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Abstract

This study examined whether pilots initiated paper or digital checklist use from environmental prompts accurately when they receive post-flight graphic and limited verbal feedback. Participants were 6 college students who are pilots with instrument rating. The task consisted of flying a designated flight pattern using a Frasca 241 Cirrus Flight Training Device. The dependent variable was the percentage of paper and digital checklist segments initiated at the proper time. A single-subject, alternating treatment, multiple baseline design with withdrawal and delayed probes was employed in this study. During baseline, participants were given only post-flight technical skills feedback. During intervention, participants were given both technical skills feedback and post-flight graphic feedback on both paper and digital checklist use and praise for improvements. A probe was used between 60-90 days to assess any decrement in participant's performance. The intervention produced highly improved paper and digital checklist timing performance, which improved to nearly perfect following the withdrawal of treatment and increased to perfect performance through the probe sessions.

Introduction

In aviation, the checklist is used during different segments of flight to sequence specific, time critical tasks and aircraft configuration adjustments that correspond to specific environmental demands (Degani & Wiener, 1990). It is divided into sub-sections with task checklists that correspond to all flight segments and, in particular, critical segments such as take off, approach, and landing.

The complexity of these task checklists cannot be overstated. Standard procedures common to some cockpits are not compatible with other cockpits or with newer generation cockpits. Additionally, the task lists can be very long. For example, on some checklists, the "before engine start" sub-section has 76 items for the first flight of the day, and 37 items for subsequent flight segments (Degani & Wiener, 1990). Thus, it is not surprising that many aviation experts have addressed their importance and design, as well as the practices and policies that surround their use (Adamski & Stahl, 1997; Degani, 1992, 2002; Degani & Wiener 1990; Federal Aviation Administration [FAA], 1995, 2000; Gross 1995; Turner, 2001). Even so, the incorrect use of flight checklists is still often cited as the probable cause or a contributing factor to a large number of crashes (Degani, 2002; Degani & Wiener, 1990; Diez, Boehm-Davis, & Holt, 2003; Turner, 2001). Crew errors have been recorded by observers using the Line Oriented Safety Audit that recorded checklist behaviors throughout the flight (Helmreich, n.d.; Helmreich, Klinect, Wilhelm, & Jones, 1999; Helmreich, Wilhelm, Klinect, & Merritt, 2001). Between 1997 and 1998, LOSAs were conducted at three airlines with 184 flight crews on 314 flight segments. Seventy-three percent of the flight crews committed errors. The number of errors ranged from zero to fourteen per flight, with an average of two. Rule-compliance errors were the most frequently occurring errors, accounting for fifty-four percent of all errors (Helmreich, n.d.; Helmreich et al., 2001). Checklist errors constituted the highest number of errors in this category. Similarly, many investigations by the National Transportation Safety Board (NTSB) have revealed that the aircraft were not properly configured for flight, which usually results from improper checklist use (NTSB, 1969, 1975, 1982, 1988a, 1988b, 1989, 1990, 1997, 1998, 2001, 2002, 2003a, 2003b, 2004a, 2004b, 2006, 2007a, 2007b, 2008a, 2008b, 2008c, 2008d).

Checklist devices or methods of presentations are described as paper, laminated paper/card, scroll paper, electromechanical, vocal, and computer-aided/electronic. The most common method of presentation for checklists is the laminated paper/card (Degani & Wiener, 1993; Turner & Huntley, 1991). While this statement may be true for all general aviation aircraft manufactured in the last one hundred years, the rise of lower cost computing hardware and software is rapidly changing how newer aircraft present checklists (Boorman, 2001a, 2001b). Within the last two decades, electronic or digital checklists have appeared on many regional and major airline flight decks, and their use is rapidly increasing in some general aviation aircraft. These digital checklists are integrated into the new aircraft panel by the manufacturer with software designed to exclude many paper checklist errors observed in past studies (Arkell, 2006; Boorman, 2001a, 2001b). In Degani and Wiener (1990), they found

> the current paper checklists have a number of design weaknesses. These problems included the lack of a pointer to the current checklist item, the inability to mark a skipped item, and difficulties in getting lost while switching between checklists. The field study on paper checklists identified a number of problems with paper checklists that may be alleviated with the use of an electronic checklist. (p. 2)

While the claim that using electronic checklists over traditional paper checklists will reduce or eliminate most paper checklist errors may be true, Boorman was concerned that without an automated alarm to alert pilots, even the electronic checklist will not prevent omitted checklists (Boorman, 2001a, p. 5). Thus, certain errant behavior of the pilot is still a source of consternation to the human factors engineer which automation may not cure. Since Boorman's study was a review of accident data and not an empirical study comparing the different performances resulting from different checklist presentations, its generality is limited. However Boorman states:

> Significant changes in crew training, pilot demographics, airplane technology, and the air traffic environment have and will continue to take place. Will the context of checklist errors, and indeed checklists, be significantly altered in the future? An answer to this question is available: the fundamental role of checklists, to ensure that critical crew actions are accomplished at critical points in a flight, is likely to remain valid; and decreasing the chance of errors in the accomplishment of those actions will continue to benefit flight safety. (p. 6)

As avionics prices continue to decline, it is very likely more digital checklists will be installed on smaller general aviation aircraft, thereby expanding the demographics of the pilot users from airline professional to recreational novice. It is still challenging to ensure pilots understand that the checklist is a textual presentation method by which flight deck safety is enhanced.

There is limited theoretical discourse regarding methods to improve checklist behavior using behavioral interventions. Rantz (2002) outlines one potential design concept that uses antecedents, targeted behavior, and consequences to address poor checklist performance and crew performance. A recent study by Rantz, Dickinson, Sinclair, and Van Houten (2009) demonstrated a behavioral intervention designed to increase the appropriate use of flight checklists. Rantz et al. examined eight instrument-rated students from an accredited collegiate flight program by measuring paper checklists errors using a personal computer aviation training device (PC-ATD). Participants used a Cessna C-172 paper flight checklist while flying radar vectors from takeoff to an instrument landing system approach and landing. During baseline, overall average checklist items were completed correctly 53% of the time. After a behavioral intervention of graphic feedback and praise for checklist improvement, performance improved to 98% items correct. Once feedback was withdrawn, performance remained high until the end of the study, with an average of 99% items correct. The importance of this study is the focus on changing the behavior of the pilots regarding checklist use.

> In this study, post-flight graphic feedback and praise increased checklist compliance to near perfect levels. This is the first time this type of behavioral intervention has been used to alter checklist use. (Rantz et al., 2009, p. 20)

From the accident reports and LOSA data, errors in using traditional paper or digital checklists have and continue to plague the industry. Given the number of aviation studies devoted to checklist use and how tasks are conducted on the flight deck, an extensive search of the aviation checklist literature revealed only one study that has examined (a) whether the traditional paper checklist could be used as a dependent variable, and (b) whether behavioral interventions could increase the appropriate use of flight checklists (Rantz et al., 2009).

The future challenge seems to be developing reliable training curricula which recognize and reinforce checklist use regardless of its presentation method. Training methods must consider the occasional misguided attending behavior of the pilot or the lack of stimuli prompt recognition. While misguided attending behavior or distractions absolutely increase the risk in not recognizing checklist prompts, so to does the lack of consistent training

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and reinforcement in developing reliable checklist prompt comprehension. Both misguided attending behavior and prompt comprehension may contribute to the low performance of consistent checklist use as observed in the LOSA data. This study attempts to improve both paper and digital checklist errors and thereby improve checklist segment timing.

Method

Participants

Participants were six undergraduate students enrolled in collegiate commercial flight courses. Participants volunteered from the commercial ground class which is taken after the private certificate and the instrument rating is earned. No monetary compensation was given to participate in the study. During the study participants maintained anonymity between fellow participants, flight instructors, and faculty. Criteria for inclusion included a private pilot certificate, instrument rating, and having experience in either a Frasca 241 and have at least been checked out for solo using actual flight time in the Cirrus SR20 aircraft. Participants averaged 186 total flight hours of which an average of 80 hours were in the Cirrus aircraft or FTD.

Setting

The Flight Training Devise (FTD) and observation camera equipment was located in a hanger used exclusively to train collegiate flight students. Within the FTD area, enclosed structures restricted the vision of the participant to only the simulator. Neither the observation area nor equipment, excluding the video cameras, were visible to the participants.

Apparatus

The Frasca 241 FTD equipment was produced by Frasca International in Champaign, IL. The aircraft shell consists of the Cirrus aircraft forward cowling and flight deck with operating doors. The flight deck is open aft of the front seats to allow for observation during training near the instructor station. The graphic instructor station (GIST) software permitted the simulation of both the SR20 and the SR22 aircraft. The Cirrus SR20 was chosen due to its increasing popularity in general aviation as well as the fact that it was the primary aircraft used in the collegiate training fleet. The GIST simulation software automatically recorded technical flight skill parameters, such as vertical and horizontal progress and enabled those tracks to be printed for technical skills feedback.

Flight patterns. For random variability there were six different flight patterns used for this study (Appendix A). Each flight pattern was divided into eight segments: (a) before takeoff, (b) normal takeoff, (c) climb, (d) cruise, (e) descent, (f) before landing, (g) after landing, and (h) shutdown. Each segment corresponds to the eight checklist segments used for each radar vectored instrument approach flight. To realistically simulate actual flight patterns and insure that the patterns were flown in a consistent way across trials and participants, the experimenter provided typical air traffic control instructions throughout each flight pattern. These scripted instructions were transmitted using a headset system.

The flight checklist. The digital and paper checklists each contained 70 identical checklist items divided into sections that corresponded to each of the eight flight segments. Using the Cirrus checklist ensures the aircraft is properly configured for the appropriate phase of flight. Each checklist segment must be completed at certain moments in time, which should be standardized from flight to flight.

Independent Variable

The independent variable was the presence or absence of post-flight (a) graphic feedback on the total number of checklist items completed correctly per flight, (b) graphic feedback on the number of items completed correctly, completed incorrectly, or omitted for each of the eight flight segments per flight and (c) praise for improvement in the number of checklist items completed correctly.

Dependent Variables

The main dependent variable was the overall average percentage of paper and digital checklist segments participants completed incorrectly per flight. For an item to be scored "correct," participants had to respond, or begin to use the appropriate checklist segment at the appropriate time during the flight.

Experimental Design

A single-subject, alternating treatment, multiple baseline design with withdrawal and delayed probe was employed in this study. The intervention was introduced to the participants at different times, only after it was apparent that baseline performance was stable. The power of the design assumes if a baseline changes after the intervention was given, the effect can be attributed to the intervention and not extraneous variables. This design was chosen for several reasons; (a) the ability to making causal statements, (b) relatively small number of participants required, (c) visually demonstrate independent effects of intervention, (d) visually demonstrate the magnitude and applied significance of the intervention (Kazdin, 1982). Sessions lasted approximately two hours, and participants flew four different flight patterns in each session. Each flight was considered a trial. The order of exposure to the six flight patterns was randomized for each participant to ensure no flight pattern was repeated during any one session. A withdrawal of treatment phase was included to assess whether checklist timing segment performance would be maintained after the post-flight feedback was withdrawn. A probe phase between sixty and ninety days was used to see if there was a long term decline in checklist segment timing performance.

Procedures

Baseline Phase. Participants were informed their behavior during each flight trial would be observed and recorded using the pre-positioned video cameras as well as an observer checklist (Appendix B). For each flight trial they were given automated terminal information concerning the weather and airport conditions, the Cirrus approved paper checklist, as well as the official ILS approach plate used to execute the instrument approach. Before the beginning of each session of four trials, a digital or paper checklist was randomly assigned for the first trial and the remaining three trials alternated between paper and digital checklists. Additionally, they were told that the experimenter would provide them with some post-flight information after each flight and that it would take him about 5 minutes to prepare that material.

After the participant completed a flight, the experimenter printed out the vertical and horizontal flight path just flown by the participant. This provided the participant with technical flight skills feedback one would expect in a normal simulator instruction session. No comments were made regarding the previous checklist use. The technical diagram was reviewed with the participant. This protocol was repeated for each flight during the baseline phase.

Intervention Phase. In addition to giving participants the technical diagram feedback that depicted critical flight parameters after each flight, the experimenter provided graphic feedback on the use of the flight checklist. After each flight trial, the experimenter immediately calculated the number of checklist items completed correctly, entered it into the computer, and printed a line graph that displayed the number of correctly completed items for each trial, including the accumulated trials the participant had completed during baseline (Figure 1). All data to the left of the vertical dotted line in Figure 1 represent baseline performance and all data to the right of the vertical dotted line represent intervention performance. The experimenter also entered the number of checklist items completed correctly, completed incorrectly, and omitted for each of the eight flight segments for that particular flight, and printed a bar graph that displayed those data. The bar graph also included the total number of possible correct checklist items for each segment as well (Figure 2). The experimenter first showed the technical flight diagram to the participant and discussed the technical merits of the flight. He then showed the two checklist feedback graphs to the participants and praised any improvements. No detailed feedback was given to the participant, such as which particular checklist item(s) were performed as incorrect or omitted or errors on timing of checklist segments. This protocol was repeated for each flight during intervention. Once a participant reached 95% correct for all checklist items, for three consecutive trials in either paper or digital, the intervention phase was terminated.

Withdrawal Phase. This phase was identical to the baseline phase in which only technical feedback was given to the participant. Graphic feedback was no longer provided for checklist performance after each flight.

60–90 Day Post-Test Probe. An over 60 day probe past the end of the withdrawal phase was used to assess performance decrements over longer periods of non-exposure to the feedback condition. Four alternating trials were done using both paper checklists (2) and digital checklists (2). Only technical feedback was given.

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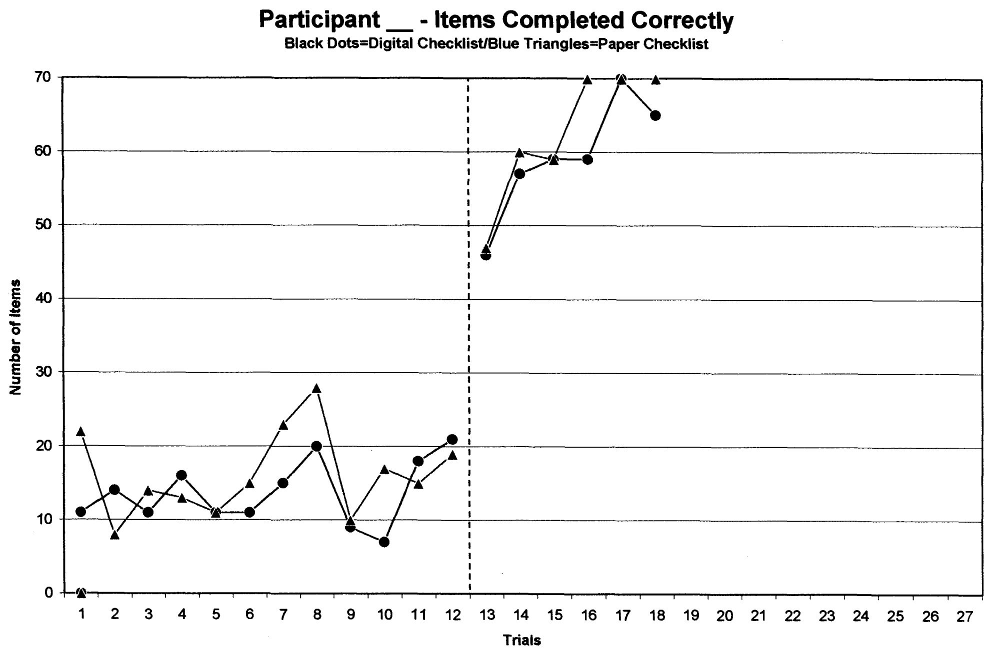

Figure 1. Line feedback graph of both paper and digital checklist items performed correctly.

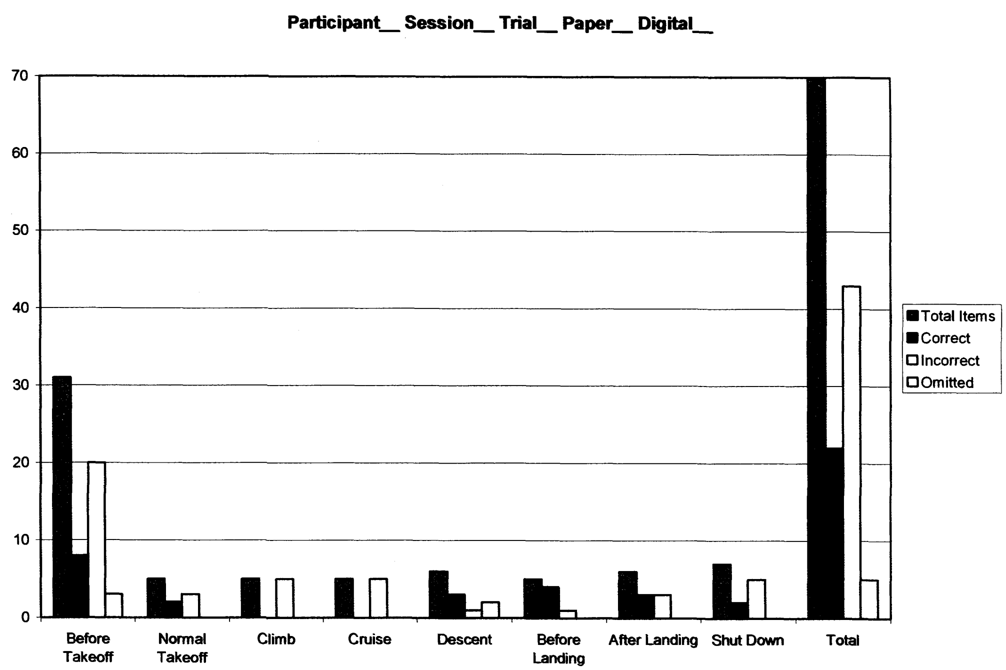

Figure 2. Bar feedback graph of one trial during intervention.

Results

Data collection took approximately 64 sessions which included 256 flight trials. 2,451 total paper checklist errors were observed and 2,562 total digital checklist errors were observed. During the study 75 paper segment timing errors occurred while 66 digital segment timing errors occurred. Due to the experimental design, homogeneity could not be maintained regarding the number of trials within phases between participants. Therefore result comparisons are expressed in percent of error.

Table 1 lists each participant, under which are columns for baseline (B), intervention (I), and withdrawal (W) phases. The probe phase is not listed since no timing errors occurred during that phase. Only paper checklist segments which resulted in segment timing errors are list on the left. The bottom row is the average percent error of each participant's checklist segment performance within each phase. While this percent is not of much use for actual performance feedback to the participant, it can be used to compare between participants' performance. This comparison illustrates the variability of performance between participants during baseline it also shows, excluding participant 1, the reduction in segment timing error during the intervention phase. All paper checklist segment timing errors were eliminated during the withdrawal and probe phase.

Table 1. Participants Paper Checklist Segment Timing Errors Per Phase

	P1			P2			P3			P4			P5			P6		
	B	I	W	B	I	W	B	I	W	B	I	W	B	I	W	B	I	W
Climb	0	0	0	67%	13%	0	22%	0	0	0	17%	0	50%	0	0	92%	0	0
Cruise	0	20%	0	17%	0	0	11%	0	0	0	0	0	0	0	0	25%	0	0
Descent	20%	0	0	50%	13%	0	33%	17%	0	56%	17%	0	67%	0	0	33%	0	0
Before Landing	20%	20%	0	0	13%	0	67%	17%	0	56%	17%	0	75%	0	0	17%	0	0
INDIV AVG % per Phase	10%	10%	0	33%	9%	0	33%	8%	0	28%	13%	0	48%	0	0	42%	0	0

Data from Table 2 represents the same performance measures as Table 1 except it is displaying digital checklist segment timing errors across each participant per phase. As with paper checklist, similar performance occurred for participants across each phase using the digital checklist. One exception was participant 2 in which one timing error did occur in the descent segment during the withdrawal phase. However all participants eliminated digital checklist segment timing errors during the probe phase.

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Table 2. Participants Digital Checklist Segment Timing Errors Per Phase

	P1			P2			P3			P4			P5			P6		
	B	I	W	B	I	W	B	I	W	B	I	W	B	I	W	B	I	W
Climb	0	0	0	33%	0	0	22%	0	0	0	0	0	25%	0	0	50%	0	0
Cruise	20%	20%	0	17%	0	0	11%	0	0	11%	0	0	8%	0	0	17%	0	0
Descent	40%	20%	0	17%	13%	17%	67%	0	0	33%	17%	0	75%	0	0	0	0	0
Before Landing	20%	20%	0	0	13%	0	67%	0	0	56%	17%	0	75%	0	0	33%	0	0
INDIV AVG % per Phase	20%	15%	0	17%	6%	4%	42%	0	0	25%	8%	0	46%	0	0	25%	0	0

Figure 3 displays the overall average percentage of paper checklist segment timing errors for all participants over all trials. For all the paper checklist trials, no segment timing errors were observed for the Before Takeoff, Normal Takeoff, After Landing, and Shutdown segments. Therefore these segments were excluded from the graph. The paper checklist had the highest overall average percentage of timing errors during the descent phase at 43 percent error over all trials. The before landing had a 39 percent timing error rate followed by the climb segment with a 38 percent timing error rate. The lowest timing error rate was for the cruise segment at 9 percent. Participants decreased the segment timing error rates and increased performance accuracy over baseline when post-flight checklist feedback was provided. During the intervention phase the timing error rate for the before landing phase was the highest at 11 percent. The remaining segments showed improved performance with reduced timing error rates for the descent (8%), climb (5%), and the cruise (3%). Again, all segment timing errors had been eliminated during the withdrawal phase as no timing errors occurred after the graphic feedback intervention was removed or during the over 60 day probe.

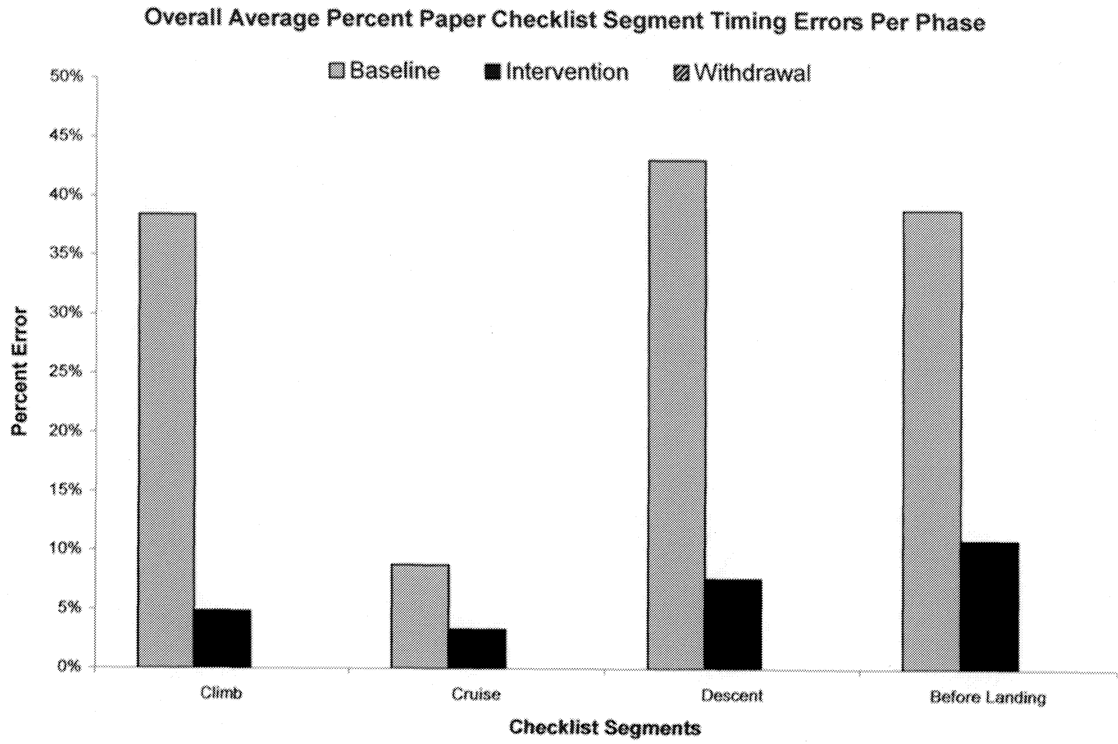

Figure 3. Paper Checklist Segment Timing Errors

Figure 4 displays the overall average percentage of digital checklist segment timing errors for all participants over all trials. Similar as the baseline paper checklist segments, no timing errors were observed for the Before Takeoff, Normal Takeoff, After Landing, and Shutdown segments and these were excluded. The highest overall average percentage of timing errors for the digital occurred during the before landing phase at 42 percent. The descent phase had a 39 percent timing error rate and the climb segment with a 22 percent timing error rate. Again the lowest timing error rate was the cruise segment at 14 percent. As with paper, participants decreased the digital segment timing error rates over baseline when post-flight checklist feedback was provided. During the intervention phase the timing error rate for both the before landing and descent were tied at 8 percent. The cruise segment had an error rate of 3 percent. There were no segment timing errors in the intervention phase for the climb segment. Due to one timing error the descent segment was problematic during the withdrawal phase by still having an overall error rate of 3 percent. No digital segment timing errors occurred during the past 60 day probe.

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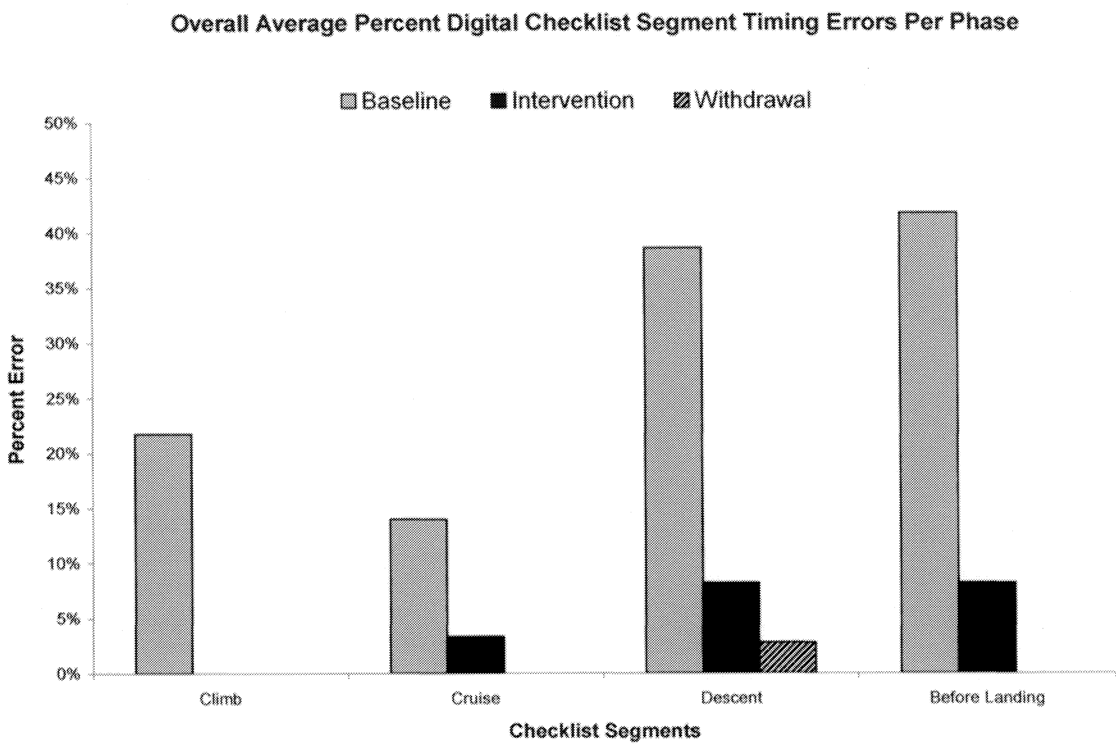

Figure 4. Digital Checklist Segment Timing Errors

Discussion

The use of checklists in the flight environment remains a vital component to safe operations. As with the airline audits conducted by Helmreich and his colleagues (Helmreich et al., 1999; Helmreich et al., 2001; Klinect, J. R., Murray, P., Merritt, A., & Helmreich, R. (2003), the results of this study revealed that checklist compliance, including timing of segments varied considerably across individuals during baseline regardless of paper or digital presentation.

In a preemptive effort not to bias the present study by specifically inquiring about past checklist use or its importance, no pre-test of stimuli prompts or rules for checklist use was given to the participants before the experiment. Figures 3 and 4, show the overall average percentage of timing errors using the checklists, these timing errors very likely indicate missed prompts by the participants. These segment timing errors appear to be nearly identical between both paper and digital checklist presentation methods. Paper and digital checklist segment timing errors in baseline occurred during the climb, cruise, descent, and before landing segments of flight. Given the overall improvement to nearly perfect performance after the feedback intervention and perfect performance during the probe, participants may have forgotten or ignored the prompts during the baseline phase or they may have believed nothing aversive or bad would happen to them while operating in a simulated flight environment and chose to proceed in the most familiar manner possible.

A review of the collegiate private pilot training curriculum revealed that training checklist use specifically occurred during lessons 1-6 with level 1 for specific performance criteria standards of checklist use and level 2 for preflight procedures for lesson 18-19. Performance criteria standards are listed in Appendix C. However the manual contained no evidence articulating formal follow up assessment or feedback specifically for checklist use. A further review of the collegiate instrument pilot training curriculum showed checklist use was required during most of the lessons. It appears that greater emphasis is being placed on using and holding a higher criteria standard for checklist use; however as with the private pilot curriculum, there is no requirement for formal follow up assessment or feedback specifically for checklist use during either instructional of non-instructional flight.

Depending on the location of the aircraft during a particular flight, salient stimuli should be obvious to the flight crews that would prompt the start of particular checklist segments. The *Pilot Operating Handbook (POH)* (2003) for the Cirrus SR20 contains descriptors identifying specific environmental stimuli for checklist prompts. Those checklist segments include, a) before starting engine, paired stimuli-prior to engine start, b) engine start, paired stimuli-start engine, c) before taxi, paired stimuli-prior to taxi, d) taxing, paired stimuli-during taxi/after taxi, e) before takeoff, paired stimuli-at end of runway/in run up area and prior to takeoff, f) takeoff, paired stimuli-prior to takeoff, g) climb, paired stimuli-1000 feet above the ground, h) cruise, paired stimuli-reaching desired or assigned cruise altitude, I) descent, paired stimuli-top of the descent into the destination, j) before landing, paired stimuli-for visual flight rules, downwind leg, for instrument flight rules, 2 nautical miles prior to final approach fix, k) after landing, paired stimuli-after clearing active runway, l) shutdown, paired stimuli-ready to shutdown. Perhaps while reading the Cirrus SR20 POH, pilots memorize these prompts, again no evidence of assessing the understanding of these prompts could be found in the curricular documents. Similar studies in behavior-based safety research have observed that using antecedents alone, or rules designed to improve safe behavior are not as effective as one would expect (Austin, Alvero, & Olson, 1998; Engerman, Austin, & Bailey, 1997; Ludwig & Geller, 1997; Olson & Austin, 2001; Streff, Kalsher, & Geller, 1993). Thus, rule statements regarding the importance of consistent checklist use may be, at best, problematic. Given this condition, combined with the difficulty of finding checklist rule statements within the training lessons and no periodic checklist assessments, unclear rule-based objectives for proper checklist use may result in poor performance regardless of the checklist presentation format.

Only the line and bar graphic feedback (Figures 1 & 2) and limited praise for improvement was given to the participants. Specific verbal feedback accentuating which items were missed and which environmental prompts were needed to improve segment timing were not provided to the participants. During the post-flight period, participants examined and compared what the graphs indicated with what they recalled from their most recent performance. For example if the bar graph (Figure 2) indicated they had incorrectly completed all 6 items of the descent checklist, yet they recollected that they had actually completed all 6 items in the descent checklist, this likely resulted in the participant making a rule statement. One such statement may have been, "I know I did all 6 checklist items in the descent as required yet the graph indicates those 6 items as being done incorrectly. The only possible conclusion to get all 6 items incorrect is to begin the descent checklist at the wrong time". This likely explains the error reduction effects during the intervention phase where timing errors were not immediately eliminated. Repeated trials using trial and error may have given the participant time to reason out the new rule statements and perhaps given those more lasting new rule impressions for future checklist use. While vague feedback may not seem to be the most efficient method to correct errors, it may have a profound effect on longer term maintenance of correct behavior.

The only problematic overall error rate of 3 percent timing error occurred while using the digital checklist in the descent segment of the withdrawal phase. While this is a very low overall average timing error, it may indicate some timing difficulty such as a distraction while using the digital checklist prior to the descent. However the end results demonstrated complete elimination of all digital checklist segment timing errors during the post 60 day probes. Since all participants eliminated all timing errors during the 60 day probes; was it due to the contingency shaping caused by the graphic feedback, new rule statements, recalling old rule statements, or a combination of them all? There is strong evidence that the applied significance of the intervention reached criteria for proper timing for both paper and digital checklist. This accomplishment is evident given that all segment timing errors were eliminated by the end of the study.

Given the results of the current study, more research is required to determine, to what extent new rules form under a feedback intervention and specifically how those new rules influence long term checklist behavior. Possible future research should pair a modified checklist curriculum, employing periodic assessment of checklist use and graphic feedback in simulated or actual flight.

Since this study was conducted in a normal

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workload environment, further study should examine increasing the workload demands of the pilots to determine if increased distractions cause higher errors using either paper or digital checklists. Even while operating in a normal workload condition, many timing errors occurred during elevated workload segments of the checklist. Generally these segments included the climb, descent and before landing portions. Providing increased workload may reveal greater differences in checklist performance given how the checklist is presented. Increased workload may also evaluate the effectiveness of the feedback intervention package regarding initial effect sizes and duration of effect.

While both paper and digital checklists have their strengths, the inherent potential weakness of each are comprised of, a) the lack of pre-existing effective rule statements regarding the consistent and proper use of the checklist, b) the lack of salient stimuli recognition to prompt the beginning of each checklist and, c) the lack of effective reinforcers to increase and maintain checklist use.

The use of line and bar graphic feedback had a direct effect on improving timing performance in both paper and digital checklist formats. Given these results and the importance of checklist use in the industry, flight training professionals should review curricular methods used to, educate, assess, and reinforce checklist use.✈

William G. Rantz holds a Ph.D. in Psychology, a Master of Arts in Industrial/Organizational Psychology, a Master of Arts in Career and Technical Education, and a Bachelor of Science, all from Western Michigan University. He is an associate professor at the College of Aviation, Western Michigan University in Kalamazoo, Michigan. Dr. Rantz holds an Airline Pilot Certificate and a Multi-engine, Instrument, Flight Instructor Certificate.

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Appendix A

NORMAL WORKLOAD-Technical Flight Pattern Parameters and Narration
Flight Pattern 2 KAZO

(EXPERIMENTER): *Session start, please begin. Contact tower when ready for takeoff.*
Using flow pattern-Before Takeoff checks completed (31 checklist items)
(PARTICIPANT): *Kalamazoo Tower Western 45 ready for departure runway 35.*
(EXPERIMENTER): *Western 45 you are cleared for departure. Fly runway heading climb and maintain 3,500'.*
(PARTICIPANT): *Fly runway heading climb and maintain 3,500' Western 45*
Using do-list-Normal Takeoff checks completed (5 checklist items)
After reaching 1000' AGL
Using flow pattern-Climb checks completed above 1000' (5 checklist items)
(EXPERIMENTER): *Western 45 contact Kalamazoo Approach on 121.2.*
(PARTICIPANT): *Contacting Kalamazoo Approach on 121.2 Western 45.*
(PARTICIPANT): *Kalamazoo Approach Western 45 is with you heading 350 climbing to 3,500'.*
(EXPERIMENTER): *Western 45 roger.*
(EXPERIMENTER): *Western 45 turn left heading of 260.*
(PARTICIPANT): *Turning left to a heading of 260 Western 45.*
Using flow pattern-Cruise checks complete after level at 3,500' (5 checklist items)
(EXPERIMENTER): *Western 45 turn left heading of 170 and descend to 3,000'.*
(PARTICIPANT): *Turning left to a heading of 170 and descending to 3,000' Western 45.*
Using flow pattern-Descent checks complete prior to IAP and 3,000' (6 checklist items)
(EXPERIMENTER): *Western 45 turn left to a heading of 080.*
(PARTICIPANT): *Turning left to a heading of 080 Western 45.*
(EXPERIMENTER): *Western 45 turn left to a heading of 030 cleared for the ILS 35 contact Kalamazoo Tower 118.3.*
(PARTICIPANT): *Contacting Kalamazoo Tower on 118.3 Western 45.*
(PARTICIPANT): *Kalamazoo Tower this is Western 45 on the ILS 35.*
(OBSERVER: *Western 45 you are cleared to land runway 35.*
(PARTICIPANT): *Cleared to land runway 35 Western 45.*
Using flow pattern-Before Landing checks complete prior to FAF (5 checklist items)
2 miles outside FAF-Power 50% 22" MP, flaps 50%, airspeed 100 knots, maintain 2,500' until established on the glide slope.
FAF inbound and established on glide slope-Power 25% 12" MP, flaps 50%, airspeed 100 knots, descent rate of 500 feet per minute is established.
Short final-Power as required, flaps 100%, airspeed 75 knots over threshold of runway.
(EXPERIMENTER): *Western 45 turn left to exit the active runway and park.*
Using flow pattern-After Landing checks (6 items)
Using do-list-Shutdown checks (7 items)
(EXPERIMENTER): *This session is over. Please relax and I will join you in a few minutes.*

Appendix B
Observer's Checklist

Participant Number: ________ Session / Trial Code: ________ Date: ____________
Approach:________ Time Start:_______________ Time Stop:_______________
Digital:_______ Paper:_______ Normal Workload:_____ Higher Workload:_____

*****RECORDER ON*****

Before Takeoff Seg. Time Error_____	**Correct**	**Correct**	**Incorrect**	**Omitted**	**Comments**
Doors...LATCHED					
CAPS Handle...Verify Pin Removed					
Belts & Harness…SECURE					
Fuel Quantity…CONFIRMED					
Fuel Selector…FULLEST TANK					
Fuel Pump...ON					
Flaps...SET 50% & CHECK					
Xponder...SET					
Autopilot...CHECK					
Nav Radio/GPS...SET for Takeoff					
Cabin Heat/Defrost...AS REQUIRED					
Brakes...HOLD					
Power Lever...1700 RPM					
Alternator...CHECK					
Pitot Heat...ON					
Nav Lights...ON					
Landing Light...ON					
Annunciator Lights...CHECK					
Voltage…CHECK					
Pitot Heat…AS REQUIRED					
Navigation Lights… AS REQUIRED					
Landing Light… AS REQUIRED					
Magnetos...CHECK Left then Right					
Ignition Switch R,note RPM,then BOTH					
Ignition Switch L,note RPM,then BOTH					
Engine Parameters…CHECK					
Power Lever...1000 RPM					
Flight Inst, HSI, & Alt...CHECK & SET					
Flight Controls...FREE & CORRECT					
Trim...SET Takeoff					
Autopilot…DISCONNECT					
Normal Takeoff Seg. Time Error_____					
Power Levers...FULL FORWARD					
Engine Parameters...CHECK					
Brakes...RELEASE					
Elevator ControlROTATEat65-70 KIAS					
At 85 KIAS, Flaps...UP					
Climb Seg. Time Error_____					
Climb Power…SET					
Flaps...Verify UP					
Mixture…FULL RICH					

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Engine Parameters...CHECK					
Fuel Pump...OFF					
Cruise Seg. Time Error_____					
Fuel Pump...OFF					
Cruise Power...SET					
Mixture...LEAN as required					
Engine Parameters...MONITOR					
Fuel Flow and Balance...MONITOR					
Descent Seg. Time Error_____					
Altimeter...SET					
Cabin Heat/Defrost...AS REQUIRED					
Landing Light..ON					
Fuel System...CHECK					
Mixture…AS REQUIRED					
Brake Pressure...CHECK					
Before Landing Seg. Time Error_____					
Seat Belt and Shoulder Harness...SECURE					
Fuel Pump...BOOST					
Mixture....FULL RICH					
Flaps...AS REQUIRED					
Autopilot....AS REQUIRED					
After Landing Seg. Time Error_____					
Power Lever...1000 RPM					
Fuel Pump...OFF					
Flaps...UP					
Transponder...STBY					
Lights...AS REQUIRED					
Pitot Heat…OFF					
Shutdown Seg. Time Error_____					
Fuel Pump…OFF					
Throttle...IDLE					
Ignition Switch...CYCLE					
Mixture...CUTOFF					
All Switches…OFF					
Magnetos…OFF					
ELT...TRANSMIT LIGHT OUT					
Response / No Response Totals					
Segment Time Error Totals					

*****RECORDER OFF*****

Observer: ____________________

*Additional Comments:*____

Appendix C

Performance Criteria Standards

Level 0 – Unsatisfactory Performance

Knowledge – Student lacks an understanding or is experiencing difficulty with the concepts, skills, or procedures for accomplishing the basic elements or maneuvers. The student achieves less than 60% on written or oral tests.

Performance – Instructor intervention is required. Student is unable to accomplish the elements of the maneuver or is unsafe while performing them even after re-teaching. Such minimal performance is a bar to further progress.

Level 1 – Instructor Demonstration – Student Performance

Knowledge – Student begins to understand concepts, skills, or procedures for accomplishing the basic elements or maneuvers. The student can achieve at least 60% on written or oral tests.

Performance – Student accomplishes elements or maneuvers by way of instructor direction, teaching, or re-teaching, and with occasional instructor intervention.

Level 2 – Understanding with Occasional Instructor Assistance

Knowledge – Student demonstrates a 70% mastery of referenced material on written or oral tests, usually applies concepts, skills, or procedures for accomplishing the basic elements or maneuvers.

Performance – The student understands and safely demonstrates elements and maneuvers consistently to within double the standards found in the appropriate PTS with occasional instructor assistance. The student only needs additional practice to meet PTS standards.

Level 3 – PTS Standard

Knowledge – Student consistently demonstrates a minimum 80% mastery of referenced material on written or oral tests; explanation of the elements and objectives of maneuvers; voluntarily evaluates and critiques his/her personal performance.

Performance – Student consistently applies concepts and skills to accomplish lesson elements and maneuvers to standards as referenced by the current PTS with minimal assistance and no instructor intervention. The student critiques and evaluates personal performance.

Level 4 – Associating Knowledge to new Situations – Mastery of the Lesson

Knowledge – Student consistently demonstrates exceptional performance in both written and oral testing above and beyond PTS. Student consistently demonstrates a minimum 90% mastery of referenced material on written or oral tests, explanation of the elements and the objectives of maneuvers.

Performance - Student consistently correlates concepts and skills, and demonstrates exceptional performance above and beyond PTS. The student demonstrates attitude, ethics, and communication skills essential for professional flight crew interaction.

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