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Diminishing the Effects of Reduced Frequency of Knowledge of Results on Generalized Motor Program Learning

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ABSTRACT. Several recent studies have shown that, compared with presenting knowledge of results (KR) on every practice trial, withholding KR on some practice trials enhances the learning of generalized motor programs (GMPs; Wulf, Lee, & Schmidt, 1994; Wulf & Schmidt, 1989; Wulf, Schmidt, & Deubel, 1993). In this study, whether this effect may result from an uncertainty on the part of participants about when KR is to be presented was determined by examining the GMP learning of two 67% relative-frequency KR groups-one that received advance information regarding the delivery of each KR (67% AKR) during practice trials and another that received no advance information (67% KR)as well as that of a 100% KR group. The task required participants to produce 3 movement patterns that shared the same relative and absolute timing and relative amplitude but differed in terms of absolute amplitude. KR was provided by displaying the rootmean-square error (RMSE) score and by graphically superimposing the participant-produced pattern on that of the goal movement. The results revealed no group differences in measures of GMP development or parameterization effectiveness during practice and no-KR retention. However, during no-KR transfer with a novel absolute amplitude, the 67% KR group demonstrated a more accurate and stable GMP than the 67% AKR and 100% KR groups. Possible explanations for why advance knowledge about KR delivery diminishes GMP development are discussed.

Key words: attentional focus, feedback frequency, generalized motor program, knowledge of results, motor learning, precuing

Before the publication of Salmoni, Schmidt, and Walters' (1984) review of the literature on knowledge of results (KR) and motor learning, it was generally assumed that the provision of more frequent or precise extrinsic feedback during practice facilitated the learning of skills (e.g., Adams, 1971; Bilodeau, Bilodeau, & Schumsky, 1959; Schmidt, 1975; Thorndike, 1927). However, since 1984, a number of studies have revealed that reducing the frequency (e.g., Nicholson & Schmidt, 1991; Winstein, 1988; Winstein & Schmidt, 1990) or average precision (Young, 1988;

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Young & Schmidt, 1992) of KR during practice trials enhances the retention and transfer of criterion movements in the absence of KR, especially when retention or transfer tests are given at least 24 hr after initial practice.

There is also evidence (Wulf & Schmidt, 1989, 1994; Wulf, Schmidt, & Deubel, 1993) that reduced frequency of KR during practice may facilitate the learning of generalized motor programs (GMPs). According to Schmidt (1975, 1985), the GMP is developed over practice and becomes the basis for generating a particular class of actions (e.g., throwing) that share similar invariant characteristics (e.g., sequencing, relative timing, relative force) but can be scaled by the assignment of parameters such as absolute duration and absolute force. Thus, depending on the parameter selected, a movement governed by the GMP may be systematically speeded up or slowed down or produced with more or less overall force while sequencing, relative timing, and relative forces remain essentially invariant. Although the notion of proportional scaling has not been without its critics (Genter, 1987, 1988; but also see Heuer, 1988, for a rebuttal), the idea of the GMP remains a viable one (see Heuer & Schmidt, 1988, for a more thorough discussion of this issue).

In an initial test of the effects of withholding KR during some practice trials on GMP learning, Wulf and Schmidt (1989) used a three-segment timing task in which participants attempted to produce movements that varied with respect to absolute movement time but had the same relative movement time for the three segments. The results revealed

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that, compared with KR after every practice trial, when KR was withheld on some trials during practice, participants produced less error in relative timing on delayed transfer (Experiment 1) and retention (Experiment 2) tests. Subsequent research by Wulf et al. (1994), using the same task, revealed that compared with presenting KR on every practice trial, reduced frequency of relative timing KR during practice enhanced GMP learning when performance was measured on a delayed transfer test. Taken together, these results suggest that KR that pertains to the development of a more stable memory representation (i.e., the GMP) should be withheld on some trials during motor skill practice.

Wulf et al. (1993) attempted to determine the generalizability of the reduced-KR-frequency effect on GMP learning by using a task that required the production of several versions of a generalized movement pattern, each with the same relative timing and relative amplitude characteristics but different absolute movement times (Experiment 1) or amplitudes (Experiment 2). Unlike the three-segment timing task, the pattern-production task allows the mathematical separation of errors associated with the production of the GMP from those related to parameterization. In both experiments, reducing the frequency of KR during practice generally enhanced GMP accuracy and stability compared with that of a 100% KR group, but tended to have slightly detrimental effects on parameterization capability when performance was measured on delayed retention and transfer tests. These findings further suggest that different processes and mechanisms may be involved in the learning of GMPs and in the ability to parameterize them. Specifically, it appears that more frequent KR during practice primarily blocks the processing of intrinsic feedback associated with the learning of fundamental movement representations (i.e., GMPs) but has little or a somewhat negative influence on the capability for selecting specific parameter values associated with changing task requirements (e.g., overall speed or amplitude).

Recently, Wulf and Schmidt (1994) demonstrated that the beneficial effects of a random practice schedule over a blocked practice schedule on GMP learning (e.g., Lee & Magill, 1983; Shea & Morgan, 1979) can be nullified by increasing the emphasis on extrinsic feedback. Using the lever-patterning task employed by Wulf et al. (1993, Experiment 2), participants attempted to produce three different movement patterns. During practice, movement versions were performed in either a blocked or a random format and participants either received or did not receive reminder feedback (i.e., KR pertaining to the previous trial with the about-to-be-performed movement version) prior to each trial. The results from immediate and delayed retention tests revealed that participants who practiced under a random schedule and received reminder feedback demonstrated significantly less GMP accuracy than did those in the other practice schedule and reminder feedback conditions. Wulf and Schmidt (1994) suggested that increasing the salience of KR during random practice (i.e., by the use of KR reminders) may have served to block the subjective analysis of intrinsic, movement-produced feedback or to facilitate GMP retrieval operations.

Taken together, the available research findings suggest that any procedure that makes KR information more usable during practice-by presenting KR more often or by making the presentation of KR more certain-degrades GMP learning. Among other things, these results suggest an alternative interpretation of findings from previous KR-frequency experiments. Specifically, it is possible that the GMP learning of participants receiving fewer KR trials during practice was superior to that of participants receiving KR on all practice trials because of differences in either the frequency of KR trials or the certainty about KR delivery. In all cases, the group that has consistently demonstrated the least GMP learning on delayed, no-KR retention and transfer tests has been the one that has received KR more frequently during practice trials and has always been certain about when KR is to be delivered (i.e., the 100% KR-frequency group). Conversely, participants in the reduced-frequency-of-KR conditions not only have received fewer KR trials during practice but have probably been uncertain about the delivery of KR on each trial. Although reduced-KR-frequency participants are usually instructed that KR will be withheld during a portion of practice trials, it is unlikely that they remember the exact schedule of KR during the practice phase. Thus, it is possible that the superior GMP learning of participants for whom KR was withheld during a portion of practice trials in previous reduced-KRfrequency experiments was caused not only by the fewer number of KR trials experienced during practice but also by an uncertainty regarding the schedule of KR delivery. If such is the case, one might predict that the procedure of withholding KR on some trials during practice would be less beneficial to GMP learning if reduced-frequency-of-KR participants were reminded or informed about whether or not KR would be delivered at the beginning of each trial.

To test this notion, in the present experiment we included two reduced-KR-frequency groups in addition to a 100% KR-frequency group. Prior to each no-KR practice trial, one reduced-KR-frequency group was precued that KR would not be delivered, whereas the other group was not. To determine the effects of advance information about KR delivery on GMP and parameterization learning, we chose a leverpatterning task similar to the one used by Wulf et al. (1993, Experiment 2). Participants performed practice trials under their respective feedback conditions and then were given delayed retention and transfer tests 24 hr later in the absence of KR. We predicted that if advance information increases the certainty of KR delivery and blocks the processing of intrinsic properties of the movement during practice, then the accuracy and stability of the GMP on delayed retention and transfer tests would be lower for the 100% KR group and the reduced-KR-frequency group given advance information about no-KR trials than for the reduced-KRfrequency group given no advance information. Moreover, if advance information about KR delivery diminishes the processing of intrinsic movement information only on trials in which KR is given, then the accuracy and stability of the GMP on delayed retention and transfer tests would be lower for the 100% KR group than for the reduced-KR-frequency group given advance information. If the reduced-frequencyof-KR effect found in previous studies was primarily caused by differences in the number of trials with KR given during the practice phase, then the GMP learning of the two reduced-KR-frequency groups would be expected to be superior to that of the 100% KR group. Consistent with the results of earlier studies (e.g., Wulf et al., 1993), no beneficial effects on parameterization learning as a function of KR-frequency condition were expected.

Method

Participants

The participants were students from the University of Munich (N = 60). They were naïve to the purposes of the experiment, had no prior experience with the apparatus, and were paid DM 15 (about \$11) for their services.

Apparatus

The apparatus was identical to that used by Wulf et al. (1993). It consisted of a wooden lever mounted horizontal-

ly and supported at one end by a vertical axle that allowed almost frictionless movement. The axle handle, affixed to the opposite end of the lever, could be adjusted so that the participant's forearm rested comfortably on the lever, with the elbow aligned over the axis of rotation. A potentiometer, attached to the base of the axle, allowed the recording of lever position. The resulting signal was sampled at 200 Hz by a Hewlett Packard Vectra QS/20 computer. We placed a wooden cover over the apparatus to mask the participant's view of the lever during task performance.

Task

The task involved a right-arm lever movement designed to produce various spatiotemporal movement patterns. A prototypic goal movement pattern was derived by selecting a particular trace of a generated time series composed of sine and cosine terms. From this pattern, four versions were produced by scaling the amplitude parameters of the trace. The four versions shared the same relative timing, relative amplitude, and goal MT (937 ms) but varied in absolute amplitude (see Figure 1).

Procedure

Each trial began with the lever positioned at 39° (0° was at the participant's frontal plane). One of the goal movement versions was then displayed on a computer screen



(EIZO Flexcan 9060S) located directly in front of the seated participant. A letter (A, B, C, or D), corresponding to the displayed version, was also presented in the upper left corner of the screen. A box superimposed around the letter served as the precue for reduced-frequency, advance-information participants on trials for which KR would not be given. After 4 s, the pattern and letter disappeared and were replaced by two vertical cursors, one in the center representing the starting position and the other representing the actual position of the lever. The participant then moved the lever to align the two cursors. Once this was done, the cursors disappeared and a tone sounded, indicating to the participant that the movement could be initiated at any time. When ready, the participant made a sequence of extensionflexion-extension-flexion movements in an attempt to produce the previously displayed goal pattern. Before and during the movement, the screen remained blank. Two seconds after movement completion, KR was provided by superimposing the participant-produced pattern on the goal pattern. The latter trace was displayed in white, whereas the former (which was always recorded for 1.6 s) was presented in yellow, extending to the right of the goal trace for added distinctiveness. In addition, the root-mean-square deviation (RMS error) of the participant's pattern from the goal pattern was displayed. These two forms of postresponse KR remained on the screen for 5 s and then disappeared. A constant 16-s intertrial interval was used for all groups on all trials.

Upon entering the laboratory on the 1st day, each participant was familiarized with the apparatus, task, and KR. They were told that on each trial they should attempt to match their movement trace with that of the goal pattern and that an error score would be presented that represented the average deviation between their pattern and the goal pattern. Participants were not told that their patterns were going to be scaled or that trials on the 2nd day would be given in the absence of KR. They then performed three practice trials with KR on Version B (see Figure 1). Following each of these trials, the purpose of the task was reiterated and the two forms of KR were discussed. Once it was clear that the participant understood the task and the KR information, the experiment was commenced.

The study comprised three phases: practice, delayed retention, and delayed transfer. During the practice phase, participants performed 30 trials with each of three versions of the movement pattern (A, B, and C) for a total of 90 trials. The structure of practice was blocked, with participants performing six successive repetitions of a particular version in each block. This resulted in 15 blocks of 6 trials each (5 blocks for each version), the order of which was randomized, with the restriction that each version appear once in each 3-block sequence. Participants were randomly assigned to three groups (n = 20/group): the 100% KR group, the 67% KR group (67% KR), and the 67% advance-information-KR group (67% AKR). The 100% KR group received KR after every practice trial, whereas the two

reduced-frequency groups were given KR on 60 of the 90 trials. The location of the KR trials was randomized, with the restriction that 10 no-KR trials be given for each amplitude. All reduced-frequency-KR participants received the same randomized order of KR trials.

On the following day, participants returned for the delayed retention and delayed transfer phases of the experiment. The retention phase involved 12 trials of Patterns A, B, and C (4 trials of each pattern) with no KR. The order of task versions was randomized. Immediately following the retention phase, participants attempted 12 no-KR trials of Pattern D (see Figure 1) that had not been performed previously and that required an absolute amplitude that was greater than that of the other patterns.

Dependent Measures

The measure of overall accuracy and variability was RMS error (calculated on the first 937 ms of the participant's movement), which comprises both constant errors (i.e., the average algebraic deviation of the participant's response from the goal pattern) and within-participant variability (Schmidt, 1988). Because RMS error is sensitive to errors in both GMP production and parameterization, however, we derived additional measures to distinguish the quality of production of the GMP from that of the time and amplitude parameters. This was accomplished with a computer program that scaled (i.e., compressed or stretched) the participant-produced movement trajectory in amplitude and in time until the remaining RMS error was as negligible as possible (see Wulf & Schmidt, 1994, or Wulf et al., 1993, for a more detailed discussion of the scaling procedure). The procedure yielded separate time and amplitude factors (i.e., gain factors describing how much one must adjust the overall time or amplitude, respectively, to generate the best fit with the goal movement pattern). The RMS error remaining after scaling was completed was termed residual RMS error.

Because residual RMS error represented the agreement of the movement with the template after errors in time and amplitude parameterization had been removed, it was assumed to reflect the accuracy of the GMP. We also calculated variable error (VE) in residual RMS error by computing the average standard deviation for each point of the rescaled participant traces across a set of trials to determine the stability of the fundamental movement pattern (GMP) with regard to itself.¹ The amplitude and time factors were considered to be measures of error in the parameterization of amplitude (i.e., making the size of the movement too large or too small) and time (i.e., performing the movement too quickly or too slowly). We calculated absolute constant error (ICEI; see Schmidt, 1988) and variable error of amplitude and time factors to indicate bias and within-participant variability in parameterization, respectively (see Wulf et al., 1993, for a more detailed description of the calculation of the different error scores).

In summary, then, the following dependent measures (with a brief description of the performance aspect reflect-

ed by each) were derived for the purposes of analysis: residual RMS error (GMP accuracy), residual RMS error VE (GMP stability), time factor ICEI (time parameter accuracy), time factor VE (time parameter stability), amplitude factor ICEI (amplitude parameter accuracy), and amplitude factor VE (amplitude parameter stability). During the practice and delayed transfer phases, VE measures were calculated across 6 and 12 consecutive trials, respectively, on the same task version. During the delayed retention phase, VEs were calculated across the 4 trials on each version and then averaged across versions.

Results

Analysis of the Unit Structure of the Movement Patterns

One assumption underlying the separation of errors in the fundamental movement pattern (GMP) and its parameterization is that the movements are controlled by a single unit (Young & Schmidt, 1990). If the movements are controlled by two or more programmed units, the scaling procedure used here would not have been justified. In addition, we needed to make sure that the timing structure was maintained across task versions. Therefore, before turning to the main results, we now report how we verified that the aforementioned conditions were met.

We used the unit analysis procedure proposed by Young and Schmidt (1990; see also Schneider & Schmidt, 1995; Wulf & Schmidt, 1994) to examine the unit structure of the movement patterns. This procedure involves computing the acceleration-time functions of participant-produced trajectories and determining temporal landmarks of these functions as defined by peaks and zero crossings. The patterns used here had seven landmarks that were present in every movement. These were labeled a, b, \ldots, g , from the earliest to the latest in the movement. The time of occurrence of each of these landmarks was determined and within-participant (across trials) correlations were computed among these measures. That is, we calculated the correlations between the first landmark and successively later landmarks (i.e., a-b, a-c, ..., a-g) as well as between the last landmark and each of the succession of earlier landmarks (i.e., $a-g, b-g, \ldots, f-g).$

For movements governed by a single unit (or GMP), the correlations should be relatively high and change only slightly and continuously from the beginning to the end of the movement, and vice versa. These patterns have been termed *Type I units* by Young and Schmidt (1990). Movements governed by more than one unit, however, should show an abrupt drop in the correlations, indicating that the landmarks spanned the border between two units. Young and Schmidt (1990) found a drop in the correlations for a movement of this type from about .80 for landmarks a-d to about .20 for landmarks a-e. Patterns such as these were labeled *Type II units*.

For our correlation analysis, we first converted each of

the correlation coefficients to Z' transformations. We then used the data of every other participant in each group and analyzed the last 18 trials (i.e., the block of 6 trials on task versions C, A, and B with the large, small, and medium amplitudes, respectively). For both sets of correlations (i.e., using the first landmark and the last landmark), there were no main effects of group or task version, nor was there a significant Group × Task Version interaction. Therefore, the data were collapsed across groups and task versions. The patterns of untransformed correlations are shown in Figure 2. These patterns were consistent with those expected of a



one-unit structure. With increasing distance between the landmark at the start of the movement and subsequent landmarks (Figure 2A), the correlations gradually decreased from .73 to .50. Similarly, as the distance increased between the last landmark and successively earlier landmarks, the correlations decreased from .94 to .50 (Figure 2B). The largest successive change in correlations was .18, and most changes were smaller than .10. These values are very similar to those reported by Wulf and Schmidt (1994). Thus, it appeared that the movement patterns we used were governed by a single unit (GMP) and that relative timing structure was preserved across task versions. We therefore felt justified in using the scaling procedure to separate errors in the fundamental movement pattern (GMP) and those associated with parameterization.

The following results are presented for each of the three phases of the experiment: practice, delayed retention, and delayed transfer. The data of 1 participant in the 67% KR group were not included in the analyses because that participant demonstrated unusually high variability in all phases of task performance. For the practice phase, separate mixed-factor 3×5 (Group \times Block) repeated measures multivariate analyses of variance (DM MANOVA) were performed for the dependent measures reflecting GMP development (i.e., residual RMS error and residual RMS error VE) and for those associated with parameterization learning (i.e., time factor ICEI, time factor VE, amplitude factor ICEI, and amplitude factor VE). Following the recommendation of Schutz and Gessaroli (1987), the block effect was evaluated by using Hotelling's T^2 (TSQ), whereas the group effect and the Group × Block interaction were interpreted by using Wilks's lambda (LRATIO). For the delayed retention and delayed transfer phases, simple MANOVAs were calculated for the two sets of dependent measures, and we used the LRATIO to evaluate group effects. Where appropriate, we employed follow-up MANOVA, ANOVA, and Student-Newman-Keuls procedures to locate the source of significant omnibus effects.

Practice

GMP Development

Group means for residual RMS error and residual RMS error VE are shown at the left of Figures 3 and 4, respectively. Inspection of these figures indicates that errors associated with both the accuracy (Figure 3) and the stability (Figure 4) of fundamental movement patterning (i.e., the GMP) diminished over practice for all groups. The 3×5 (Group × Block) DM MANOVA revealed a significant omnibus Hotelling's T^2 for the block effect (TSQ = 132.37, p < .0001) and that both residual RMS error (TSQ = 96.59, p < .0001) and residual RMS error VE (TSQ = 83.72, p <.0001) were responsible for this significant effect. Neither the group effect (LRATIO = .901, p = .21) nor the Group × Block interaction (LRATIO = .755, p = .54) were statistically reliable. Taken together, these results suggest that KR



FIGURE 3. Mean (across participants in each condition) residual RMS error remaining between the participant's movement and the template after linear rescaling of each movement in time and amplitude had removed parameterization errors; this measure reflects the accuracy of the GMP.



manipulations introduced during the practice phase exerted a similar influence on GMP development.

Parameterization Learning

Group means for the time and amplitude factors during the practice phase are presented at the left of Table 1. Inspection of this table reveals that all groups improved in the accuracy and stability of parameterization over practice. The 3×5 (Group × Block) DM MANOVA revealed a

Practice block							
Group	1	2	3	4	5	Del. ret.	Del. trn
		Time factor	CEI (time	parameter d	iccuracy)		
67% KR	.15	.10	.08	.06	.05	.23	.25
67% AKR	.19	.13	.12	.09	.08	.23	.18
100% KR	.19	.10	.08	.08	.05	.17	.18
		Time facto	or VE (time j	parameter s	tability)		
67% KR	.19	.14	.12	.11	.10	.13	.08
67% AKR	.21	.16	.17	.15	.14	.16	.09
100% KR	.22	.15	.13	.13	.13	.12	.12
	Ampl	itude factor	ICEI (ampli	itude param	eter accur	acy)	
67% KR	.17	.12	.09	.10	.09	.25	.19
67% AKR	.21	.18	.14	.13	.12	.22	.20
100% KR	.16	.14	.12	.13	.12	.28	.22
	Amp	litude facto	r VE (ampli	tude param	eter stabil	ity)	
67% KR	.23	.24	.18	.15	.15	.23	.11
67% AKR	.25	.22	.20	.21	.21	.19	.11
100% KR	.26	.22	.20	.19	.18	.27	.13

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significant omnibus effect of block (TSQ = 190.38, p < .0001) and that all four dependent measures (TSQs = 62.73, 137.53, 20.31, and 34.66, ps < .01, for time factor ICEI, time factor VE, amplitude factor ICEI, and amplitude factor VE, respectively) were responsible for this significant effect. However, neither the group effect (LRATIO = .896, p = .65) nor the Group × Block interaction (LRATIO = .556, p = .66) were statistically reliable. Therefore, these results also suggest that KR manipulations during the practice phase produced a comparable influence on parameterization learning.

Delayed Retention

GMP Development

Residual RMS error and the variability of residual RMS error during the delayed retention phase is shown in the middle of Figures 3 and 4, respectively. Inspection of these figures indicates little difference among groups for either measure. The simple MANOVA procedure yielded a nonsignificant omnibus group effect, LRATIO = .917, p = .31. Contrary to our prediction, the effect of KR manipulations on GMP development during the practice phase resulted in similar levels of accuracy and stability in the performance of previously practiced versions of the movement during the delayed retention phase when KR was removed.

Parameterization Learning

Group means for the time and amplitude factors during the delayed retention phase are presented at the right of Table 1. Mean differences between groups were small for all four measures, and there was no reliable omnibus group effect; LRATIO = .805, p = .16. This result suggests that the parameterization process during delayed retention trials in the absence of KR was influenced similarly by the different KR manipulations that occurred during practice.

Delayed Transfer

GMP Development

Residual RMS error and residual RMS error VE during the delayed transfer phase are depicted at the right of Figures 3 and 4, respectively. Inspection of these figures reveals that the performance of the 67% KR group was superior to that of the two advance-information groups on both measures. The MANOVA yielded a significant omnibus group effect; LRATIO = .752, p < .01, F(2, 56) =8.36, MSE = .00076, p < .001. Follow-up univariate tests revealed a reliable effect for both residual RMS error, F(2,56) = 3.72, MSE = 1,572, p = .03; and for residual RMS error VE, F(2, 56) = 8.36, MSE = .00076, p < .001. Post hoc testing indicated significantly lower scores on both error measures for the 67% KR group than for the two advanceinformation groups, which were not different on either measure. These results provided support for our prediction that, compared with no advance information about the presentation of KR during practice, advance information results in a GMP that is less accurate and stable during transfer performance. However, there was no support for the prediction that the 67% AKR group would demonstrate GMP accuracy and GMP stability that was superior to that of 100% KR participants.

Parameterization Learning

Descriptive statistics for the time and amplitude measures are presented at the right of Table 1. Similar to the pattern found for retention, differences between groups were small for all measures. The MANOVA yielded a nonsignificant group effect, LRATIO = .849, p = .35. Thus, it appeared that the parameterization process during transfer was not differentially influenced by KR manipulations during the practice phase.

Discussion

Previous studies have shown that procedures that make KR more salient during KR practice trials-by withholding KR less often (e.g., Wulf et al., 1993) or by providing KR reminders (e.g., Wulf & Schmidt, 1994)-result in diminished GMP accuracy and stability during performance on delayed retention and transfer tests in the absence of KR. Wulf and Schmidt (1994) suggested that such procedures may shift participants' attention away from the intrinsic properties of the movement and thereby inhibit development of the GMP. In the present study, we attempted to determine whether the reduced-KR-frequency effect on GMP learning found in previous experiments (e.g., Wulf et al., 1993) may have been caused in part by differences in the certainty of KR delivery between participants who received KR on 100% of their practice trials and those who received KR on a fewer number of practice trials.

Our participants performed three versions of a movement pattern that differed in absolute amplitude but had the same absolute and relative timing and the same relative amplitude. During the practice phase, one group received KR on every trial (100% KR) and thus had the highest frequency of KR and the most certainty about KR delivery. Two reduced-frequency-KR groups were given KR on 67% of the trials but differed with respect to the certainty of KR delivery. One reduced-frequency-KR group was precued prior to each no-KR practice trial (67% AKR), whereas the other group was not (67% KR). It was predicted that if differences in the certainty of KR delivery during practice trials in previous studies contributed to differences in GMP development between 100% KR-frequency and reduced-KR-frequency groups, then GMP accuracy and stability during no-KR delayed retention and transfer tests would be (a) lower for the 100% KR group than for the two reduced-KR-frequency groups and (b) lower for the 67% AKR group than for the 67% KR group. If greater KR frequency During the practice phase, significant improvements in the measures of GMP development and parameterization learning occurred for all three groups. However, there were no significant differences among groups. These results are similar to those reported in earlier research (e.g., Winstein & Schmidt, 1990; Wulf et al., 1993, Experiment 2) and suggest that KR manipulations exert no differential influence on measures of GMP development or parameterization learning when KR is present.

To determine the more permanent effects of the experimental conditions on GMP development and parameterization learning (i.e., when the temporary influence of practice manipulations had presumably dissipated), we tested our participants 24 hr later on the three movement versions performed during the practice phase as well as on one movement version that required an absolute amplitude that had not been previously attempted. Although no between-group differences were observed on the delayed retention test,² the 67% KR group displayed levels of GMP accuracy and consistency on the delayed transfer test that were superior to those of the two advance-information groups, which did not differ from each other on either measure. Thus, it appears that, compared with presenting KR on every practice trial, the beneficial effects of withholding KR during a portion of practice trials on GMP learning found in earlier studies (e.g., Wulf & Schmidt, 1989; Wulf et al., 1993) may have been caused in part by an uncertainty among reduced-frequency-KR participants about KR delivery. Our results are in one sense analogous to those of Wulf and Schmidt (1994) in suggesting that procedures that direct participants' attention to augmented extrinsic feedback have the potential for diminishing GMP learning. In their study, reminder feedback about KR from the previous trial of an about-to-be performed movement was shown to diminish the typical benefits of a random practice schedule on GMP learning. In our study, advance information prior to practice trials on which KR would not be delivered diminished the previously reported benefits of a reduced-frequency feedback schedule on GMP learning (Wulf et al., 1993). In both our study and the Wulf and Schmidt (1994) experiment, the effect of enhancing extrinsic feedback was limited to measures of GMP development and not to those dealing with parameterization learning. This pattern of results is consistent with that of earlier studies (Wulf et al., 1993; Wulf et al., 1994; Wulf & Schmidt, 1994) and offers additional support for the separation of GMP and parameterization processes postulated by general motor program theory (Schmidt, 1975).

Exactly why advance information about the delivery of KR should diminish the benefits of a reduced-frequency schedule of KR on GMP learning is unclear. It is reasonable to assume that participants in the two advance-informaton

groups were encouraged to focus more on KR during the practice phase. Therefore, they may have had more difficulty adjusting to the context of the delayed retention and transfer tests involving performance in the absence of KR. Although the GMP accuracy and stability of the two advance-information groups were significantly lower than that of the no-advance-information group on the delayed transfer test, no group differences were found on the no-KR retention test. Thus, it appears that change of context between the practice phase (with KR) and the delayed retention and transfer phases (without KR) was not responsible for group differences on the delayed transfer test.

It is also possible that increasing advance-information participants' focus on KR functioned in other ways to diminish GMP learning. An increased focus on KR may have operated in a proactive fashion by diminishing participants' attention to the upcoming movement. If such was the case, an increased variability of movement production would have been expected during the practice phase. However, the fact that there were no group differences on either the GMP accuracy or stability measures during the practice phase seems to argue against this explanation.

Advance information about KR delivery may have also operated retroactively to inhibit GMP development. Indeed, the most common explanation offered for diminished motor learning by participants who practice under enhanced feedback conditions is that extrinsic feedback functions to block the subjective analysis of intrinsic movement-produced feedback (Schmidt, Lange, & Young, 1990; Wulf et al., 1993). In the present study, advance-information participants may have ignored movement-produced feedback in anticipation of the upcoming KR information. For individuals in the 67% AKR group, to do this would suggest that they operated in a fashion more similar to that of participants in the 100% KR group than to those in the 67% KR group. That is, persons in the 67% AKR group may have devoted more of their attention to trials in which KR would be given and may have bypassed the opportunity for processing intrinsic feedback during trials for which they knew KR would not be administered. Perhaps these participants believed, as did many researchers until a few years ago, that little benefit could be derived from a no-KR practice trial. It is possible that during KR practice trials, participants would benefit from instructions to direct some of their attention to intrinsic task-related feedback. Previous research has shown that movement accuracy during delayed retention tests is higher for participants who are instructed to engage in the subjective estimation of movement errors during KR practice trials than for those who are not (Hogan & Yanowitz, 1978; Swinnen, 1990; Swinnen, Schmidt, Nicholson, & Shapiro, 1990). Thus, it might be predicted that if participants in the present study had been instructed to pay attention to the movement, greater processing of intrinsic feedback that contributes to GMP development would have occurred-at least for advance-information participants-and group differences in GMP accuracy and stability during delayed-transfer performance as a function of KR manipulations during practice would have been reduced or eliminated.

In summary, the results of the present study suggest that procedures that increase the certainty of KR delivery diminish GMP development, even when KR is withheld during a portion of practice trials. Future KR research is needed in which practice trials with KR are combined with attentionfocusing instructions that encourage participants to forego emphasis on short-term adjustments in the movement (i.e., trial-to-trial parameterization) in favor of the processing of intrinsic movement-produced feedback that leads to longterm GMP learning. Without such instructions-or some other manipulation that increases the attention of participants to the intrinsic properties of the movement during KR practice trials—it appears that extrinsic KR will continue to be an overriding attraction for learners, especially during early practice when they are less confident in their own ability to interpret movement information (Salmoni et al., 1984).

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NOTES

1. We are equating the GMP with the imposed goal movement pattern and not with ones subjectively defined by individual participants.

2. The accumulating evidence (cf. Wulf et al., 1993, 1994) suggests that transfer performance is a more reliable indicator of GMP learning than is retention performance.

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