Applying Bandwidth Feedback Scheduling to a Golf Shot

Peter J. K. Smith, Stephen J. Taylor, and Keith Withers

Bandwidth knowledge of results (KR) involves the presentation of precise error KR only on those trials in which a preset criterion of accuracy is not met. When the criterion is met, only a general statement referring to this success is given. It has been shown that bandwidth KR increases movement consistency relative to 100% relative frequency KR (Lee & Carnahan, 1990). While this and other KR schedules have been successful in promoting motor learning, there has been no attempt to generalize this finding to a motor task requiring whole-body coordination. This study examined whether, by using information feedback suited to a complex task (Kernode & Carlton, 1992), the findings relating to bandwidth feedback would transfer to such a task. Participants practiced a golf chipping task with either KR or error correcting transitional information, under 0, 5, or 10% bandwidth conditions. Participants in the 10% bandwidth condition who had received transitional information performed more consistently in retention than all other participants. This result provides support for the generalization of bandwidth feedback principles to complex tasks.

Key words: motor skill learning, knowledge of results, knowledge of performance, golf

Understanding the role of information feedback in learning has been a primary focus of motor skills research (Newell, Morris, & Scully, 1985; Salmoni, Schmidt, & Walter, 1984). More recently, there has also been a strong focus on understanding how much of this research is applicable outside the laboratory settings which have typically been used (Kernode & Carlton, 1992; Newell, Quinn, & Carlton, 1987; Young & Schmidt, 1992a, 1992b). Specifically, the role of information feedback in motor learning has been traditionally investigated by radically simplifying the motor task to ensure that the information conveyed to the learner after each trial is meaningful, in that it reliably prescribes the required change in the movement on the next trial. Such research has helped to develop an understanding of the way in which information feedback should be scheduled so as to prevent learners from developing a dependency on it (Schmidt, Young, Swinnen, & Shapiro, 1989; Weinstein & Schmidt, 1990).

This practice of task simplification has allowed outcome information, or knowledge of results (KR), to guide the error correction process rather than information regarding the movement itself. But KR can only provide this guidance when it reliably prescribes the required change in movement. Tasks such as the linear slide achieve this by constraining the movement in one dimension and setting either a movement distance (Sparrow & Summers, 1992) or a movement timing goal (Schmidt et al., 1989). Providing the distance or timing error as feedback, then, exactly prescribes the change needed on the next trial. No additional information is needed, as the hand and arm are constrained to act in the appropriate manner by the rigidity of the apparatus.

This isomorphic relationship between feedback and error correction has been identified as a problem for the generalization of KR research, as the relationship can rarely hold for a complex task (Fowler & Turvey, 1978; Newell, 1985; 1991). Increasing the task complexity poses two related problems for KR research. First, providing outcome information no longer prescribes the change in the movement required to correct the error. The task will typically involve many body parts acting in a coordinated fashion, and any one of these body parts may be in error. Outcome information is not specific enough to address this issue. This problem may be resolved by using feedback relating to the process of the movement, or knowledge of performance (KP) rather than KR, but the solution is still not satisfactory. As
Fowler and Turvey (1978) pointed out, the number of pieces of information needed by the learner to correct the movement is directly related to the number of body segments used to produce the movement. Hence, to fully prescribe the required change in movement, many pieces of information may have to be presented to the learner after each trial rather than just one. This would probably overload the learner's already drained attentional resources (Kahneman, 1973; Magill, 1993), and is, therefore, not practicable.

As a result, studies examining the role of information feedback in learning complex motor skills have tended to focus on what aspect of the information should be presented between trials, rather than how often it should be presented (Kernodle & Carlton, 1992; Landin, 1994). The purpose of the present study is to outline one way in which scheduling principles arising from KR research can be applied to learning a complex motor skill. Young and Schmidt (1992b) demonstrated that KR scheduling principles can be applied to kinematic feedback, but their study still used a simple task in which the movement was constrained to rotation about the elbow joint. As a result, it was not necessary to give feedback about the nature of the interaction of the various limbs used to produce the movement.

Kernodle and Carlton (1992) examined the value of several types of information feedback for promoting over-arm throwing capability. They found that neither KR nor KP (in this case, videotape feedback) enhanced learning as much as either providing attention-focusing cues in tandem with videotape feedback or providing transitional cues in tandem with videotape feedback. The transitional cues provided information about required changes in the movement pattern. For the purposes of the present study, it was decided to combine aspects of the attention-focusing and the transitional cues by directing learners' attention to errors in their movement pattern while also providing corrective feedback. In addition, Kernodle and Carlton's (1992) technique for selecting which cue to present on each occasion was also adopted (see the Methods section of this article). These procedures were intended to optimize the utility of the information presented.

Bandwidth KR uses the learner's performance to determine what kind of feedback to present. A criterion of accuracy is set prior to data collection, and precise feedback regarding error magnitude is only given on trials in which this criterion of accuracy is not met. When performance falls within this bandwidth, the precise error magnitude is not given, but the learner is told to interpret the lack of feedback as a sign of accurate performance. To apply this to providing process rather than outcome information is difficult, as there would have to be bandwidths for each of the possible movement errors. For this reason, the learners' outcome errors were used to determine when the corrective cues would be given. If the outcome error was outside a preset bandwidth, then the appropriate corrective cue was given; and if the performance was accurate (i.e. inside the bandwidth), then no cue was given. This is somewhat akin to what occurs in instructional settings, in which learners feel the greatest need for corrective feedback when they are not achieving the desired outcome.

In summary, this study compares the utility of attention focusing transitional information to traditional KR across three bandwidth conditions. It is expected that transitional information will be generally more effective than KR (Kernodle & Carlton, 1992; Newell, 1991) and that, in line with Sherwood (1988) and Lee and Carnahan (1990), larger bandwidths will promote greater consistency in a retention test.

**Method**

**Participants**

Twenty-four female and 24 male undergraduate physical education students, ages 19–34 years (M = 22.1 years, SD = 3.6) participated in the study. All were right-handed, had little previous golfing experience, and were naive as to the purposes of the study. Informed consent was obtained from all participants prior to testing.

**Design**

Participants were randomly assigned to one of three feedback schedules and one of two feedback types, giving six conditions. The two types of feedback were either KR or transitional information (Kernodle & Carlton, 1992). The three feedback schedules were 0, 5, and 10% bandwidths.

The acquisition phase of the experiment consisted of 50 trials, with an intertrial interval of 10 s. A retention phase followed 24 hours later, consisting of a further 10 trials without KR or transitional information. The 50 trials in acquisition were broken down into 5 blocks of 10 for analysis, and the 10 trials in retention also formed 1 block. Absolute constant error and variable error were calculated for each of these trial blocks, and constituted the dependent variables for analysis. This resulted in a mixed model, 2 x 5 x 5 (feedback information x bandwidth x trial blocks) design for acquisition and a 2 x 3 (feedback information x bandwidth) factorial design for retention.

**Apparatus and Task**

The apparatus included a pitching wedge, a bristle mat, standard golf balls, and a mask designed to occlude...
vision of the target. The mask consisted of a helmet, with a visor attached. The visor was made of clear plastic and covered the face from ear to ear. The portion of the visor to the left of the left eye was covered with opaque tape so that participants could not see the target unless they moved their heads to follow the ball, which they were instructed not to do. The apparatus was situated in a closed room to ensure the participant’s anonymity. While wearing the mask, participants chipped the golf ball from the mat toward a target line located 10 m away. Participants were encouraged to flight the ball and follow through on the stroke. To maintain a constant distance from the tee to the target line, the target line formed an arc, so that the target area resembled that of a shot put arena.

Procedure

Before starting the experiment, all participants received instructions on how to grip the club and address the ball. They were also told that the goal of the task was to chip the ball so that it landed as near as possible to the target line; it did not matter where the ball stopped after rolling or bouncing.

Participants received feedback according to the bandwidth condition to which they were assigned. Participants in the 0% bandwidth condition received feedback after every trial and served as control groups (this was equivalent to a 100% relative frequency condition). Participants in the 5 and 10% bandwidth conditions only received feedback when the ball’s landing point deviated from the target line by more than 5 or 10% of the tee to the target distance, thus by more than 0.5 m and 1 m, respectively. Hence, in all cases feedback provision was cued by the participants’ outcome accuracy. Participants in the bandwidth groups were told that a lack of feedback indicated that the shot was very close to the target line.

Participants in the KR condition only received outcome information, which was the deviation of the ball’s landing point from the target line to the nearest 10 cm. Participants in the transitional information condition received one of a number of verbal cues and no outcome information. These verbal cues were designed to focus attention on areas of importance and were based on four subcomponents of the shot, these being the set up, the backswing, the impact, and the follow-through. It is important to note that neither the cues themselves nor the order in which they were given were selected specifically to adhere to principles derived from motor learning theory. Rather, they were based on the recommendations of a leading golf coach (Leadbetter, 1988). Other approaches may well have led to different sets of cues. The set of cues was explained briefly to the participants in the transitional information condition before they began practice.

1. Focus on keeping your eye on the ball.
2. Focus on bringing the club back to the correct (4 o’clock) position.
3. Focus on bringing the club far enough through after hitting the ball (8 o’clock position).
4. Focus on the speed of your swing (told to either speed it up or slow it down).
5. Focus on keeping your arms straight during the backswing and hitting through the ball.
6. Focus on body movement during the backswing not just arm movement—your navel should move.
7. Focus on keeping the club head outside the hands.

The cues were designed to flow sequentially, in that Cue 1 was a generic instruction for the entire skill; Cues 2 and 3 focused on club head position at the beginning and end of the stroke; Cues 4, 5, and 6 focused on body movement during the stroke; and Cue 7 focused on the club head movement during the stroke. It was assumed that the order of the cues reflected the order in which they should be mastered by the learner, so the cue presented after each trial depended on the number of conditions mastered by the participant. If the condition for Cue 1 was met, then Cue two was used; if Cues 1 and 2 were met, then Cue 3 was used, and so on. This method was adapted from Kernodle and Carlton (1992).

Data Analysis

A three-way (feedback condition x bandwidth size x trial block) analysis of variance (ANOVA) with repeated measures on trial block were conducted for both variable and absolute constant error for acquisition data. Retention data were analyzed using a two-way ANOVA (feedback condition x bandwidth size), again for both variable and absolute constant error. Previous research enabled generation of distinct hypotheses for the variable error analyses (Lee & Carnahan, 1990; Sherwood, 1988), but the analyses involving absolute constant error were only included for exploratory purposes.

The α level was set at .05 for all analyses. Huynh-Feldt’s adjusted F values were used for all effects incorporating a within-subjects factor, except where ε < .75, when the Greenhouse-Geisser adjustment was used. Significant effects were assessed using η².

Results

Acquisition

Variable Error. The three-way ANOVA yielded a main effect of trial block, F(2.92, 122.83) = 149.95, p < .01, η² = .78, and a feedback information by trial block interaction, F(2.92, 122.83) = 6.21, p < .01, η² = .15. For the trial
block main effect, pairwise comparisons (Tukey’s) revealed that the consistency of the first trial block was significantly poorer than all others. For the interaction, simple main effects revealed that the difference in consistency between the feedback information conditions emerged over the course of the five trial blocks. There was no significant difference between feedback information conditions on the first three trial blocks, but both Block 4, \(F(1, 209) = 9.477, p < .01\), and Block 5, \(F(1, 209) = 9.503, p < .01\), revealed significant differences, with the transitional information condition achieving better consistency in both cases. No other effects reached statistical significance. Means and standard deviations for the interaction and main effect are presented in Table 1.

**Absolute Constant Error.** The three-way ANOVA elicited only a main effect of trial block, \(F(2.10, 88.18) = 26.44, p < .01, \eta^2 = .39\). The first block of trials (\(M = 1.74, SD = 1.21\)) had a significantly larger response bias than all other blocks (Block 2, \(M = .61, SD = .49\); Block 3, \(M = .61, SD = .45\); Block 4, \(M = .66, SD = .45\); Block 5, \(M = .58, SD = .50\)). No other effects were statistically significant.

**Retention**

**Variable Error.** The two-way ANOVA yielded a significant feedback information effect, \(F(1, 42) = 23.518, p < .01, \eta^2 = .36\), a significant bandwidth effect, \(F(2, 42) = 4.068, p < .05, \eta^2 = .16\), and a significant two-way interaction, \(F(2, 42) = 3.500, p < .05, \eta^2 = .14\). The means and standard deviations for these significant effects are presented in Table 2. Follow-up pairwise comparisons (Tukey’s HSD) revealed that participants in the 10% bandwidth condition who received transitional information performed more consistently than any other condition, \(p < .05\).

**Absolute Constant Error.** No statistically significant effects were found.

### Discussion

The principal hypotheses of the study were that transitional information would promote greater consistency in retention than would KR and that bandwidth conditions greater than 0% (100% relative frequency KR) would result in the most consistent retention performance. Although main effects in the predicted directions for both feedback information and bandwidth size were obtained from the retention analysis, the significant interaction between the two variables precludes a straightforward interpretation of support for the two principal hypotheses. The 10% bandwidth condition only improved consistency in retention for those given transitional information during acquisition rather than traditional KR.

<table>
<thead>
<tr>
<th>Feedback condition</th>
<th>1 M</th>
<th>SD</th>
<th>2 M</th>
<th>SD</th>
<th>3 M</th>
<th>SD</th>
<th>4 M</th>
<th>SD</th>
<th>5 M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge of results</td>
<td>4.84</td>
<td>.70</td>
<td>3.16</td>
<td>1.27</td>
<td>2.17</td>
<td>.59</td>
<td>2.55</td>
<td>.56</td>
<td>2.41</td>
<td>.52</td>
</tr>
<tr>
<td>Transitional information</td>
<td>5.23</td>
<td>.77</td>
<td>3.32</td>
<td>.69</td>
<td>2.50</td>
<td>.47</td>
<td>1.94</td>
<td>.43</td>
<td>1.80</td>
<td>.52</td>
</tr>
<tr>
<td>Total</td>
<td>5.03</td>
<td>.75</td>
<td>3.24</td>
<td>1.01</td>
<td>2.34</td>
<td>.55</td>
<td>2.24</td>
<td>.58</td>
<td>2.10</td>
<td>.60</td>
</tr>
</tbody>
</table>

**Note.** \(M = \text{mean}; SD = \text{standard deviation}.

<table>
<thead>
<tr>
<th>Feedback condition</th>
<th>0% M</th>
<th>SD</th>
<th>5% Bandwidth condition</th>
<th>10% M</th>
<th>SD</th>
<th>Total M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge of results</td>
<td>3.17</td>
<td>.68</td>
<td>2.90</td>
<td>.55</td>
<td>3.04</td>
<td>.51</td>
<td>3.04</td>
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<tr>
<td>Transitional feedback</td>
<td>2.68</td>
<td>.36</td>
<td>2.50</td>
<td>.39</td>
<td>1.77</td>
<td>.56</td>
<td>2.32</td>
</tr>
<tr>
<td>Total</td>
<td>2.92</td>
<td>.57</td>
<td>2.70</td>
<td>.50</td>
<td>2.41</td>
<td>.84</td>
<td></td>
</tr>
</tbody>
</table>

**Note.** \(M = \text{mean}; SD = \text{standard deviation}.

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The most straightforward interpretation of this interaction is in terms of the guidance hypothesis (Salmoni et al., 1984; Schmidt et al., 1989), which implies that augmented feedback given during skill acquisition guides the learner towards the desired target performance. Reduced relative frequencies of feedback reduce the amount of guidance available. Although increased guidance can be beneficial for acquisition performance (e.g., Schmidt et al., 1989), it has been found to impair retention performance (Schmidt et al., 1989; Young & Schmidt, 1990a). As can be seen from Table 3, the retention results are in line with the guidance hypothesis, as those who received transitional information only when outside a 10% performance bandwidth received the lowest relative frequency of feedback during acquisition and achieved the best retention performance. However, an explanation that is purely in terms of the relative frequencies of feedback presentation cannot fully explain the pattern of results obtained here. The nature of bandwidth feedback implies that the learner’s performance itself is responsible for setting the relative frequency during acquisition; therefore, any explanation of the results must account for the genesis of the relative frequency effect, as well as for its subsequent effect on retention.

The feedback condition by trial block interaction during acquisition suggests that simply providing outcome information was not sufficient to guide participants toward consistent performance; at the end of practice those participants receiving transitional information were performing more consistently than those receiving KR. However, despite the fact that the three bandwidth groups given transitional information throughout acquisition performed equally consistently, the stricter criteria for feedback presentation within the 0 and 5% bandwidth conditions resulted in higher relative frequencies than that of the 10% bandwidth condition (see Table 3). Thus, the reduced relative frequency of transitional feedback for the 10% condition could be due to a genuine interaction between the type of information provided and the size of the bandwidth used. The guiding effect of the transitional information, combined with the wider bandwidth criteria, enabled this group to effectively reduce the relative frequency with which they received feedback.

It is difficult to unambiguously interpret the mechanism underlying the superior retention performance of the group which combined transitional information with a 10% bandwidth condition. Although it certainly seems to be a function of the relative frequency of feedback, this same pattern of relative frequencies was obtained by both Sherwood (1988) and Lee and Carnahan (1990). The latter study demonstrated that, although bandwidth feedback resulted in reduced relative frequencies, the retention benefit of bandwidth feedback could not be explained by this alone. Lee & Carnahan (1990) proposed that the effect also depended on the fact that KR was withheld only when a certain criteria of accuracy was achieved. Thus, withholding KR under bandwidth conditions could be seen as another form of feedback, namely no-error KR. This could be seen as providing two benefits for the learner: First, no-error KR directs the learner not to alter performance from the previous trial and, therefore, prevents maladaptive short-term corrections in performance (Lee & Carnahan, 1990; Young & Schmidt, 1992a). These maladaptive short term corrections are caused, according to Lee and Carnahan, by the motor system being required to reduce an error smaller than it is capable of correcting. Second, no-error KR directs learners to maintain a standard of performance rather than change it so that they might form a more stable representation of the task. In the present study, no direct evidence is provided to suggest that these, rather than other qualities of reduced relative frequencies (see Young & Schmidt, 1992a, for a full description), are responsible for the retention effects. This awaits further research. However, it is clear that transitional information was more useful than traditional KR in enabling bandwidth feedback scheduling to be applied to this complex, multiple degree of freedom task.

### Table 3. Relative frequency of feedback during acquisition for each of the feedback and bandwidth conditions, across trial blocks

<table>
<thead>
<tr>
<th>Feedback condition</th>
<th>1 M</th>
<th>1 SD</th>
<th>2 M</th>
<th>2 SD</th>
<th>3 M</th>
<th>3 SD</th>
<th>4 M</th>
<th>4 SD</th>
<th>5 M</th>
<th>5 SD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Knowledge of results</strong></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5% bandwidth</td>
<td>90.00</td>
<td>10.69</td>
<td>91.25</td>
<td>8.35</td>
<td>82.50</td>
<td>11.65</td>
<td>76.25</td>
<td>16.85</td>
<td>71.25</td>
<td>12.46</td>
</tr>
<tr>
<td>10% bandwidth</td>
<td>88.75</td>
<td>6.41</td>
<td>68.75</td>
<td>15.53</td>
<td>51.25</td>
<td>16.42</td>
<td>65.00</td>
<td>22.04</td>
<td>53.75</td>
<td>13.02</td>
</tr>
<tr>
<td><strong>Transitional information</strong></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5% bandwidth</td>
<td>92.50</td>
<td>11.65</td>
<td>82.50</td>
<td>13.89</td>
<td>71.25</td>
<td>12.46</td>
<td>86.25</td>
<td>23.87</td>
<td>58.75</td>
<td>18.08</td>
</tr>
<tr>
<td>10% bandwidth</td>
<td>78.75</td>
<td>6.41</td>
<td>51.25</td>
<td>18.08</td>
<td>33.75</td>
<td>15.06</td>
<td>21.25</td>
<td>10.53</td>
<td>25.00</td>
<td>17.32</td>
</tr>
</tbody>
</table>

*Note. M = mean; SD = standard deviation.*

ROE: September 1997
The interaction between feedback condition and trial blocks in acquisition is also similar to the effect found by Kernodle and Carlton (1992), despite the fact that the present study used only 50 trials, in comparison to Kernodle and Carlton’s 600. It is likely, judging from Kernodle and Carlton’s results, that the separation between the two feedback types would have continued to grow as the practice period lengthened. The findings here represent differences in the early stages of learning, as reflected in the relative frequency of presentation of each of the seven process cues. Recall that Cue 7 would only be given if the aspects of the movement to which Cues 1–5 alluded had been performed without error, and so on for each of the other cues. For trials on which a cue was given, the frequency of presentation of each cue across the three bandwidth conditions throughout acquisition were: 9, 30.49, 58, 20, 1.5, 1, and 0.01% for Cues 1–7, respectively. Evidently, there were very few trials on which the first five cues were performed correctly, and on most trials participants did not progress beyond the first four cues (accounting for 97.49% of cue usage).

It should be noted also that no significant differences in response bias were obtained throughout acquisition and retention, except for a general reduction in error from the beginning to the end of acquisition. This is in line with previous findings (Lee & Carnahan, 1990; Lee, White, & Carnahan, 1990; Sherwood, 1988). The facilitation of consistency rather than response bias is typical of bandwidth feedback and has been attributed to the effects of no-error feedback alluded to above. One might hypothesize that in the present experiment such no-error trials are likely to have been especially important due to the complexity of the skill. The more components of the motor system involved in the skill, the more noise may result in the output, so the more important it is to use a wide bandwidth to determine whether to give feedback. This is especially true for a task such as a golf chip, in which small changes in endpoint (club head) variability can have a large effect on outcome.

In summary, two conclusions may be drawn from the study. With regard to the use of KR, or transitional information with a complex task, the hypotheses of Newell (1985) and Fowler and Turvey (1978) have been supported, in that transitional information has been shown to be more useful than KR in reducing error during acquisition. In addition, some evidence has been presented which suggests that bandwidth KR findings do generalize to complex tasks, provided steps are taken to ensure that appropriate information feedback is used.

References


Authors' Notes

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