DOT/FAA/AM-02/13

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# A Laboratory Comparison of Clockwise and Counter-Clockwise Rapidly Rotating Shift Schedules, Part II: Performance

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July 2002

Final Report

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## Technical Report Documentation Page

| 1. Report No. | 2. Government Accession No. | 3. Recipient's Catalog No. |
|---|---|---|
| DOT/FAA/AM-02/13 | | |

| 4. Title and Subtitle | 5. Report Date |
|---|---|
| A Laboratory Comparison of Clockwise and Counter-Clockwise Rapidly Rotating Shift Schedules, Part II: Performance | July 2002 |
| | 6. Performing Organization Code |
| 7. Author(s)<br>Cruz, C., Boquet, A., Detwiler, C., and Nesthus, T. | 8. Performing Organization Report No. |
| 9. Performing Organization Name and Address<br>FAA Civil Aerospace Medical Institute<br>P.O. Box 25082<br>Oklahoma City, OK 73125 | 10. Work Unit No. (TRAIS) |
| | 11. Contract or Grant No. |
| 12. Sponsoring Agency name and Address<br>Office of Aerospace Medicine<br>Federal Aviation Administration<br>800 Independence Ave., S.W.<br>Washington, D.C. 20591 | 13. Type of Report and Period Covered |
| | 14. Sponsoring Agency Code |

15. Supplemental Notes
This work was performed under Task AM-A-00-HRR-519.


16. Abstract:
INTRODUCTION. Many Air Traffic Control Specialists (ATCSs) work a relatively unique counter-clockwise, rapidly rotating shift schedule. Although arguments against these kinds of schedules are prevalent in the literature, few studies have examined rotating shifts such as those seen with ATCSs. The present study directly compared clockwise and counter-clockwise rapidly rotating shiftwork schedules on measures of complex task performance from the Multiple Task Performance Battery (MTPB) and vigilance from the Bakan Vigilance Task. METHODS. Participants (n=28) worked day shifts for the first week of the study (0800-1600), followed by two weeks of either a clockwise ($n$ = 14) or counter-clockwise ($n$ = 14) shiftwork schedule. Participants completed three 1.5-hour sessions on the MTPB on each shift following the first day of training. Each session contained low, medium, and high workload periods, as well as active- and passive-task components. In addition, participants completed a .5-hour Bakan Vigilance Test at the beginning and end of each shift. RESULTS. There were no group differences in the overall or passive task composite scores for the MTPB. Instead, a shift by session interaction, $F(8, 19) = 5.2, p = .001$, indicated that performance was maintained across the afternoon shifts, was lower at the end of the early morning shifts, but fell by a much greater margin at the end of the midnight shift. Results for the active task composite scores indicated a 3-way interaction between week, shift, and rotation condition, $F(4, 23) = 4.7, p = .006$. This complex relationship indicated that performance was consistently higher in the counter-clockwise rotation and was less variable across shifts than in the clockwise rotation. Results of the Bakan Vigilance Task revealed a significant Rotation Condition by Shift interaction, $F(4, 23) = 6.2, p = .001$. While the counter-clockwise group appeared to perform consistently better than the clockwise group across all shifts, results of the simple effects analyses indicated a significant difference only on the first afternoon shift. DISCUSSION. These data do not support the hypothesis that a clockwise rotation will result in better outcomes on complex or vigilance task performance. In fact, performance in the two groups was generally equivalent, with a few exceptions in which the counter-clockwise group performed better. The empirical evidence gained from this study suggest that particular shifts, such as early morning and midnight shifts, may adversely affect sleep and performance more than the direction of shift rotation.


| 17. Key Words | 18. Distribution Statement |
|---|---|
| Shiftwork, Shift Rotation, Vigilance, Complex Task Performance, Workload | Document is available to the public through the National Technical Information Service Springfield, Virginia 22161 |

| 19. Security Classif. (of this report) | 20. Security Classif. (of this page) | 21. No. of Pages | 22. Price |
|---|---|---|---|
| Unclassified | Unclassified | 33 | |

**Form DOT F 1700.7** (8-72) Reproduction of completed page authorized

## ACKNOWLEDGMENTS

The authors acknowledge Pamela Della Rocco, Ph.D., for her foundational work in shiftwork and fatigue research at the Civil Aerospace Medical Institute, for proposing this project as part of the larger research program, and for her contributions to the protocol for this study. In addition, we thank Mr. Blake Sanders for his contribution to the data collection and test administration for this study, Ms. Susan Buriak for her work to append and reduce the database for the Multiple Task Performance Battery, and Mrs. Jane Brooks for providing the food service for the study.

# A Laboratory Comparison of Clockwise and Counter-Clockwise Rapidly Rotating Shift Schedules, Part II: Performance

This report is the second in a series on the findings from a laboratory study comparing clockwise and counter-clockwise rapidly rotating shiftwork schedules. As discussed in the first report, debate exists in the shiftwork literature regarding the benefit of rotating versus fixed-shift schedules (Folkard, 1992; Wedderburn, 1992; Wilkinson, 1992), but there is little debate that if shift schedules are to rotate, they should do so in a clockwise direction (Barton & Folkard, 1993; Czeisler, Moore-Ede, & Coleman, 1982; Folkard, 1989; Knauth, 1993). Akerstedt (1990) and Barton and Folkard (1993) have conceded, however, that there is very little empirical evidence to support the arguments against counter-clockwise rotations. This is especially true with regard to measures of performance.

Air traffic control specialists (ATCSs) in the United States have worked variations of counter-clockwise, rapidly rotating shift schedules since the early 1970s. The most common and well-known of these schedules is called the 2-2-1 (Cruz & Della Rocco, 1995) and involves working two afternoon shifts, followed by two morning shifts, followed by one midnight shift. Summarizing laboratory and field research on the 2-2-1 schedule, Della Rocco, Cruz, and Schroeder (1995) demonstrated that vigilance, problem solving, and reaction time on the 2-2-1 schedule occurred primarily during the midnight shift, with performance declining progressively across the night. There was some evidence that reaction times might also be negatively affected on the first morning shift of the schedule following the "quick turn" (Schroeder, Rosa, & Witt, 1995). None of these findings was particularly surprising since performance decrements are expected during the midnight shift in any shift schedule configuration (Akerstedt, 1988; Klein, Bruner, & Holtman, 1970; Monk, 1990).

Specifically, Akerstedt (1996) reported that "reaction time, computation and problem solving ability are markedly less satisfactory during night work." Erroneous monitoring of meters, single vehicle accidents, and a number of major environmental disasters like the Exxon Valdez oil spill and the Three Mile Island accident were also reported to be associated with sleepiness and decrements in performance on the night shift. In a review of shiftworker performance, Monk (1990) described performance rhythms as the result of complex processes involving circadian rhythmicity, sleep disruption, social and domestic disruptions, and such differences in shift-related variables as supervision levels, motivation levels, and group morale. In addition, different kinds of tasks have demonstrated different performance rhythms. For example, performance on immediate memory tasks is generally better in the morning than in the afternoon or evening, whereas performance on long-term memory and perceptual-motor tasks tends to follow the circadian temperature rhythm more closely, resulting in better performance in the afternoon.

Still, while most researchers will agree that performance is worse during the night than during the day (Bjerner & Swensson, 1953; Folkard & Monk, 1979; Hildebrandt, Rohmert, & Rutenfranz, 1974), the impact of shift rotation, particularly with regard to rapidly rotating shiftwork schedules, remains unresolved. Indeed, of the limited studies examining the direction of rotation, none appear to include information regarding the performance of individuals working these schedules. A survey conducted by Barton and Folkard (1993) of shiftworkers in five different industries indicated that those working advancing (counter-clockwise) rotation schedules reported poorer physical and psychological health, greater sleep disruption, more social and domestic disruption, and lower job satisfaction than those working delaying (clockwise) shift rotation schedules. Likewise, a study of microelectronic factory workers as they moved from a counter-clockwise to a clockwise shift rotation (with 5 days on each shift) indicated that results for the sleep-wake cycle and subjective measures of fatigue supported the clockwise rotation of shifts (Lavie, Tzischinsky, Epstein, & Zomer, 1992). And finally, a study of 14 air traffic controllers in the US Air Force (USAF) working a rapidly rotating (i.e., two days on each shift type), clockwise shiftwork schedule found that diurnally oriented circadian rhythms were maintained (Luna, French, Mitcha, & Neville, 1994). However, as with the other studies mentioned here, no performance data were reported.

The present study was conducted to address the need for more research regarding direction of rotation in rapidly rotating shift schedules. The purpose of the study was to directly compare clockwise and counter-clockwise rapidly rotating schedules in the laboratory to provide empirical evidence (quantitative as well as qualitative) regarding a variety of outcomes relevant to shiftwork. Specifically, Part 2 in this series of reports examined the effects these schedules had on vigilance and multiple task performance.

## METHODOLOGY

A 3-week protocol was designed for a laboratory comparison of rapidly rotating clockwise and counter-clockwise shift schedules. Data were collected using groups of five participants at a time. The direction of rotation was balanced such that the first group was assigned to the clockwise rotation; the second group was assigned to the counter-clockwise rotation, and so on. Although the experiment was extensive, including multiple computer tests, physiological measures, and saliva sampling, this paper will focus on only those variables related to vigilance and complex task performance measures.

### Participants

Thirty participants between the ages of 20 and 55 (*M* = 41.2 years) were recruited and screened from the general population to participate in the study. Participants gave informed consent to participate in the study and were paid for their participation. Two participants withdrew before completing the study. The remaining participants were assigned to either the clockwise (*n* = 14) or the counter-clockwise (*n* = 14) rotation condition based on the order in which they were recruited. The clockwise rotation included 7 males and 7 females with an average age of 40.6 years (*sd* = 9.4 yrs.), while the counter-clockwise rotation included 5 males and 9 females with an average age of 41.9 years (*sd* = 9.0 yrs.). All participants were non-smokers and light- or non-users of caffeine and alcohol. Additional details regarding the participant sample, their recruitment, and selection can be found in Part 1 of this series of reports (Cruz, Detwiler, Nesthus, & Boquet, in press).

### Procedures and Apparatus

Participants in the study reported to the laboratory at the Civil Aerospace Medical Institute (CAMI) for 8 hours per day, 5 days per week, for 3 weeks. The first week (Monday-Friday) for both shift rotation conditions was comprised only of day shifts (0800-1600). During this week, participants were trained on computerized tasks and habituated to the laboratory environment and to wearing a physiological monitor. During the next two weeks, participants worked 1 of the shift rotation schedules shown in Table 1, as determined by their group assignment. The clockwise rotation allowed 24 hours off at each shift rotation and a 48-hour weekend before returning to work on Monday. The counter-clockwise rotation allowed only 8 hours off at each shift rotation and an 80-hour weekend before returning to work again.

On the first day of the study, participants were provided with an orientation to the laboratory and a detailed daily schedule for the study. Two one-time questionnaires were completed, a Morningness-Eveningness Questionnaire (Horne & Ostberg, 1976) and a biographical questionnaire. In addition, participants were given physiological monitoring devices and daily logbooks and were trained on their use. Finally, participants were trained on the Multiple Task Performance Battery (MTPB) and the Bakan Vigilance Task. The physiological monitors and all sensors, except the chest band, were worn 22.5 hours per day to accommodate a 1.5-hour break for showers and leisure activities. The only restriction was that the monitor should not be removed while sleeping or napping. The chest band sensor was only worn while working at the laboratory. The Bakan Vigilance Task

**Table 1.**

*Clockwise and Counter-Clockwise Shift Rotation Schedules*

| Clockwise Rotation | | | Counter-Clockwise Rotation | | |
|---|---|---|---|---|---|
| **Day** | **Work Hours** | **Hours Between** | **Day** | **Work Hours** | **Hours Between** |
| Monday | 0600-1400 | 16 | Monday | 1400-2200 | 16 |
| Tuesday | 0600-1400 | 24 | Tuesday | 1400-2200 | 8 |
| Wednesday | 1400-2200 | 16 | Wednesday | 0600-1400 | 16 |
| Thursday | 1400-2200 | 24 | Thursday | 0600-1400 | 8 |
| Friday-Sat | 2200-0600 | | Thur-Friday | 2200-0600 | |

was administered at the beginning and end of each workday, and the MTPB was performed 3 times each day. The daily protocol is presented in Table 2.

Participants were instructed to treat their participation in the study as a full-time job and to refrain from drinking alcohol or taking any drugs or medications during the course of the study, with the exception of ibuprofen, birth control pills, estrogen replacement, and/or a non-drowsy formula allergy medications such as Claritin™. In addition, subjects were instructed not to consume any caffeinated beverages or chocolate and were not allowed to eat bananas because of potential interference with the radioimmunoassays for cortisol. Diet was not otherwise controlled in the study. Participants were tested with the Intoxilyzer 9000™ breath alcohol test at the beginning of each workday to ensure compliance with the study protocol. None of the participants tested positive during the study. A final day of testing on Day 22 of the study included a final Bakan test session, checking in of equipment, an exit questionnaire regarding the study experience, and a group cohesiveness questionnaire. Bringing participants back to the laboratory on this final day was done to mitigate an end-of-study effect at the end of the previous week and to allow for data collection on the weekend following the last shiftwork week.

### *Bakan Vigilance Task*

On Day 1 of the study, participants were trained on a modified version of the Bakan Vigilance Task (Dollin et al., 1993; Figure 1). The Bakan test had two components: a stimuli comparison and an estimation task. A sequence of 3-digit numbers was presented on

**Table 2.**

*Daily Experimental Protocol*

| Time (in hours) | | Activity |
|---|---|---|
| Start | End | |
| 00:00 | 00:30 | Download & initialize Miniloggers; Subjective ratings; Collect saliva |
| 00:30 | 01:00 | Bakan Session 1 |
| 01:00 | 02:30 | MTPB Session 1 |
| 02:30 | 02:45 | Subjective ratings; Collect saliva |
| 02:45 | 03:15 | Break |
| 03:15 | 04:45 | MTPB Session 2 |
| 04:45 | 05:00 | Subjective ratings; Collect saliva |
| 05:00 | 05:30 | Meal Break |
| 05:30 | 07:00 | MTPB Session 3 |
| 07:00 | 07:30 | Bakan Session 2 |
| 07:30 | 08:00 | Download & initialize Miniloggers; Subjective ratings; Collect saliva |

| (Computer Screen Image) | (Example sequence) | (Action Taken) |
|---|---|---|
| | 1 3 6 E | |
| | 2 3 6 1 | |
| 2 5 7 A | 2 3 6 A | ←Press Spacebar |
| | 2 4 6 3 | |
| | 8 4 6 4 | |

**Figure 1.** Illustration of Bakan Vigilance Task Computer Screen Image and Example of Sequence

a computer screen every 1.5 seconds for 30 minutes. When a sequence of 3-digit numbers was repeated in sequence, depressing the space bar on the keyboard indicated a correct response. In addition, a single digit or letter was presented simultaneously to the right of the 3-digit stimuli. At the end of each 5-minute block of trials, subjects were required to indicate the proportion of numbers to letters presented in the secondary task during that block. The configuration for this study involved 132 possible correct responses on the primary task out of 1200 total stimuli (6 blocks of 200 stimuli each) for a 30-minute session. Participants were given one practice session on the Bakan on day 1, with an experimenter watching to make sure they understood when to press the spacebar. For the remainder of the study, participants completed a 0.5-hour Bakan test at the beginning (session a) and end (session b) of each shift.

For these analyses, only the number of correct responses, or "hits" on the primary stimuli comparison task, were analyzed. The secondary estimation task was not included in the analyses primarily because the data were compromised due to an error in the setup procedure for the task. The manual for the task recommended using a set-up file for each subject to avoid re-entering subject and testing configuration information. Unfortunately, by using the set-up feature of the program, the proportions for the letter estimation task were no longer randomly generated on each trial. Instead, the initial randomly generated proportions were used for each subsequent test. This problem was identified during testing for the fourth group of subjects; therefore, all data for the letter estimation task for these groups was considered contaminated, and the decision was made not to analyze these data.

### *Multiple Task Performance Battery (MTPB)*

The CAMI MTPB was used as the synthetic work environment in this study. The MTPB provided an established approach to an intrinsically motivating synthetic work situation requiring time-shared performance of several tasks under varying workload conditions (Chiles, Alluisi, & Adams, 1968). Time-sharing and variations in workload are essential features of the ATC work environment. The MTPB consists of 5 tasks including static and dynamic monitoring, mental arithmetic, a complex visual discrimination task, and a problem-solving procedural task. A full description of each task is provided below. These tasks measure basic psychological or behavioral functions relevant to control of complex systems in general and ATC and pilot tasks in particular. The tasks were computerized to control all signal presentations. The laboratory included 5 personal computer workstations and 1 controller station, using Pentium processors and 21" touch-screen monitors. Inputs were made via the touch screen and the 10-key pad on the keyboard.

#### *Red and green light monitoring*

Five pairs of boxes or "lights" (1 red and 1 green per pair) were graphically represented at each corner and in the center of the touch screen monitor. The red box was directly over the green box. The normal state of the red "light" was off, displayed as a red outline of a box. The normal state of the green "light" was on, displayed as a filled in, green box. A signal consisted of a change in the normal state of either box to "on" in the case of the red light or to "off" in the case of the green light. The subject was instructed to respond to the signal by touching the box that changed. A correct response returned the signal to the normal state. The box automatically returned to the normal state if no response was initiated within 15 seconds of signal onset. Response time was recorded in milliseconds separately for red and green lights.

#### *Meter monitoring*

Four graphic representations of meters with full-scale values of –50 to +50 were presented in the upper quarter of the touch screen monitor. A red needle on each meter fluctuateed at random with an average position of zero. A signal was present when the needle deflected by an identifiable amount to the left or right and began to fluctuate with an average position at a non-zero value. Each subject was asked to respond to a signal by pressing one of two white boxes above each meter on the side of the meter to which the signal was deflected (i.e., left or right of zero). When the correct box was pressed, the pointer stopped on its "true" average value, giving immediate feedback as to the accuracy of the response. The pointer then began to fluctuate again. The response time was recorded in milliseconds.

#### *Mental arithmetic*

Arithmetic problems were presented about one-third of the distance from the bottom of the screen. Problems consisted of three 2-digit numbers in the following form, "XX + YY – ZZ = ." Each subject was instructed to perform the computation mentally and to enter the answer in reverse serial order through the "10 key" keypad on the keyboard. The response was displayed on the screen and the subject could correct the answer before pressing the enter key by using the backspace key. If the answer was correct, a blue box appeared next to the answer. If the response was incorrect, a yellow-orange box appeared. Response time was measured between the time the problem was presented and a press of the enter key.

*Target identification*

A standard histogram pattern was displayed in the upper center portion of the screen on a 6 x 6 cell matrix such that each bar length of 1 to 6 units appeared only once. A "target" pattern was displayed, followed by successive presentations of 2 comparison patterns that could be rotated 0, 90, 180, or 270 degrees. Subjects were instructed to decide if one, both, or neither of the comparison patterns matched the initial target pattern and then to press the box on the screen with the correct response (i.e., 0, 1, or 2) to indicate their answer. If the response was correct, a blue box appeared next to the task. If the response was incorrect, a yellow-orange box appeared with the correct answer inside.

*Code lock*

At the bottom of the screen, 5 white boxes labeled A through E were displayed when this task was active. Just above these boxes, feedback/response boxes appeared that were white, red, or orange-yellow. The subject was instructed to decode a series of 5 letters using a left-to-right search pattern. This resulted in a predictable number of errors if the subject maintained the requested search pattern. As in previous tasks, a correct response resulted in a blue box on the screen; an incorrect response resulted in the presentation of a yellow-orange box. When a subject received an indication of an incorrect response, he/she was instructed to enter the portion of the sequence already decoded and then proceed with the left to right search pattern to find the next letter. After the correct sequence was entered, a 15-second delay occurred, and the subject was instructed to enter the correct sequence again (short-term recall).

*MTPB Training*

On the first day in the laboratory, participants received standardized training on the MTPB including a training manual that described each task in addition to receiving 30 minutes of part-task training on each task individually followed by the full 1.5-hour schedule of tasks (Table 3). Participants were briefed about the importance of this research in the context of ATC, as well as the relationship of the MTPB tasks to the complex tasks performed by ATCSs in an attempt to maintain the motivating qualities of the synthetic work environment. Beginning on the second day and throughout the remainder of the study, three 1.5-hour sessions on the MTPB were completed each day. A previous study suggested that 75% of the improvement in performance on the MTPB was attained in 12 to 14 hours of practice and that overall composite scores stabilized after 16 hours of practice (Cruz, Della Rocco, & MacLin, 1993). Therefore, participants completed 19.5 hours of practice on the MTPB by the end of the training week and received a feedback report of their performance through the fourth day of training.

*MTPB scoring*

Dependent variables for each task of the MTPB included a percent correct and reaction time measure. The scores from the shiftwork weeks were combined into 3 composite scores: 1) active task composite, 2) passive task composite, and 3) overall composite. Composite scores were computed using the procedure reported by Mertens, McKenzie, and Higgins (1983), which computed the standardized score for each mea-

**Table 3.**

*Schedule of MTPB Tasks by 15-minute Segment*

| | Segments (in minutes) | | | | | |
|---|---|---|---|---|---|---|
| **Tasks** | 1-15 | 16-30 | 31-45 | 46-60 | 61-75 | 76-90 |
| Light Monitoring | x | x | x | x | x | x |
| Meter Monitoring | x | x | x | x | x | x |
| Mental Arithmetic | | x | x | | | |
| Target Identification | | | | x | x | |
| Code Lock | | | x | x | | |

sure with a mean of 500 and a standard deviation of 100. Reaction time scores were multiplied by negative one (-1) so that higher scores indicated faster response times. In addition, efficiency ratios were calculated for all tasks except code lock in order to examine the speed-accuracy trade-off. These ratios were calculated using the standardized scores for the percent correct measures in the numerator and the standardized scores for the reaction time measures (not multiplied by −1) in the denominator. In this way, high accuracy and low reaction time scores combine into efficiency ratios greater than 1, while low accuracy and high reaction time scores combine into efficiency ratios less than 1. Efficiency ratios were not calculated for the code lock measures due to severely skewed distributions for the reaction time measures. This problem may have influenced the findings for the active and overall composite scores as well. A number of transformations were considered to alleviate the problem; however, none resulted in an impact on the statistical outcome. Therefore, the composite scores were computed as they have been in the past (Mertens, McKenzie, & Higgins, 1983).

### Design and Data Analysis

The design of the study was a mixed model repeated measures design where schedule rotation represented the between-groups variable, and week, shift, and session represented the within-subjects, repeated measures. Due to the nature of the shiftwork schedule design in this study, shift type and day of the week were inherently confounded. Therefore, for purposes of analysis, data were organized by shift type instead of day of the week. The majority of analyses utilized the General Linear Model (GLM) for Repeated Measures procedure. To mitigate inflated alpha due to the large number of repeated measurements in this design, the Greenhouse-Geisser correction (Greenhouse & Geisser, 1959) to the ANOVA for repeated measures was selected. Post-hoc comparisons using the Bonferroni adjustment for multiple comparisons were conducted for main effects. Simple effects analyses and Bonferroni multiple comparisons were conducted to investigate significant interactions. Given the suggestion by Akerstedt (1996) that shiftwork may become more intolerable after one's mid-40s, follow-up analyses examining the effects of age were also conducted. Splitting the sample at age 40 produced 2 nearly evenly split age groups, with 15 participants under age 40 ($n$ = 7 clockwise; $n$ = 8 counter-clockwise) and 13 participants over age 40 ($n$ = 7 clockwise; $n$ = 6 counter-clockwise).

## RESULTS

Results of the analysis of the Bakan Vigilance Task and the Multiple Task Performance Battery are presented. Each dependent measure was assessed in terms of potential performance differences between the 2 rotation conditions and patterns of performance within each condition.

### Bakan Vigilance Task

Participants received a total of 4.5 hours of training (9 sessions) on the Bakan test during week 1 of the study and completed 20 additional sessions during weeks 2 and 3 of the protocol. Twelve out of 812 data points were missing (1.5%). A system failure on Day 2 of the training week in 1 group and an electrical storm on the first midnight shift in another group caused trials for the participants in those groups to be lost. In addition, two participants arrived late on 1 occasion. The lost training session data were replaced with the average of the session scores immediately before and after the missing session. All other missing data were replaced with the average of each participant's own same session- and shift-type scores (i.e., beginning or end of shift and early morning, afternoon, or midnight shift) across all non-training trials.

Analysis of variance and multiple comparisons indicated that there were no significant differences between rotation conditions on any of the trials during the training week. In addition, while the scores do not appear to have achieved complete asymptote (See learning curve figure in Appendix A.), there were no significant within-group differences between the sessions on days 4 and 5 of the training week at the beginning or end of the day.

A MANOVA was conducted on the 2 (Week) x 5 (Shift) x 2 (Session) x 2 (Rotation Condition) factorial. A main effect for Week, $F(1, 26) = 7.0, p = .014$, indicated that performance during the first week of shiftwork was significantly better ($M$ = 101.7) than during the second week of shiftwork ($M$ = 97.5). In addition, a main effect for Session, $F(1, 26) = 15.8$, $p = .000$, indicated that performance was significantly better at the beginning of shifts ($M$ = 102.8) than at the end ($M$ = 96.4). There was also a significant interaction for Rotation Condition by Shift, $F(4,23) = 6.2$, $p = .001$. The data for this interaction are presented in Figure 2. While it appears that the counter-clockwise group performed consistently better than the clockwise group across all sessions, results of the simple effects analyses indicated a significant difference only on the first afternoon shift, where the

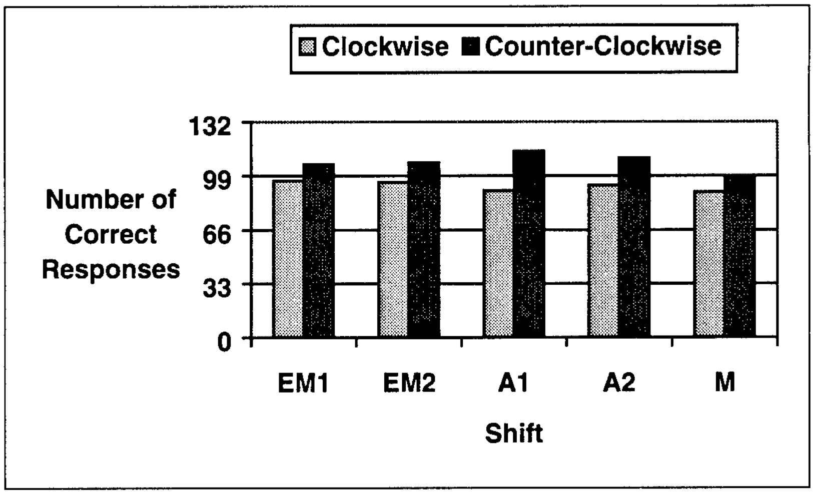


**Figure 2.** Rotation Condition by Shift Interaction on the Bakan Vigilance Task

counter-clockwise group ($M$ = 113.5) performed significantly better than the clockwise group ($M$ = 90.2), $F(1, 26) = 7.2, p=.012$. This shift was the first day of the workweek for the counter-clockwise rotation condition and the third day for the clockwise rotation condition.

### Multiple Task Performance Battery

Participants received 19.5 hours of training (13 sessions) on the MTPB during Week 1 of the study and completed 30 additional sessions on the MTPB during Weeks 2 and 3 of the protocol. Fifteen out of 1,204 session data points were missing (1.2%). The same system failures and electrical storm that affected the Bakan Vigilance Test also impacted the MTPB and accounted for the bulk of the missing data. Missing data during the shiftwork trials were replaced with the average of each participant's own same shift- and session-type scores (i.e., morning, afternoon, or midnight shift and sessions 1, 2, or 3).

To ensure that the groups were not different at baseline, unadjusted t-tests were conducted on the Day 4 (Thursday) data for each measure. The only significant difference between groups was on the response time measure for the recall portion of the code lock task on the first session of the day, $t(26) = 2.2, p = .037$. Response time in the clockwise condition ($M$ = 13.9 sec.) was significantly slower on this session than in the counter-clockwise condition ($M$ = 8.1 sec.). There were no differences, however, for sessions 2 or 3 of that same day or any other baseline training day for any of the measures, indicating that the two groups were not significantly different from each other at baseline. In addition, examination of the learning curves for each measure (See learning curve figures in Appendix A.) shows that the majority of improvement in performance had occurred by Day 5 of the training week. Unadjusted t-tests were conducted within each rotation condition to compare Day 4 performance with Day 5 performance. Within the clockwise rotation there was no significant improvement between Days 4 and 5 on any of the measures. Within the counter-clockwise rotation, however, the green light monitoring task did show significant improvement from Day 4 ($M$ = 93.5%, 4.7 sec.) to Day 5 ($M$ = 98.5%, 3.7 sec.), $t(13) = 2.2, p = .049$ and $t(13) = 2.2, p = .045$ on the second session of the day. There were no differences on any of the other tasks or on sessions 1 or 3.

Results of each measurement from the MTPB are discussed individually below. In order to give an overview of the data for the numerous measurements analyzed from the MTPB, however, the Shift by Session means for each variable are presented in Figure 3. The graphs for the overall composite, passive composite, red light ratio, probability meter ratio, and target identification ratio represent statistically significant Shift by Session interactions. The other 3 variables (active composite, green light ratio, and arithmetic ratio) are also presented for a full picture of this relationship. In addition, the Rotation Condition by Shift means for each variable are presented in Figure 4. Only the green light ratio graph represents a statistically significant Rotation Condition by Shift interaction; however, both the active composite and the arithmetic ratio resulted in significant three-way interactions that included Rotation Condition and Shift.

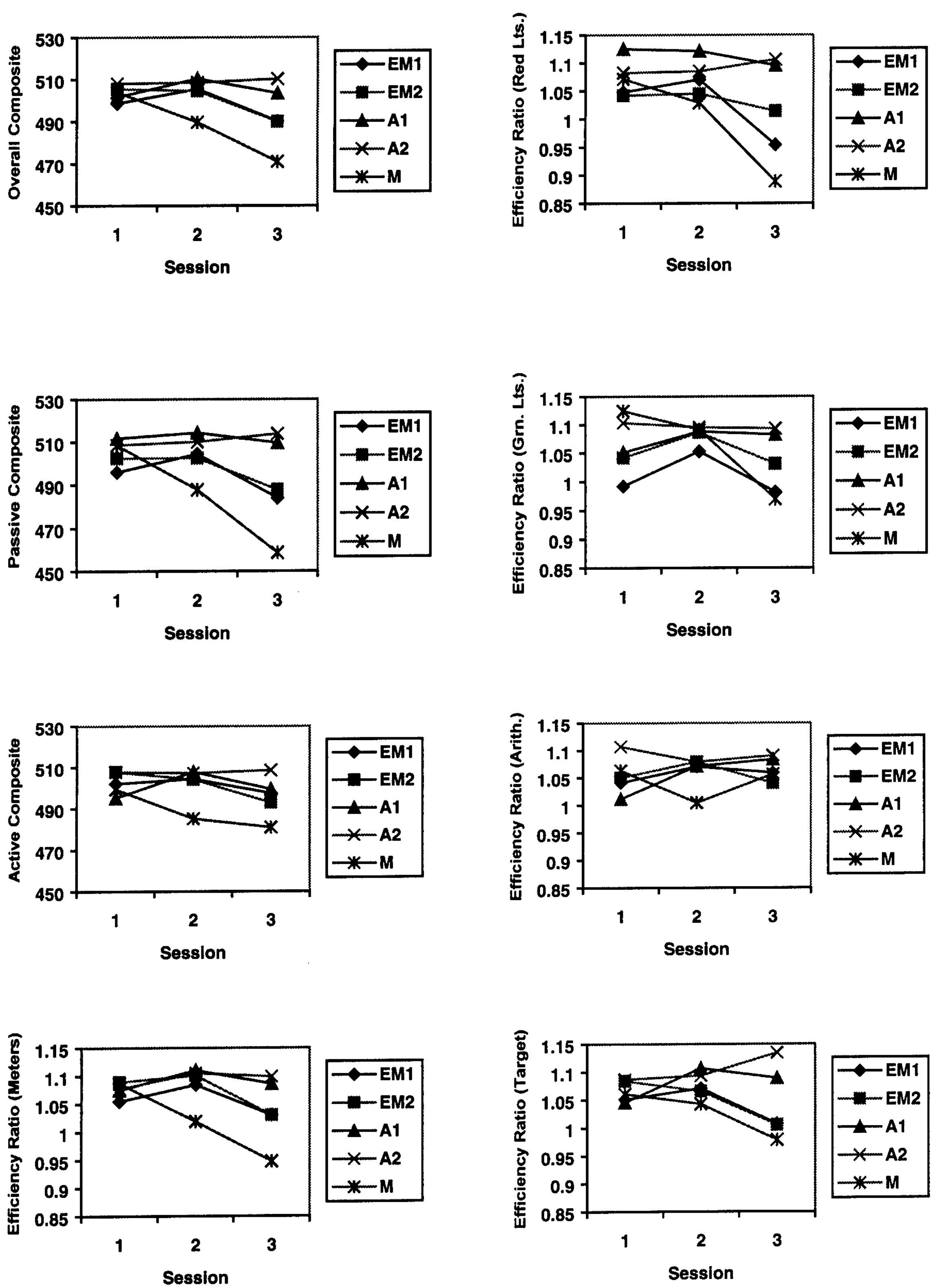


**Figure 3.** Shift by Session Interaction for Each Measure of the MTPB

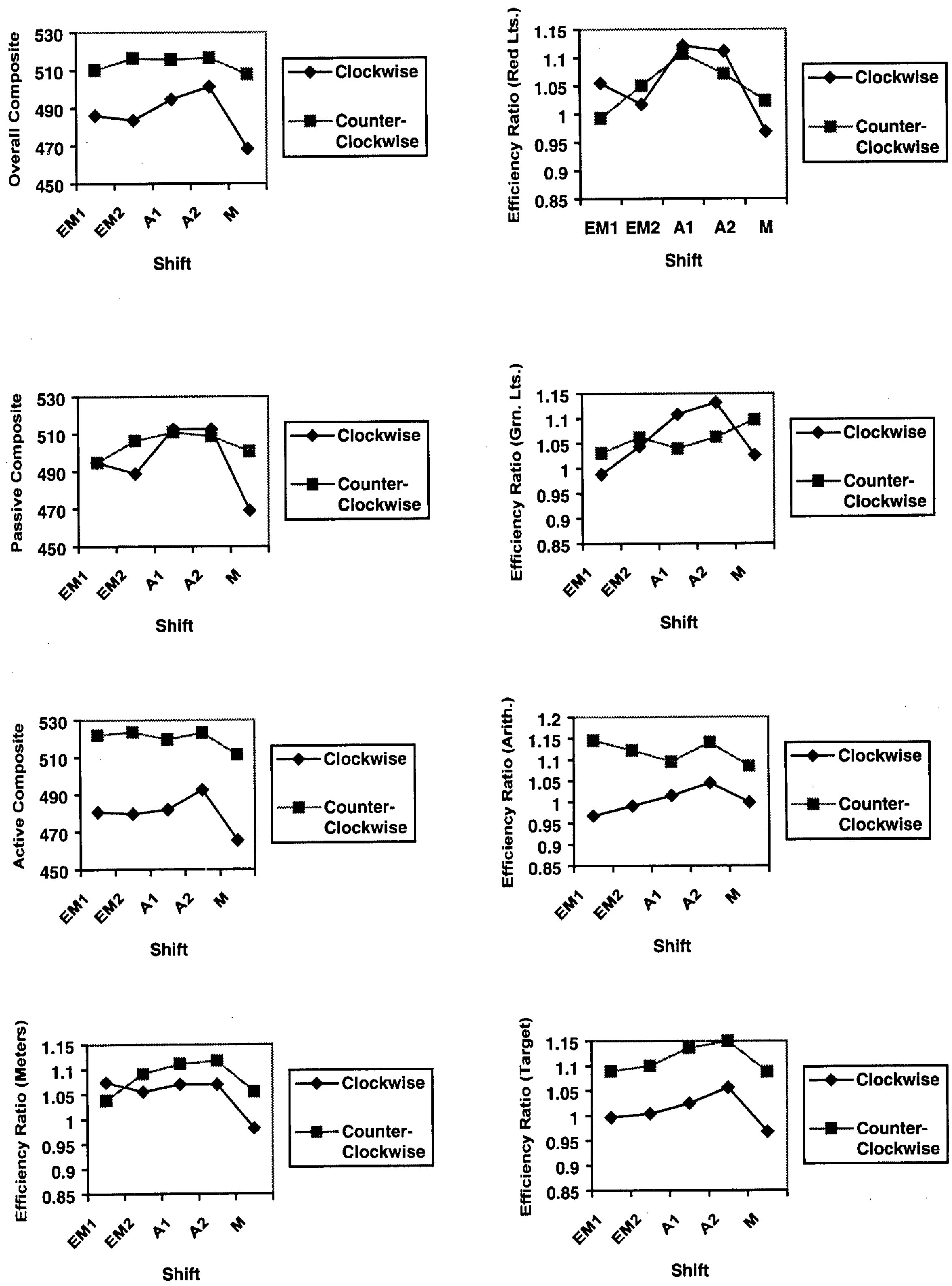


**Figure 4.** Rotation Condition by Session Interaction for Each Measure of the MTPB

### *Composite Scores*

Analysis of both the overall composite and passive task composite scores revealed a significant Shift by Session interaction, $F(8, 19) = 3.4, p = .01$ and $F(8, 91) = 5.2, p = .001$, respectively (Figure 3). Simple interaction effects analyses of the overall composite scores revealed a significant main effect for Shift on the third Session, $F(4, 23) = 4.3, p = .019$ as well as a significant main effect for Session on the midnight shift, $F(2, 25) = 9.7, p=.000$. Bonferroni pairwise comparisons revealed that performance at the end of the second afternoon shift ($M = 510.2$) was significantly higher than at the end of the first early morning shift ($M = 490.1$) and that performance at the end of the midnight shift ($M=470.9$) was significantly lower than at the beginning of the midnight shift ($M = 503.9$). Simple interaction effects analyses of the passive composite scores also revealed a significant main effect for Shift on the third Session, $F(4, 23) = 7.0, p = .002$ as well as a significant main effect for Session on the midnight shift, $F(2, 25) = 16.5, p = .000$. Bonferroni pairwise comparisons revealed that performance at the end of the 2 afternoon shifts ($M = 509.4$ and $513.6$, respectively) was significantly better than at the end of either the first early morning shift ($M = 483.8$) or the midnight shift ($M = 458.6$). In addition, performance showed a significant decline across the midnight shift, such that performance on the first session ($M = 508.3$) was significantly better than performance on either the second ($M = 487.7$) or third sessions ($M = 458.6$) and performance on the second session was significantly better than on the last session.

Analysis of the active task composite scores revealed a significant Rotation Condition by Shift by Session interaction, $F(8, 19) = 3.0, p = .019$. Simple interaction effects analyses of the 3-way interaction were conducted for each Session (Figure 5). On Session 1, there was no significant effect of rotation condition. On Session 2, there was a significant effect for rotation condition on the first early morning shift, $F(1, 26) = 4.3, p = .049$, with the counter-clockwise rotation ($M = 525.9$) performing better than the clockwise rotation ($M = 483.0$). On Session 3, there was a significant effect for rotation condition on the first afternoon shift, $F(1, 26) = 5.2, p = .032$, with the counter-clockwise rotation ($M = 534.1$) performing better than the clockwise rotation ($M = 464.8$).

### *Efficiency Ratios*

*Green Light Efficiency.* Analysis of the green light ratio data revealed a significant Rotation Condition by Shift interaction, $F(4, 23) = 3.2, p = .027$ (Figure 4). Examination of the figure indicates that efficiency for the clockwise rotation was lower than for the counter-clockwise rotation on both early morning shifts and the midnight shift but was higher on the 2 afternoon shifts. Multiple comparisons to examine these differences, however, were not statistically significant. In addition to the interaction, there was a significant main effect for Week, $F(1, 26) = 13.4, p = .001$, indicating that efficiency in the second week of shiftwork ($M = 1.08$) was significantly better than in the first week of shiftwork ($M = 1.03$). There was also a significant main effect for Session, $F(2, 25) = 4.1, p = .025$, such that efficiency on Session 2 ($M = 1.08$) was significantly higher than on Session 3 ($M = 1.03$).

*Red Light Efficiency.* Analysis of the red light ratio data revealed a significant Shift by Session interaction, $F(8, 19) = 2.8, p = .018$ (Figure 3). Simple effects analyses revealed a significant main effect for Shift at the third Session, $F(4, 23) = 7.5, p=.000$ and a significant main effect for Session on the midnight shift, $F(2, 25) = 12.7, p=.000$. Bonferroni multiple comparisons revealed that performance at the end of the first afternoon shift ($M = 1.095$) was significantly higher than at the end of the first early morning shift

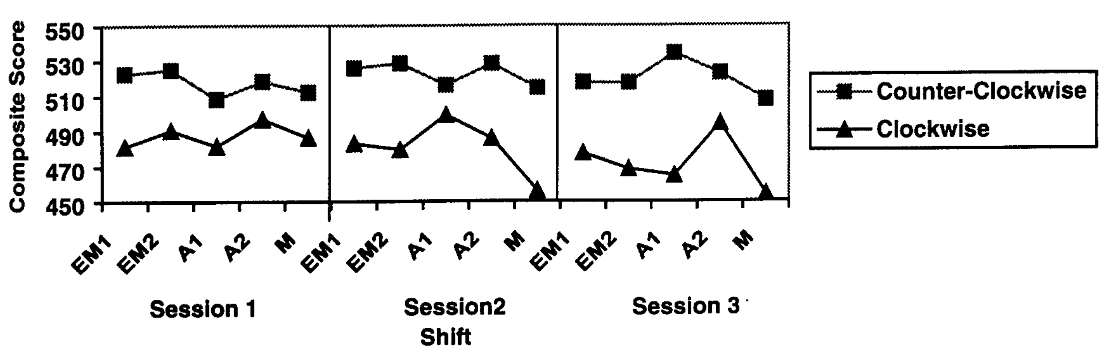


**Figure 5.** MTPB Active Task Composite Scores for Rotation Condition by Shift Interaction for Sessions 1, 2, & 3

($M$ = 0.954) and that performance at the end of both the afternoon shifts ($M$ = 1.095 and 1.106, respectively) was significantly higher than at the end of the midnight shift (M = 0.889). In addition, performance on the last session of the midnight shift ($M$ = 0.889) was significantly lower than on either the first ($M$ = 1.071) or second ($M$ = 1.029) sessions of the midnight shift. In addition to the interaction, there was also a significant main effect for Week, $F$ (1, 26) = 10.67, $p$ = .003, indicating that efficiency in the first week of shiftwork ($M$ = 1.08) was significantly higher than in the second week of shiftwork ($M$ = 1.02).

*Probability Meter Efficiency.* Analysis of the Probability Meter ratio data revealed a significant Shift by Session interaction, $F$ (8, 19) = 2.81, $p$ = .012 (Figure 3). Simple effects analyses revealed a significant main effect for Shift on the second and third Sessions, $F$ (4, 23) = 3.0, $p$= .029 and $F$ (4, 23) = 7.9, $p$ = .000, respectively. Bonferroni multiple comparisons revealed that performance on the second and third sessions of both afternoon shifts ($M$ = 1.11 and 1.105 respectively for Session 2 and $M$ = 1.086 and 1.099, respectively for Session 3) was significantly higher than on the second and third sessions of the midnight shift ($M$ = 1.019 and 0.948, respectively). In addition, simple effects analyses revealed a significant main effect for Session on the second early morning shift, $F$ (2, 25) = 3.6, $p$ = .039 and the midnight shift, $F$ (2, 25) = 9.1, $p$ = .001. Bonferroni multiple comparisons revealed that performance on the last session of the second early morning shift ($M$ = 1.03) was significantly lower than performance on the second session ($M$ = 1.101), and performance on the last session of the midnight shift ($M$ = 0.948) was significantly lower than performance on the first session ($M$ = 1.087).

*Arithmetic Efficiency.* Analysis of the Arithmetic ratio data revealed a significant Rotation Condition by Week by Shift interaction, $F$ (4, 23) = 2.90, $p$ = .032 (Figure 6). Simple effects analyses, however, revealed only a main effect for Week for the first early morning shift, $F$ (1, 26) = 6.3, $p$ = .018, indicating that performance on the first early morning shift was significantly better during the second week of shiftwork ($M$ = 1.097) than for the first week ($M$ = 1.017). No simple effects of rotation condition were significant.

*Target Identification Efficiency.* Analysis of the Target Identification ratio data revealed a significant Shift by Session interaction, $F$ (8, 19) = 2.64, $p$ = .021 (Figure 6). Simple effects analyses revealed a significant main effect for Shift at the third Session, $F$ (4, 23) = 6.4, $p$ = .000 such that performance at the end of the second afternoon shift ($M$ = 1.134) was significantly better than performance at the end of either of the two early morning shifts ($M$ = 1.008 and 1.006, respectively) or the midnight shift ($M$ = 0.979).

### *Age Effects*

To account for the potential confound of age with rotation condition, a number of subsequent analyses were conducted. Although group sizes were made relatively small by the addition of the age category, analyses were conducted using age as an additional between-subjects factor in order to determine if there were any interactions of age with rotation condition. No interactions between rotation condition and age group were statistically significant for either number of correct responses on the Bakan vigilance task or any of the MTPB measures. A number of interactions between age group and week, shift, and session were identified, but given the small sample sizes, the complexity of the model (i.e., 5 factors with 2 between-subjects), and the fact that these interactions did not speak to the question of interest in the study, these findings were not investigated further. Subsequent analyses of each full model with age as a covariate were conducted, however, in order to hold the effects of age constant. Again, these analyses did not reveal any new relationships with regard to rotation condition.

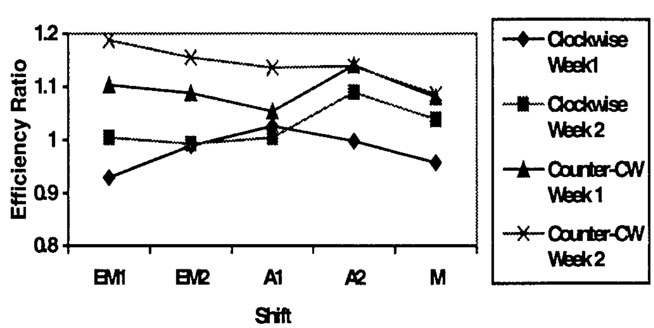


**Figure 6.** Arithmetic Efficiency Ratio for Rotation Condition by Week by Shift Interaction

## DISCUSSION

This study represents one of the first experimentally controlled investigations of direction of rotation in rapidly rotating shift schedules. The purpose of this paper was to directly compare individual performance on a vigilance and complex, time-shared task while working clockwise and counter-clockwise rapidly rotating shift schedules to test the hypothesis that the clockwise rotation results in better outcomes. Measures included in this report did not support the hypothesis. Instead, results of the study indicated that for the most part, performance was similarly affected on each shift for both rotation conditions, and that if anything performance was actually better during the counter-clockwise condition. Results of the study were similar to past research on the 2-2-1 schedule performed by Della Rocco and Cruz (1996) indicating that performance is maintained on early morning and afternoon shifts and drops more dramatically across the midnight shift. Again, Monk (1990) and others (Akerstedt, 1988; Klein, Bruner, & Holtman, 1970) have consistently found that performance decrements on the midnight shift are to be expected in any shift schedule configuration. A significant benefit of the 2-2-1 schedule worked by many ATCs, then, is that it generally includes only one midnight shift, which is placed at the end of the workweek and is followed by several days off. This is in keeping with European recommendations that no more than 2 to 4 midnight shifts should be worked in succession (Wedderburn, 1991).

For obvious reasons, vigilance is a concern within the field of air traffic control. Our investigation here suggests that the only significant difference between rotation conditions was observed on the first afternoon shift of the workweek, such that correct responses were higher in the counter-clockwise than in the clockwise rotation condition. An examination of Figure 2 reveals that performance remained relatively stable across the week for the clockwise rotation condition, but it changed more according to shift type for the counter-clockwise condition. Specifically, in the clockwise rotation condition, the number of correct responses ranged from a high of 96 to a low of 89, which represents a 7.3% decline in performance from the first early morning shift (Day 1) to the midnight shift (Day 5). In comparison, the number of correct responses in the counter-clockwise condition ranged from a high of 114 to a low of 98, which represents a 14.0% decline in performance from the first afternoon shift (day 1) to the midnight shift (day 5). Although scores in the counter-clockwise condition were still not lower than the clockwise condition on the midnight shift, the larger decrease in performance for that shift may suggest that performance on the midnight shift is more problematic in the counter-clockwise rotation. Because of the compressed nature of the schedule, the counter-clockwise rotation may be less tolerant of disruptions such as family illness, etc. Therefore, the natural decline in performance on the midnight shift might be exaggerated if workers encountered unexpected time demands that did not allow them to rest during the time off before the midnight shift.

As with the Bakan Vigilance Task, most of the measures on the MTPB indicated that the direction of shift rotation was not a significant factor in terms of performance. Instead, shift type and session interacted in similar ways for both rotation conditions. For the overall and passive task composite scores, a shift by session interaction revealed that performance was better at the beginning of the midnight shift than at the end, and that performance at the end of the afternoon shifts was better than performance at the end of the midnight shift. This relationship was also true for efficiency ratio scores for the red light monitoring task and the probability meters task. Both of these tasks were passive in nature, requiring vigilance to the presence of a signal. The efficiency score for the target identification task also revealed a shift by session interaction; however, performance did not decline across the midnight shift as dramatically as it did for the passive tasks. This was most likely because subjects were better able to protect their performance on the active tasks than the passive tasks during the midnight shift. Della Rocco and Cruz (1996) reported a similar trend in an earlier study of the 2-2-1 schedule utilizing the MTPB.

In addition to findings regarding the midnight shift, the shift by session interactions also revealed that performance at the end of the first early morning shift was often significantly lower than performance at the end of one or both afternoon shifts. This was true for the overall and passive composite scores as well as for the red light monitoring and target identification efficiency scores. Given the reduced sleep duration obtained during the quick-turn-around before the first early morning shift in the counter-clockwise rotation (Cruz, Detwiler, Nesthus, & Boquet, in press), these differences in performance would have been expected. In the clockwise rotation condition, however, the first early morning shift follows the weekend, when sleep might have been expected to be adequate. Sleep duration, however, was similarly reduced in the clockwise rotation for the first early morning shift; the result of a weekend effect (Cruz, Detwiler, Nesthus, & Boquet, in press). Therefore, we see a reduction in sleep duration and performance on the first early morning shift in both rotation conditions.

Two of the active task scores from the MTPB revealed more complex relationships. The active task composite score revealed a 3-way interaction with rotation condition, shift, and session. This interaction indicated that those in the counter-clockwise condition performed better on the second session of the first early morning shift and on the last session of the first afternoon shift than those in the clockwise condition. One reason that performance may have been better in the counter-clockwise condition at the end of the first afternoon shift is that the first afternoon shift was also the first day of the workweek for this condition, as compared with the third day for the clockwise condition. The fact that performance was also better on the second session of the first early morning shift, however, does not follow because this shift was the third day of the workweek, following an 8-hour quick-turn-around. Indeed, individuals in the counter-clockwise condition might have been expected to perform more poorly than those in the clockwise condition, for whom the first early morning shift was also the first day of the workweek following a weekend. Taken together, these data do not support the suggestion that performance in the counter-clockwise condition was better due to a day-of-week effect, but rather indicate that performance in the counter-clockwise condition was simply at least as good as or better than performance in the clockwise condition on all shifts.

**Summary**

The results from the performance tasks in this study do not support the suggestion that clockwise rotations should be preferable to counter-clockwise rotations. Instead, these results support more recent suggestions that there may be fewer differences in these kinds of schedules than was once thought (Tucker, Smith, Macdonald, & Folkard, 2000). In addition, the results agree with the findings from the first report in this series, which showed that rotation condition did not significantly affect sleep duration, sleep timing, or subjective reports of mood and fatigue. In short, evidence is growing that direction of rotation, particularly in rapidly rotating shift schedules, does not affect outcomes such as sleep, subjective ratings of fatigue, and performance. Replications of this kind of research in the laboratory and the field are needed to make reliable conclusions with regard to shift rotation.

While the schedules examined in this study are relevant to real-world shiftwork scheduling practices, one limitation of this study is that it only represents short-term adaptation to the clockwise and counter-clockwise rotation schedules investigated. It is not clear that performance would be similar for experienced shiftworkers or over longer periods of exposure to these shift schedules, although the results for the counter-clockwise group are similar to the results obtained in field studies of air traffic controllers (Schroeder, Rosa, & Witt, 1995). Nevertheless, the results from this study indicate that the counter-clockwise shiftwork schedules currently in use by air traffic controllers in the United States would not likely be improved by reversing the direction of rotation. Perhaps, more importantly, it is clear that midnight and early morning shifts remain the major concern for maintaining performance in *both* clockwise and counter-clockwise rapidly rotating shift schedules.

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# APPENDIX A

## Learning Curves for Bakan and MTPB Tasks

**Figure A1. Bakan Vigilance Task Learning Curve for Correct Responses**

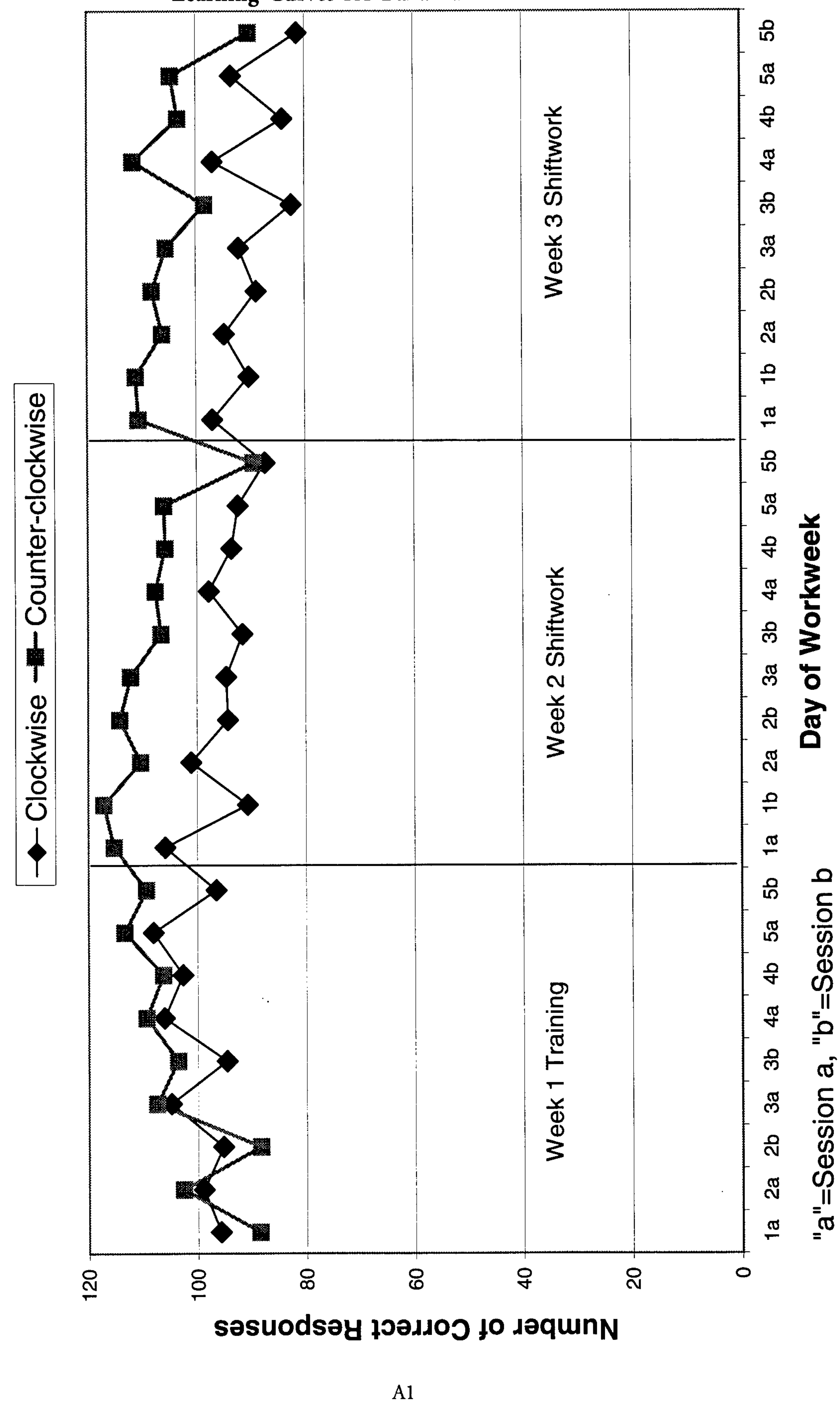
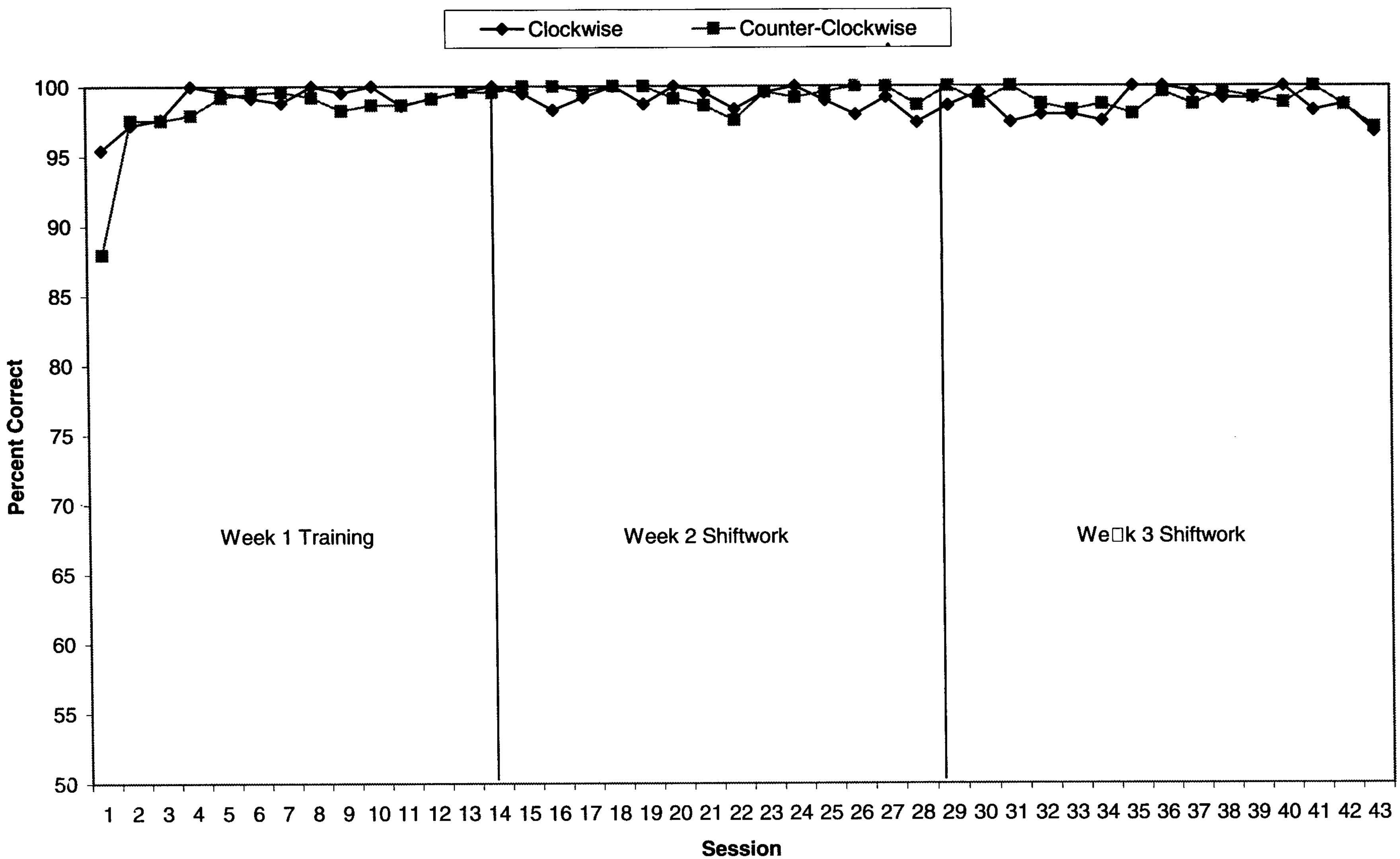


**Figure A2. Red Lights Learning Curve (Percent Correct)**



## Figure A3. Red Lights Learning Curve (Reaction Time)

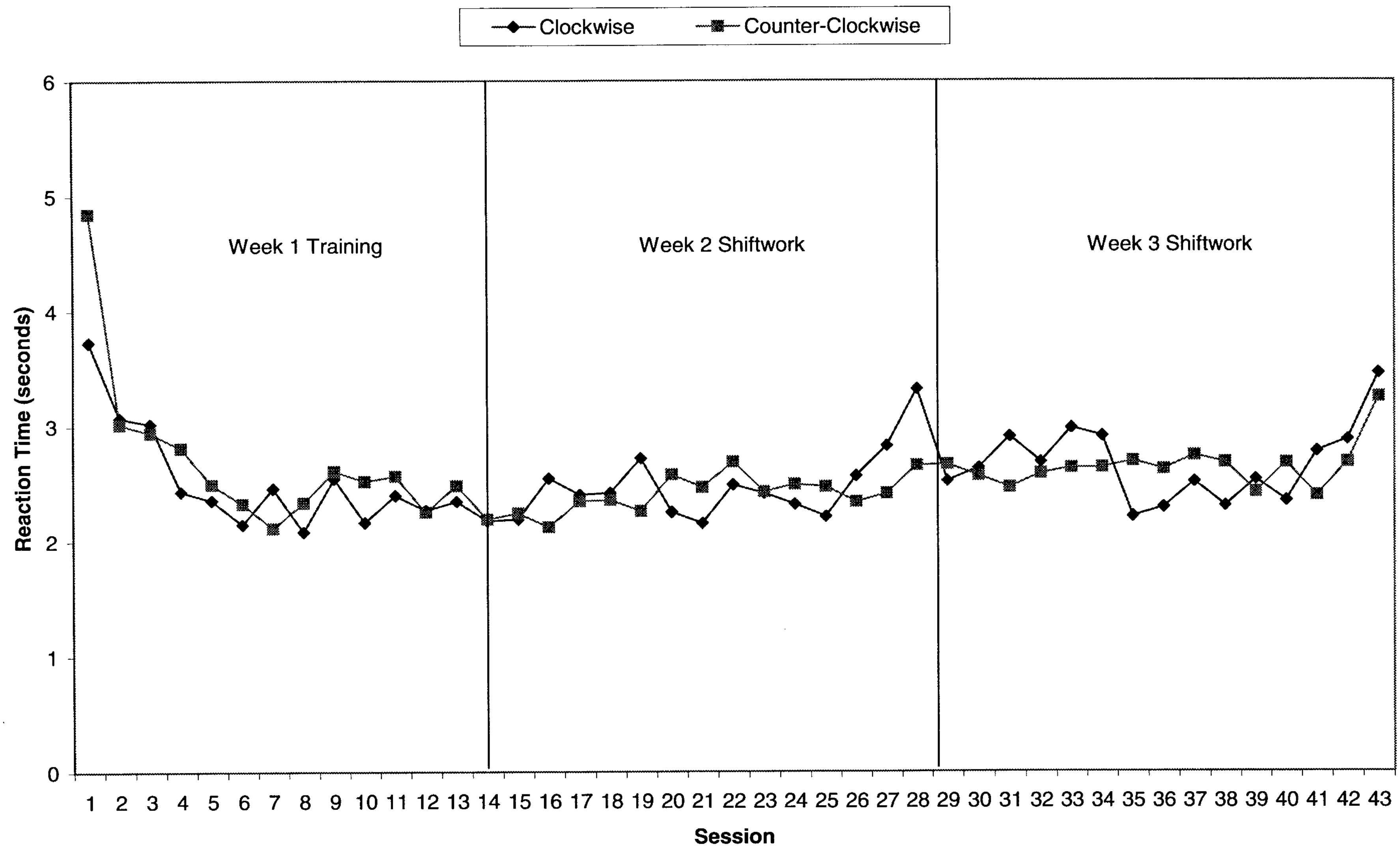
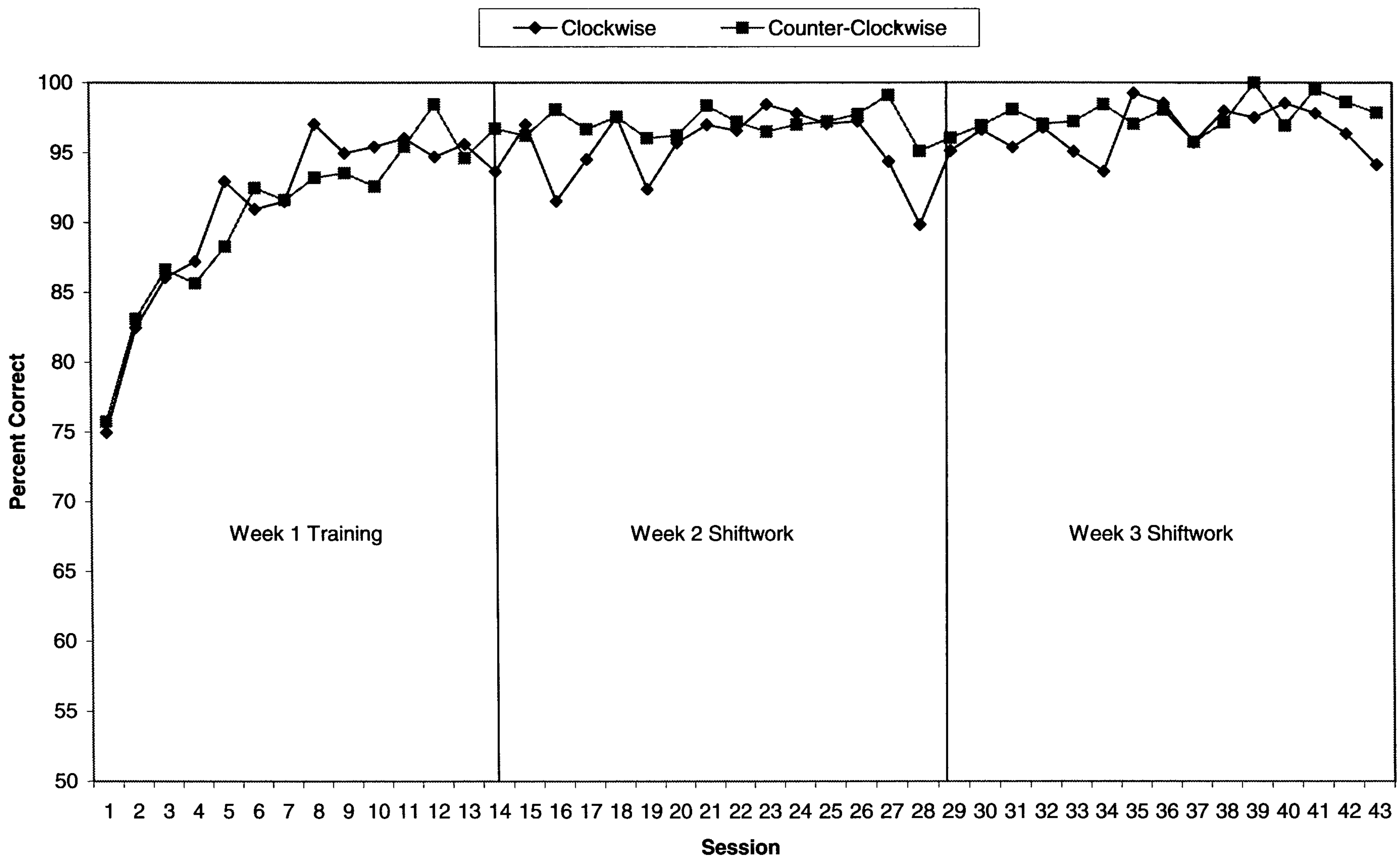


**Figure A4. Green Lights Learning Curve (Percent Correct)**



## Figure A5. Green Lights Learning Curve (Reaction Time)

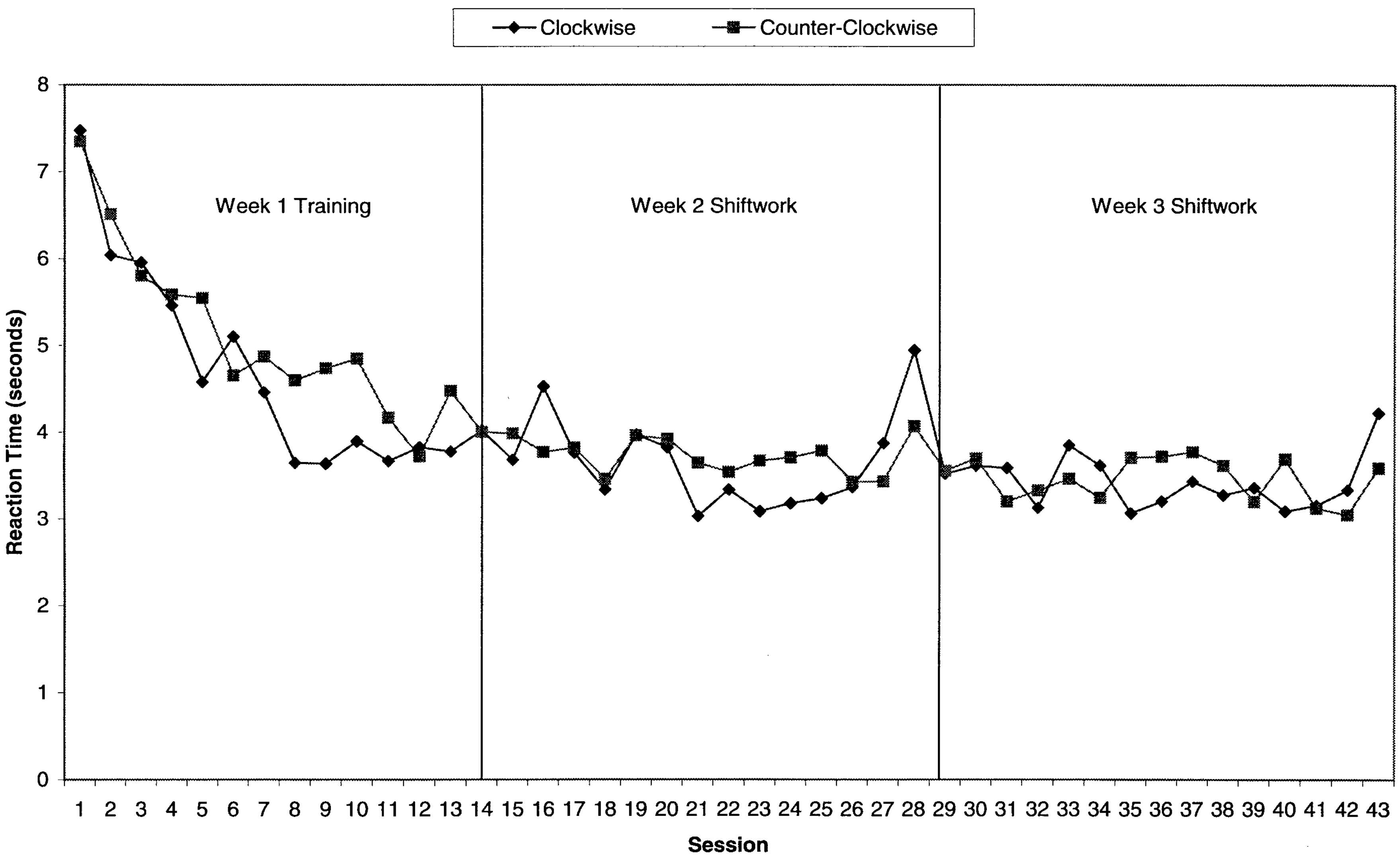


**Figure A6. Probability Meters Learning Curve (Percent Correct)**

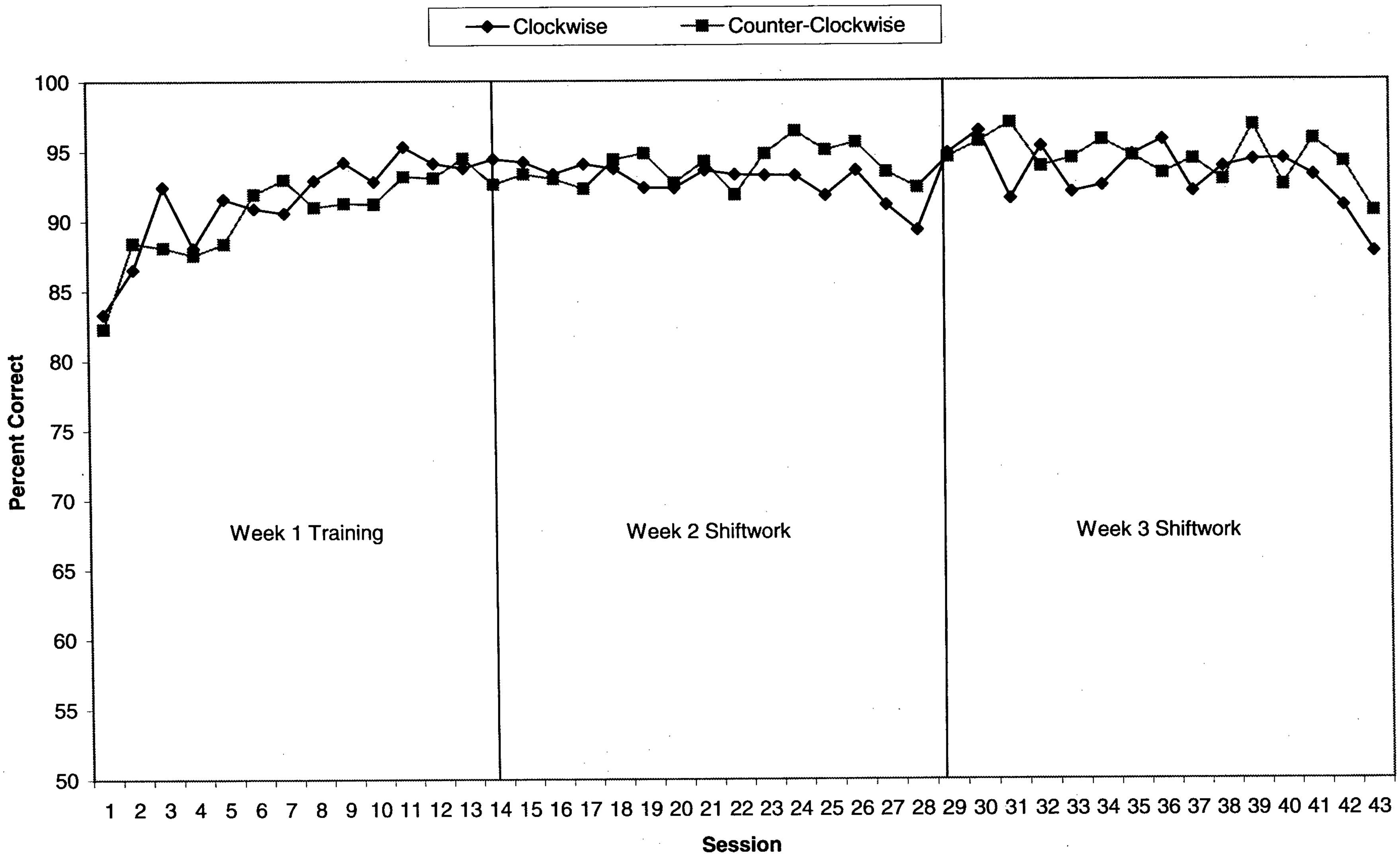


**Figure A7.  Probability Meters Learning Curve (Reaction Time)**

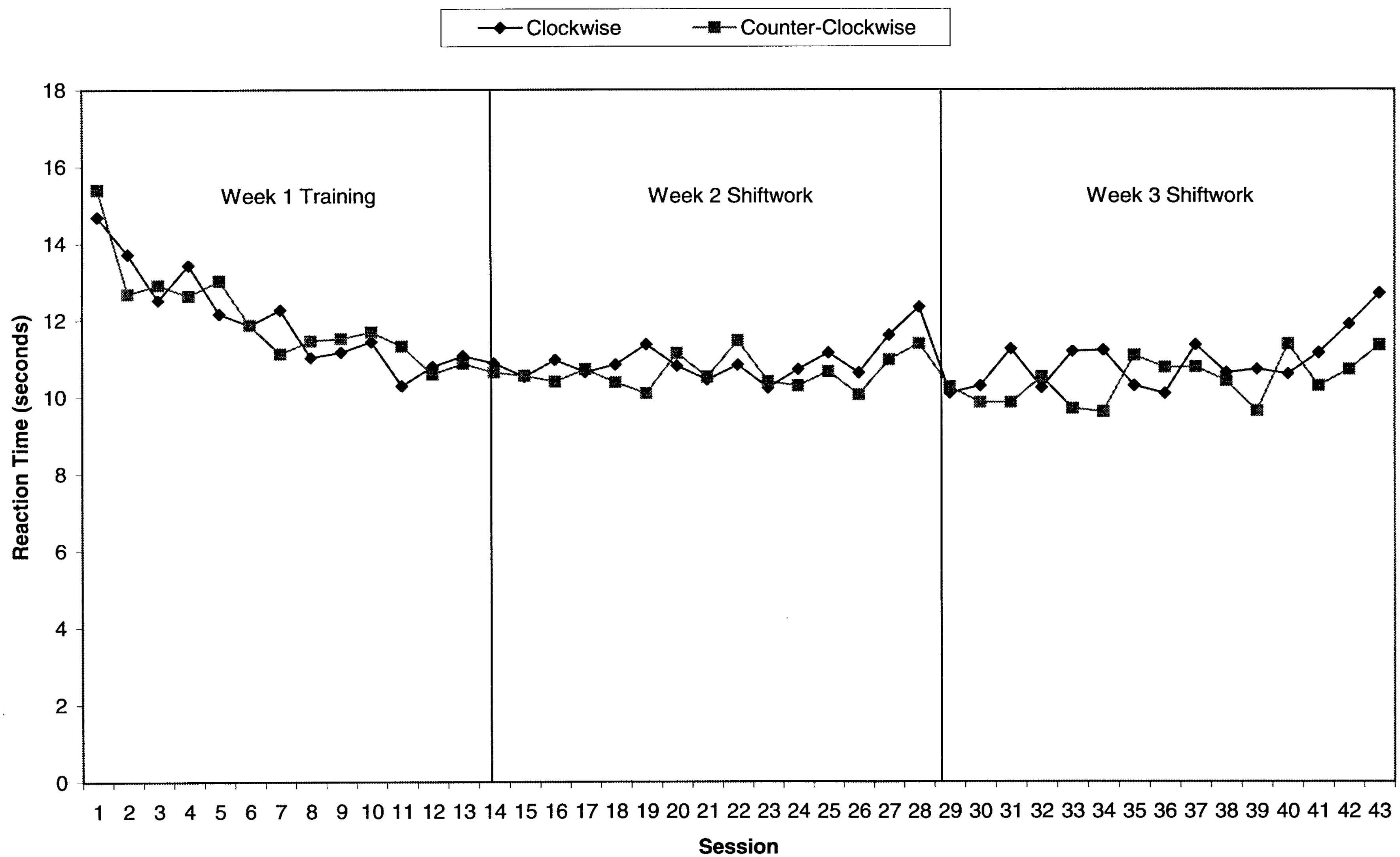
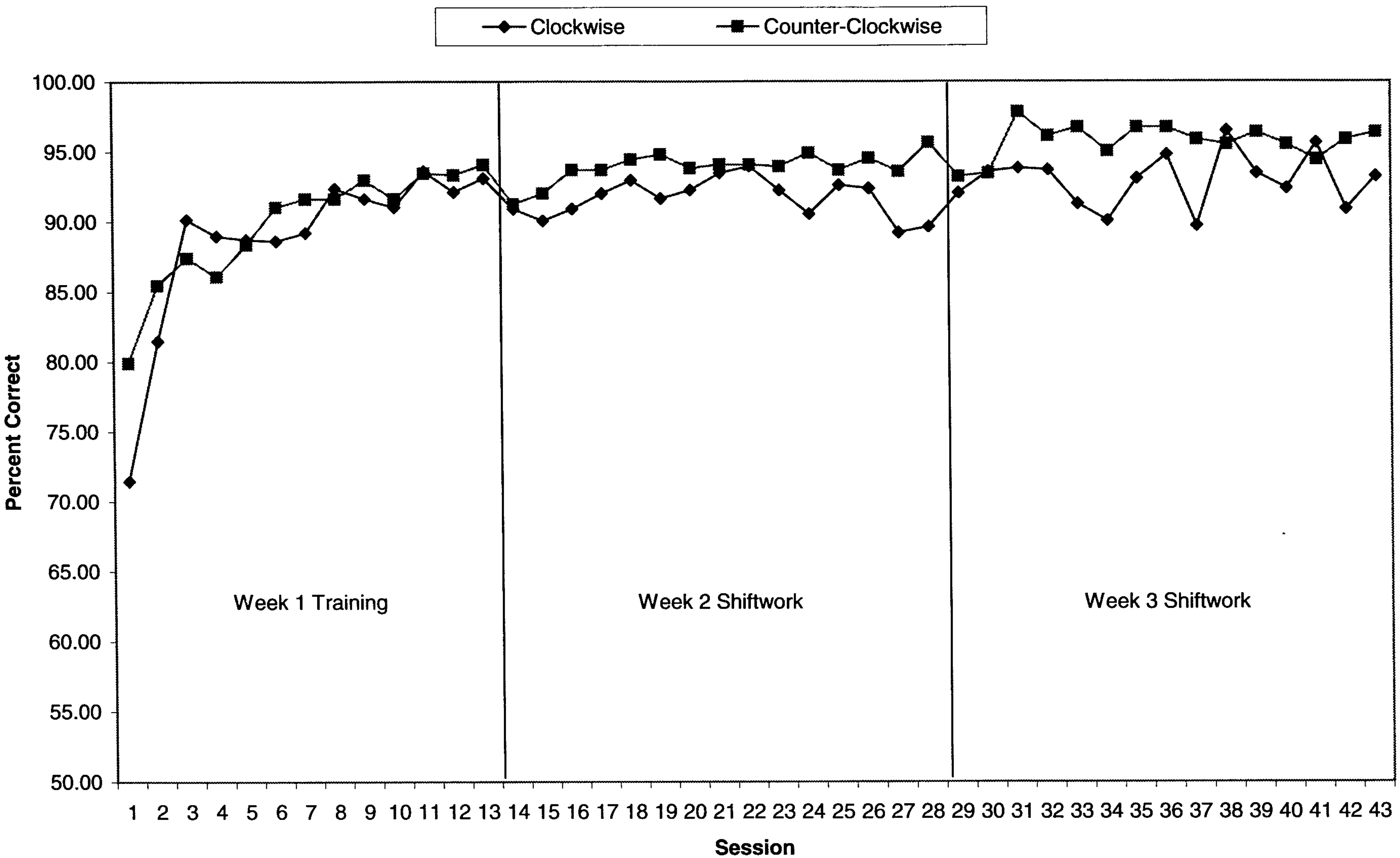


**Figure A8. Arithmetic Learning Curve (Percent Correct)**



## Figure A9. Arithmetic Learning Curve (Reaction Time)

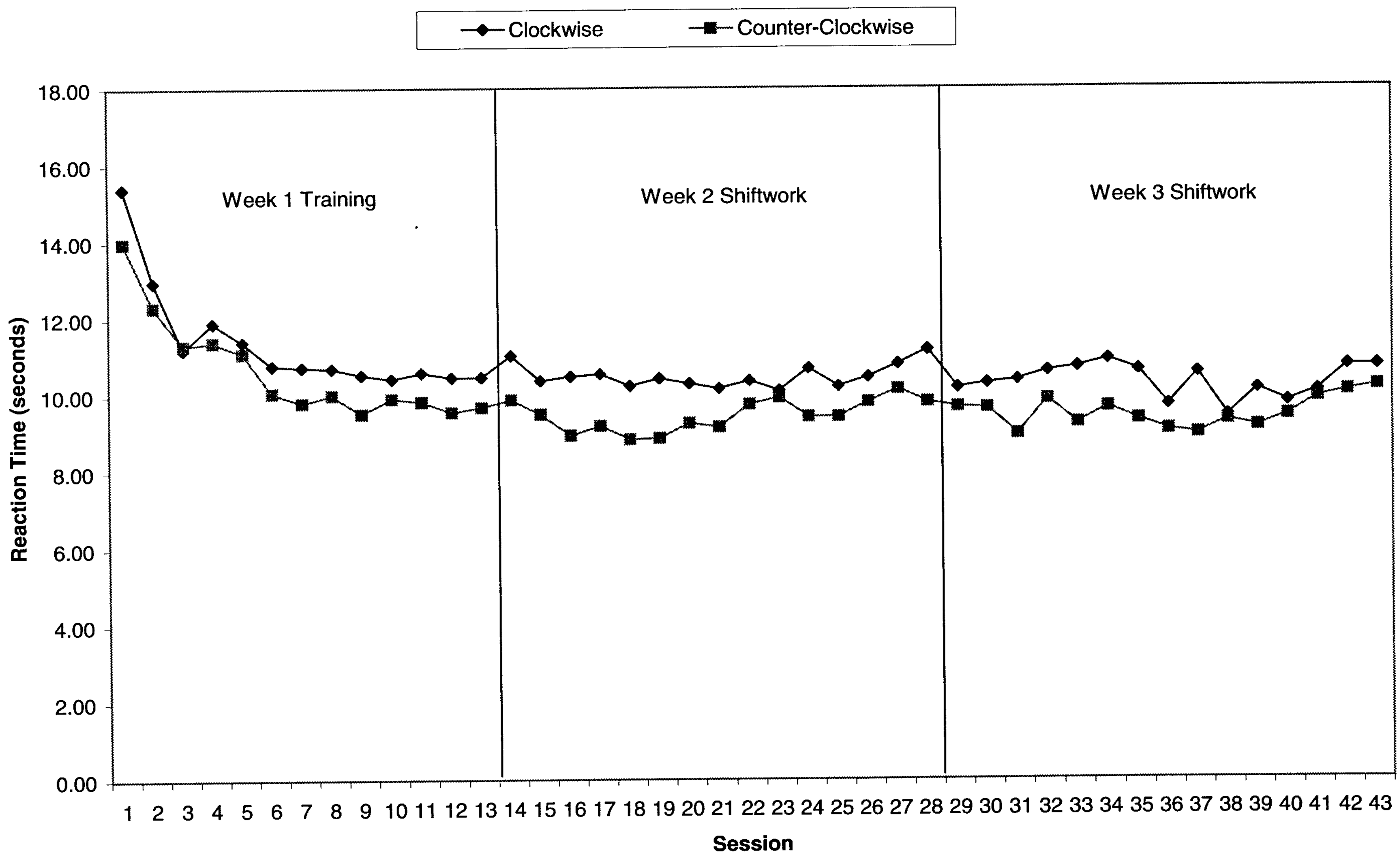
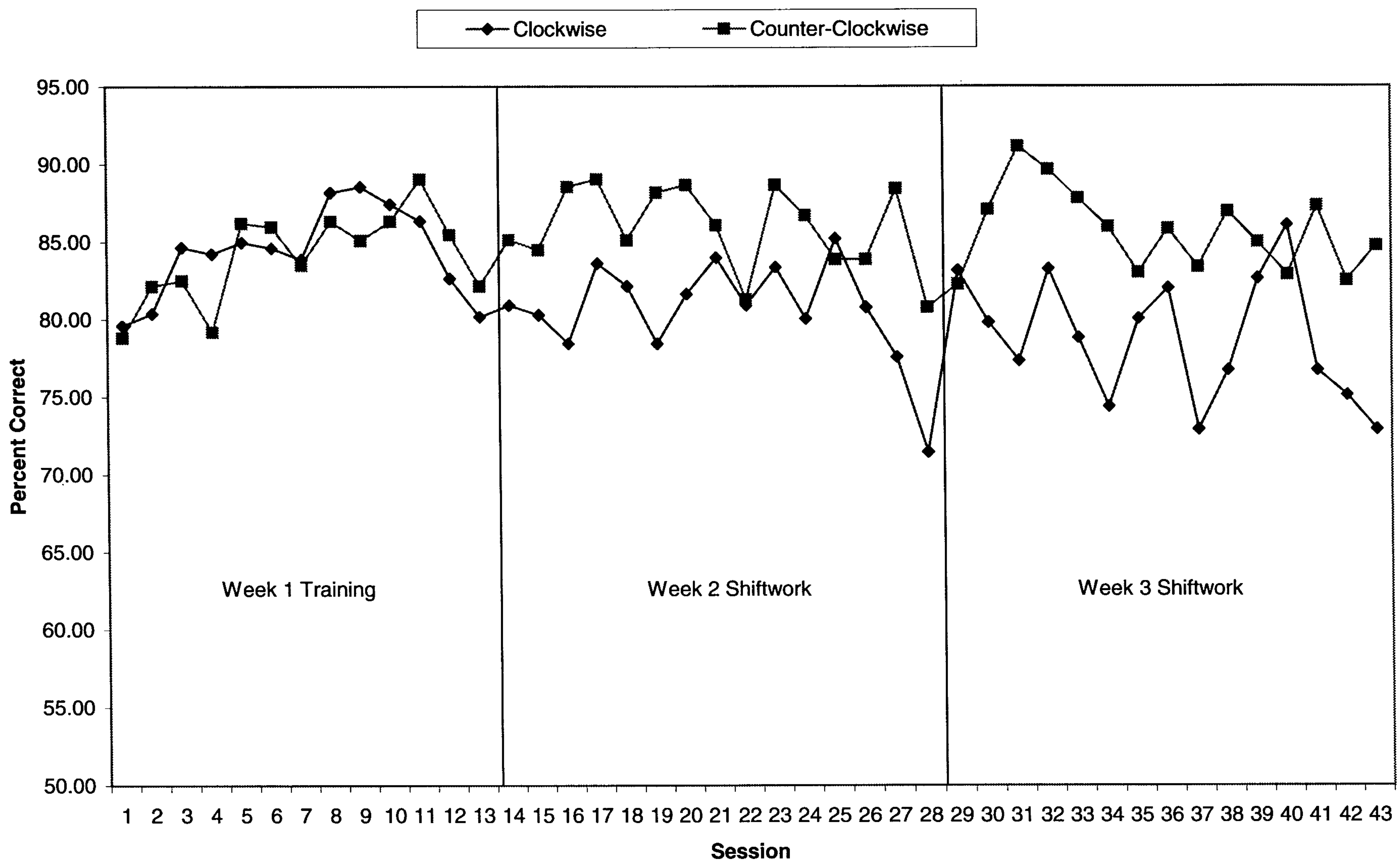


**Figure A10. Target ID Learning Curve (Percent Correct)**



## Figure A11. Target ID Learning Curve (Reaction Time)

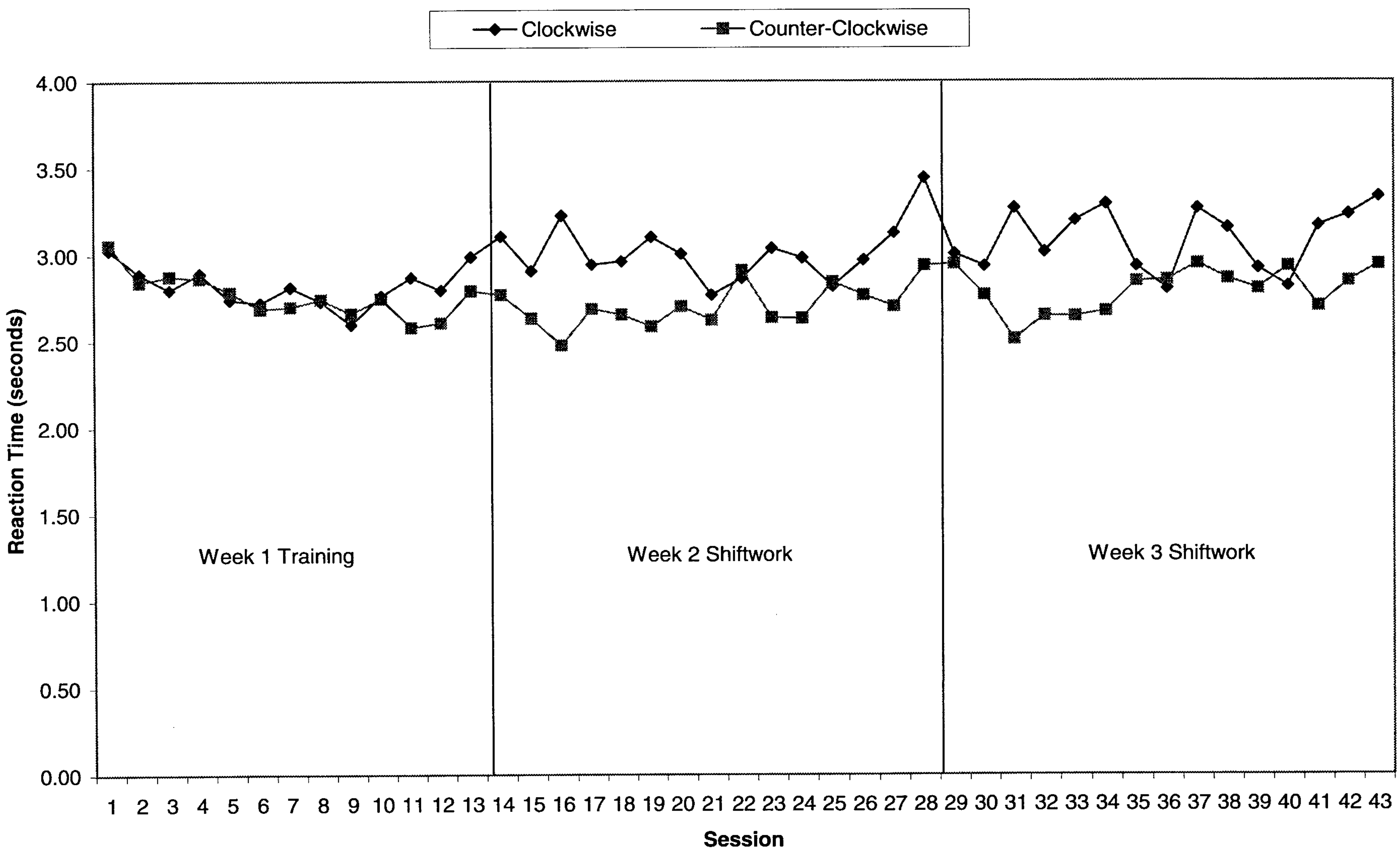


**Figure A12. Code Lock Solution Learning Curve (Percent Correct)**

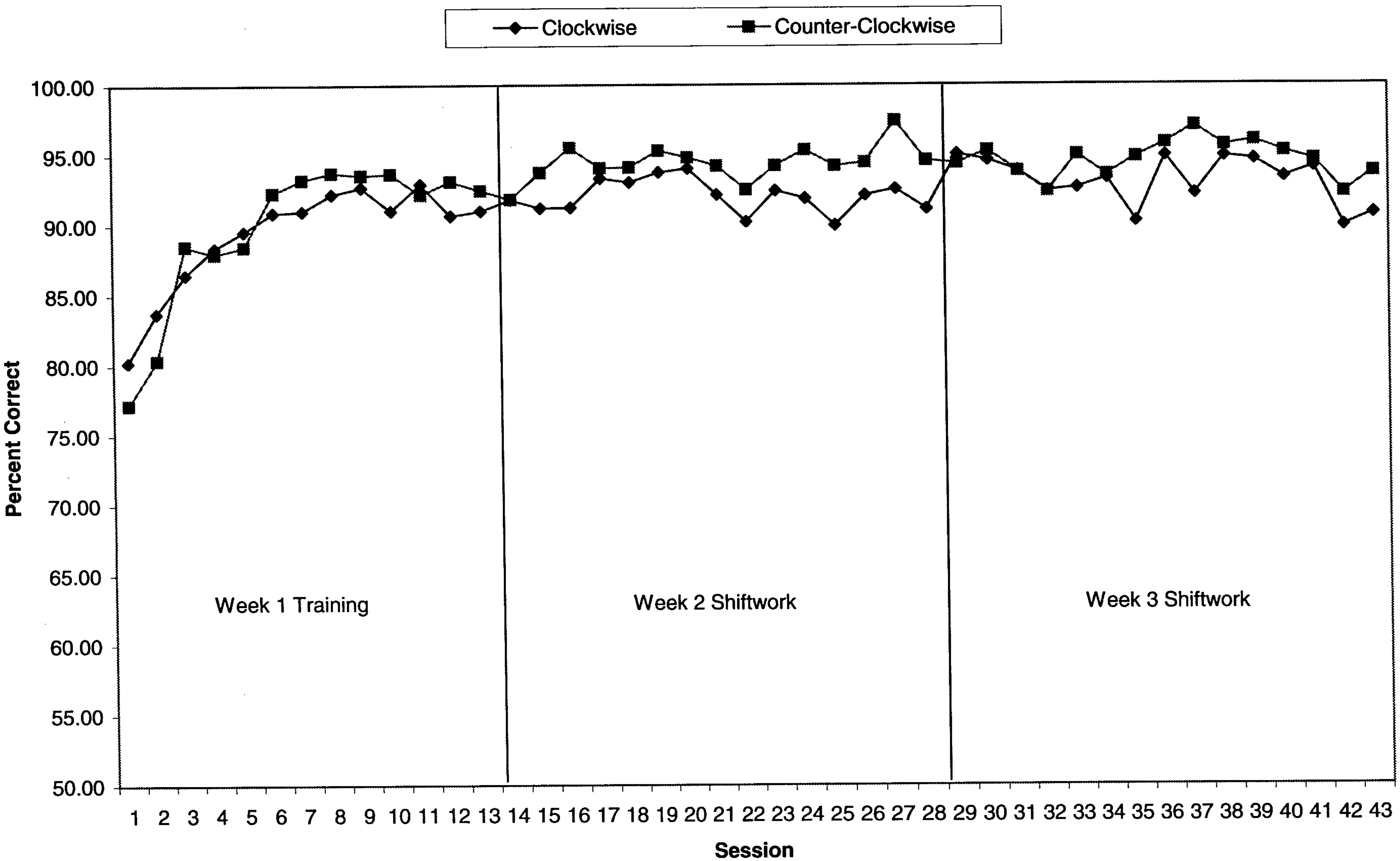
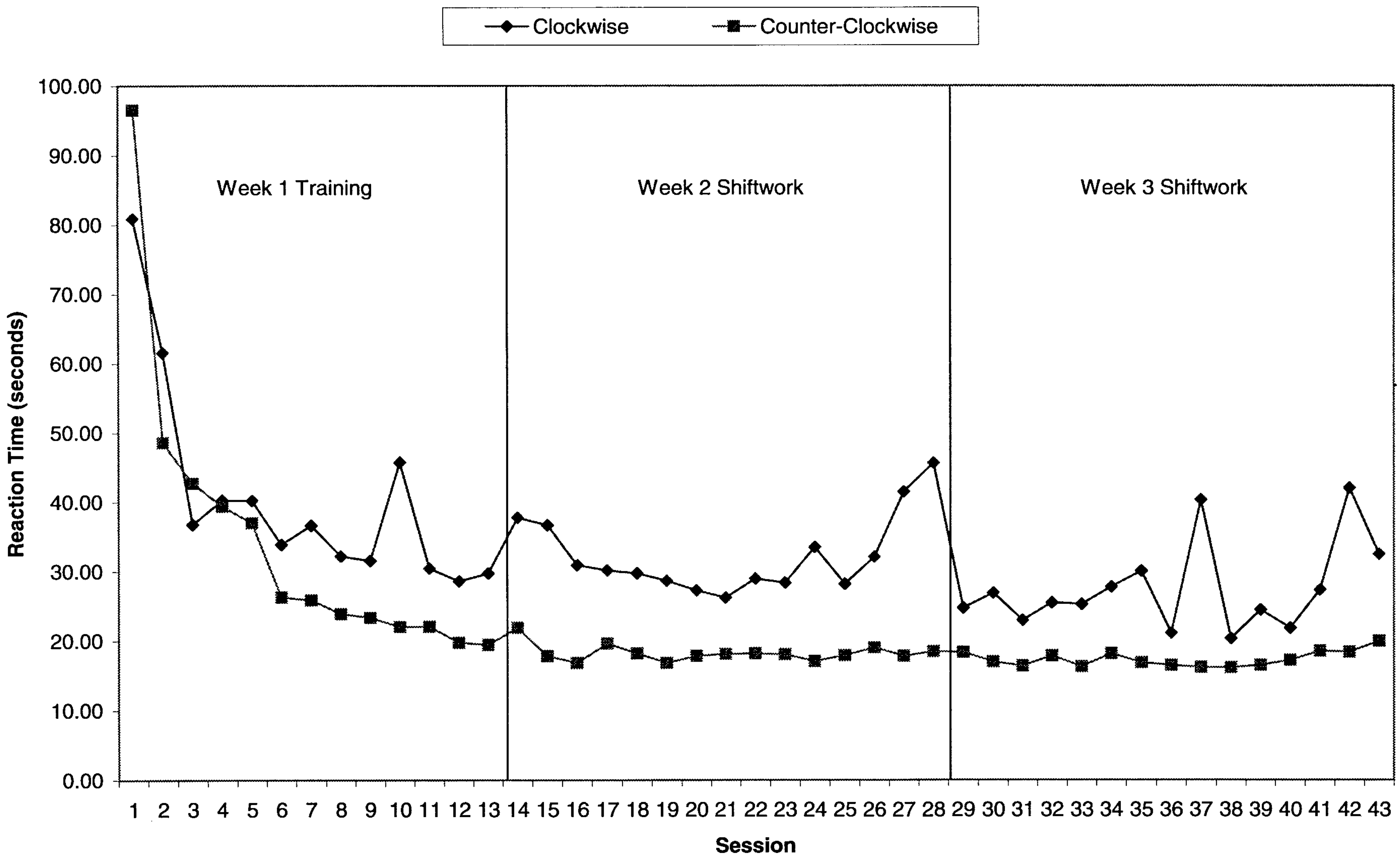


Figure A13. Code Lock Solution Learning Curve (Reaction Time)



## Figure A14. Code Lock Recall Learning Curve (Percent Correct)

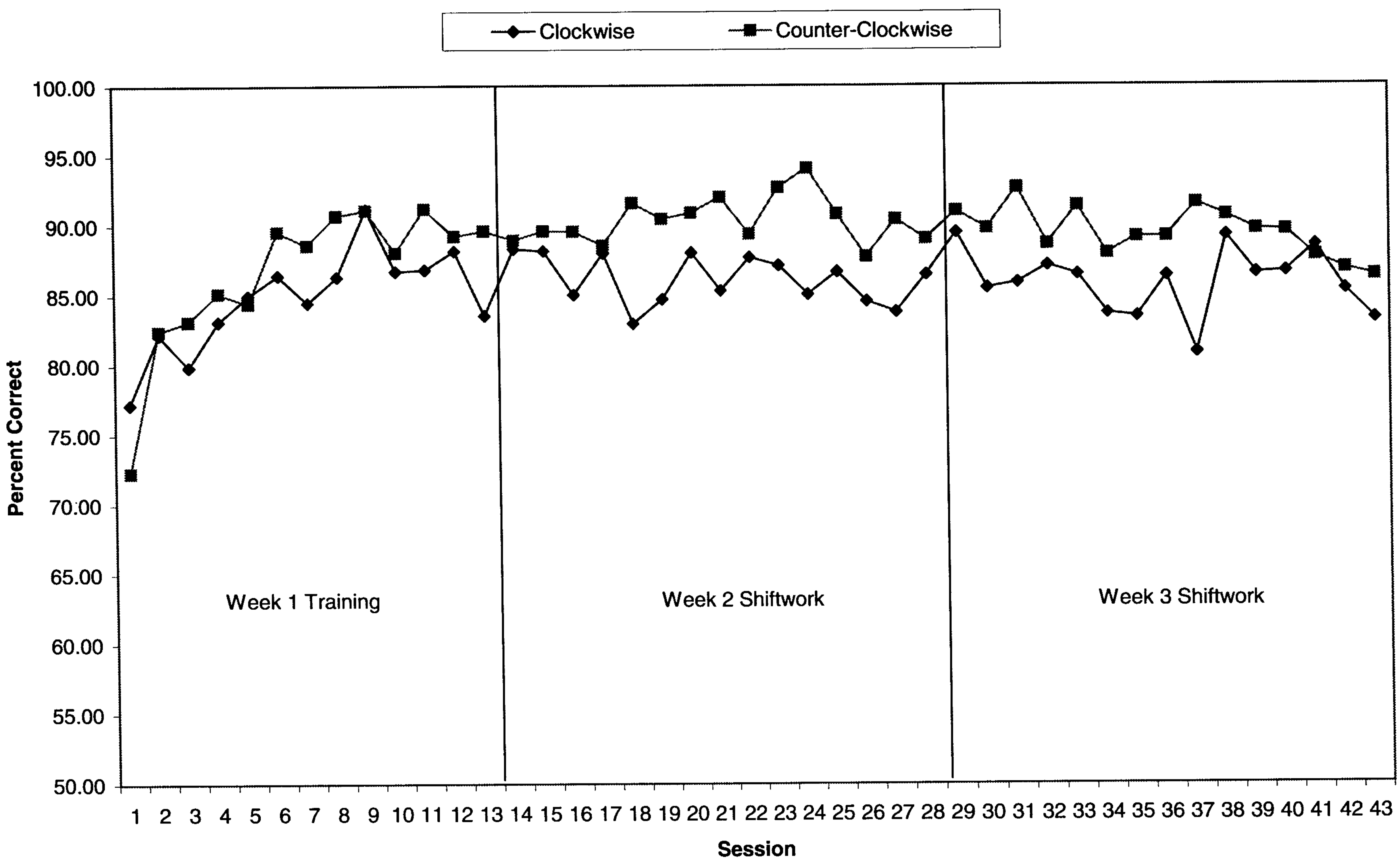


**Figure A15. Code Lock Recall Learning Curve (Reaction Time)**