Self-Controlled Concurrent Feedback Facilitates the Learning of the Final Approach Phase in a Fixed-Base Flight Simulator

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Objective: This study (a) compares the effectiveness of different types of feedback for novices who learn to land a virtual aircraft in a fixed-base flight simulator and (b) analyzes the informational variables that learners come to use after practice. Background: An extensive body of research exists concerning the informational variables that allow successful landing. In contrast, few studies have examined how the attention of pilots can be directed toward these sources of information. Method: In this study, 15 participants were asked to land a virtual Cessna 172 on 245 trials while trying to follow the glide-slope area as accurately as possible. Three groups of participants practiced under different feedback conditions: with self-controlled concurrent feedback (the self-controlled group), with imposed concurrent feedback (the yoked group), or without concurrent feedback (the control group). Results: The self-controlled group outperformed the yoked group, which in turn outperformed the control group. Removing or manipulating specific sources of information during transfer tests had different effects for different individuals. However, removing the cockpit from the visual scene had a detrimental effect on the performance of the majority of the participants. Conclusion: Self-controlled concurrent feedback helps learners to more quickly attune to the informational variables that allow them to control the aircraft during the approach phase. Applications: Knowledge concerning feedback schedules can be used for the design of optimal practice methods for student pilots, and knowledge about the informational variables used by expert performers has implications for the design of cockpits and runways that facilitate the detection of these variables.

INTRODUCTION

Landing is the most critical phase of visually controlled flights (Langewiesche, 1944; Mulder, Pleisant, van der Vaart, & van Wieringen, 2000). Wiener (1988), for instance, reported that 30% of the crashes in commercial aviation occur during the final approach and landing, even though these phases account for less than 4% of the total flight time. A main cause of landing accidents is that pilots sometimes rely on sources of information that lead them to misperceive the altitude of the aircraft or the angle of approach to the runway (Gibb, 2007). However, useful informational variables are typically available, even under fairly impoverished circumstances (Galanis, Jennings, & Beckett, 1998; Gibson, Olum, & Rosenblatt, 1955; see a detailed presentation of these variables later). How can one focus the attention of pilots toward these more useful sources of information? The present study addresses this question. We aim to apply recent advances in theories of perceptual learning to the design of practice conditions in a fixed-base flight simulator (cf. Lintern, 1995).

Landing consists of three subtasks. First, in the base-to-final turn, the flight direction of
the aircraft is aligned with the runway (Beal & Loomis, 1997). Second, in the **approach phase**, the pilot gradually decreases speed and altitude to reach the beginning of the runway with a reasonable speed and approach angle (Lintern, 2000). Finally, just before ground contact, the aircraft is tilted slightly nose-up in a maneuver that is called the **landing flare** (Mulder et al., 2000). The approach phase and landing flare are the more dangerous subtasks (Benbassat & Abramson, 2002; Gibb, Schvaneveldt, & Gray, 2008). A common type of accident during the approach phase is attributable to the black hole illusion: In the absence of distinguishable ground features, pilots have been shown to overestimate the actual height of the aircraft, often resulting in too-low flight trajectories (Gibb, 2007; cf. Palmisano & Gillam, 2005).

To assist pilots with the landing task, some airports are equipped with precision approach path indicators (PAPIs). As shown in Figure 1, the PAPIs consist of four red or white lights that indicate the aircraft’s current glide slope (CGS). Two red lights and two white lights indicate that the aircraft flies in the correct glide slope area ($2.5^\circ < \text{CGS} < 3.1^\circ$), three red lights or four red lights indicate that the aircraft flies below the optimal glide path ($2.3^\circ < \text{CGS} < 2.5^\circ$ or $\text{CGS} < 2.3^\circ$, respectively), and three white lights or four white lights indicate that the aircraft flies above the optimal path ($3.1^\circ < \text{CGS} < 3.3^\circ$ or $3.3^\circ < \text{CGS}$).

Pilots must also be able to control the approach on the basis of more natural information, among other reasons because PAPIs or similar devices are not available at all airports. Which sources of information are available? A first type of information can be found in the optic flow (Gibson et al., 1955). Optic flow can be characterized as a vector field. Each flow vector indicates how the projection of a point moves because of the motion of the aircraft. Higher-order patterns in the flow specify properties that are of interest to the pilot. For instance, the point toward which the aircraft is heading is specified by the focus of the optical expansion, and the glide slope angle is specified by the angle between the focus of expansion (the aiming point) and the line at which the flow vectors diminish (the horizon; see also the definition of the H-angle later).

A second type of information can be found in the perspective structure of the ground texture. Consider, for example, the projections of lines that are parallel to the direction of motion. The angles formed by such projections at the vanishing point are called **splay angles**. The higher an aircraft flies, the smaller the splay angles. Splay angles thereby carry information about flight altitude and changes therein (Flach & Warren, 1995). Information related to altitude is also available through the projections of lines that are perpendicular to the direction of motion (i.e., through depression angles; Flach, Warren, Garness, Kelly, & Stanard, 1997) and, more generally, through gradients of texture elements with a stochastically regular size distribution (Lintern, 2000). Kraft (1978) claimed that
information about altitude is indeed required during the approach phase. Furthermore, Lintern and Walker (1991) showed that the presence of ground texture improves the accuracy of approach performance, and Lintern and Liu (1991) showed that texture improves the detection of other sources of information, such as the position of the horizon.

Glide slope information is available also in more impoverished environments in which the runway is the only visible element. For instance, a particular angle of approach corresponds with a particular length-over-width ratio of the optical projection of the runway, a ratio referred to as form ratio. Consistent with the use of the form ratio, pilots have been reported to execute lower approaches to narrow or long runways as compared with wide or short runways (Mertens, 1981; Mertens & Lewis, 1982). Two final informational variables found to be used in the approach phase are (a) the angle between the horizon and the aiming point and (b) the angle between the aiming point and an arbitrary point on the aircraft, both as seen from the perspective of the pilot (Langewiesche, 1944). These angles are referred to as the absolute H-angle and the relative H-angle, respectively (cf. Galanis et al., 1998; Galanis, Jennings, & Beckett; 2001; Lintern & Liu, 1991).

In sum, information about glide slope is available during informationally rich daylight approaches as well as during approaches in more impoverished environments. However, the different types of accidents show that pilots do not always detect and/or use the information. Would it be possible to orient their attention to the appropriate variables? Several studies indicate that this might indeed be possible (Fajen & Devaney, 2006; Jacobs, Runeson, & Michaels, 2001; Michaels, Arzamarski, Isenhower, & Jacobs, 2008). Fajen and Devaney (2006) used an emergency braking task. Participants in their study drove through a virtual environment and were asked to wait as long as possible and then to brake strongly so as to stop as closely as possible to the stop sign. With practice, participants abandoned the use of less useful variables (i.e., expansion rate) to the benefit of more useful variables (i.e., time to contact or tau; see Lee & Reddish, 1981, for a definition of tau). This shift toward the more useful perceptual invariants is referred to as the education of attention (Gibson, 1966, 1979).

Several factors affect the speed with which learners converge toward the more useful sources of information (e.g., Camachon, Jacobs, Huet, Buekers, & Montagne, 2007; Fajen & Devaney, 2006; Jacobs et al., 2001; Lintern, 1980, 1995; Linter & Koonce, 1991, 1992). Camachon et al. (2007), for instance, tried to facilitate the acquisition of perceptual motor skills with concurrent feedback (i.e., feedback given during the execution of the trial). Participants in their study walked through virtual corridors and adjusted their walking speed to pass through rhythmically opening and closing sliding doors (cf. Cinelli & Patla, 2008; Montagne, Buekers, Camachon, de Rugy, & Laurent, 2003). The concurrent feedback indicated whether observers would arrive early or late at the door crossing if the walking speed remained constant. The study did not show a beneficial effect of the concurrent feedback. Camachon et al. (2007) attributed this result to the fact that the concurrent feedback was imposed rather than self-controlled (i.e., the learners could not control when they received the feedback).

Self-controlled procedures have been shown to have an advantage for terminal feedback (Janelle, Barba, Frehlich, Tennant, & Cauraugh, 1997; Wulf & Toole, 1999; Chiviacowski & Wulf, 2002, 2005). Huet, Camachon, Fernandez, Jacobs, and Montagne (2009) used the same door-crossing task as Camachon et al. (2007) to test a self-controlled procedure in combination with concurrent feedback. A group that received self-controlled concurrent feedback indeed reached the highest level of performance. Also, with practice, learners gradually decreased the number of feedback requests. This spontaneous strategy has been argued to prevent feedback dependence (cf. Salmoni, Schmidt, & Walter, 1984).

The aims of our study are (a) to test whether self-controlled concurrent feedback helps learners to more quickly converge on the information required to control the approach phase and (b) to obtain an indication of the information that learners come to use after a short practice. Three groups of participants practiced the approach phase in a flight simulator. One group,
the self-controlled group, was allowed to request concurrent feedback in the form of a PAPI. If they pushed a button, a PAPI indicated the current glide slope during 2 s. A second group, the yoked group, received concurrent feedback in the form of a PAPI following an imposed schedule. A control group did not receive concurrent feedback. Transfer tests were used to study the information that the different groups used after practice. We reasoned that the use of a particular type of information should be evidenced by a deterioration of performance in a transfer test in which that information is manipulated or not presented.

**METHOD**

**Participants**

Participants in the experiment were 15 novice pilots (mean age = 27, SD = 4.11). All of them had normal or corrected-to-normal vision. They were divided into three experimental groups of equal size (n = 5). Participants had no prior flight experience, and they were not informed about the purpose of the study. Informed consent was obtained prior to testing.

**Task**

Participants were asked to land the virtual aircraft (a Cessna 172) while trying to follow the correct glide slope area as accurately as possible. No on-board information displays were used, meaning that the control of the aircraft was purely visual. Participants were placed in conditions that were as similar as possible to real approach situations. At the beginning of each trial, the aircraft was located at a distance of 2,700 m (1.46 Nm) from the intended landing point and at a starting altitude randomly chosen from 15 equidistant values between 101 and 131 m (331 and 430 ft). The aircraft flew on a straight line at a speed of 82 knots (42.18 m/s). As a result, the aircraft always started below the glide slope area. The trial duration was about 50 s. The trials started with countdown of 3 s, during which the autopilot was enabled. For the rest of the trial, the participants controlled the altitude of the aircraft by pushing the joystick forward or backward. The lateral position of the aircraft remained aligned with the center of the runway throughout the trials. Trials ended 500 m before the landing point.

**Apparatus**

The setup (Figure 2) consisted of an aviation game joystick (Saitek AV8R), a 2.3-m-high by 3-m-wide projection screen, a Barco-Projector, and a PC (Dell Precision 380). Participants were seated at a distance of 1.2 m from the screen, which hence had an angular size of 87° (vertically) by 102° (horizontally). The data from the joystick were sampled with a frequency of 100 Hz. From this data, the PC calculated the updated position and the dynamics of the aircraft in the virtual environment. The modified visual scene was projected on the screen with a delay of less than 50 ms. According to experimenters and participants, this delay was not noticeable. The visual scene was changed at a rate of 60 frames per second.

The dynamics of the aircraft were simulated using the JSBSim open-source flight dynamics model (Berndt, 2004). This model computes flight characteristics from the combination of the forces of nature and the forces and moments applied through the control mechanisms. The graphical environment (e.g., runway, ground surface, cockpit; see Figure 3) was produced with I.C.E. (Imagine, Create, Experiment), a software package developed at the Institute of Movement Sciences in Marseille (cf. Bastin, Craig, & Montagne, 2006; Craig, Berton, Rao, Fernandez, & Bootsma, 2006). We used a simple runway with a centerline and an aiming point. The landing point was shown by two white rectangles, one on each side of the runway’s
centerline, placed 300 m from the beginning of the runway. The runway was 1200 m long and 30 m wide. With a length-over-width ratio of 40, this is a standard runway for novice pilots.

**Experimental Groups and Feedback Conditions**

There were three experimental groups: self-controlled, yoked, and control. The self-controlled group received concurrent feedback using a self-controlled feedback schedule (cf. Chiviacowski & Wulf, 2002; Huet et al., 2009). Participants in this group could request concurrent feedback by pressing a trigger located on the front of the joystick. When a participant pressed the trigger, the concurrent feedback appeared for 2 s and then disappeared automatically. Participants could ask for concurrent feedback as often as they wished, and they could also decide not to ask for feedback. We recorded how many times and when the feedback was requested. The concurrent feedback was provided in the form of PAPIs located near the aiming point on the left-hand side of the runway (as seen from the approaching aircraft).

The yoked group followed an imposed concurrent feedback schedule. We randomly associated a participant in the self-controlled group with each participant in the yoked group. Each yoked-group participant received the feedback schedule recorded for his or her associate from the self-controlled group. Participants in the control group did not receive concurrent feedback. Terminal feedback was given in each group; after each practice trial, this feedback showed the aircraft’s trajectory on that trial together with the glide slope area.
**Procedure**

The experiment consisted of a calibration period, a pretest, an acquisition phase, a retention test, and three transfer tests. The calibration period consisted of 15 trials during which the participant aimed to fly through 20 rings. The purpose of this exercise was to familiarize the participant with the characteristics of the simulator. Then, before the pretest, instructions concerning the experimental task were given and a video of a typical approach was shown to ensure that the participant understood the task. This video also might have helped participants to recognize the correct glide slope area. The pretest consisted of 15 successive approaches without concurrent feedback and without terminal feedback. The acquisition phase consisted of three blocks of 15 trials per day, during a 4-day period, resulting in a total of 180 trials. The experimental groups differed in the concurrent feedback that they received in this phase, but all participants received the same terminal feedback. An additional block of 5 trials without concurrent feedback and without terminal feedback was performed at the end of each daily session.

Finally, a 15-trial retention test and three 5-trial transfer tests without feedback were run the day after the last day of acquisition. The retention test was identical to the pretest. The order of the transfer tests was counterbalanced among participants. Only 5 trials were used in the transfer tests to prevent adaptation to the test conditions. The transfer tests were identical to the pretest and retention test with the following exceptions. In the first transfer test, the cockpit was not shown in the visible scene (Figure 3B). In the second transfer test, we used a runway with a width of 13.5 instead of 30 m (Figure 3C). The resulting length-over-width ratio of 89 approximates the ratio of the narrowest runways typically encountered by pilots. In the third transfer test, we removed the ground texture: All landmarks were replaced by a uniform ground color (Figure 3D).

**Dependent Variables**

We used data obtained between 2,500 m and 500 m before the landing point. The variable time flown within the glide slope area indicates the accuracy of performance. This measure was expressed as a percentage (i.e., \[\frac{\text{time flown within the glide slope area}}{\text{total time of the trials}} \times 100\]). We also calculated the vertical distance between the aircraft’s position and the bisecting line of the glide slope area (2.8°). This variable, expressed in meters, is called the altitude deviation (cf. Gibb et al., 2008). In the majority of our analyses, we considered the absolute value of the altitude deviation.

The self-controlled feedback data were analyzed through the frequency of requests and the moment of requests. The frequency of the requests (i.e., the total number of requests per day) was calculated for each day of the acquisition phase and for each participant in the self-controlled group, permitting a view on the evolution of the feedback requests across days of practice. To analyze the moments of the requests, the acquisition trials were divided in intervals of 100 m (from 2,500 m to 500 m before the landing point). The number of requests in each of these intervals was determined, permitting a view on the within-trial evolution of the number of requests.

**RESULTS**

This section concerns (a) the percentage of time that participants flew within the glide slope area, (b) the altitude deviations, (c) the feedback requests, and (d) the transfer tests.

**Percentage of Time in Glide Slope Cone**

Figure 4 shows the average percentage of time flown within the glide slope area for the different experimental groups in the pretest, acquisition blocks, and retention test.

**Pretest.** As expected, a one-way ANOVA on the percentage of time within the area did not reveal a significant effect of experimental group, \(F(2, 12) = 3.55, p > .05\).

**Acquisition phase.** We first address the additional daily blocks of five trials without concurrent or terminal feedback (Days 1 to 4 in Figure 4). A two-way ANOVA with day as within-subjects factor and group as between-subjects factor was performed with the percentage of time within the area as dependent measure. The analysis revealed significant effects for day, \(F(3, 36) = 4.27, p < .05, \eta^2_p = 0.26\); for group, \(F(2, 12) = 11.29, p < .05, \eta^2_p = 0.65\); and for the interaction Day \(\times\) Group, \(F(6, 36) = 2.89, p < .05, \eta^2_p = 0.32\). A posteriori comparisons (Newman-Keuls)
indicated that the performance increased significantly only for the self-controlled group; for this group, significant differences were observed between Day 1 and Day 3 and between Day 1 and Day 4 ($p < .05$).

We also analyzed the three daily blocks of 15 trials in which the concurrent feedback was given (not shown in Figure 4). A two-way ANOVA with day as within-subjects factor and group as between-subjects factor was performed on the percentage of time within the area. This analysis revealed significant effects of day, $F(3, 36) = 14.99, p < .05, \eta_p^2 = 0.55$, and group, $F(2, 12) = 14.46, p < .05, \eta_p^2 = 0.7$. A posteriori comparisons (Newman-Keuls) performed on the group effect indicated that the percentage of time that participants flew within the glide slope area was greater for the self-controlled and the yoked groups than for the control group ($p < .05$). The difference between the self-controlled and yoked groups was marginally significant.

Retention test. A two-way ANOVA with group (self-controlled, yoked, and control) as between-subjects factor and test phase (pretest, retention test) as within-subjects factor was performed, again with percentage of time within the glide slope area as dependent measure. Significant effects were observed for test phase, $F(1, 12) = 257.1, p < .05, \eta_p^2 = 0.95$; for group, $F(2, 12) = 14.98, p < .05, \eta_p^2 = 0.71$; and for the interaction Test Phase × Group, $F(2, 12) = 12.90, p < .05, \eta_p^2 = 0.68$. A posteriori comparisons (Newman-Keuls) revealed an increase in performance from pretest to retention test for all three groups ($p < .05$). In the retention test, the self-controlled group performed better than the yoked group and the control group ($p < .05$). The difference between the yoked and the control groups was also significant ($p < .05$).

**Altitude Deviation**

**Pretest.** The averaged absolute altitude deviations are presented in Figure 5. A one-way ANOVA on these altitude deviations did not show a significant effect of group in the pretest, $F(2, 12) = 1.22, p > .05$. It is worth noting that the (nonsignificant) higher value in altitude deviation exhibited by the control group reflects the difficulties encountered by one of the participants in performing the task.

**Acquisition phase.** We performed a two-way ANOVA with day as within-subjects factor, group as between-subjects factor, and absolute altitude deviation as dependent measure using the data from the additional daily blocks of five trials. The analysis revealed significant effects for day, $F(3, 36) = 6.00, p < .05, \eta_p^2 = 0.33$; for group, $F(2, 12) = 7.08, p < .05, \eta_p^2 = 0.54$; and for the interaction Day × Group, $F(6, 36) = 2.40, p < .05, \eta_p^2 = 0.28$. A posteriori comparisons (Newman-Keuls) indicated a significant decrease in altitude deviation for the self-controlled and the yoked groups between the 1st and 4th days of practice ($p < .05$). No significant decrease was observed for the control group.

**Retention test.** A two-way ANOVA with group (self-controlled, yoked, and control) as
between-subjects factor and test phase (pretest, retention test) as within-subjects factor was performed with absolute altitude deviation as dependent measure. Only the main effect of test phase was significant, $F(1, 12) = 377.01, p < .05$, $\eta^2_p = 0.74$. A posteriori comparisons (Newman-Keuls) revealed a decrease in altitude deviation from pretest to retention test for all three groups ($p < .05$).

Figure 6 presents the time evolution of the altitude deviations. As a consequence of the design of the experiment, participants entered the glide slope area from below (i.e., with negative altitude deviations). In the pretest (left panels), participants in all three groups tended to fly above the glide slope area in the latter parts of the approach. For the control group, this average overshoot was still present in the
retention test (right panels). On the other hand, in the retention test, this overshoot was very small or nonexistent for the yoked and self-controlled groups.

**Use of Feedback**

*Frequency of feedback requests.* On average, participants in the self-controlled group asked for feedback about five times per trial. An ANOVA on the number of requests did not reveal a significant effect of day, $F(3, 12) = 0.76, p > .05$; hence, we did not observe a significant reduction in the amount of requests. As can be seen in Figure 7, participants showed a high level of variability in the use of the feedback. For instance, Participant 2 (squares) asked more frequently for the feedback at the beginning of the experiment than at the end. Participant 5 (cross symbols) increased the number of requests from Day 1 to Day 4. Finally, Participant 3 (triangles) showed less change in the frequency of requests. Despite this variability, all these participants reached a high level of performance.

*Moments of feedback requests.* In contrast to the frequency of requests, participants did not seem to differ and change in the moments at which they asked for the feedback. Figure 8 shows that the number of requests gradually increased during the approach ($R^2 = 0.67, p < .05$). This increase corresponds with the reduction of the glide slope area: The closer to the runway, the smaller the glide slope area, and the higher the number of requests.

**Transfer Tests**

*Percentage of time within glide slope area.* A two-way ANOVA with group (self-controlled, yoked, control) as between-subjects factor and test phase (pretest, retention test, cockpit transfer, ratio transfer, texture transfer) as within-subjects factor was performed with percentage of time within the glide slope area as dependent measure (see also Figure 9). The analysis revealed significant effects of test phase, $F(4, 48) = 15.51, p < .05, \eta^2_p = 0.56$, and group, $F(2, 12) = 5.13, p < .05, \eta^2_p = 0.46$. The interaction Test Phase × Group was not significant, $F(8, 48) = 1.16, p > .05$. A posteriori comparisons (Newman-Keuls) revealed that the percentage of time within the area was greater in the retention test than in any other test phase and that the percentage was greater in the ratio and texture transfer as compared with the pretest and the cockpit transfer ($p < .05$).

*Altitude deviation.* We performed a two-way ANOVA with group (self-controlled, yoked, control) as between-subjects factor and test phase (pretest, retention test, cockpit transfer, ratio transfer, texture transfer) as within-subjects factor on the absolute altitude deviations. The only significant effect was the main effect of test phase, $F(4, 48) = 13.20, p < .05, \eta^2_p = 0.52$. A posteriori comparisons (Newman-Keuls) showed that the altitude deviations were lower in the retention test than in any other test phase and that the deviations were lower in the ratio and texture transfer than in the pretest and in the cockpit transfer ($p < .05$).

*Individual differences.* Figure 10 presents the percentage of time within the glide slope area as a function of test phase for each individual and each experimental group. The figure illustrates that this measure differs more across the different transfer tests for the self-controlled group than for the yoked and control groups. Furthermore, manipulating the perceptual information appears to have different effects on the performance of different individuals, with the notable exception of the information related to the cockpit. Removing the cockpit from the visual scene gave rise to a decrease in the time spent within the cone for all participants. In contrast, manipulating the information related
**DISCUSSION**

The current experiment was designed to test whether self-controlled concurrent feedback helps learners to discover the more useful sources of information when approaching the runway during landing. A first group of individuals practiced the landing task with concurrent feedback available whenever they requested (the self-controlled group), a second group practiced the task with imposed rather than self-controlled feedback (the yoked group), and a third group practiced without concurrent feedback (the control group). The highest level of performance (i.e., the highest percentage of time flown inside the glide slope area) was achieved by the self-controlled group, followed by the yoked and control groups. This means that practice with self-controlled concurrent feedback is the most effective practice schedule for this task.

Our second purpose was to provide an indication about the information that learners come to use after a short practice. To achieve this, transfer tests were performed in which different sources of information were manipulated. The manipulations were found to have different effects for different individuals. Removing the cockpit, however, was shown to have a systematic and detrimental effect on the performance of the majority of the participants. These results are further discussed in the following sections.

**Self-Controlled Feedback Procedures and the Education of Attention**

The self-controlled procedure tested in this experiment is based on the hypothesis that providing learners the possibility to access the current relation to the environment (i.e., the current position of the plane in relation to the glide slope to the runway ratio and to the ground texture gave rise to very different (sometimes opposed) effects for different participants.

![Figure 8. Distribution of feedback requests during the approach.](image1)

![Figure 9. Time flown within the glide slope area as a function of experimental group (self-controlled, yoked, and control) and test phase (pretest, retention test, and transfer tests).](image2)
Education of Attention and Landing

area) allows the learners to more easily identify the informational variables that specify that relation (e.g., H-angle, form ratio). Said differently, the self-controlled procedure might help learners to come to rely on the perceptual regularities that characterize successful landing. Our results confirm this hypothesis; in the retention test, the percentage of time spent in the glide slope area was greater for the self-controlled group than for the other groups. Furthermore, the increase in performance exhibited by the self-controlled group was attributable not only to the availability of the concurrent feedback but also to the possibility of receiving the concurrent feedback whenever it was requested. The benefits of self-controlled terminal feedback have previously been described by Janelle et al. (1997), Wulf and Toole (1999), and Chiviacowski and Wulf (2002, 2005), among others. Our results are consistent with these previous studies. In addition, our results reveal the benefits of feedback that is both concurrent and self-controlled, and they reveal the benefits of such feedback for a complex and practically relevant perceptual motor task.

Types of Feedback Requests

Our study also revealed an unexpected result: The number of feedback requests did not decrease during the acquisition phase. This is surprising because previous studies on self-controlled procedures had shown that with practice, participants come to ask for feedback less frequently (e.g., Huet et al., 2009; Janelle et al., 1997). Such a fading strategy has been hypothesized to prevent the so-called guidance effect (Salmoni et al., 1984). That is, by spontaneously applying a fading schedule, participants avoid a feedback dependency that might otherwise have caused less accurate performance in retention tests without feedback. Although participants in the self-controlled group did not exhibit a fading strategy, they still showed high levels of performance in the retention test. More precisely, 1 participant in the self-controlled group showed a fading schedule, whereas the other 4 participants did not, even though they all reached a high level of performance.

Let us consider a tentative explanation for the finding that a lack of a spontaneous fading did not prevent these individuals from learning the task. On the 1st day of practice, 63% of the requests occurred while the virtual aircraft was located in the correct glide slope area. This percentage increased to 90% during the last day of practice. From these results, one might hypothesize that the functional role of the requests changed with practice. That is, the initial requests might have been used to discover the relation between the relative location of the aircraft and the informational variables, whereas the later requests may have had a more confirmatory role, allowing the learners to make sure that the plane was located in the correct area. Relatedly, Chiviacowski and Wulf

![Figure 10. Time flown within the glide slope area for each participant in each experimental group in the retention test and in the transfers tests (cockpit, ratio, and texture).](image-url)
(2002) showed that learners ask for terminal feedback mostly after successful trials. In sum, we hypothesize that a feedback dependency might have been avoided in our experiment by a gradual change in the functional role of the feedback requests rather than by a spontaneous fading strategy.

The Transfer Tests and the Information Used After Practice

Transfer tests were included in the experiment to obtain an indication about the information that the participants came to use after practice. In the transfer tests, specific sources of information were manipulated or removed. The results from the transfer tests allow a number of comments. First, the self-controlled group seemed to be more affected by the transfer tests than did the other groups. This indicates that the self-controlled procedure allowed learners to come to attend to the more useful informational variables; as a consequence, manipulating that information gave rise to a substantial decrease in performance. Furthermore, not presenting the cockpit has a larger detrimental effect than does modifying the size ratio of the runway or removing the ground texture. Given that the relative H-angle is defined with regard to the visible cockpit (Galanis et al., 1998; Lintern & Liu, 1991), observers who rely on this variable in a retention test might be predicted to perform less accurately in a transfer test that does not include a visible cockpit. Hence, overall, the results of the transfer tests are consistent with the use of the relative H-angle.

The results of the transfer tests should be interpreted with caution, however, because the individuals were differentially affected by the manipulations. Whereas some of them showed a decrease in performance only when the cockpit was removed, others were more affected by the texture transfer. This illustrates that the previously identified informational variables (e.g., form ratio, relative H-angle, and texture gradients) provide different degrees of freedom to perform the task. Individuals apparently rely on different perceptual regularities. As a first implication, this finding indicates that it might be useful to apply individually tailored learning methods that adapt the conditions of practice according to the variables used by an individual.

Concluding Remarks

Taken together, our results reveal that self-controlled concurrent feedback is indeed beneficial for this task, and they provide tentative support for the claim that the relative H-angle is used after practice. However, it would be worthwhile to further establish the later finding, among other reasons because of the observed individual differences. It would be especially useful to perform experiments in which the implied variables are biased and experiments with participants with different levels of expertise (e.g., expert pilots, student pilots, and novices). The observed individual differences also indicate that larger pools of participants are needed to discover trends in variable use in the different groups. To conclude, we briefly indicate possible applications of knowledge about feedback schedules and variable use.

Results concerning feedback schedules might be relevant to pilot instructors. Current training methods are based on detailed procedures in which the more extended landing phase is split up in subtasks that together define a circuit (upwind leg, crosswind leg, downwind leg, base leg, final approach, and landing flare). Each subtask is characterized by recommendations relative to altitude, among other things, with the result that in the end, the student pilot is able to perform the complete task. The method proposed in this study is not designed to replace existing methods but rather to complement them. If pilots control the approach phase on the basis of optimal informational variables, then they might be more flexible in the sense that they might be more able to compensate (cumulative) errors produced during the earlier phases of the landing circuit.

Knowledge about variable use has important implications too. For instance, if expert pilots often use the form ratio, then the visibility of the runway outline is crucial, which implies that one should consider ways to enhance this visibility. On the other hand, if pilots rely on relative H-angles, then the visibility of the aiming point and the edge of the cockpit are more important. In addition, if pilots use relative H-angles,
then changes in this variable predict changes in approach trajectories. Relative H-angles can be changed (or biased) as a result of changes in the eye position of the pilot in the cockpit or as a result of the use of different aircraft. The occurrence of such changes together with reliance on this variable hence predicts the occurrence of accidents, such as black hole accidents, especially if no other information is available to overrule the control based on the biased angles. In short, knowledge about variable use might help us to understand accidents and perhaps to avoid them.

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