of intrinsic feedback that they reported to the experimenter.

Results

The primary dependent variables were radial error (*RE*) and radial variable error (*RVE*). Those measures reflect distance from the target and variability in the distance from the target over trials (Hancock, Butler, & Fischman, 1995). We calculated *RE* as the square root of the sum of the squared deviations in the *x*- and *y*-axes, whereas we calculated *RVE* as the square root of the total sample variance (i.e., the sum of the two variances) in the *x*- and *y*-axes. The total sample variance is simply the sum of the variances in the *x*- and *y*-axes. We blocked trials into groups of 20 for the purpose of analysis. The mean *RE* and *RVE* scores for groups and blocks in acquisition and retention are plotted in Figures 1 and 2.

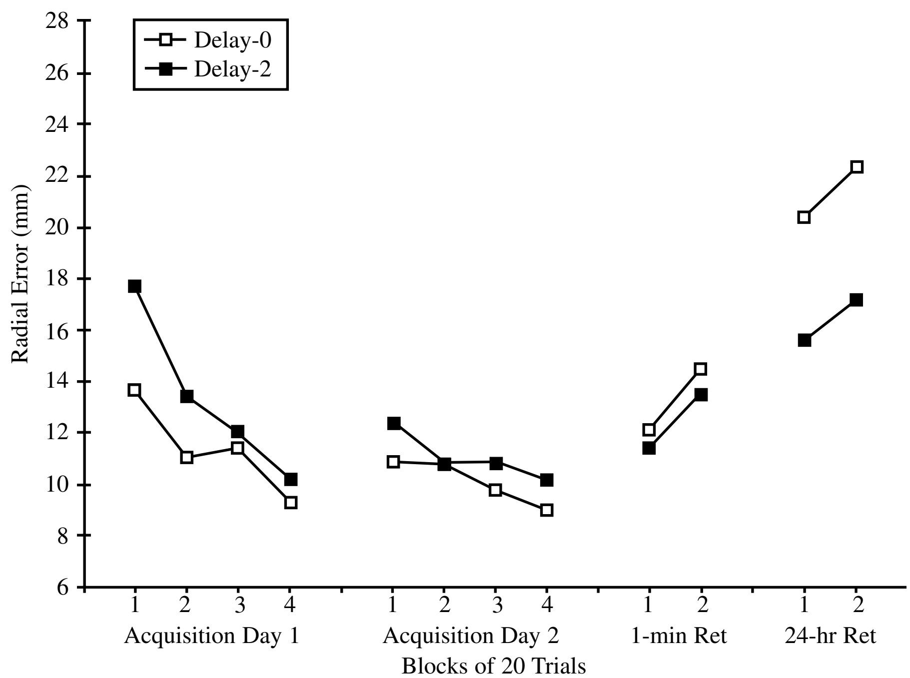

FIGURE 1. Group × Block means for radial error in acquisition and retention. The Delay-0 group received knowledge of results immediately after each trial. The Delay-2 group received knowledge of results after a delay of two trials. Ret = retention.

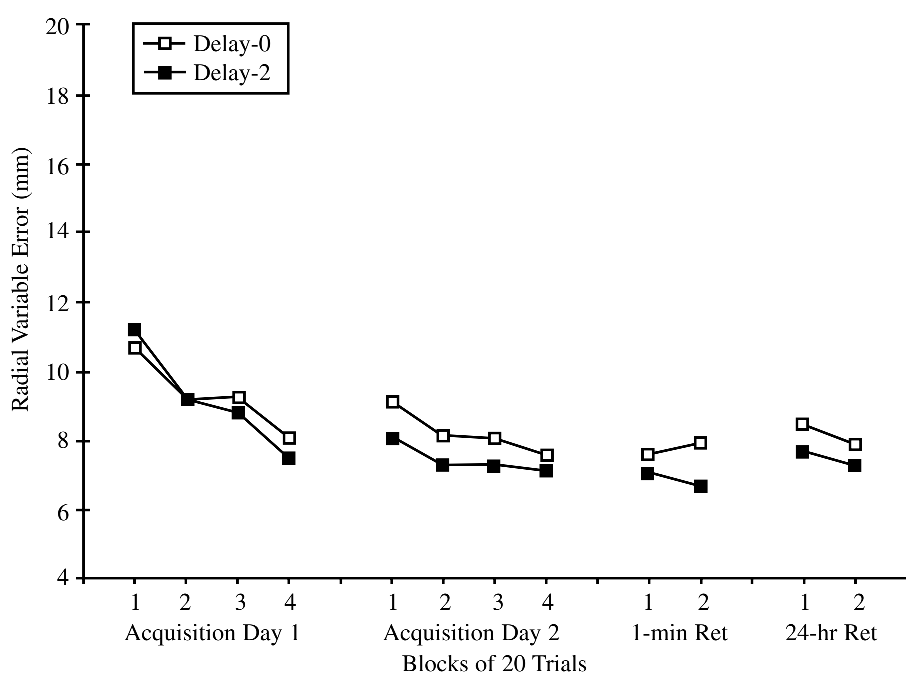

FIGURE 2. Group × Block means for radial variable error (*RVE*) in acquisition and retention. The Delay-0 group received knowledge of results immediately after each trial. The Delay-2 group received knowledge of results after a delay of two trials. Ret = retention.

We analyzed the acquisition data with a 2 × 2 × 4 (Group × Day × Trial Block) analysis of variance (ANOVA) with repeated measures on day and trial block. We analyzed the five-trial test with a one-way ANOVA. We analyzed the 1-min and 24-hr retention tests with separate 2 × 2 (Group × Trial Block) ANOVAs with repeated measures on trial block. Finally, we analyzed relative retention performance by calculating a difference score on the basis of the last block of acquisition trials and each of the first blocks of trials on the retention tests (see Christina & Shea, 1993, for more information on difference scores). We analyzed the difference scores with simple ANOVAs. To protect against any violations to the assumptions of sphericity, we computed the probability level for all statistical analyses involving repeated measures by using the Greenhouse–Geisser degrees-of-freedom adjustment (Greenhouse & Geisser, 1959).

Acquisition

For *RE*, there was a significant effect of day, $F(1, 54) = 20.2$, $p < .001$, and trial block, $F(3, 162) = 44.9$, $p < .001$, although the main effects were overshadowed by a significant Day × Trial Block interaction, $F(3, 162) = 11.5$, $p < .001$. A Newman–Keuls post hoc test indicated that participants were more accurate on Blocks 1, 2, and 3 of Day 2 than on the corresponding blocks on Day 1. A strong trend toward a group effect, $F(1, 54) = 3.8$, $p = .06$, was overshadowed by a significant Group × Block interaction, $F(3, 162) = 3.0$, $p < .05$. The Newman–Keuls post hoc test revealed that the Delay-0 group performed more accurately than the Delay-2 group on Blocks 1 and 4.

The *RVE* analysis revealed significant main effects for day, $F(1, 54) = 32.0$, $p < .001$, and trial block, $F(3, 162) = 29.9$, $p < .001$, and a significant Day × Trial Block interaction, $F(3, 162) = 5.4$, $p < .01$. The Newman–Keuls post hoc test indicated that participants were less variable on Block 1 of Day 2 than on the corresponding block on Day 1.

Five-Trial Retention at Start of Day 2

The Delay-2 group tended to be more accurate and less variable than the Delay-0 group on the five-trial retention test; however, the differences were not significant ($p = .10$ for *RE* and $p = .21$ for *RVE*).

1-min Retention Test

Trial block was the only significant effect for *RE*, $F(1, 54) = 18.7$, $p < .001$. As can be seen in Figure 1, that effect resulted from the substantial deterioration in accuracy that occurred from Block 1 to Block 2. There were no significant findings for *RVE*. However, there was a trend for the Delay-2 group to perform with less variability than the Delay-0 group, $F(1, 54) = 3.2$, $p = .08$.

24-hr Retention Test

There was a significant trial block effect for *RE*, $F(1, 54) = 5.6$, $p < .05$, which revealed that the accuracy of performance for both groups rapidly deteriorated from Block 1 to Block 2. The Delay-2 group performed more accurately than the Delay-0 group; however, the group differences apparent in Figure 1 showed only a trend toward significance, $F(1, 54) = 3.0$, $p = .08$. An effect size of 0.48 suggested that the differences between the two groups approached a moderate level (Thomas, Salazar, & Landers, 1991).

Relative Retention Performance

For *RE*, there were significant differences between groups on the difference scores that were calculated from the end of acquisition to the beginning of immediate retention, $F(1, 54) = 6.0$, $p < .05$, and on the difference scores calculated from the end of acquisition to the beginning of delayed retention, $F(1, 54) = 5.4$, $p < .05$. Both analyses revealed that the relative decline in performance from the end of acquisition to the beginning of retention was smaller in the Delay-2 group than the Delay-0 group. No significant group differences were found for *RVE*.

Intrinsic Feedback Sources

The percentage of participants in each group who reported using each of the intrinsic-feedback sources during practice and who used either one or multiple sources are reported in Table 1. Also reported are the percentages of participants in each group who indicated that they changed sources as practice continued. One of the most interesting findings from those data was that a greater percentage of participants in the Delay-2 group reported using each of the four sources of intrinsic feedback (hand location, movement distance, movement time, and spring tension) that were available during practice. Furthermore, participants in the Delay-0 group were much more likely than participants in the Delay-2 group to use only one source of intrinsic feedback, whereas participants in the Delay-2 group were more likely

TABLE 1. Sources (and Number of Sources) of Intrinsic Feedback Used by Learners in Each Group

Source of intrinsic feedback used	Percentage of learners in each group: Delay-0	Delay-2
Hand location	57	61
Movement distance	43	64
Movement time	11	18
Spring tension	82	93
Number of sources used		
One	32	4
Two	43	64
Three	25	25
Four	0	7

Note. Delay-0 and Delay-2, respectively, refer to the presentation of KR immediately after the task was performed or after a delay of two trials.

to use either two or four sources. A chi-square test of the number of intrinsic feedback sources used revealed that usage was significantly different for the two groups, $\chi^2(3, N = 56) = 36.3$, $p < .0001$.

Finally, only 8 of the participants (29%) in the Delay-0 group, compared with 21 of the participants (75%) in the Delay-2 group, indicated that the intrinsic feedback they used changed with practice. Again, the chi-square test revealed a significant difference between groups, $\chi^2(1, N = 56) = 5.88$, $p < .05$. Note that in that test, the expected frequency is assumed to equal $([8 + 21]/56) \times 28 = 14.56$. In other words, the test is conservative because the expected frequencies are based on a null hypothesis of no group differences in change in usage over practice.

Discussion

Consistent with expectation, the learners who received KR after a delay of two trials reported using a greater number and variety of intrinsic feedback sources than did participants who received KR directly after each trial. There is evidence here along two lines. First, a higher percentage of participants in the Delay-2 group reported using each of the sources of information available during performance. Moreover, the number of information sources differed as a function of group. Almost 33% of the Delay-0 group used only one source of information, whereas about 67% of the Delay-2 group used two sources of information. Moreover, three sources of information were used by 25% of each group, whereas none of the participants in the Delay-0 and 7% of those in the Delay-2 group reported using four sources of information. Second, a significantly higher proportion of participants in the Delay-2 group than in the Delay-0 group reported experimenting with different sources of intrinsic feedback as practice continued. That difference was reinforced by comments from participants in the Delay-2 group. For example, 1 participant noted, “I am very right-handed, so at the beginning I relied on the spring a great deal. Slowly, I was able to refine my hand position and muscle control so that time and distance became easier to judge.” Another participant stated, “I would experiment with different sources now and then, but movement time was used the most.” Similarly, another participant remarked, “More feedback sources were picked up as I went along, but I used combinations of these sources as I progressed.” Such comments were extremely rare in the Delay-0 group.

Together, those observations imply that, relative to KR provided directly after each trial, the delay of KR over trials encouraged learners to pay closer attention to and more thoroughly explore the intrinsic feedback available in the task. To our knowledge, in no previous studies has it been shown that different schedules of KR presentation encourage learners to attend differently to intrinsic feedback, although it has been speculated for some time that learners are more likely to notice and use intrinsic feedback when KR is difficult to use (e.g., Annett, 1961; Salmoni et al., 1984). In addition, the findings provide evidence about the way in which intrinsic feedback is used when KR is delayed over trials. An important question posed by Salmoni et al. in their critical review of the KR literature was whether task cues (sources of intrinsic feedback) are processed to a deeper level or whether different task cues are used when KR is difficult to use. The responses to the questions posed at the end of the present experiment seem to indicate that participants noticed a greater variety of cues when KR was difficult to use. However, it must be noted that the current findings do not rule out the possibility that intrinsic feedback is also processed more deeply or with greater effort (e.g., Lee, Swinnen, & Serrien, 1994) when KR is difficult to use.

With respect to our secondary purpose in the experiment, delaying KR over trials led participants to experience a smaller decline in performance from the end of acquisition to the beginning of both immediate and delayed retention. According to Christina and Shea (1988, 1993), the amount of performance change from the end of acquisition to the beginning of retention provides evidence about how much forgetting of what was learned occurred over the retention interval. It was quite surprising to note how quickly the performance of the Delay-0 group declined over the 1-min retention interval, leading us to question whether the Delay-0 group had actually acquired much knowledge of task properties during practice (Christina & Shea, 1993). Whatever knowledge they had acquired was certainly susceptible to forgetting. In contrast, the Delay-2 group showed a much less rapid decline in performance once KR had been removed, suggesting that knowledge of task properties had been acquired and that the knowledge was more resistant to decay or interference.

Again, with respect to our secondary purpose in the experiment, the findings in acquisition were largely consistent with those of Anderson et al. (2001). Delaying KR by two trials degraded performance in acquisition, although in the current experiment the significant group differences were specific to Blocks 1 and 4 of acquisition. It is not uncommon in this type of experiment to find group differences at the start of acquisition but not thereafter (Schmidt, 1991); however, it is much less common to find differences again at the end of acquisition. Presently, we do not have an explanation for that finding, although the localized group differences might be linked to localized stability or change in the intrinsic feedback that was used during practice. Unfortunately, another limitation of the questioning procedure is that we did not ask participants to indicate when they changed their use of intrinsic feedback, so we are unable to offer any data to support that speculation.

Finally, it should be noted that there was only a trend toward absolute group differences in delayed retention. That result lies somewhere in between the results of Anderson et al. (2001), who found no differences at all between the Delay-2 and the Delay-0 groups for this particular task, and the results of virtually every other experiment on the trials delay of KR. In the latter experiments, the performance of the group that received delayed KR was superior to that of the group that received KR directly after each trial (Anderson et al., 1994, 2001; Lavery, 1964; Lavery & Suddon, 1962; Suddon & Lavery, 1962). How does one reconcile those findings? We do so by following the claim made by Anderson et al. (2001) that delaying KR over trials (or generally making KR difficult to use) is unlikely to facilitate retention performance when the feedback intrinsic to the task is unfamiliar to the learner. It is pertinent to note again here that several researchers have argued that considerable practice may be required before participants can effectively use the intrinsic feedback associated with aiming or positioning movements that are resisted by spring loading (e.g., Anderson, 1999; Bahrick, Bennett, et al., 1955; Bahrick, Fitts, et al., 1955; Williams, 1974). On the basis of that suggestion, and consistent with Lavery and Suddon's experiment, in which delaying KR over trials facilitated retention of a force-production task after 90 but not after 30 trials, we reasoned that doubling the practice trials given by Anderson et al. (2001) might allow the superiority of the Delay-2 group to reemerge on this task.

We were only partially correct. Superiority emerged on the relative measures of immediate and delayed retention performance, but only weakly on the absolute measure of delayed retention performance. However, it must also be noted that the Delay-0 group was significantly more accurate than the Delay-2 group at the end of practice, and that difference likely attenuated the absolute differences in retention. Consequently, investigators may need to again increase the amount of practice with the current version of the task before the superiority of the group that received delayed KR would reemerge on the absolute measure of delayed retention performance. Another possibility is that the superiority of the Delay-2 group would have emerged on the absolute measure if the retention test had been given after a longer delay (e.g., 48 hr or 1 week). That scenario is quite likely given the differences between groups in the rate at which knowledge of task properties was forgotten.

In summary, the present findings provide clear evidence that the schedule on which KR is provided influences the extent to which learners attend to and use intrinsic feedback. Participants explored the task-intrinsic feedback more thoroughly and were more likely to report using different sources of intrinsic feedback as practice continued when KR was delayed over trials than when it was presented directly after each trial. The more thorough processing of intrinsic feedback was associated with inferior performance on the first and last blocks of practice with KR; however, the relative measures of retention suggest that it also led to a knowledge of task properties that was more resistant to forgetting. That conclusion was further supported by the trend toward absolute group differences in delayed retention, given that the task-intrinsic feedback was unfamiliar to the learner and that the beneficial effects of delaying KR over trials had not been apparent for this task when only half the amount of practice was provided in a previous experiment.

ACKNOWLEDGMENT

Preparation of this manuscript was supported by a Research Infrastructure in Minority Institutions Award from the National Center on Minority Health and Health Disparities, P20 MD00262.

REFERENCES

Anderson, D. I. (1999). The discrimination, acquisition, and retention of aiming movements made with and without elastic resistance. *Human Factors, 41,* 129–138.

Anderson, D. I., Magill, R. A., & Sekiya, H. (1994). A reconsideration of the trials-delay of knowledge of results paradigm in motor skill learning. *Research Quarterly for Exercise and Sport, 65,* 286–290.

Anderson, D. I., Magill, R. A., & Sekiya, H. (2001). Motor learning as a function of KR schedule and characteristics of task-intrinsic feedback. *Journal of Motor Behavior, 33,* 59–66.

Annett, J. (1961). *The role of knowledge of results in learning: A survey* (Tech. Rep. No. 342-3). Port Washington, NY: U.S. Naval Training Device Center.

Bahrick, H. P., Bennett, W. F., & Fitts, P. M. (1955). Accuracy of positioning responses as a function of spring loading in a control. *Journal of Experimental Psychology, 49,* 437–444.

Bahrick, H. P., Fitts, P. M., & Schneider, R. (1955). Reproduction of simple movements as a function of factors influencing proprioceptive feedback. *Journal of Experimental Psychology, 49,* 445–454.

Buekers, M. J., & Magill, R. A. (1995). The role of task experience and prior knowledge for detecting invalid augmented feedback while learning a motor skill. *The Quarterly Journal of Experimental Psychology, 48A,* 84–97.

Christina, R. W., & Shea, J. B. (1988). The limitations of generalization based on restricted information. *Research Quarterly for Exercise and Sport, 59,* 291–297.

Christina, R. W., & Shea, J. B. (1993). More on assessing the retention of motor learning based on restricted information. *Research Quarterly for Exercise and Sport, 64,* 217–222.

Greenhouse, S. W., & Geisser, S. (1959). On methods in the analysis of profile data. *Psychometrika, 24,* 95–112.

Guadagnoli, M. A., Dornier, L. A., & Tandy, R. D. (1996). Optimal length for summary knowledge of results: The influence of task-related experience and complexity. *Research Quarterly for Exercise and Sport, 67,* 239–248.

Hancock, G. R., Butler, M. S., & Fischman, M. G. (1995). On the problem of two-dimensional error scores: Measures and analyses of accuracy, bias, and consistency. *Journal of Motor Behavior, 27,* 241–250.

Lavery, J. J. (1964). The effect of one-trial delay in knowledge of results on the acquisition and retention of a tossing skill. *American Journal of Psychology, 77,* 437–443.

Lavery, J. J., & Suddon, F. H. (1962). Retention of simple motor skills as a function of the number of trials by which KR is delayed. *Perceptual and Motor Skills, 15,* 231–237.

Lee, T. D., Swinnen, S. P., & Serrien, D. J. (1994). Cognitive effort and motor learning. *Quest, 46,* 328–344.

Magill, R. A., & Wood, C. A. (1986). Knowledge of results precision as a learning variable in motor skill acquisition. *Research Quarterly for Exercise and Sport, 57,* 170–173.

Patrick, J., & Mutlusoy, F. (1982). The relationship between types of feedback, gain of a display and feedback precision in acquisition of a simple motor task. *Quarterly Journal of Experimental Psychology, 34A,* 171–182.

Proteau, L., Marteniuk, R. G., Girouard, Y., & Dugas, C. (1987). On the type of information used to control and learn an aiming movement after moderate and extensive training. *Human Movement Science, 6,* 181–199.

Proteau, L., Marteniuk, R. G., & Lévesque, L. (1992). A sensorimotor basis for motor learning: Evidence indicating specificity of practice. *The Quarterly Journal of Experimental Psychology, 44A,* 557–575.

Salmoni, A. W., Schmidt, R. A., & Walter, C. B. (1984). Knowledge of results and motor learning: A review and critical reappraisal. *Psychological Bulletin, 95,* 355–386.

Schmidt, R. A. (1991). Frequent augmented feedback can degrade learning: Evidence and interpretations. In J. Requin & G. E. Stelmach (Eds.), *Tutorials in motor neuroscience* (pp. 59–75). Amsterdam: Kluwer.

Schmidt, R. A., Lange, C., & Young, D. E. (1990). Optimizing summary knowledge of results for skill learning. *Human Movement Science, 9,* 325–348.

Schmidt, R. A., & Lee, T. D. (1999). Motor control and learning: A behavioral emphasis (3rd ed.). Champaign, IL: Human Kinetics.

Schmidt, R. A., & White, J. L. (1972). Evidence for an error detection mechanism in motor skills: A test of Adams' closed-loop theory. *Journal of Motor Behavior, 4,* 143–153.

Shea, C. H., Kohl, R., & Indermill, C. (1990). Contextual interference: Contributions of practice. *Acta Psychologica, 73,* 145–157.

Suddon, F. H., & Lavery, J. J. (1962). The effect of amount of training on retention of a simple motor skill with 0- and 5-trial delays of knowledge of results. *Canadian Journal of Psychology, 16,* 312–317.

Swinnen, S. P., Schmidt, R. A., Nicholson, D. E., & Shapiro, D. C. (1990). Information feedback for skill acquisition: Instantaneous knowledge of results degrades learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 16,* 706–716.

Thomas, J. R., Salazar, W., & Landers, D. M. (1991). What is missing in $p < .05$? Effect size. *Research Quarterly for Exercise and Sport, 62,* 344–348.

Williams, I. D. (1974). Practice and augmentation in learning. *Human Factors, 16,* 503–507.

Winstein, C. J., & Schmidt, R. A. (1990). Reduced frequency of knowledge of results enhances motor skill learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 16,* 677–691.

Young, D. E., & Schmidt, R. A. (1992). Augmented feedback for enhanced skill acquisition. In G. E. Stelmach & J. Requin (Eds.), *Tutorials in motor behavior II* (pp. 677–693). Amsterdam: North-Holland.

Submitted July 15, 2003
Revised February 10, 2004