THE IMPACT OF TRANSMERIDIAN FLIGHT ON DEPLOYING SOLDIERS

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During the past two decades we have witnessed a growing military concern over our readiness to deploy combat units rapidly overseas. In most instances, such airlifts require a sudden shift in the work-sleep schedule of deploying soldiers. These shifts are dictated by the crossing of multiple time zones during the flight. While the physiological and behavioral consequences of rapid transmeridian flight are a common experience for today's commercial international travelers, they translate into a potentially serious problem for troops expected to fight with maximal effectiveness upon arriving at their destination. The modern, high technology battlefield leaves little room for performance failures due to "jet lag."

In designing a series of studies to deal with this potential problem, there are two considerations which must be addressed. The first concerns the extent to which rapid transmeridian flight detrimentally affects the ability of deploying soldiers to carry out their mission. The second concerns our ability to counteract these detrimental effects caused by the disruption of circadian rhythms. Civilian studies have demonstrated that several days or more are required for a person to adjust to a five or six-hour time zone shift (Aschoff, Hoffman, Pohl, & Wever, 1975). Is it possible to develop countermeasures which might accelerate this rate of adjustment in soldiers?

The literature contains numerous studies describing the desynchronization of circadian rhythms resulting from rapid transmeridian flight. These include documentation of various physiological and behavioral rhythms after eastward or westward flights crossing two to eleven time zones. The composite results were summarized by Aschoff and his colleagues (1975) who confirmed previous reports (Klein & Wegmann, 1974) that it requires longer to adjust the phase of a traveler's circadian rhythms after an eastward flight than after a westward flight. Averaging across all dependent variables they calculated a mean daily shift rate of 92 min/day after westward flights and 57 min/day after eastward flights. Klein and Wegmann (1974) have further demonstrated that this asymmetrical effect can not be attributed to the relative direction of flight, i.e., either outgoing or homegoing.

Military Populations

While these studies provide valuable information about the general characteristics of transmeridian dyschronism and the adjustment to new time zones, they do not necessarily provide a sound basis for assessing the extent of the problem among military populations. Their findings are primarily limited by the nature of the subjects who usually consist of small groups of students or individual civilian travelers. As compared to combat soldiers, these samples differ with regard to physical fitness, intelligence, motivation, age, social cohesion, and experience with disrupted work-sleep schedules. Furthermore, the civilian subjects were transported together with other paying passengers on commercial airliners flying normally scheduled routes. Thus, their cabin environment contrasts greatly with that encountered by deploying troops who may be transported on cramped military cargo jets equipped with suspended nylon web seats. The environmental factor also extends beyond the aircraft to those time periods surrounding the flight. Ambient temperature and weather conditions can change drastically as troops move from comfortable barracks and private homes into tents and makeshift quarters after landing. Furthermore, preparations for emergency deployment require a short, but intense period of activity just before the flight when equipment is readied and final personal arrangements are completed. Following the flight, the individual soldier may disembark only to encounter a life-threatening situation where alertness, rapid responding, and sound judgment are the keys to survival.

Whether these military factors combine to exacerbate the "jet lag" problem is not known. In fact, it may not be unreasonable to expect that the intense activity schedule and high stress of preparing for combat might actually reduce the desynchronization problem by minimizing the influence of external time cues on the soldier's circadian system. Of course, it is impossible to examine such predictions under peace-time conditions; however, there are other military factors noted previously which are common to all deploying units regardless of their entering the combat arena. The impact of these factors can be investigated in the course of normal transfer or training deployments.

Until we began our research only one other military translocation study had been reported in the open literature. It was conducted by the British Army in the late 1960's under the title "Exercise Medex" (Adam, Brown, Colquhoun, Hamilton, Orsborn, Thomas, & Worsley, 1972). A group of forty-nine enlisted men were airlifted eastward across 7.5 time zones from the United Kingdom to Singapore. Urine was collected and oral temperatures and pulse rates were measured every four hours over alternate 24-hr periods for 14 days in the U.K. and for 16 days immediately after arrival in Singapore. Subjects were equally divided into two groups which alternated measurement periods so that each group was undisturbed every other day. Also, during the usual waking hours, a series of cognitive performance tests was administered four times per day interspersed between the physiological measurements.

A preliminary report of the findings for the first ten days after arrival suggested rapid post-flight adaptation of the circadian rhythm for oral temperature. The temporal location of the daily minimum for group mean temperature indicated appropriate phase adjustment within the first three days for both groups. In one group, there was equally rapid adjustment of the daily maximum, although overall mean daily temperature remained elevated over baseline (U.K.) levels for nine days. The other group's daily maximum did not recover its baseline phase until Day 8. Furthermore, there was considerable variability for both groups in the daily range of oscillation during the ten days after arrival. Thus, the authors noted that, although adjustment of the temperature rhythm appeared to be unusually rapid, there may be reason to doubt the completeness of adaptation to the new time zone within the observation span. Unfortunately, there is no additional evidence to clarify the issue of physiological adjustment since no analyses of the urinary cortisol or electrolytes have been forthcoming. Results are available from two of the performance tests, simple addition and auditory vigilance. In general, they also indicate rapid, if not immediate, adjustment of performance rhythms to the new time zone.

In a subsequent paper, Colquhoun (1979) reanalyzed the temperature data from this study by using the cosinor procedure to fit simple 24-hour sine curves to each individual's daily set of readings. Using the daily shift in the mean estimated acrophase as the measure of adaptation, he concluded that the extent of initial adaptation was indeed greater than that usually observed in civilian studies, but that total adaptation was not actually completed any faster. Thus, in conjunction with the behavioral results reported earlier, it still appears that the British soldiers experienced less overall disruption of their circadian rhythms than that reported for civilians undergoing eastward transmeridian flights. Whether the same advantage holds for other military populations remains to be seen.

Several factors may have combined to produce this result. The subjects were highly select and specially trained paratroopers of above average intelligence who were experienced in conducting transmeridian airborne deployments. They formed a highly cohesive and motivated unit in which social synchronizers could be expected to strongly facilitate the rate of post-flight circadian adjustment. The outdoor nature of their activity upon arrival may also have contributed to more rapid adjustment, as Klein and Wegmann (1974) have demonstrated with students. Although the potential importance of these factors in explaining the results should not be underestimated, caution may be exercised especially since the contribution of the abrupt change in climate, from temperate to tropical, is unknown.

"Jet Lag" Countermeasures

In the past, several attempts have been made to develop chronobiologic remedies for the circadian desynchronization which accompanies rapid transmeridian flight. For the most part these attempts have met with failure or very limited success. Christie and Moore-Robinson (1970) tested the efficacy of a corticosteroid as a chronobiotic for a group of seven experimental and seven control subjects flown from London to San Francisco and back after a ten-day stay. Although their report does not provide the name, dosage, or dose schedule for the drug, it states that the compound was designed to deliberately upset the body's biochemical rhythms in an attempt to influence post-flight adaptation. Results based on oral temperatures indicated that there were no differences between the two groups following the flights in either direction.

A second double-blind trial of a chronobiotic was conducted in 1973 by Simpson and his colleagues. They studied the effects of "Quiadon" (3-alkyl pyrazolyl piperazine dihydrochloride, E. Merck, Darmstadt, FRG) on twelve, mostly young, males undergoing an 8-hr phase delay in the continuous daylight of the arctic environment. After a 7-day control span on British Standard Time, they initiated the 14-day treatment be resetting their watches and consuming a once daily dose of drug or placebo just before retiring at 2300 hrs. The treatment rationale was based on independent evidence that the drug acted both as a tranquilizer which lacked any sedative effects and a depletor of 5-hydroxytryptamine (5-HT) in the central nervous system. The former characteristic would reduce anxiety during delays in falling asleep or in disrupted sleep, while its role as a 5-HT depletor would serve to drive the circadian rhythm of pineal 5-HT, and presumably other components of the circadian system, onto the new daily schedule. Unforturately, both groups of subjects exhibited extremely rapid resynchronization of their circadian rhythms for urine temperature, urinary electrolytes, and performance. Thus, there was no group phase-lag for the drug to act upon. Possible explanations offered for this atypical result include rigid meal and rest-exercise schedules, a lack of competing synchronizers, the relative youth of the subjects, and the potential predisposing effect of natural arctic illumination towards a phase delay. No subsequent trials of "Quiadon" were ever conducted.

Although human research in this area has remained dormant for several years, Ehret and colleagues have undertaken a series of animal experiments using rats to demonstrate the usefulness of dietary manipulations and mealtiming to induce more rapid phase-shifting after changes in synchronizer schedules. The first of these studies demonstrated that injections of methylated xanthines, i.e., theophylline, can advance or delay the daily maximum for body temperature depending on when they are administered with respect to the circadian cycle (Ehret, Potter, & Dobra, 1975). If they are administered just before or during the early active phase of the cycle (i.e., rising body temperature), a phase delay results, whereas if they are administered during the late active, early inactive phase (i.e., just before or just after the thermal peak), a phase advance results.

Secondly, it can be shown that more rapid phase adjustment of the temperature rhythm can be induced by (a) fasting a rat on the day prior to a phase delay in the light-dark (LD) cycle and (b) restoring food coincidental with the first new active phase of the LD cycle (Ehret, Groh, & Meinert, 1978). Presumably, this chronobiotic effect is mediated by the depletion of liver glycogen stores during the fast followed by the reinitiation of feeding at the chronotypically appropriate time in the revised LD cycle. Other investigators have also demonstrated the importance of mealtiming as a synchronizer of circadian rhythms in humans (Levine, Halberg, Halberg, Thompson, Graeber, Thompson, & Jacobs, 1977; Graeber, Gatty, Halberg, & Levine, 1978) and other mammals (Edmonds & Adler, 1977; Fuller & Snoddy, 1968; Krieger & Hauser, 1978; Mayersbach, Muller, Phillipens, Scheving, & Brock, 1973; Nelson, Scheving, & Halberg, 1975; Sulzman, Fuller, & Moore-Ede, 1978).

Related work by Wurtman and Fernstrom has demonstrated that changes in nutritional state can rapidly affect neurotransmitter synthesis (Fernstrom, 1976; Fernstrom & Wurtman, 1971, 1973; Wurtman, 1979). Rats fasted for 15 hrs exhibit a significant increase in brain tryptophan and serotonin following a single, high carbohydrate, low protein meal. This effect occurs within one hour after the meal and appears to be mediated by an increase in serum tryptophan levels elicited by insulin secretion. Fasted rats also manifest a rapid increase in brain catecholamine levels, particularly norepinephrine, following a meal which is relatively rich in protein. This enhanced synthesis of catecholamines can be traced directly to disproportionate increases in plasma tyrosine which in turn produce similar increases in brain tyrosine levels. In the case of noradrenergic brain neurons, catecholamine synthesis has been shown to be directly dependent on the availability of this amino acid precursor (Gibson & Wurtman, 1978); while in dopaminergic neurons, tyrosine hydroxylase must be activated before tyrosine levels can control dopamine formation (Scally & Wurtman, 1977).

Ehret and his colleagues have combined these findings into a suggested "diet" plan for individuals undergoing rapid transmeridian flight (Ehret, Groh, & Meinert, 1978). The underlying concept is to maximize the synchronizing effects of mealtiming by alternating daily fasts with three regular meals on alternate days preceding the flight, to restrict consumption of the methylated xanthines (i.e., coffee, tea, and other caffeinated beverages) to the appropriate time in the circadian cycle on the day of departure (i.e., to morning only, if traveling west), and upon arriving to vary the protein: carbohydrate content of meals according to the appropriate phase of the rest-activity cycle for the new time zone. The latter action is based on the assumption that meals high in protein taken in the morning and at lunch on the day of arrival will facilitate the rise in brain catecholamine synthesis associated with the active phase of the circadian rest-activity cycle (e.g., Perlow, Ebert, Gordon, Ziegler, Lake, & Chase, 1978). Conversely, a large, high carbohydrate dinner eaten at a time in synchrony with the destination populace will facilitate the increase in brain serotonin synthesis which typically precedes sleep (e.g., Quay, 1965).

In designing countermeasures for use with eastward deploying soldiers, we decided to follow the basic notions of Ehret's model in conjunction with the manipulation of social cues, light-dark cycles, and rest-activity patterns which are known to be effective synchronizers of human circadian rhythms. The operational requirements of a large-scale military exercise limited the extent and duration of possible experimental interventions to those which could be instituted on the day of departure and carried out with minimal disruption to mission accomplishment. Likewise, operational considerations required that data collection be restricted to relatively few days before and after the flight with minimal interference in the ability of subjects to carry out their military duties. The basic strategy in both studies was to induce a more rapid phase advance of the circadian system by controlling the timing of rest-activity schedules, social interaction, meals, and caffeine/theophylline consumption.

Field Study Procedures

The countermeasures were tested in two field studies with troops deploying from the U.S. to West Germany. A more complete description of the methods can be found in Graeber, Cuthbert, Sing, Schmeider, and Sessions (in press) and Cuthbert, Graeber, Sing, and Schmeider (in press). Subjects in the first study were 179 male soldiers being transferred overseas as a unit in October, 1978. The study design divided the participants into an experimental aircraft ($n = 84$) and a control aircraft ($n = 95$); both flights departed the U.S. in mid-day and arrived in Germany early the next morning, CET.

Oral temperature was recorded from all subjects. A sub-sample of 15 soldiers in each group was studied more intensively: in addition to temperature, measures taken at each test session included addition of random pairs of single digits, four-choice reaction time, a fatigue checklist, and a 24-hour diary of sleep, eating and drinking, bowel movements, and physical illness symptoms. Subjects in these "intensive" subgroups, all living in the barracks, were tested every four hours around-the-clock for four days about two weeks prior to departure. Baseline measurements for the remaining subjects were taken at 0800, 1200, and 1600 only, as these subjects lived off-post and were unavailable outside of normal duty hours. All subjects were tested every four hours for six days after arrival in Germany.

The flights utilized chartered commercial aircraft and involved a time advance of six hours. Experimental subjects received the countermeasures procedures, which were initiated on the morning of departure. Subjects were restricted to a light, low carbohydrate breakfast with fruit juice, milk, and decaffeinated coffee; however, the majority ate nothing that morning. Napping was prohibited throughout the day by constant monitoring of the subjects' activities. Upon boarding the airplane, subjects were instructed by the senior sergeant to reset their watches 6 hours ahead. A light "supper" was then served at 1745 CET (1145 CDT), consisting of a ham and cheese sandwich, salad, cheese, and fresh fruit, with no caffeinated beverages or sweetened soft drinks allowed. At 2220 CET subjects were each given 100 mg dimenhydrinate to induce sleepiness, and at 2300 the lights were turned off and everyone was instructed to sleep. The lights were turned on again at 0405 CET. A high-protein breakfast including steak and a 2-egg cheese omelet was served at 0430, and consumption of caffeinated beverages was encouraged. Napping was again prohibited for the rest of the day, which was largely spent unpacking at the training base following a ninety-minute bus ride from the airport.

Control subjects followed a normal airline routine. Subjects ate lunch and dinner on the aircraft at normal U.S. times, and were then given a breakfast snack at 0810 CET. Alcoholic beverages were unavailable. The cabin lights were turned off from 0215 to 0550 CET, but individual reading lights were available and no constraints were placed on subjects' activities. Control subjects were also allowed to nap when duties permitted following arrival at the training base.

All subjects were assigned light duties for the remaining 6 days of the study. No physical training or heavy labor were scheduled.

The second study, comprising two distinct experiments, was carried out in January, 1979 during a NATO field training exercise from the central U.S. to Germany. Conditions differed markedly from the first study. Extreme winter weather prevailed on both sides of the Atlantic, and in Germany troops lived in field tents. The aircraft were USAF C-141 jet transports. They were configured with nylon webbed seats in four rows down the length of the aircraft, an uncomfortable and cramped arrangement which made sleeping difficult. Testing in Germany was done mostly in large tents which were poorly illuminated and heated.

Training and baseline testing were carried out for both experiments during the week immediately prior to deployment from the troops' home post. Formal testing was conducted for four days, with three test periods each day roughly corresponding to breakfast (0800), lunch (1200), and dinner (1630) times. Following deployment (+ 7 hours), troops were tested for 3 to 5 days beyond the day of arrival. An additional night test (at about 2100 hours) was added so that four test sessions were held each day after arrival.

The first part of the experiment duplicated as much as possible the earlier study. The approximately 120 subjects were deployed on four aircraft; two followed the countermeasures regimen while the others maintained usual military airlift procedures. The countermeasures were necessarily adapted slightly to conform to operational limitations of Air Force flight schedules, standardized in-flight meals, poor seating arrangements, etc., but remained essentially the same as those for the October study. Subjects filled out the fatigue scale and sleep and bowel movement logs as in the first study; temperature was not recorded due to the weather conditions. In addition, new measures included a map coordinate alpha-numeric encoding-decoding task (3 min), and self-report scales for the subjects to rate their ability to process information, reason clearly, make accurate decisions, and concentrate.

The second part of the experiment was designed to investigate age differences in cognitive performance following deployment. Subjects were selected to form two disparate age groups, with a mean age of 21.0 for the 31 younger subjects as compared to 34.2 years for the 29 "older" subjects. Due to subject availability problems, this difference was not as great as had been hoped. These soldiers deployed on several different C-141 aircraft. No countermeasures were administered, and schedules varied for the different flights.

The test battery was expanded to include several more tasks in addition to those for the countermeasure subjects. These included a logical reasoning task (Baddely, 1968), the trails test, letter cancellation (Fort & Mills, 1972), and short-term word recall. This battery was printed in a small booklet and required about 15 minutes to complete. All testing for both parts of the study was carried out under the supervision of the investigators and technical staff. Each performance test was allotted a fixed time, with the length predetermined to preclude subjects from ever finishing the test.

Countermeasure Effectiveness

Fatigue and sleep. The primary complaint of persons experiencing "jet lag" is fatigue with a corresponding desire for sleep. The countermeasures appeared to be effective in this regard. The experimental subjects slept for a significantly shorter time as compared to control soldiers during the first two days in Germany (Figure 1). This was true even when sleep before 1800 on the first day was excluded from the analysis (4.4 vs. 8.1 hrs, $p < .005$, t-test), as countermeasure subjects were prohibited from daytime napping. It also appears that the results can not be attributed to group differences in the amount of sleep obtained aboard the aircraft. Measures by on-board observers of the amount of time spent by subjects resting with their eyes shut (the best available estimate of sleep) revealed that both groups slept about 5.5 hours. The fatigue scale results showed a consonant effect. Control subjects reported significantly greater levels of fatigue during the first 24 hrs than countermeasure subjects, who indicated little change from baseline levels (Figure 2). The somewhat short overall sleep durations may be attributable to the testing procedure, which necessitated awakening subjects at 0200 and 0600. While the countermeasure sleep times in particular seem somewhat low, these subjects' lower fatigue scale scores suggest that this is not due to difficulties in falling or staying asleep. A design which allows ad libitum, uninterrupted sleep is probably necessary to resolve any uncertainty about this point.

The second field study confirmed the effectiveness of the countermeasures under rigorous field conditions. while all subjects reported some increases in fatigue relative to baseline following deployment, once again the experimental subjects reported significantly lower fatigue than the controls ($p < .05$, t-test) for the first two days in Germany (Figure 3). Both groups recovered partially by the third day, but persisted in slightly elevated fati-

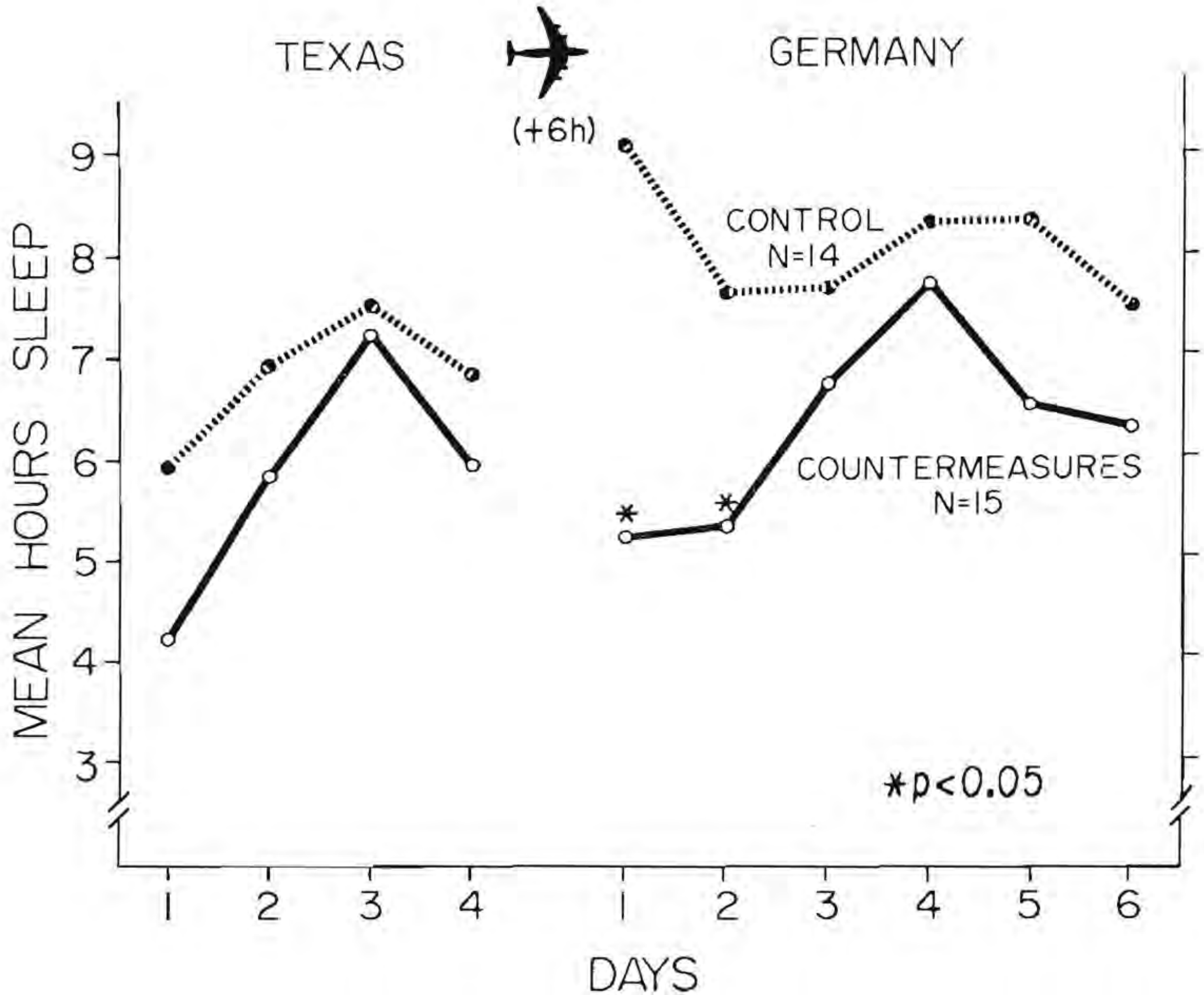

Figure 1. Sleep results for groups in Experiment 1. One control subject is omitted due to loss of the sleep diary in Germany.

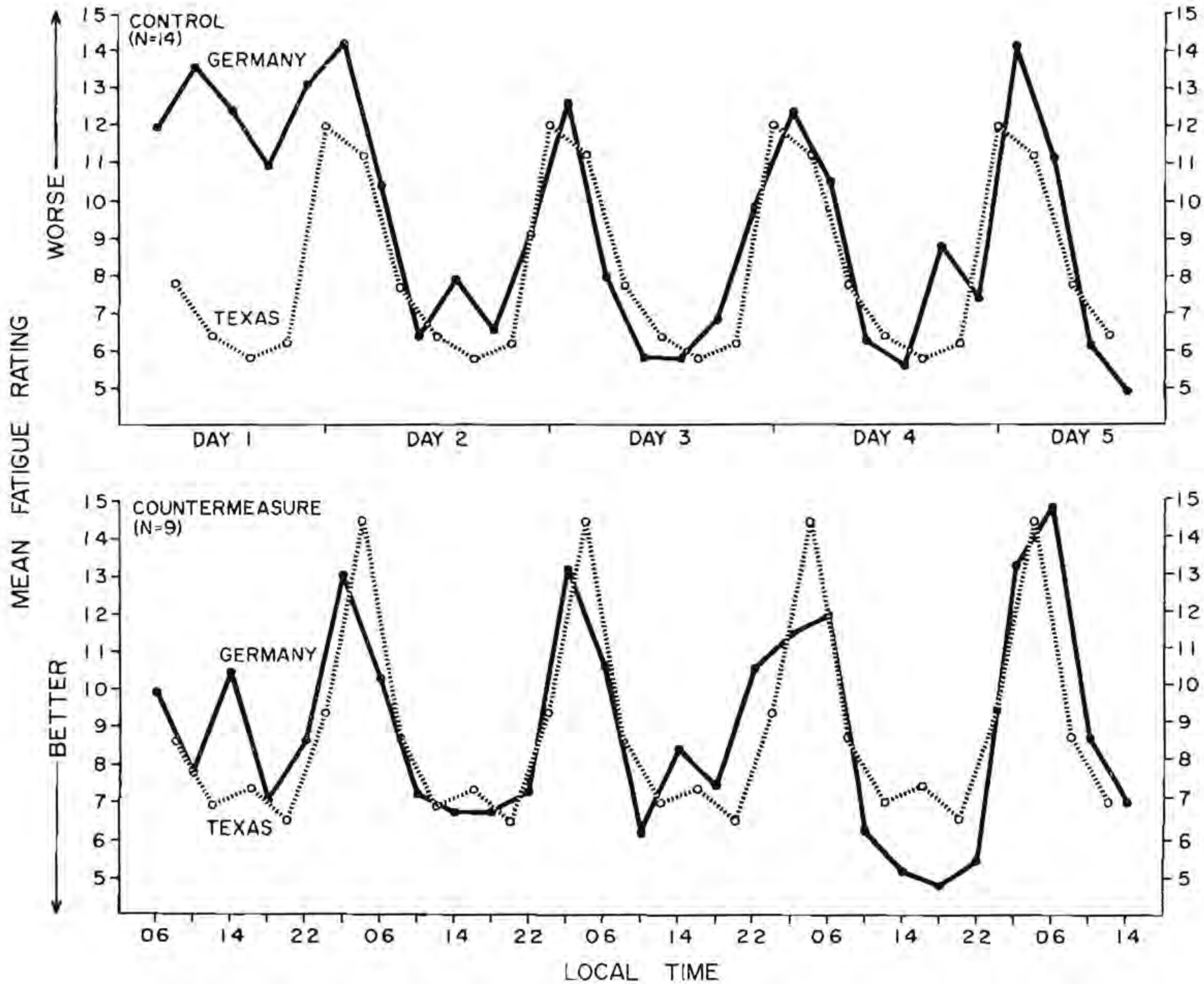

Figure 2. Self-rating of fatigue following deployment to Germany superimposed upon each group's phase-shifted (+6 hrs) 4-day mean baseline ratings in Texas. Seven subjects are omitted because of contradictory checklist responses or loss of diary.

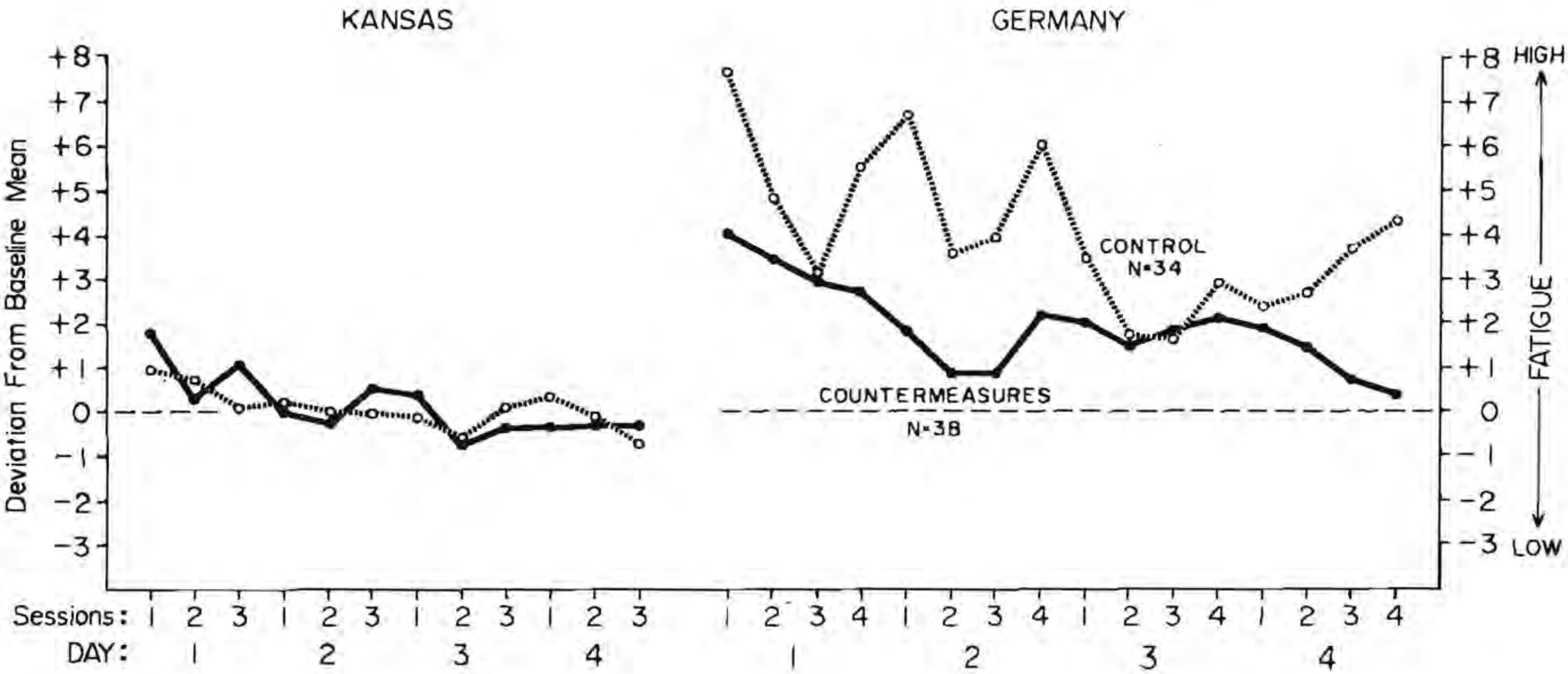

Figure 3. Group differences in self-rated fatigue in winter study as compared to mean baseline ratings during last day in Kansas.

gue ratings for the remainder of the study. This effect was further confirmed by the data for the self-report scales of information processing, concentration, etc. (Figure 4). Control subjects rated themselves significantly poorer than those in the experimental group for the first two days in Germany ($p < .05$, t-test), after which both groups exhibited partial recovery for the remaining days. Sleep results are difficult to interpret due to operational effects. Mean sleep time for control subjects was significantly less on the first night in Germany, due to the requirement for one plane-load of soldiers to draw equipment most of the night of arrival (Figure 5). A possible compensating effect is seen in the longer sleep for control subjects on the second post-flight night. While this initial sleep deficit may have contributed to the second day's fatigue scores, the significant fatigue differences on the first day were recorded before the sleep loss occurred; additionally, the unaffected control subjects also reported higher fatigue than experimentals on the second day. Thus, the fatigue self-rating results cannot be considered an artifact of sleep differences.

Body temperature. The oral temperature results are more equivocal than the fatigue data regarding countermeasure effectiveness. In general, their interpretation is limited by the lack of an adequate around-the-clock baseline for the large groups and the relatively short five-day post-flight observation span for all subjects. Although some support is provided for accelerated adaptation by the experimental group, substantial individual differences require that caution be exercised before any firm conclusions can be made about more rapid physiological adaptation to the new time zone.

The mean oral temperature rhythms for both groups exhibited very rapid initial adaptation to the new time zone. This finding is consistent with the reports on "Exercise Medex" (Adam et al., 1972; Colquhoun, 1979). As Figure 6 shows, however, there were subtle differences that suggest a beneficial effect of the countermeasure procedures. Note that the shape of the countermeasure function is almost identical to that of the intensive group's phase-shifted baseline function on the day after landing, whereas the control function's shape and amplitude do not begin to approximate the appropriate pattern until the third day. Whether both groups have reached their final state of adaptation by Day 6 is unclear since no baseline data are available for these particular subjects and additional post-arrival data could not be collected.

The use of group mean temperatures to assess time zone adaptation may obscure the oscillatory nature of this process. While Figure 6 implies a smooth and continuous progression toward ultimate adaptation of phase and amplitude, more detailed rhythmic analyses indicate that this is not the case. Figure 7 represents the combined outcome of a complex demodulation (CD) analysis (Walter, 1968; Orr & Hoffman, 1974) of each subject's post-arrival temperature data. The results are expressed as the percentage of subjects whose CD-estimated acrophase was outside a one standard deviation range about the predeployment mean acrophase (1713 ± 2.9 hrs) of the combined intensive groups. Here it can be seen that phase adaptation for both groups continues to vary throughout the six-day span in a manner resembling a three-day cycle. While on some days one group appears to have adapted better, on other days the reverse is true.

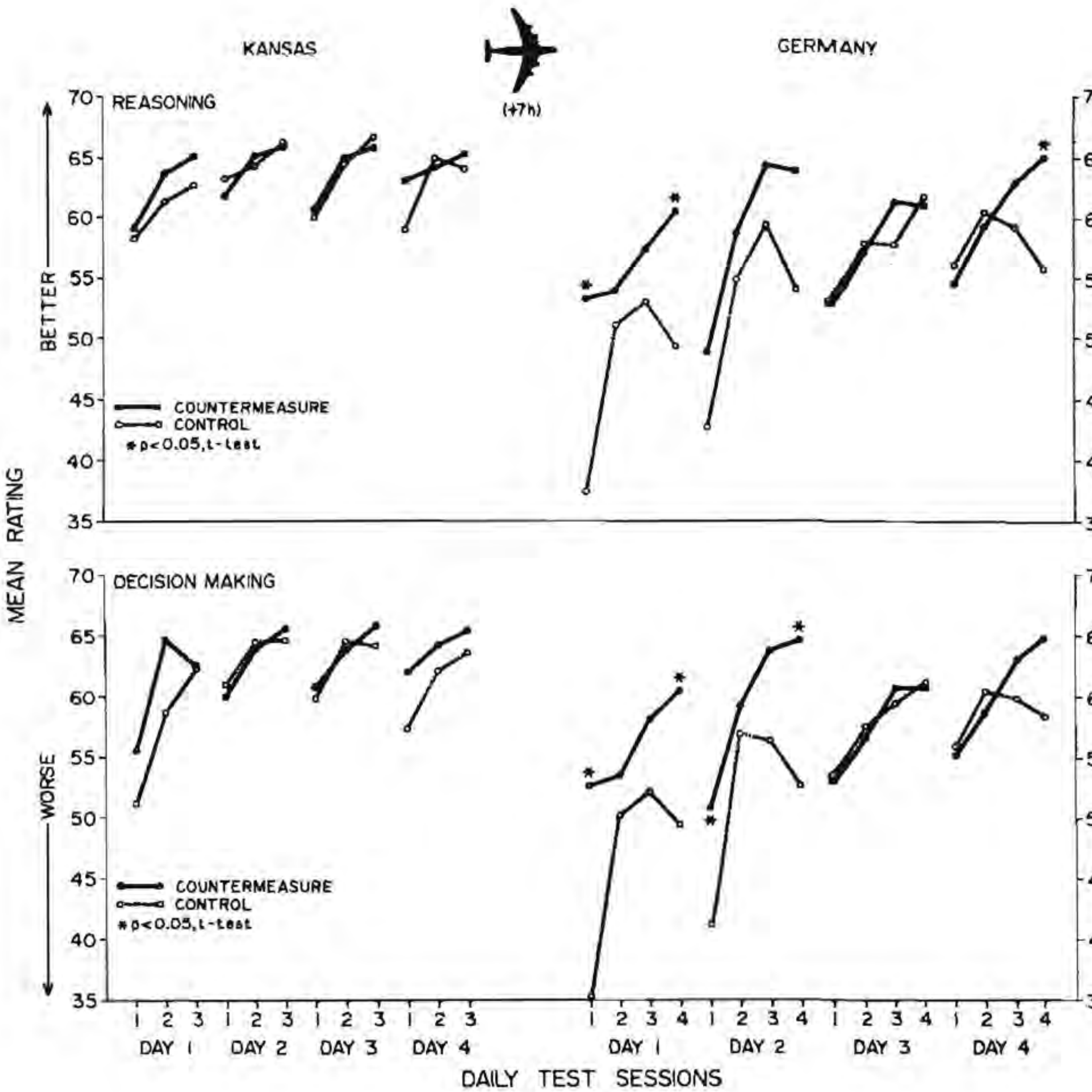

Figure 4. Influence of countermeasures on two self-rated cognitive abilities following transmeridian deployment.

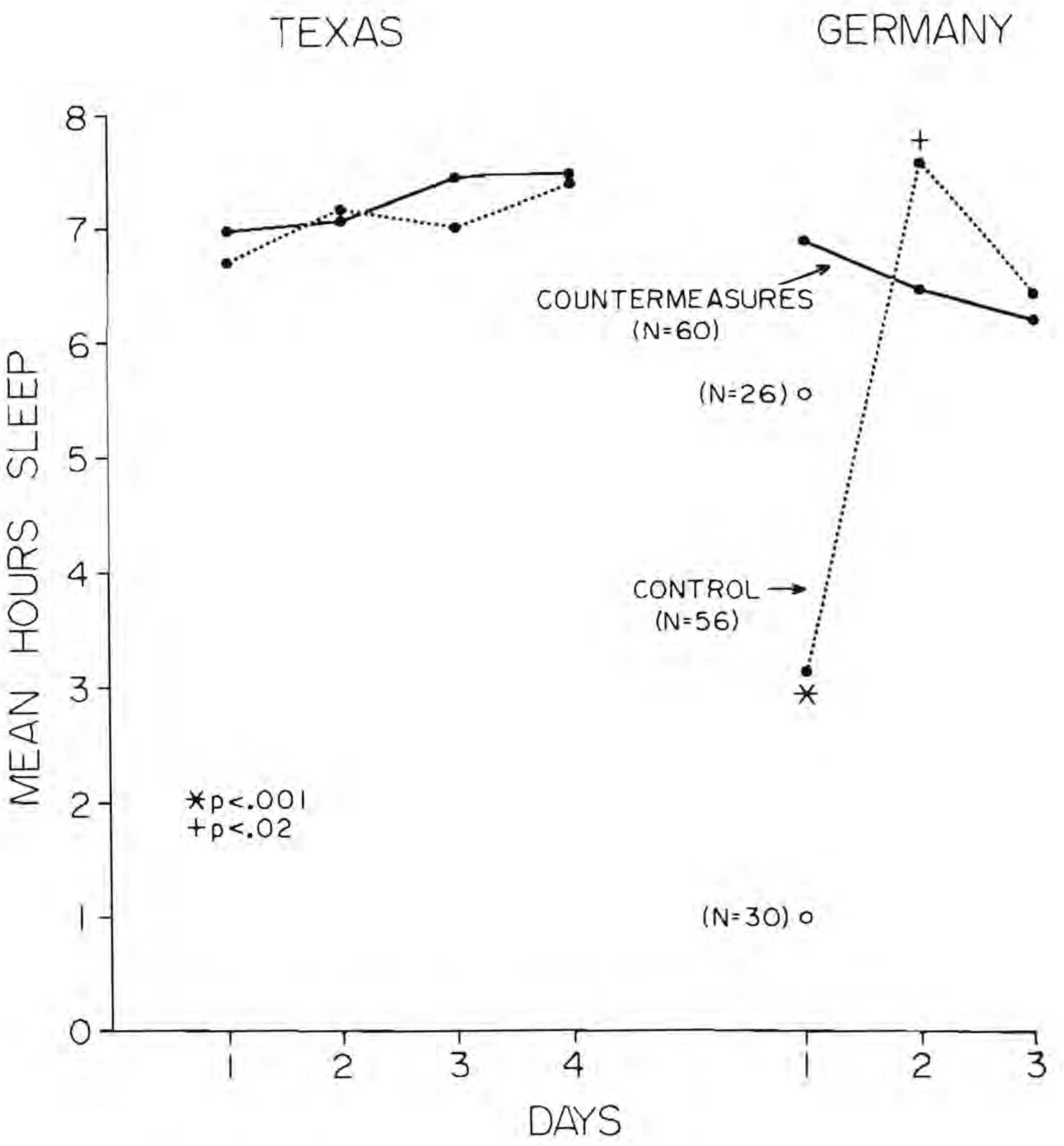

Figure 5. Sleep results for countermeasure and control groups in winter study. Open circles for Day 1 in Germany denote separate means for the two planeloads of control subjects (see text).

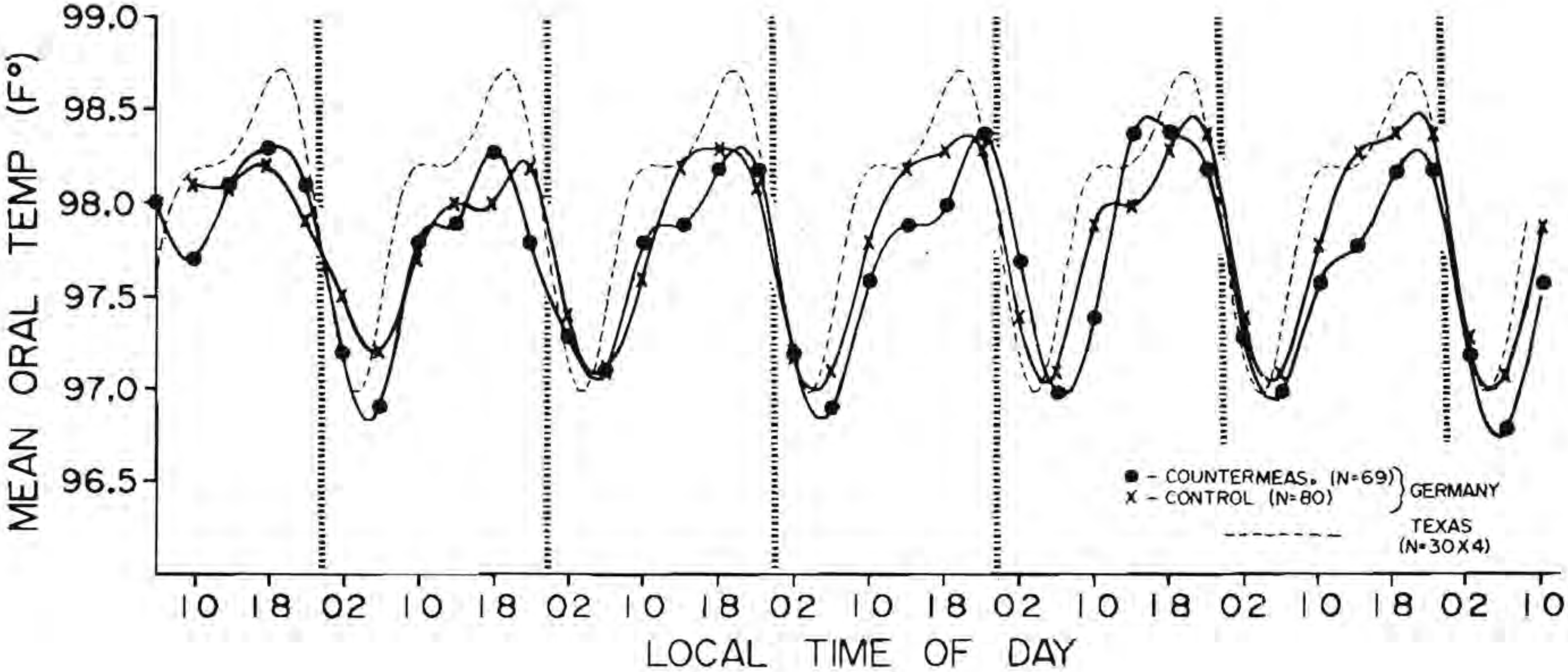

Figure 6. Mean oral temperature rhythms of large groups after deployment. Spline-fit functions are superimposed upon a phase-shifted (+6 hrs) estimate of the predeployment rhythm based on the mean daily temperature variation of the combined intensive groups in Texas.

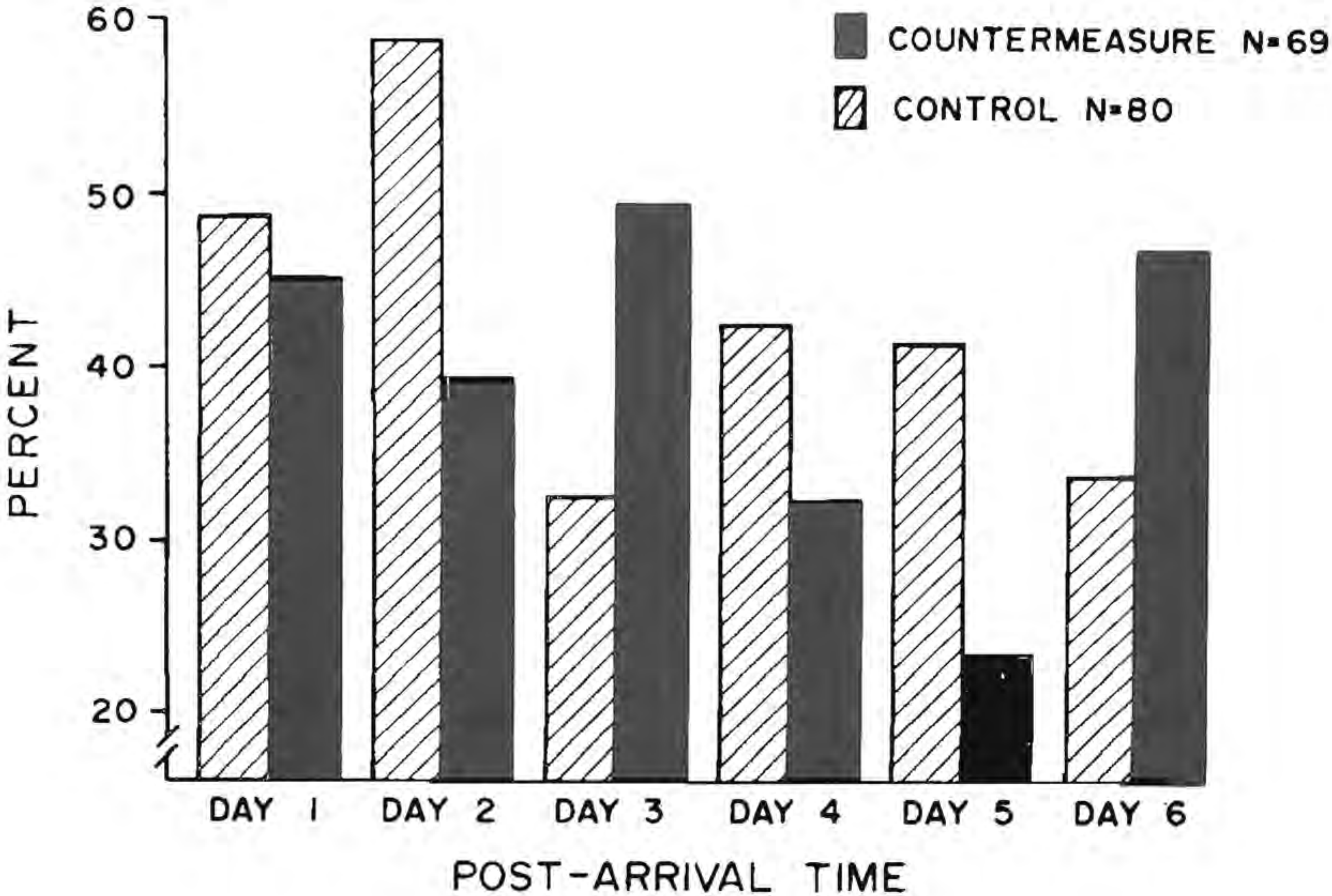

Figure 7. Daily percent of subjects in large groups whose CD-computed thermal acrophase indicated lack of phase adjustment after arrival (i.e., outside a one s.d. range about the mean thermal acrophase of the combined intensive groups in Texas).

Figure 8 presents the mean oral temperature results for the intensive groups who underwent around-the-clock measurements every 4 hrs in both Texas and Germany. It is evident that these curves are not consistent with those for the large groups (Figure 6), especially during the first four days following arrival. Both groups exhibit significant daily variability in both phase and amplitude, possibly due, in part, to the rather small number of subjects and the rigorous schedule which required subjects to be awakened for 30-45 min at each night test session. As in the large groups, adaptation as judged by group means appears to be largely complete by Day 6.

More detailed individual analyses by CD reveals the rhythmic structure underlying this adaptation process. Given a Nyquist frequency of 3 cycles per day, we were able to reduce each subject's raw data into a circadian and an ultradian component. Initially, these CD results were collapsed over days into the pre- and post-flight observation spans. Then subjects in each group were further subdivided into those who showed an increase in the percent of mean spectrum energy due to the circadian component following the flight and those who showed a decrease. As Figure 9 indicates, the countermeasure subjects maintained a relatively higher percentage of ultradian spectral energy regardless of whether they increased or decreased the percentage of spectral energy derived from the circadian component. The presence of significant ultradian components strongly suggests an active transitional state wherein the underlying oscillator is readjusting itself to the phase requirements of a shift in the synchronizer schedule. A similar explanation may underlie the pattern of variability seen in Figure 7. If this were the case, one would expect that the percentage of spectral energy derived from the ultradian component would gradually diminish as the individual becomes more and more adapted to the new time zone. Such a shift is apparent in Figure 10, where the daily mean power ratios are plotted for each group. While there is considerable day-to-day variability during the baseline measurement period, even greater fluctuations occur after the flight. During the six post-flight days the control group displays inconsistent fluctuations in the higher frequency components, while the countermeasure group exhibits a gradual and steady progression from days of relatively high ultradian energy to lesser amounts until it reaches baseline levels.

Previous reports on the effects of rapid transmeridain flight on body temperature have noted that the mean daily temperature is often affected in addition to the phase and amplitude of the circadian rhythm for temperature (Klein, Wegmann, & Hunt, 1972). In the present study a similar effect was seen in the lowering of mean body temperature (Figure 11). Both the control and experimental intensive groups had identical mean daily temperatures over the four days in Texas; however, the control group exhibited a consistently greater decrease in this value after the first day in Germany. This finding offers further support for the beneficial effect of the countermeasure procedures.

Cognitive Performance

Self-report scales and physiological measures provide only an indirect assessment of whether the countermeasures will improve human performance after rapid transmeridain flight. It is obviously more desireable to obtain direct measurements of cognitive performance changes following the deployment of con-

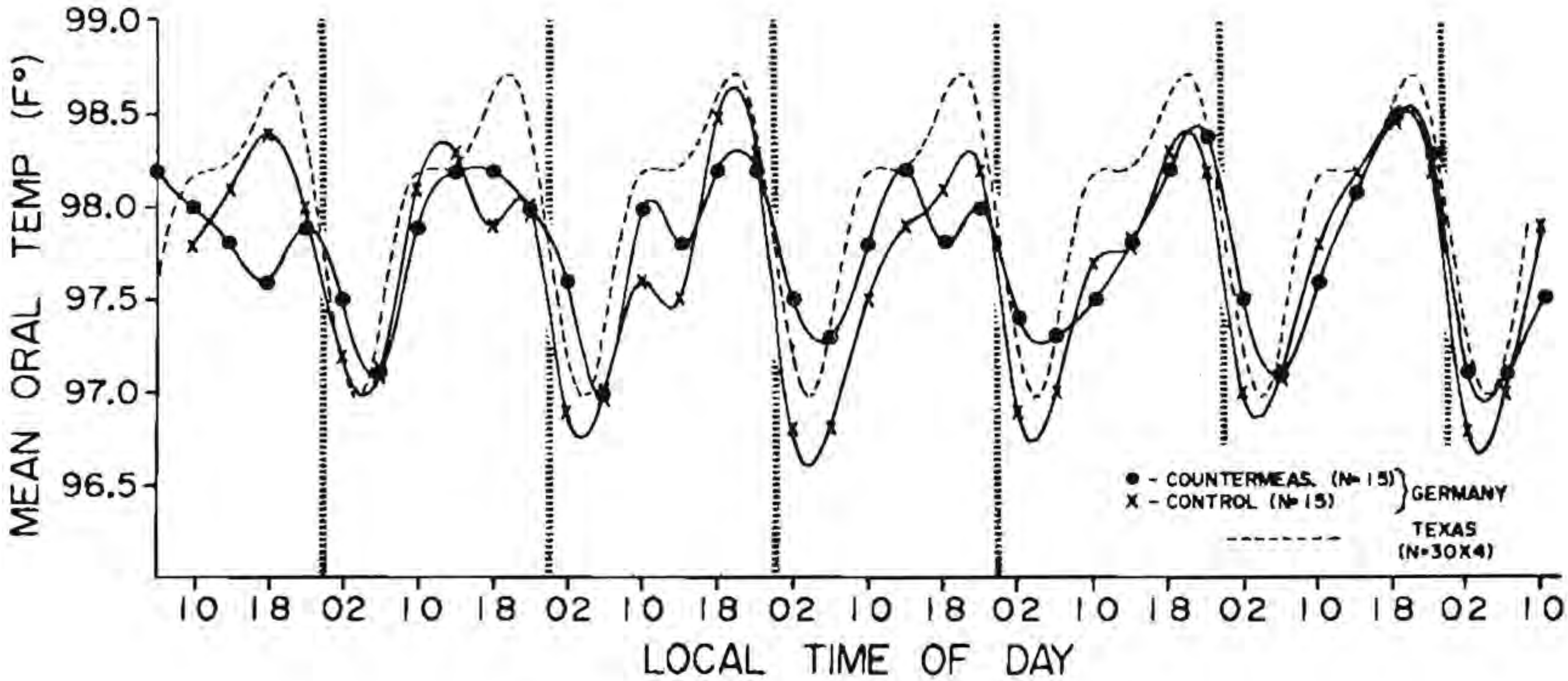

Figure 8. Mean oral temperature rhythms of intensive groups after deployment. Spline-fit functions are superimposed upon the phase-shifted (+6 hrs) predeployment rhythm of their combined mean daily temperature variations in Texas.

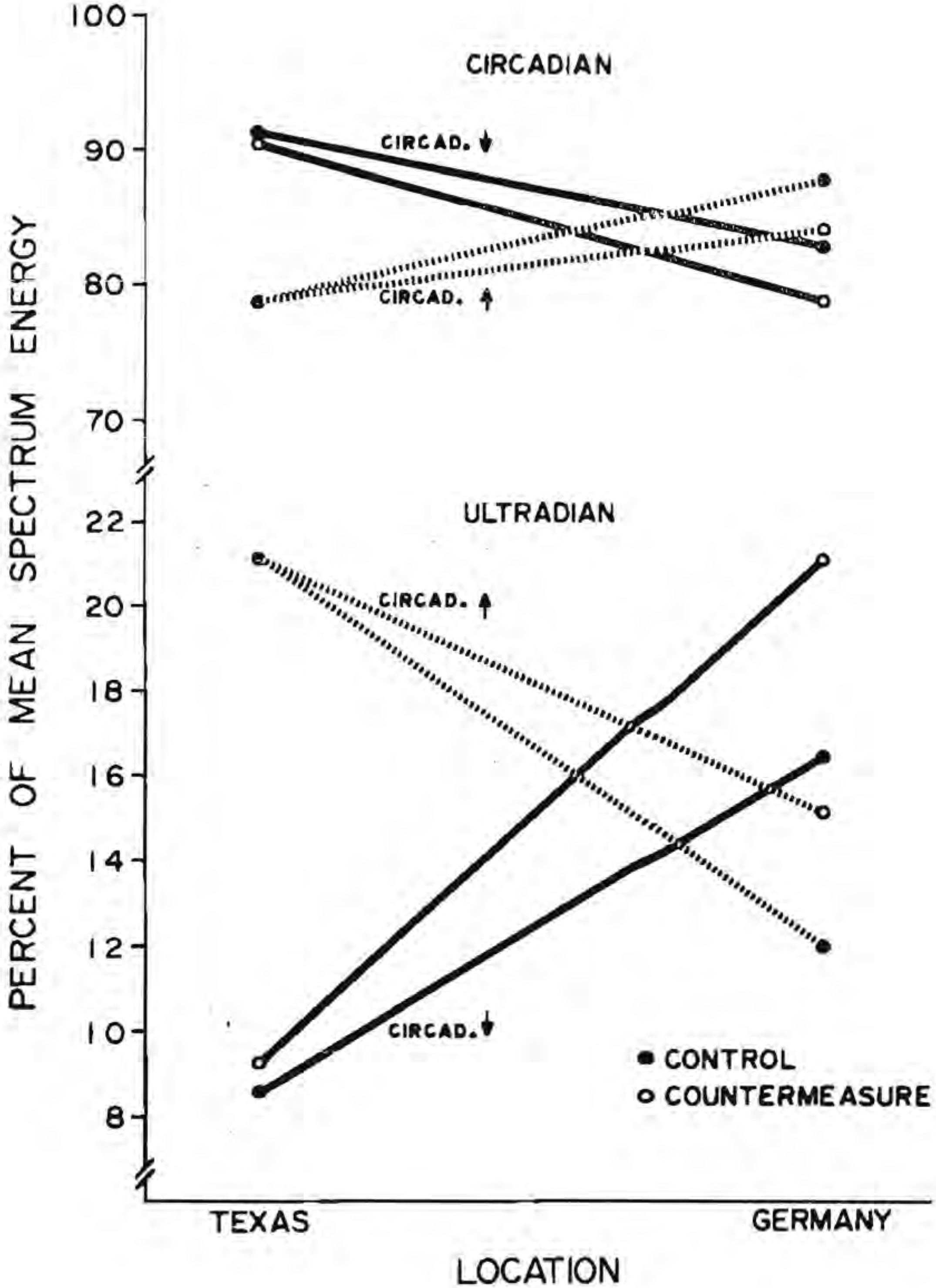

Figure 9. Shifts in CD-computed spectral energy of oral temperature rhythms after eastward (+6 hrs) transmeridian flight. Results are taken from intensive groups subdivided into subjects who increased circadian energy (Control = 7, Countermeasure = 6) and those who decreased circadian energy (Control = 8, Countermeasures = 9) during the post-flight observation span as compared to the pre-flight span.

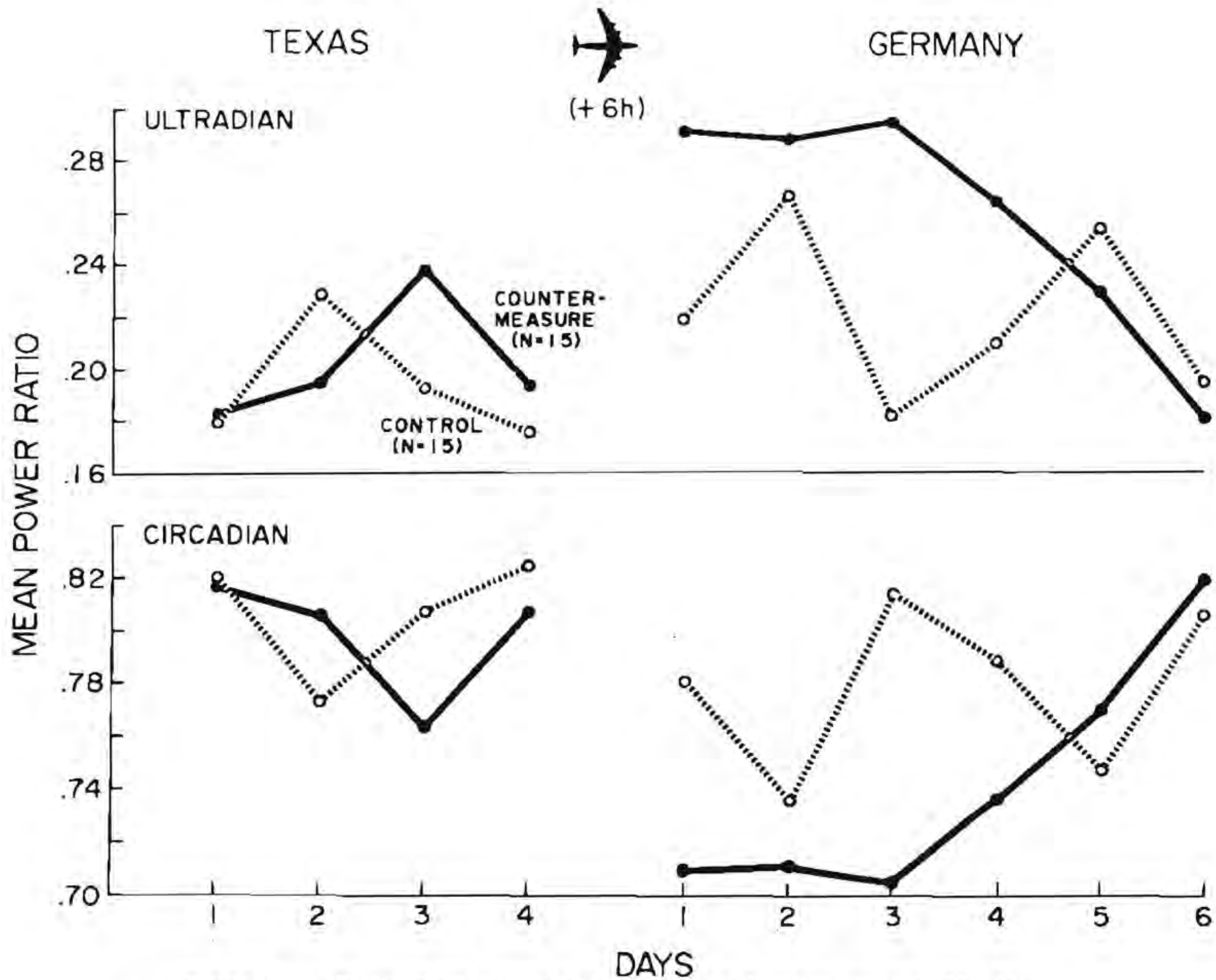

Figure 10. Daily mean power ratios of thermal circadian and ultradian frequencies before and after deployment of intensive groups. Ultradian and circadian components of the control group are significantly different ($p < .001$, t-test on arc sin transforms) from those of the countermeasure group on Days 1, 3, and 4 in Germany and on Day 3 in Texas ($p < .01$ for circadian).

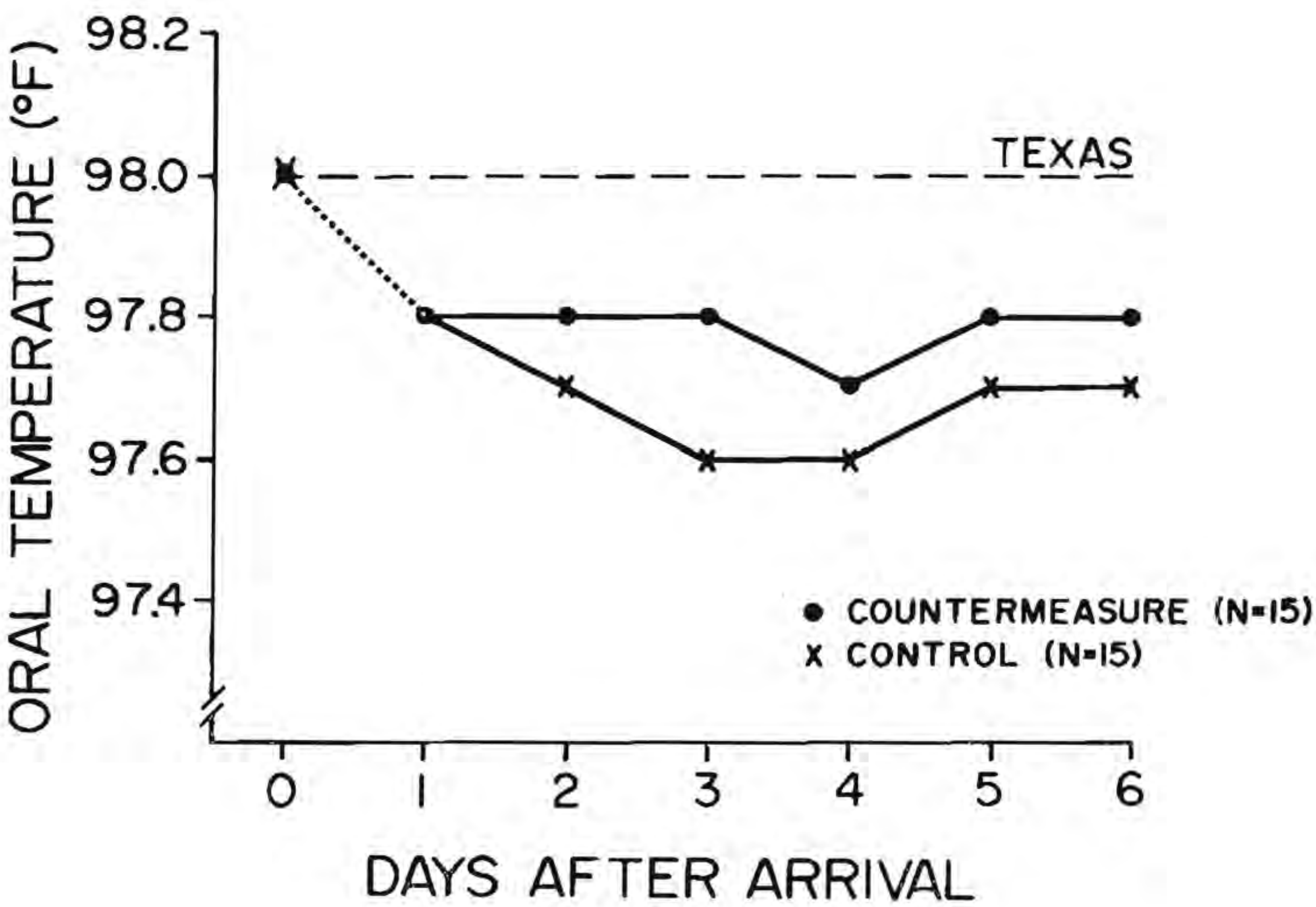

Figure 11. Mean daily oral temperatures of intensive groups after arrival in Germany as compared to their respective overall mean daily temperatures in Texas.

trol and experimental subjects. Due to operational limitations, our efforts have not been as complete as we would like. Because the four-choice reaction time data are still being analyzed, the only results currently available from the first study are for the sequential digit-pair addition task.

Figure 12 presents the adding speed data for the intensive groups of Experiment 1. The post-flight scores are superimposed upon the corresponding average baseline performance. Clear circadian patterning is evident, as is the persisting learning effect shown by the higher scores in Germany. However, no losses in performance speed or accuracy were observed by either group. Some loss of synchrony occurred on Day 4, but returned to normal phase again by Day 6. In retrospect, it would seem that this task was insufficiently demanding to produce any tangible deficits following the flight.

The encoding-decoding task used in the winter study proved more successful in detecting a post-flight performance decrement. Countermeasure subjects consistently completed more items than controls on this task. However, no differential changes in response speed (i.e., number correct) were seen following deployment (Figure 13). Both groups exhibited decreases in the number correct on the first day, followed by gradual recovery over the next three days (Figure 14). Experimental subjects maintained stable accuracy levels of 97-98% following the flight; controls matched this performance for the first two days, then dropped five percent in accuracy on Day 3 (Figure 13). Control subjects thus increased their response rate only at the cost of a loss in accuracy.

While there is thus some suggestion that the countermeasures may preserve post-flight performance, a more comprehensive assessment in this area is necessary before any firm conclusions can be made. Such an expansion is indicated for physiological measures as well in order to document thoroughly the relationship between self-reports, cognitive performance, and physiological rhythms after deployment with or without countermeasure procedures. A thorough analysis would also require a longer post-flight observation period than was possible in the present studies. Ideally, stable rhythm parameters should be documented before terminating any such experiment.

Age and Cognitive Performance

As mentioned earlier, any concern for the successful development of "jet lag" countermeasures is predicated upon the extent to which performance is degraded by rapid transmeridian deployment. The types of performance deficits typically associated with intercontinental flight involve losses in cognitive ability and psychomotor skills. Most previous field studies have limited themselves to examining the impact of such flights on eye-hand coordination, reaction time, manual dexterity, visual search, flicker perception, and simple addition (Aschoff et al., 1975). Although these data are relevant for predicting performance decrements for pilots and other equipment operators, they provide little information about commonly reported deficits in abstract thinking, information processing, decision making, and other higher order cognitive processes. From a military standpoint, it is the latter type of performance loss which is most likely to have a serious impact upon the largest number of soldiers in a combat situation. Command and control elements are required to operate under a high, continuous cognitive load and to make decisions

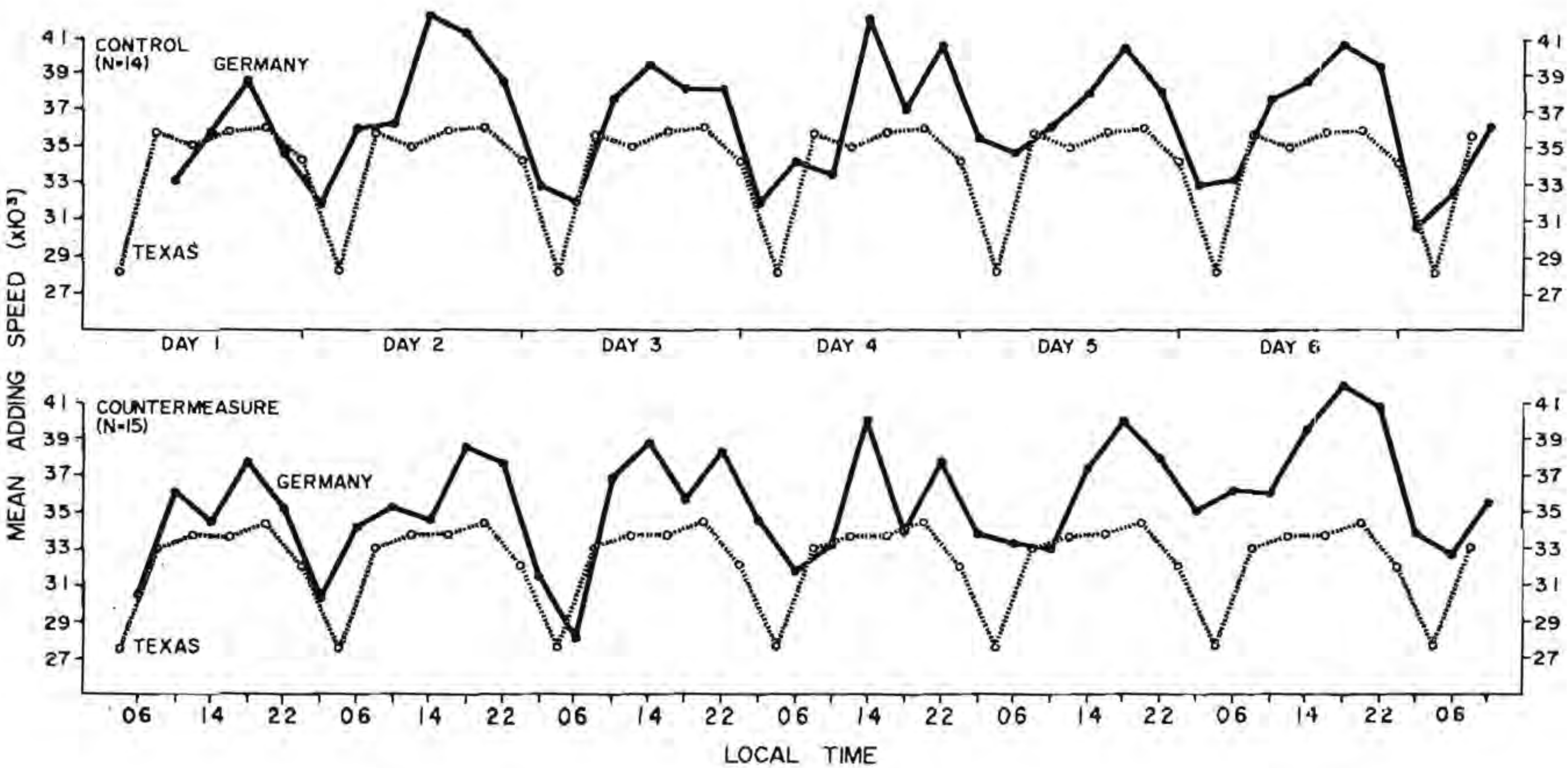

Figure 12. Performance on sequential digit-pair addition task by intensive groups after deployment to Germany. Adding speed, i.e., (1/sec) X 10^3, is compared to phase-shifted (+6 hrs) predeployment rhythm of their combined mean performance in Texas.

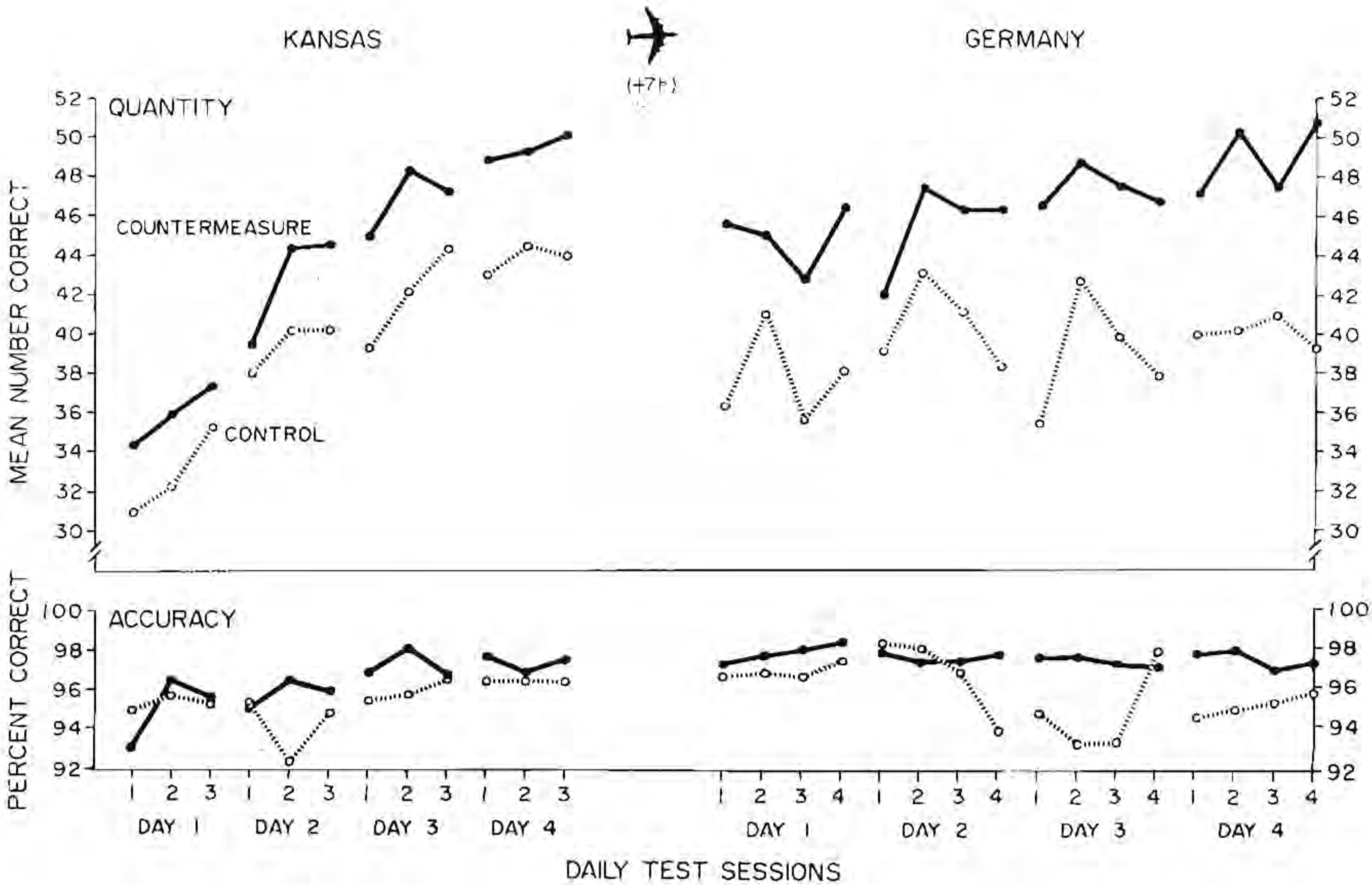

Figure 13. Influence of countermeasures on mean encoding-decoding performance during winter study (Control N = 34, Countermeasure N = 38).

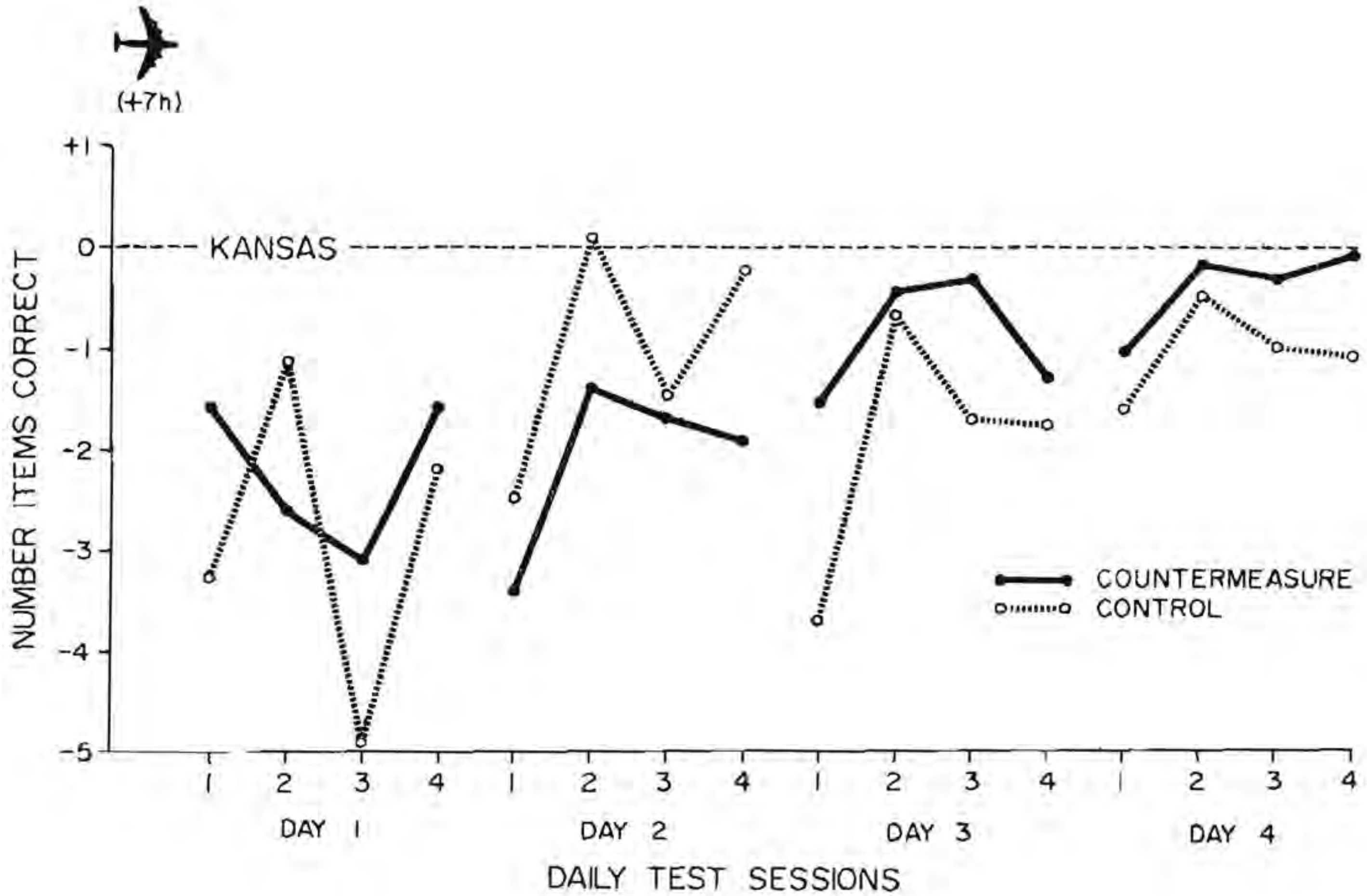

Figure 14. Mean differences in pre- vs. post-flight encoding-decoding performance of countermeasure and control groups. Each subject's post-flight scores were compared to his own overall mean performance on the last day in Kansas.

which directly affect the welfare of all troops under their supervision. It is for this reason that we carried out the second part of the winter deployment study. Furthermore, we decided to specifically examine the interaction of age with cognitive performance for two reasons. First, commanders and the senior staff of most units greater than company size tend to be older than about thirty-five years of age. Secondly, other investigators have previously suggested that older individuals may experience greater difficulty in adjusting to time zone transitions (Klein, Wegmann, Athanassenas, & Hohlweck, 1976).

Fatigue scale ratings did not differ between older and younger subjects in the second part of the winter study. Both age groups exhibited a post-flight increase in fatigue followed by partial recovery, similar to that seen in the control group used for countermeasure comparison (Figure 15). Younger subjects did report consistently lower scores on the cognitive self-rating scales throughout the study; however, scores were not differentially affected by deployment. Both these measures duplicated the previously described pattern of post-deployment decrements followed by recovery on Day 3. Sleep duration reports indicated that older soldiers slept about 20 min less per day than younger troops throughout the study. It is not clear whether this reflects differential duties, decreased sleep need for older subjects, or other factors.

The cognitive performance battery generally failed to reveal any marked or consistent differences between old and young subjects. The general pattern was one of decreased performance after arrival followed by a gradual recovery to baseline over the next one to four days, depending on the task.

Logical reasoning, generally rated by subjects as the most difficult of the tests, was the most severely affected. During the first day in Germany the mean number of items correct decreased a maximum of 20% and 27% for young and old respectively as compared to the final pre-deployment day and did not regain the baseline level of performance until the fourth day (Figure 16). Accuracy was more variable after the flight but, except for Day 3, remained consistent enough so that number correct was primarily related to the number of items attempted. Performance for the griddle task was similar to that of subjects in the countermeasure part of the study. The number of correct responses (i.e., response speed) was down 10 to 15 percent after arrival, and returned to baseline by Day 3 (Figure 17). Accuracy during the first two post-flight days tended to be highest in the morning and then decline towards night. This diurnal pattern disappeared over the next two days, and by Day 4 accuracy stablilized at pre-flight levels. Mean word recall dropped about one word per test on Day 1 and returned essentially to baseline on Day 2. No change at all was seen for either group in the speed or accuracy of performance on the letter cancellation task. While the false positive rate was much higher for the first two than for the last two days in Germany, the high rate seen also in the U.S. renders this result somewhat difficult to interpret.

The general pattern thus accords with other reports (e.g., McCally, Wegmann, Lund, & Howard, 1973) that the recovery time for performance tasks is directly proportional to task complexity. One measure, the trails test, actually showed an increase in performance following deployment which persisted at or above baseline levels for the remainder of the study (Figure 18). This task required the subject to draw an unbroken line connecting a series of irreg-

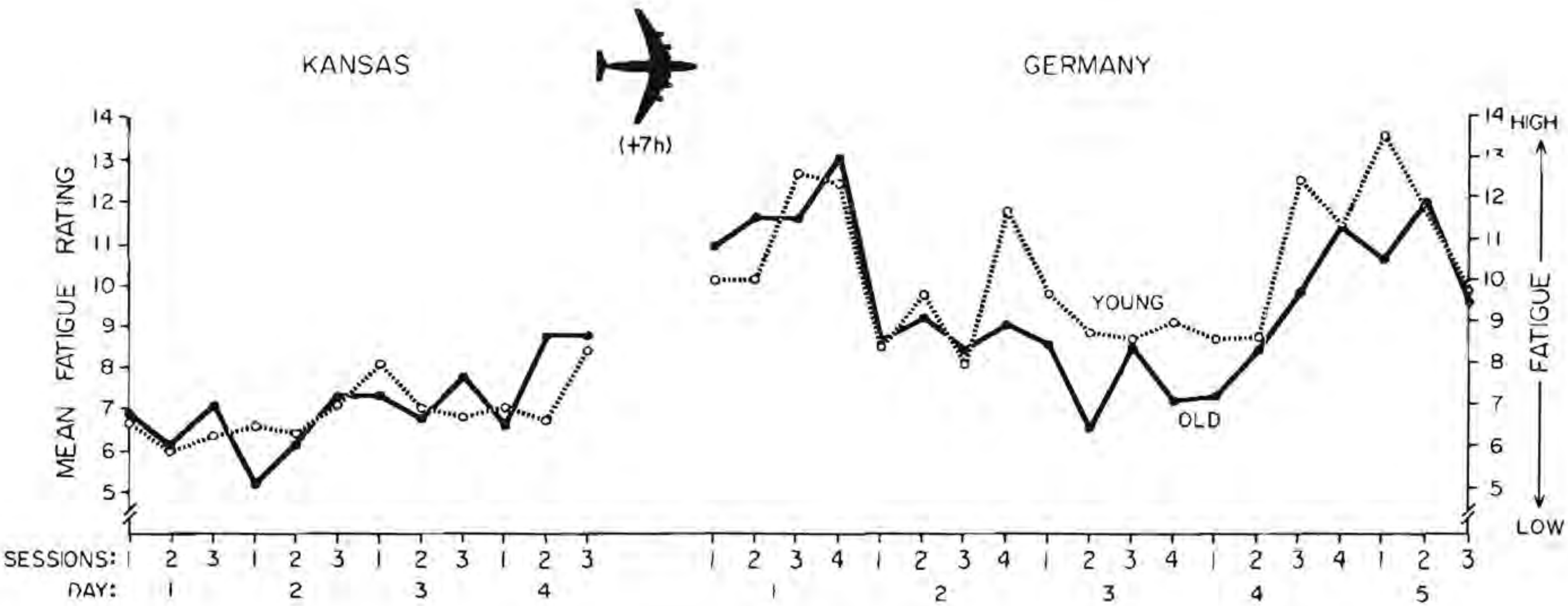

Figure 15. Self-ratings of fatigue following winter deployment of older and younger soldiers to Germany.

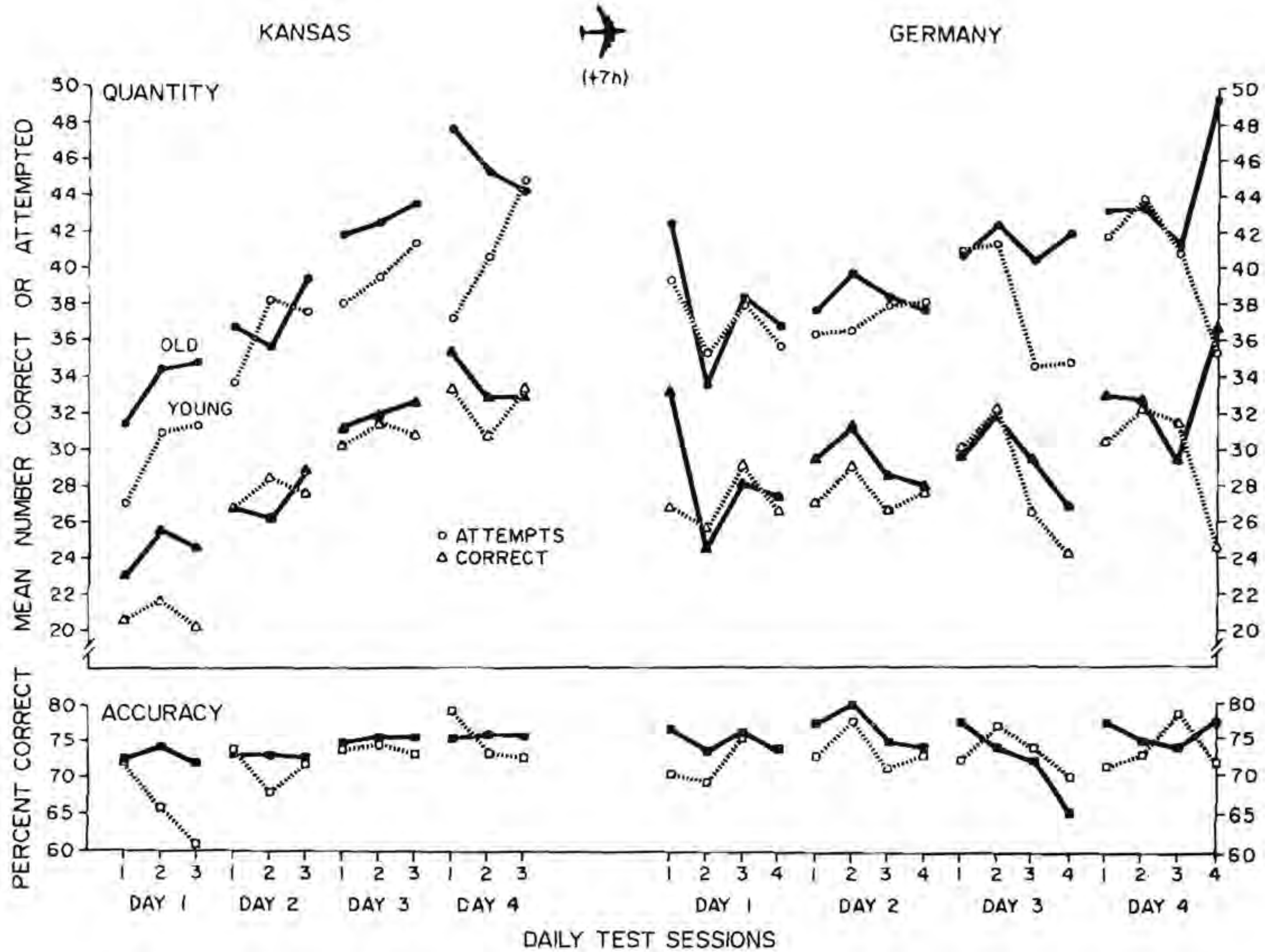

Figure 16. Effects of winter deployment on logical reasoning by older and young soldiers.

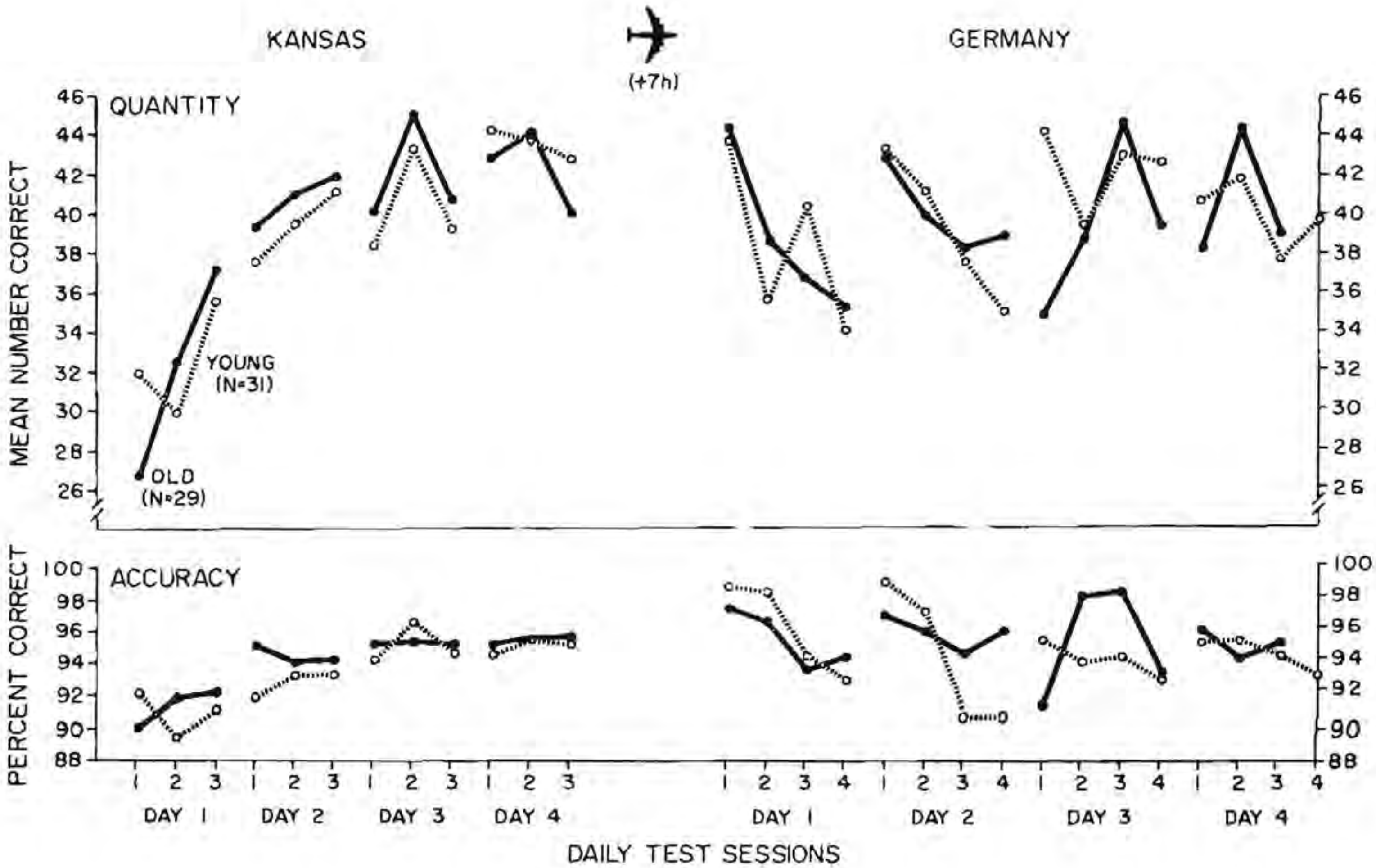

Figure 17. Effects of winter deployment on encoding-decoding performance by older and younger soldiers.

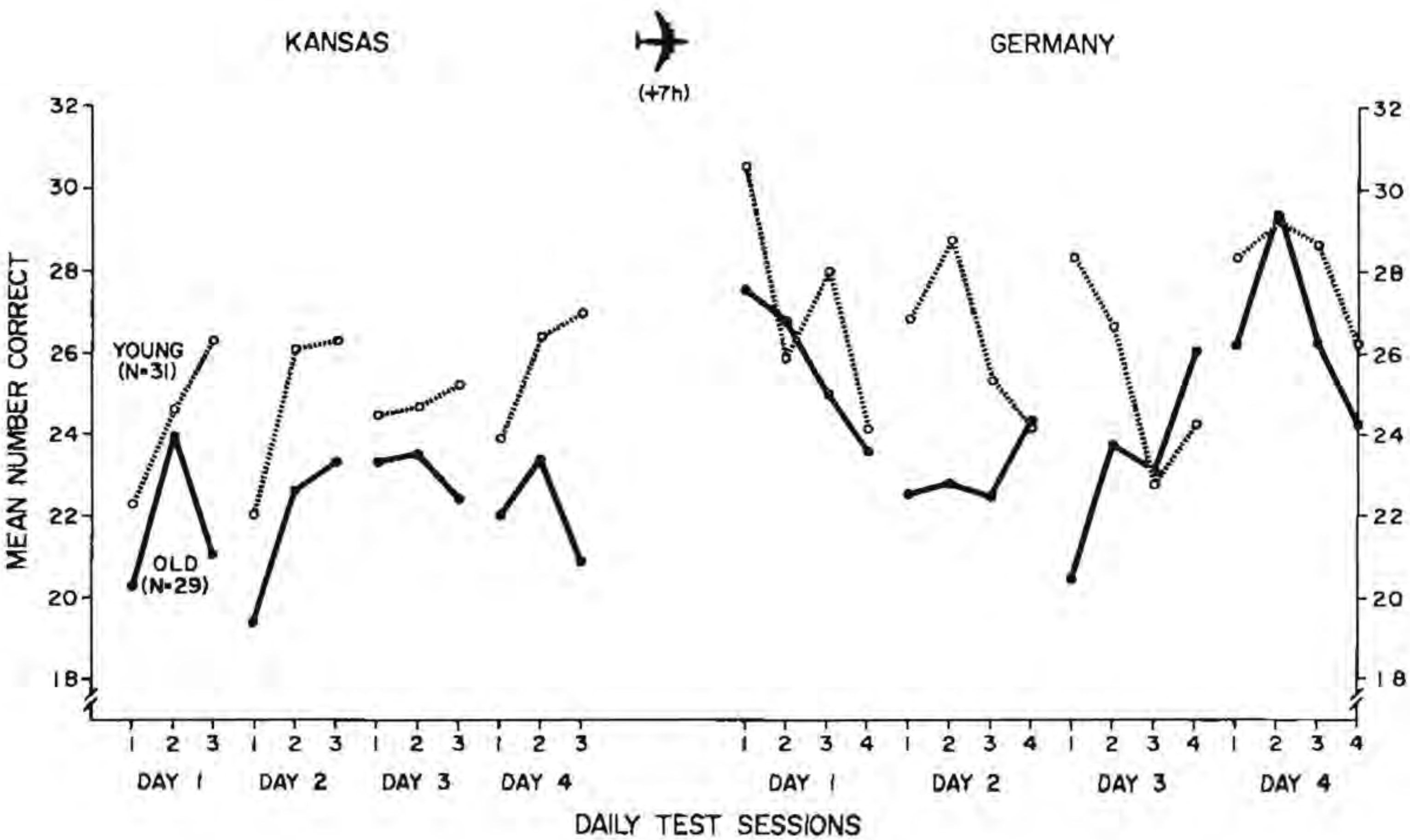

Figure 18. Effects of winter deployment on trails test performance by older and younger soldiers.

ularly spaced small circles (Figure 19). A fixed sequence had to be followed in which circles were connected in ascending order alternating between the numbered and lettered items. Thus, successful performance required substantial visuospatial ability and an ability to alternate response set between alphanumeric stimuli. The meaning of this unanticipated finding is not yet clear. Given the dramatically sharp rise in performance, especially for the older group, it is unlikely that the shift reflects a practice effect. Possibly, the enhancement was due to true facilitation of some performance capacity unique to this task or to a disinhibition of non-verbal, non-quantitative response tendencies. This hypothesis is supported by Wever's (in press) recent discovery that performance and psycholoical mood often show an improvement when subjects become desynchronized in a chamber environment where the light-dark cycle is beyond the range of entrainment. However, additional data need to be collected on similar tasks before any conclusions can be drawn. Regardless, this finding underscores the need for more comprehensive cognitive test batteries which assess performance mediated by the right, as well as by the left, cerebral hemisphere.

Immediately following each test session, subjects were asked to rate their own performance (Figure 20). As with the subjective rating scales for concentration, etc., older subjects consistently marked themselves higher than did the younger soldiers. This was particularly marked in Germany, where older subjects' ratings followed approximately the course of actual performance recovery while younger subjects consistently rated their performance much lower than it actually was. This finding suggests that young, inexperienced soldiers may be more likely to underestimate their performance ability following transmeridian deployment.

Despite the lack of any significant differences in cognitive performance or fatigue related to age, we are currently somewhat reluctant to conclude that age may not be an important factor in determining the effects of rapid transmeridian deployment. There are several reasons for our hesitancy. The primary one is that the age of the older group was probably too low to demonstrate the more serious adjustment difficulties usually described by older travelers. Although their mean age was 34.2 years, their individual ages ranged from 27.1 to 43.8 years, while the younger group ranged in age from 18.4 to 25.1 years. The age of most senior personnel in the division headquarters originally targeted for this study was at, or beyond, the upper limit of this "older" age range. Secondly, the test battery was designed to challenge individuals accustomed to performing high-level cognitive tasks. The use of maintenance personnel as subjects may have inadvertently resulted in a "floor" effect which restricted the sensitivity of the tasks to flight induced cognitive deficits. This possibility is suggested by the consistently much higher scores obtained by a few of the subjects. Finally, it should be noted that the adverse winter weather and relatively poor lighting conditions may have contaminated the data by introducing excessive variance and lower mean scores throughout the entire post-deployment observation span.

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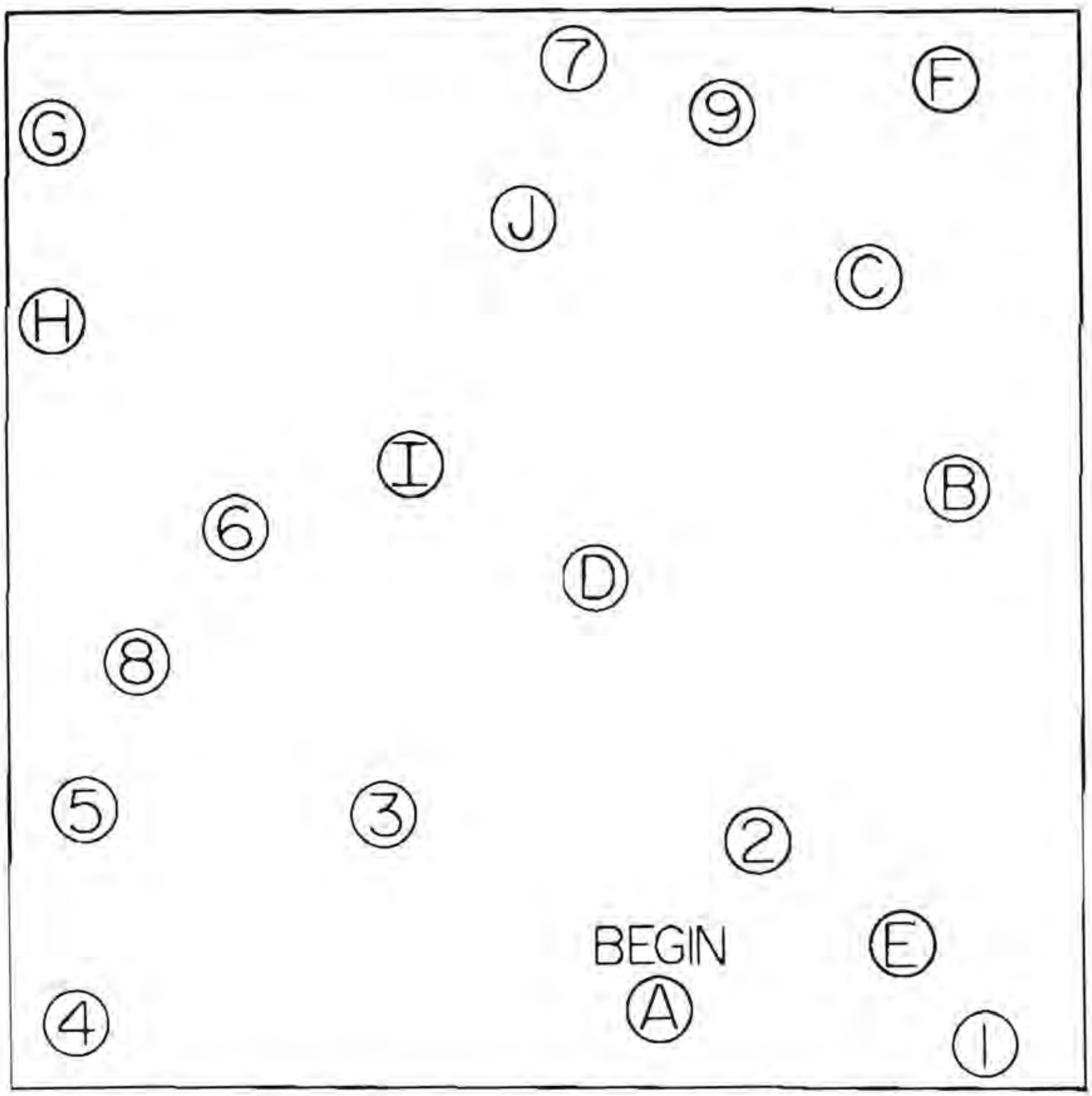

Figure 19. Sample form of trails test. Subjects were required to draw a continuous line starting at "Begin" and alternately connecting lettered and numbered circles in ascending order. They were given 1 min per session to complete as many of the four forms (out of 48) as possible. Only 1 error was scored for an incorrect connection providing the subsequent connections were in alternate and ascending order.

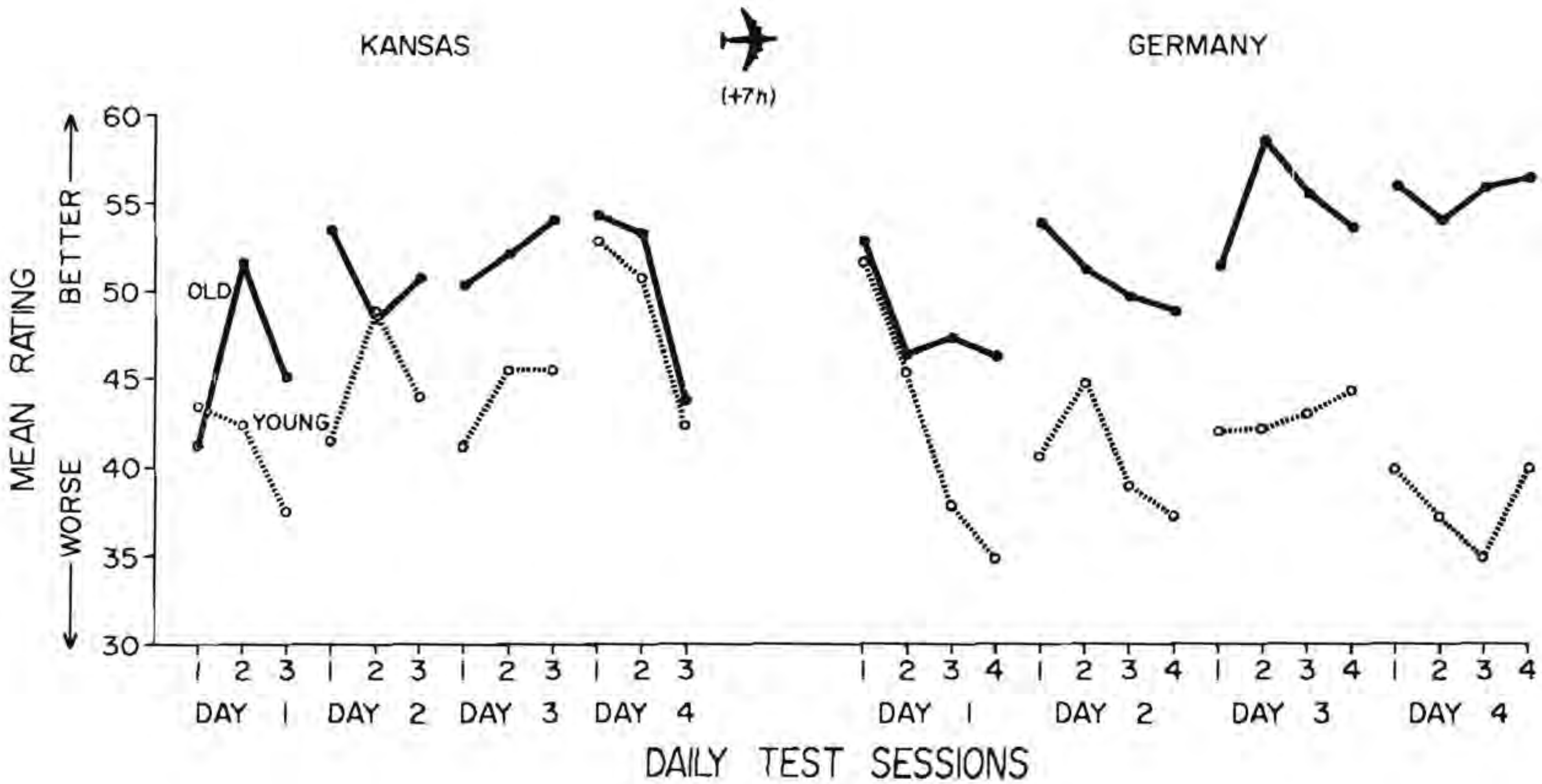

Figure 20. Self-rated estimates of performance on cognitive test battery by older and younger soldiers before and after winter deployment. Significant group differences ($p < .05$, t-test) occurred only on post-flight Day 3 (Session 2) and Day 4 (Sessions 1, 2, & 3).

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