Feedback Effects on Learning a Novel Bimanual Coordination Pattern: Support for the Guidance Hypothesis

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ABSTRACT. The authors tested specificity and the guidance hypothesis by examining the effects of continuous or discrete concurrent feedback during acquisition, retention, and transfer of a 90° phase offset bimanual coordination pattern. The authors tested both groups immediately following acquisition, 1 week later under retention conditions (i.e., identical feedback as acquisition) and under transfer conditions with a change in feedback (i.e., discrete to continuous or vice versa) and with no feedback. Acquisition results revealed superior performance by the continuous feedback group. However, during immediate transfer conditions, the continuous group showed decreased pattern accuracy and stability, whereas the discrete group improved its performance. These results support the guidance hypothesis, as the participants with a high amount of feedback in acquisition became reliant on the feedback and could not adapt their learning to a new situation. These results also show partial support for the specificity of practice hypothesis as the continuous group was only able to mimic their acquisition performance under identical conditions as practice. Practice specificity effects were not found for the discrete group, as performance was not negatively affected with a change or removal of afferent information.

Keywords: augmented feedback, bimanual coordination, guidance, motor learning, specificity

The role and effect of extrinsic feedback on learning have been a topic of debate and study for many years (see reviews by Adams, 1987; Newell, 1977; Salmoni, Schmidt, & Walter, 1984; Schmidt, 1991; Swinnen, 1996; Wulf & Shea, 2004). However, researchers are still far from understanding the exact role of feedback and how to maximize its effectiveness in the acquisition, retention, and transfer of a motor skill. As feedback from an extrinsic source helps guide the performer to the correct response, it would seem logical that more feedback would be beneficial to the learner. However, it has been proposed that too much feedback would actually harm performance; this is a theory known as the guidance hypothesis (Salmoni et al.; Schmidt; Schmidt, Young, Swinnen, & Shapiro, 1989). The rationale behind this hypothesis is that the constant provision of external feedback may create a dependence on this feedback source, causing the learner to disregard his or her own internal feedback. Furthermore, constant feedback may cause performers to consistently adjust their performance, resulting in less stable (or more variable) performance.

Guidance Hypothesis

Support for the guidance hypothesis has been shown by a number of studies whereby increased feedback results in immediate benefits during acquisition performance and decrements in performance during delayed transfer testing or when feedback is removed (see Salmoni et al., 1984, for an early review). In a series of studies, Wulf and colleagues (Wulf, 1992; Wulf, Lee, & Schmidt, 1994; Wulf & Schmidt, 1989; Wulf, Schmidt, & Deubel, 1993) found that the relative timing of a movement pattern was enhanced with reduced feedback but that absolute timing was degraded. In a similar study by Winston and Schmidt (1990), faded feedback resulted in better performance during a delayed retention test, again supporting the guidance hypothesis. Following that study, Winston, Pohl, and Lewthwaite (1994) examined the effects of type (guidance vs. knowledge of results) and frequency (high vs. faded) of feedback for an arm movement to a target. As predicted by the guidance hypothesis, high-frequency feedback resulted in the least accurate transfer performance, and high-frequency guided feedback resulted in the poorest retention performance.

The aforementioned studies have involved relatively simple movements, with feedback provided at the end of the movement (i.e., terminal knowledge of results). However, guidance effects have also been shown for feedback presented during a movement (i.e., concurrent; Park, Shea, & Wright, 2000; Schmidt & Wulf, 1997; Vander Linden, Cauraugh, & Greene, 1993). The inability to transfer a skill acquired with guidance-type feedback has also been shown for a complex multilimb coordination task. In a study by Maslovat, Bredin, Chua, and Franks (2005), participants learned a bimanual coordination pattern whereby the right limb was offset from the left limb by one quarter of a movement cycle (i.e., a 90° phase offset between limbs). Two forms of feedback were used to acquire the pattern and evaluate performance at the start and end of the acquisition period: discrete visual metronomes with terminal feedback and concurrent online feedback (i.e., Lissajous trace). During acquisition, concurrent feedback resulted in better performance of the pattern; however, participants were unable to transfer this performance to the discrete condition (a result that did not occur when participants practiced with discrete feedback and transferred to concurrent condition). The lack of transfer from a concurrent, highly guiding form of feedback (such as that provided by the Lissajous figure) to terminal feedback has also been shown in previous work.

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involving acquisition of a new coordination pattern (Maslovat, Chua, Lee, & Franks, 2004), and it is consistent with the predictions of the guidance hypothesis.

Although there is evidence supporting the guidance hypothesis, recent reviews of the literature have suggested this support is somewhat equivocal (Swinnen, 1996; Wulf & Shea, 2004). Specifically, it is suggested that much of the research showing a guidance effect involves simple laboratory tasks with feedback provided in the form of a terminal-error score. Examining a more complex multitask coordination task, whereby one limb flexed while the other limb concurrently performed a flexion–extension or flexion–reversal movement, Swinnen, Walter, Lee, and Serrien (1993) showed that greater amounts of augmented feedback were more effective in decoupling the limbs to produce a new coordination pattern. In fact, researchers have shown the use of continuous, concurrent feedback to be effective for acquisition of a new bimanual coordination pattern (i.e., Fontaine, Lee, & Swinnen, 1997; Lee, Swinnen, & Verschueren, 1995; Maslovat, Chua, Lee, & Franks, 2006; Wenderoth & Bock, 2001; Wenderoth, Bock, & Krohn, 2002) and for a ski-simulator task (Wulf, Shea, & Matschner, 1998). Using a 90° offset coordination task, Swinnen, Lee, Verschueren, Serrien, and Bogaerts (1997) compared participants receiving concurrent Lissajous feedback (augmented) to those receiving only vision of the hands (normal) and to a group that was blindfolded (reduced). In addition to acquisition performance, the researchers examined how these participants transferred to all three feedback conditions. The augmented group outperformed the others not only during acquisition, but also during transfer to all three feedback conditions, suggesting a lack of dependence on the feedback source.

One explanation regarding the controversy surrounding the guidance hypothesis may involve how the feedback is presented during acquisition and transfer. Superior transfer performance has been shown when Lissajous feedback was presented concurrently during acquisition rather than terminally (Hurley & Lee, 2006). This may be because concurrent feedback directs the learner’s attention away from the movement itself to an environmental effect of the movement, which has been shown to be beneficial for learning (for a review, see Wulf & Prinz, 2001). Furthermore, it has been argued that if transfer testing involves removal of the guidance present during acquisition, this may crucially alter the requirements of the task (Masters & Maxwell, 2004; Maxwell, Masters, Kerr, & Weedon, 2001). It is well established that transfer performance is greatly affected by the similarity of practice conditions and processing, a concept known as practice specificity (e.g., Barnett, Ross, Schmidt, & Todd, 1973; Henry, 1968).

**Practice Specificity**

Practice specificity involving visual feedback has been studied quite extensively (for reviews, see Khan & Franks, 2004; Proteau, 1992). Early work by Proteau, Marteniuk, Girouard, and Dugas (1987) found that participants who practiced an aiming task with vision showed a performance decrement during transfer to a no-vision condition, which became worse with more extensive practice (shown more recently by Khan, Franks, & Goodman, 1998). Reliance on vision is thought to occur because of integration of proprioceptive and visual information sources during practice that do not allow the learner to compare their performance to the integrated sensory store once vision is removed (Proteau, 1992). Although it is not surprising that the removal of visual information causes a decrease in performance, it has also been shown that the addition of visual information can result in a performance decrement if participants have received extended practice without vision (Proteau, Marteniuk, & Levesque, 1992). In fact, performance in the vision transfer test was worse than the pretest under the same conditions, showing negative transfer effects of practice without vision. Support for the specificity of practice principle has been shown extensively for simple aiming movements (i.e., Proteau, 2005; Proteau & Carnahan, 2001; Soucy & Proteau, 2001; Yoshida, Cauraugh, & Chow, 2004) and in more complex tasks, including walking (Proteau, Tremblay, & DeJaeger, 1998), powerlifting (Tremblay & Proteau, 1998), and ball interception (Tremblay & Proteau, 2001). However, much like the guidance hypothesis, a number of studies have not shown support for practice specificity in such varied tasks as gymnastics (Robertson, Collins, Elliott, & Starkes, 1994), powerlifting (Bennett & Davids, 1995), and one-handed ball catching (Whiting & Savelbergh, 1992; Whiting, Savelbergh, & Pijpers, 1995; for a detailed review, see Khan & Franks, 2004).

**Feedback Effects on Learning**

The purpose of this study was to examine the guidance and specificity hypotheses by manipulating feedback in the acquisition, retention, and transfer of a 90° offset bimanual coordination skill. An examination of feedback effects with this task has supported and contradicted predictions that are based on the guidance effect. Thus, it is unclear if providing additional feedback during acquisition is a benefit or a hindrance to transfer performance. Presentation of feedback in the current study differs from previous research involving a 90° coordination task in an attempt to clarify the role of feedback during learning. Rather than mixing concurrent and terminal feedback sources, we decided to contrast two types of concurrent, augmented feedback, differing in the amount of information offered, during the acquisition process. Although one group received continuous concurrent feedback (i.e., Lissajous feedback), the other group only received concurrent feedback at discrete points of the movement (i.e., movement endpoints). Instead of using extremes of feedback presentation, a more moderate amount of feedback may allow for the positive effects of the information to be processed by the learner, but it may help the learner avoid dependency on the feedback source (as
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similarly hypothesized with regards to practice schedules by Lee & Wishart, 2005). Furthermore, providing concurrent feedback to all participants should have ensured a common external focus of attention, removing this as a possible explanation for any feedback effects.

To examine the feedback effects, we tested participants on the task in three different conditions following acquisition: identical feedback to acquisition (which will be referred to as retention), transfer to a change in feedback (i.e., from continuous to discrete or vice versa), and transfer to no feedback. We predicted better acquisition performance with continuous feedback, as more information is present for the learner. An examination of how performance was affected during transfer allowed us to assess the guidance and specificity hypotheses, as both hypotheses would predict a decrease in performance when feedback sources are high in acquisition and then reduced or removed during transfer (because of increased dependence on the feedback source). The specificity of practice hypothesis would also predict a similar performance decrement during transfer for the discrete group because of a change, albeit an increase, in the visual information being used by the learner.

Method

Participants

In all, 12 university-aged (19–24 years), self-declared right-handed participants (5 men, 7 women) were randomly assigned to one of two groups (6 per group) that were differentiated by the feedback received during the acquisition period (continuous or discrete). Participants were naive to the purpose of the experiment, and the study was conducted in accordance with the ethical guidelines of the University of British Columbia. All participants attended three experimental sessions: Sessions 1 and 2 took place on consecutive days and were approximately 1 hr in duration, whereas Session 3 took place 1 week later and was approximately 30 min in duration. All participants received a remuneration of $5 per session (for a total of $15) and a completion bonus of $10. Participants were also informed that the best performer in the group would receive a performance bonus of $50.

Apparatus

A schematic of the apparatus used is illustrated in Figure 1. Participants were seated in front of a color monitor (VGA, 640 × 480 pixels) measuring 27 × 20 cm (Model #ZCM-1490; Zenith, Lincolnshire, IL). Attached to the table on each side of the monitor were lightweight manipulanda that participants used to perform horizontal flexion–extension movements about the elbow joint. Participants’ arms were positioned such that the elbow joint was aligned with the axis of manipulanda rotation and the hands were placed palm down on adjustable metal plates. The middle finger was secured between two vertical pins; and velcro straps secured the forearms and hands. The required movement amplitude was 40°, specified by in, out, and mid markers on the table for each arm, which translated to a 15-cm movement of the cursor on the computer screen. Angular position was recorded using two optical encoders (E20-2500-130; Dynapar, Gurnee, IL): one attached to the shaft of each manipulandum. Three-axis Quadrature Encoder interface cards (PCL-833; Advantech, Cincinnati, OH) were used to enable high-speed sampling of angular position at a rate of 1000 Hz and a spatial resolution of 0.036°/bit. A computer motherboard was used to generate the audio metronome tones. The metronome signal was amplified by a speaker.
on each side of the monitor (EP-691; Alpha and Omega Computer Corporation, Industry, CA).

Experimental Design

All trials lasted 16 s and were to be performed at a rate of 0.75 Hz, which involved 12 cycles of movement. To start, a total of eight familiarization trials were administered, involving natural in-phase (0°) and antiphase (180°) coordination patterns, so that participants would become comfortable with the manipulanda and with proper speed and amplitude of the movement. Participants then performed between 5 and 25 practice trials of a 90° phase-offset pattern with Lissajous feedback, until their mean root mean squared error (RMSE) of relative phase for their last five trials reached a criterion value of less than 40°. Lissajous feedback was explained with movements of the right manipulandum producing horizontal movements of the cursor on the screen and movements of the left manipulandum producing vertical movements of the cursor on the screen. During these practice trials, participants were instructed to flex and extend their arms to try to produce the movement template shown on the computer screen. These trials ensured that participants understood the movement pattern and that starting performance of the two groups was at approximately the same level.

Following practice, 180 acquisition trials of 90° were performed over the next 2 days in blocks of 15 trials (six blocks per day). These trials were performed with a 3-Hz metronome, which resulted in four equally spaced metronome pulses per cycle. Participants were instructed to coordinate each limb endpoint (i.e., right arm in, left arm in, right arm out, left arm out) with the corresponding metronome pulse.

Prior to acquisition, terminal and concurrent feedback was explained to all participants, and they were shown a sample of the terminal feedback with which they would be provided (see Figure 2). The continuous group (see Figure 2A) saw a circular Lissajous template (thick line) projected on the computer screen with the participants’ movement (thin line) superimposed over the template (60-Hz refresh rate). Throughout the trial, there was continuous feedback showing the current position of the participant and the previous 500 ms of movement. In addition, targets were shown on the Lissajous template that corresponded to the correct arm position for each metronome pulse. During each metronome pulse, a number appeared on the screen for 333 ms—corresponding to the participant’s arm location at the moment—and they were to match it with the appropriate target on the linear template. For example, during the first metronome pulse, the number 1 would appear below the right limb horizontal line, representing where the right arm of the participant was at that moment (1 = right arm in; 2 = left arm in; 3 = right arm out; 4 = left arm out). At the end of the trial, terminal feedback was provided on the computer screen for 7 s, showing the mean relative phase value for the entire trial (and the target of 90°) and the limb position numbers for the entire trial. Thus, both groups received concurrent and terminal feedback regarding their arm position during each of the metronome pulses; however, the continuous group also received information regarding arm position throughout the rest of trial.

Immediately following the acquisition trials on the 2nd day of testing and 1 week after initial testing, participants performed three trials of the 90° coordination task under three feedback conditions. The first condition involved testing participants with identical feedback to acquisition,
which we refer to as retention. Although retention tests are often administered without feedback, this test allowed for an evaluation of baseline performance with the acquisition feedback, which could be compared with transfer performance to evaluate feedback dependency. The first transfer condition involved a change in feedback from continuous to discrete or vice versa. The second transfer condition involved a withdrawal of feedback such that participants were performing the pattern with no concurrent or terminal feedback. Conducting these tests immediately following acquisition and 1 week after initial testing allowed for separation of the temporary performance effects during practice from the more stable learning effects.

**Dependent Measures and Analyses**

Continuous measures of relative phase were calculated at a rate of 1,000 Hz for all complete cycles of movement within the final 14 s of each trial, allowing participants 2 s to adopt a stable, consistent performance. Relative phase of the left arm in relation to the right was calculated for each point after the speed, and position of the limbs was rescaled to the interval [−1, 1]. The phase angles were calculated using the methods described by Scholz and Kelso (1989), from which two measures of performance were determined. Absolute error of relative phase (ABSE) was considered an accuracy measure and was determined by calculating the ABSE of each relative phase value and then taking a grand mean for each trial. Within-trial standard deviation of mean relative phase was considered a measure of consistency.

To ensure the groups were starting acquisition at a similar level of performance, we subjected the RMSE of relative phase for the last five trials of practice to an independent samples t test. For acquisition, performance was split into 12 blocks of 15 trials. Both dependent measures were subjected to a 2 (group: continuous, discrete) × 12 (block) analysis of variance (ANOVA), with repeated measures on the last factor. Retention and transfer performance was analyzed for both dependent measures by a 2 (group: continuous, discrete) × 3 (condition: retention, feedback change, no feedback) × 2 (time: immediate, delayed) ANOVA, with repeated measures on the last two factors. The alpha level for the entire experiment was set at .05, with partial eta squared ($\eta^2$) values reported as a measure of effect size. The Greenhouse-Geisser Epsilon factor was used to adjust the degrees of freedom for violation of the sphericity assumption (Greenhouse & Geisser, 1959).

**Results**

The result of the analysis of the last five practice trials confirmed no significant difference between the two groups prior to acquisition ($p = .771$; continuous $M = 26.09^\circ; SD = 4.1^\circ$; discrete $M = 27.27^\circ; SD = 8.8^\circ$). The similarity of performance of the two groups at the start of acquisition suggests any differences seen during acquisition, retention, and transfer were likely to be because of feedback differences rather than any initial group differences.

**ABSE**

Figure 3A illustrates the ABSE of the two groups during acquisition, retention, and transfer performance. Participants did reduce their error during the acquisition period, as shown by a main effect for block, $F(11, 110) = 4.16, p = .029, \eta^2_p = .29$. In addition, there was a main effect for group, $F(1, 10) = 14.37, p = .004, \eta^2_p = .59$, and the continuous group performed with less overall error ($M = 11.2^\circ; SD = 3.8^\circ$) than did the discrete group ($M = 37.2^\circ; SD = 20.2^\circ$). Examination of Figure 3 shows that this difference is present from the first block of acquisition, showing the immediate effects of different feedback (although the first data point does represent the mean of 15 trials). During retention–transfer performance, the only effect to reach significance was a Condition × Group interaction, $F(2, 20) = 6.74, p = .013, \eta^2_p = .40$. To examine this interaction, we calculated a difference score between performance during retention and the feedback-change condition as well as between retention and the no-feedback condition for each participant. As there was no effect for time ($p = .715$), we collapsed these data between the immediate and delayed testing days. These difference scores represented the dependency on the feedback and were analyzed through one-way ANOVAs to determine if group effects were present. Analysis of the difference scores showed a significant group effect for the change in feedback, $F(1, 10) = 8.63, p = .015$, and removal of feedback, $F(1, 10) = 6.09, p = .033$. This is shown on the graph by a large increase in error by the continuous group when feedback was changed ($M = 32.1^\circ; SD = 26.1^\circ$) or removed ($M = 26.7^\circ; SD = 34.5^\circ$), as opposed to the decrease in error seen in the discrete group when feedback was changed ($M = −10.1^\circ; SD = 15.9^\circ$) or removed ($M = −4.1^\circ; SD = 7.35^\circ$).

**Standard Deviation**

Analysis of the standard deviation data produced similar results to the ABSE (see Figure 3B). Participants did reduce their variability during the acquisition period, as shown by a main effect for block, $F(11, 110) = 6.21, p = .003, \eta^2_p = .38$. As with ABSE, there was a main for group, $F(1, 10) = 19.13, p = .001, \eta^2_p = .66$, with the continuous group performing with less variability ($M = 12.9^\circ; SD = 4.2^\circ$) than the discrete group ($M = 28.7^\circ; SD = 10.6^\circ$). During retention–transfer performance, the only effect to reach significance was a Condition × Group interaction, $F(2, 20) = 12.78, p = .001, \eta^2_p = .56$. Analysis of this interaction effect (as outlined with ABSE) showed a significant group effect for the feedback change, $F(1, 10) = 20.08, p = .001$, and the transfer to no feedback, $F(1, 10) = 9.41, p = .012$. Mirroring the ABSE data, the continuous group showed an increase in variability with a change ($M = 19.3^\circ; SD = 13.8^\circ$) or removal ($M = 10.5^\circ; SD = 8.4^\circ$) of feedback, whereas the discrete group showed a mean decrease in variability when feedback was changed ($M = −10.7^\circ; SD = 8.9^\circ$) or removed ($M = −10.5^\circ; SD = 14.6^\circ$). A complete list of the repeated
measure ANOVA results for both dependent measures is shown in Table 1.

**Discussion**

The purpose of this study was to examine the effect of two different types of feedback during the acquisition, retention, and transfer of a novel bimanual coordination pattern. Our experimental setup allowed us to test the guidance hypothesis and practice specificity for a complex task with concurrent feedback. During acquisition, one group received continuous feedback throughout the trial through a Lissajous figure, and the other group only received discrete information regarding arm position at four points of each movement cycle. By manipulating the amount of feedback (i.e., continuous vs. discrete) but not the type (i.e., concurrent) that the groups received, we
hoped to determine how reliant the participants became on the feedback.

For acquisition performance, our results indicated that both groups improved their performance of the pattern by decreasing their error and reducing their variability. However, as predicted, the group receiving continuous feedback performed better throughout the acquisition period, as there was a greater amount of augmented information available. Immediately following acquisition testing and 1 week after testing, participants were tested under the same conditions as the acquisition period, and they performed at a similar level (see Figure 3), giving a stable baseline of performance with their respective feedback condition. Their performance when feedback was either changed or removed allowed for an assessment of feedback dependency. The deterioration of performance by the continuous group during transfer testing suggests a strong reliance on the feedback with which they acquired the skill. This was not observed for the discrete feedback group, which actually showed an increase in performance in both transfer situations. Although a change in feedback for the discrete group consisted of additional feedback compared with that received at acquisition, the increase in performance when feedback was removed strongly suggests less reliance on the acquisition feedback source. These results support the guidance hypothesis, as the participants with a high amount of feedback in acquisition became reliant on the feedback and could not adapt their learning to a new situation.

These results appear to be quite different than the results obtained from Swinnen et al. (1997), who found that Lissajous feedback during acquisition of a 90° offset coordination pattern resulted in better transfer performance in reduced feedback conditions. However, the present study does differ from their work in a number of ways. First, all participants in the present study received some form of enhanced feedback. In the study by Swinnen et al. (1997), only the Lissajous group received augmented feedback, whereas the other two groups had either vision of their hands or no vision at all. Second, we examined the performance data differently in the present study, as difference scores were used as a gauge of feedback dependency and not as performance scores during acquisition and transfer (as done by Swinnen et al.). We believe this is a valid measurement, as examination of how performance changes with changing feedback allowed for a test of transferability and dependency on the feedback source. Last, participants in the Swinnen et al. (1997) study performed the reduced-feedback and no-feedback transfers at the end of each of the 3 days of acquisition testing. In the present study, the transfer tests were not performed until all acquisition trials had been completed, and thus participants were not aware that they would need to transfer the skill they were learning to a new situation. This may have affected their learning strategy or motivation to determine how the pattern would be performed in the absence of concurrent feedback. This is partially supported by the trend toward significance for a Group × Time × Condition interaction effect for variability of performance during transfer ($p = .069$). The continuous feedback group appeared to have different performance for the immediate and delayed tests of transfer to the no-feedback condition (see Figure 3). The immediate transfer showed large performance decrements; however, this difference was largely reduced in the delayed testing (an effect not seen by the discrete group). This may have been because of participants’ being made aware during postacquisition testing that they would need to perform the task under different feedback conditions, as well as the participants’ having an additional week of time for increased memory consolidation (although no difference was seen during the immediate and delayed testing of the feedback change condition).

### TABLE 1. Results of the Acquisition, Retention, and Transfer of Repeated Measures of Analysis of Variance for Relative Phase Absolute Error (ABSE) and Standard Deviation

<table>
<thead>
<tr>
<th>Variable</th>
<th>ABSE</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$F$</td>
<td>$df$</td>
</tr>
<tr>
<td>Acquisition</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Block</td>
<td>4.16</td>
<td>11, 110</td>
</tr>
<tr>
<td>Group</td>
<td>14.37</td>
<td>1, 10</td>
</tr>
<tr>
<td>Block × Group</td>
<td>1.21</td>
<td>11, 110</td>
</tr>
<tr>
<td>Retention and Transfer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Condition</td>
<td></td>
<td></td>
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<tr>
<td>Time</td>
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<td>2, 20</td>
</tr>
<tr>
<td>Group</td>
<td>&lt; 1.00</td>
<td>1, 10</td>
</tr>
<tr>
<td>Condition × Group</td>
<td>6.74</td>
<td>2, 20</td>
</tr>
<tr>
<td>Time × Group</td>
<td>2.84</td>
<td>1, 10</td>
</tr>
<tr>
<td>Condition × Time</td>
<td>2.38</td>
<td>2, 20</td>
</tr>
<tr>
<td>× Group</td>
<td>1.20</td>
<td>2, 20</td>
</tr>
</tbody>
</table>

*Note.* Significant effects are presented in bold.

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January 2009, Vol. 41, No. 1
The experimental setup also allowed for assessment of the practice specificity hypothesis. Although specificity effects were present for the continuous feedback group, they were absent for the discrete feedback group. The continuous feedback group showed large performance decreases in accuracy and stability when feedback was changed or removed, whereas the discrete feedback group showed improvement under these same conditions. Although it could be argued that all participants received Lissajous feedback during the initial practice trials and thus were introduced to continuous feedback, the small number of practice trials makes this argument less than convincing. However, it does not explain why they showed improvements in performance in the absence of feedback, which would not be predicted by the specificity hypothesis.

The current data also outline some of the problems associated with testing of feedback effects. Although we have argued that continuous feedback may create a greater dependency than discrete feedback, examination of performance for the no-feedback condition during delayed testing (which Swinnen [1996] argued as the best indicator of learning) revealed little difference between the groups (see Figure 3). However, confounding this evaluation is the fact that removal of the feedback that guides the performer to the desired task outcome may change the characteristics of the task itself (as previously outlined, see Maxwell et al., 2001). If the goal of the acquisition period is to teach participants how to perform the required skill without feedback, different strategies may be more beneficial (i.e., ensuring the participants are aware of this goal, gradually reducing feedback frequency). However, the goal of the current study was to examine how feedback affects the acquisition, retention, and transfer of a complex coordination skill. In addition to the results pertaining to guidance and specificity, there also appears to be a benefit to considering more moderate feedback manipulations instead of extremes. Although concurrent feedback may assist in the acquisition of a complex coordination task, limiting (but not fully removing) the amount of feedback available to the learner may have important implications for optimizing transferability of newly acquired skills under conditions when feedback sources are changed or removed.

Overall, the results obtained in this study support a guidance effect, even with concurrent feedback for a complex coordination skill. Lissajous feedback, although effective for acquiring a new coordination pattern (and for retention under the same feedback conditions), may not be helpful when feedback is changed or disrupted. This also supports the concept of practice specificity for the continuous group and raises the question of what is being learned with Lissajous feedback. Although acquisition and retention performance was better for the continuous group, examination of their transfer performance (see Figure 3) showed similar accuracy values to those of the discrete group in the first block of acquisition, even though these participants had completed 180 acquisition trials.

Guidance effects are typically explained by dependence on the external feedback source, which results in the learner’s disregarding his or her own internal feedback. More recent theories of feed-forward control may help add to this explanation. Feed-forward control can be used for error detection and correction, and it involves preparing the system for feedback by creating a copy of the motor output as a reference (Schmidt & Lee, 2005). In reaching and grasping movements, feed-forward control has been incorporated into a forward model that predicts the behavior of the motor system, which can then be compared with the actual movement (see Desmurget & Grafton, 2000; Wolpert, Ghahramani, & Flanagan, 2001). This model has been more recently applied to bimanual coordination (Klaiman & Karniel, 2006; Riddochhoff, Peper, & Beek, 2007) and may help explain the results of the current study. Reducing the feedback available to the learner should result in a greater dependence and development of feed-forward control, as more planning and anticipation will be necessary. This dependence may lead to better development of feed-forward control mechanisms and would contribute to greater adaptability of performance if feedback is removed or reduced. Alternately, providing continuous feedback may be less conducive to the development of feedforward control processes, as information is constantly provided for the learner.

ACKNOWLEDGMENTS

Acknowledgements for this study go to a Natural Sciences and Engineering Research Council of Canada grant awarded to Ian M. Franks. The authors also recognize Paul Nagelkerke for his technical support.

NOTE

1. All p values have been adjusted by the Greenhouse–Geisser Epsilon Factor (degrees of freedom reported have not been adjusted).

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Submitted September 27, 2007
Revised December 7, 2007