The Effects of Work Shift and Strategy on an Orientation Task

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Abstract

Cognitive alertness decreases at night due to circadian rhythms with adverse effects on performance across domains and tasks, including real-world tasks like driving and flying. Additionally, the strategy used on a task may have a substantial effect on performance. However, little is known about whether and how circadian rhythms and strategy interact to affect performance. The current study investigates participants' performance on an orientation task performed over a period of two weeks. Participants were assigned to simulated day or night shift conditions, and were trained to use one of two strategies for the orientation task. The results indicated that shift condition had little impact on a more declarative strategy for the task, but had a significant impact on a more spatial strategy. The results illustrate how different aspects of cognitive functioning may be affected differently by circadian rhythms, and point to some important implications for training and task performance in real-world contexts.

Keywords: spatial; sleep; circadian rhythm; fatigue; learning; shift work

Introduction

Critical, safety-sensitive activities, such as driving and air traffic control, are performed at all times of the day and night. Yet, it is not well understood how nighttime operations affect task performance in contexts such as these. Most research on night and shift work has focused on how shift differences affect sleep and frequency of accidents (e.g., Åkerstedt, 1988). Little work has focused on how shift work and task differences affect different cognitive processes alone or in interaction.

Variations in alertness due to circadian rhythms and sleep loss have been shown to affect various components of cognitive functioning (Jackson & Van Dongen, in press). For example, vigilant attention (Lim & Dinges, 2008), perceptual learning (Mednick, Nakayama & Stickgold, 2003), and motor learning (Walker, Brakefield, Morgan, Hobson & Stickgold, 2003) are all affected by fluctuations in alertness associated with time awake and circadian rhythms.

For shift work, circadian rhythms are particularly important. Circadian rhythms are driven by a biological clock in the suprachiasmatic nuclei of the hypothalamus, which imposes cyclical changes in alertness throughout the day, leading to increased pressure for sleep at night. This leads to nocturnal degradations in cognitive performance (Van Dongen & Dinges, 2005), as demonstrated in a variety of tasks and domains (e.g. Caldwell, 2003; Dinges, 1995).

The present research investigates how strategies recruiting different cognitive-perceptual processes may be differentially affected by fluctuations in alertness resulting from circadian rhythms in laboratory-simulated shift work. This is accomplished within the context of a spatial direction task, where distinct alternative cognitive strategies have been identified (Gunzelmann, Anderson & Douglass, 2004). In this task, participants are presented with two views of a set of objects (Figure 1). One of the views (the left side in Figure 1) is an overhead, ego-oriented perspective, based on a viewpoint at the bottom of the screen. Within the ego-oriented view, one of the objects (small circles) in each trial is filled in to identify it as a target. The other view (the right side in Figure 1) shows a map-like perspective with the viewpoint indicated by the arrow, which may be misaligned relative to the ego-oriented view on the left. The task requires participants to identify the location of the target in the map-like perspective.

In the study described here, participants were taught to use one of two strategies for the spatial direction task: one based on counting and the other on mental rotation, as in Gunzelmann et al. (2004). The strategies are described in more detail below. The key feature is that the strategies emphasize different cognitive functions, declarative and spatial, and lead to reliably different performance in participants trained to use them.

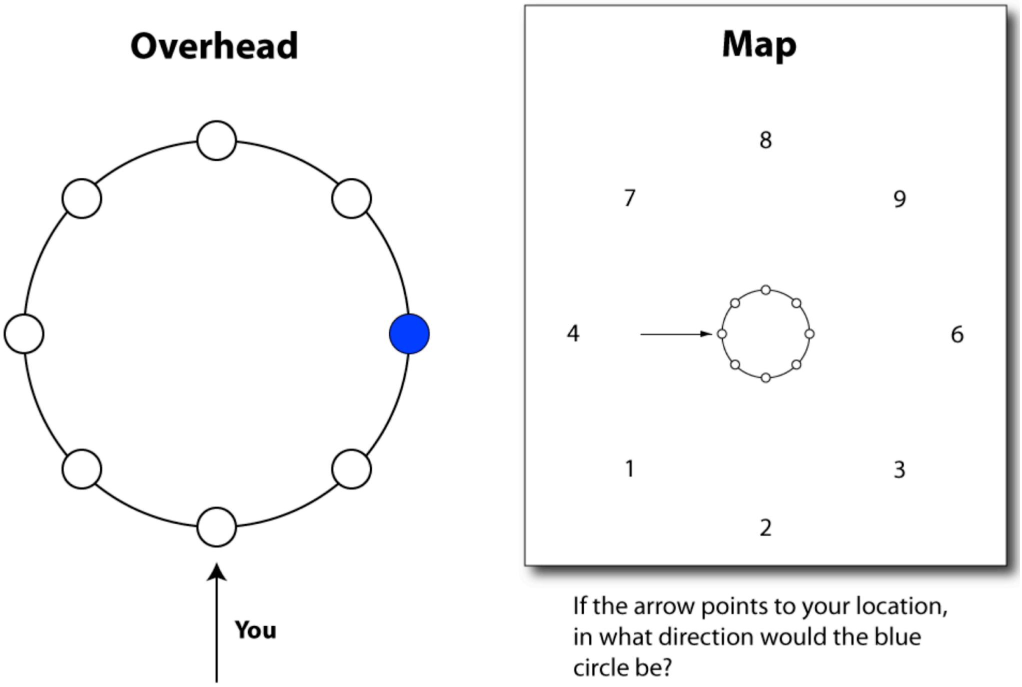
The alternative strategies for the spatial direction task offer an opportunity to explore how different cognitive capabilities may vary in their susceptibility to fluctuations in alertness. Such variations can be important in naturalistic contexts, where a variety of strategies may be available. To address this issue in the context of a common situation, we compare performance on the spatial direction task between individuals placed on a simulated night shift schedule for two weeks versus individuals sleeping according to a simulated day shift schedule.

Method

This experiment was conducted as part of a larger study to understand how circadian rhythms and sleep disruption affect performance in a variety of domains.

Participants

Twenty-six individuals, 14 female and 12 male, ranging in age from 22 to 39 years old (mean = 27), from the general community of Spokane, Washington participated in the experiment. The participants were screened to be healthy and without sleep disorders, with no evidence of brain damage or learning disabilities, and free of drugs of abuse. Participants gave written informed consent, and were paid for their participation.



If the arrow points to your location, in what direction would the blue circle be?

Figure 1: An example trial. The target on the overhead ego-oriented view (left side), indicated by the filled circle, is at middle distance to the right of center. The perspective on the map view (right side), indicated by the arrow, is misaligned by 90° clockwise. The correct response in this example trial is “2.”

Stimuli

Participants completed the task shown in Figure 1. There are 8 possible target locations and 8 possible misalignments (45 degree intervals). However, performance is roughly equivalent for right-left mirrored stimuli (see Gunzelmann et al., 2004). For instance, response times for targets located in the lower-left and lower-right positions are similar for a given misalignment. Likewise, response times are similar for misalignments that differ only in the rotation direction, such as assumed perspectives at positions 4 versus 6 on the map. Because of this correspondence, participants were presented with only one of these trials in each session. There were therefore 25 trials per session — 5 target locations (bottom, near, middle, far, and top) crossed with 5 misalignments (0, 45, 90, 135, and 180 degrees) — which were presented in random order.

Participants responded using the numeric keypad portion of a computer keyboard, which was spatially mapped to the possible response locations on the map view. So, if the correct response was the bottom position on the map (as it is in the sample trial shown in Figure 1), participants responded by pressing the “2” on the numeric keypad.

Procedure

Participants were in the laboratory for fourteen consecutive days. The first day was a baseline day with 10 hours in bed for sleep (22:00–08:00). Subsequently, some of the participants (n = 12) changed to a simulated night shift. Night shift participants were given five hours in bed (15:00–20:00) on the second baseline day, before starting five consecutive work days with 10 hours in bed during the daytime (10:00–20:00) on each day. On the seventh and eighth day, night shift participants had a simulated weekend during which they had 5 hours in bed (10:00–15:00), 7 hours awake, 10 hours in bed during the night (22:00–08:00), 7 hours awake, and then 5 hours in bed (15:00–20:00) before resuming their night shift schedule for the next 5 days. This schedule represented a stereotypical schedule for individuals working a night shift, who frequently shift back to a nighttime sleep schedule during weekends. After the last night shift day, night shift participants received 5 hours in bed (10:00–15:00), 7 hours awake, and then, on the final day of the study, were given 10 hours in bed (22:00–08:00) for recovery.

Participants on the day shift (n = 14) maintained the same sleep schedule throughout the study, with 10 hours in bed (22:00–08:00) each night. Note that participants on the day shift and night shift schedules were given the same amount of time in bed over the course of the experiment, although it was distributed differently.

Participants completed fifty-one test sessions of the spatial direction task over the fourteen consecutive days, with 2 to 4 sessions per day. On the first baseline day, participants completed three sessions; on the second baseline day, they completed two sessions. On each of the remaining days of the study, participants completed four sessions up until the last day when they completed two sessions.

Before the first session, participants were presented with instructions for the task, including training for either the rotation (n = 13) or counting (n = 13) strategy for which they completed four practice sessions. Training on the rotation strategy encouraged the participants to mentally rotate the relative positions of the viewpoint and the target on the overhead view (left side) to align them with the viewpoint indicated on the map view (right side). Specifically, they were taught to imagine an angle that connects the viewpoint (indicated by the "You" arrow) to the target on the overhead view, with the vertex at the center of the field (a 90 degree angle in Figure 1). They were then told to mentally shift to the map view, and to rotate the angle so that the arrow in the overhead view was aligned with the arrow in the map view (a rotation of 90 degrees clockwise in the trial shown in Figure 1). At this point, the answer could be determined by finding the target end of the angle.

Training on the counting strategy taught the participants to count the number of objects from the arrow at the bottom of the ego-oriented view to the target position (the count is 2 in Figure 1) and note the direction in which the target was located (counterclockwise in Figure 1). They were then told to count the same number of steps around the map view in the appropriate direction from the location indicated by the smaller arrow.

Results

The analyses focused on how the study condition (night shift versus day shift) interacted with the trained task strategy to affect performance. Previous research using this task has shown that some people use special-case strategies when the target is at the top ("across from where I am") or bottom ("where I am") of the ego-oriented view (Gunzelmann et al., 2004). In order to ensure that the analysis truly reflected differences in the use of the counting and rotation strategies, these special cases were removed from the analysis. Additionally, we only included data in the analysis for sessions when the sleep schedules were different for the two groups (i.e., when the night shift group was up at night), that is, days 3 to 7 and days 9 to 13.

Linear mixed-effect models were used for the analysis, using the R environment (R Development Core Team, 2009) with the nlme package (Pinheiro, Bates, DebRoy, Sarkar & the R Core Team, 2009). The skewed distribution of the response time data was corrected using an inverse square root. An alpha level of .05 was used for all statistical tests.

The analysis concentrated on the effects of the *strategy* that the participant was taught (rotation or count), the work *shift* of the participant (day or night), the *day* of participation, the location of the *target* (near, mid, and far), and *misalignment* between camera and target view (0°, 45°, 90°, 135°, and 180°). These were all included in the nlme analysis as multi-level factors, except for day, which was continuous. Participant was used as a repeated-measure grouping factor, and intercept, target and misalignment were included as random factors.

Table 1 shows the mean response times by strategy and shift. Neither the strategy, $F(1, 22) = 0.05$, $p = .83$, nor the shift, $F(1, 22) = 0.47$, $p = .50$, displayed a simple main effect on response time. As seen in Figure 2, participants performed better in later days, $F(1, 15458) = 2{,}300$, $p < .001$, reflecting a learning curve. As seen in Figure 3, targets located further away required more time, $F(2, 15458) = 81$, $p < .001$, and larger misalignments also required more time, $F(4, 15458) = 150$, $p < .001$. Additionally, misalignment had a larger effect when targets were further away, $F(8, 15458) = 26$, $p < .001$.

Performance improved more as time progressed for participants using the rotation strategy than for participants using the count strategy, $F(1, 15458) = 11$, $p < .001$. Performance of participants on the day shift improved faster than that of participants on the night shift, $F(1, 15458) = 21$, $p < .001$. Figure 2 shows the interaction of strategy, shift, and day, which was significant, $F(1, 15458) = 15$, $p = .008$. Up until day six, participants using the rotation strategy were performing worse, no matter which shift they worked, than those using the counting strategy. Later, participants using the rotation strategy on the night shift eventually reached the performance level of those using the count strategy, and participants using the rotation strategy on the day shift outperformed the other groups.

Observed error rates were low ($M = 4\%$, $SD = 3\%$). The error rates tended to correlate with the response time ($r^2 = 0.58$), suggesting that the between-group differences did not stem from a speed-accuracy trade-off.

An analysis of the baseline data alone was conducted to explore the possible influence of differences among the groups at the start on the observed effects. Importantly, neither the strategy, $F(1, 22) < 0.01$, $p = .99$, the shift, $F(1,$

Table 1: Mean (SD) response times (ms) by strategy and shift.

		Shift	
		Day	Night
Strategy	Counting	2016 (802)	2113 (945)
	Rotation	2015 (1033)	2210 (1041)

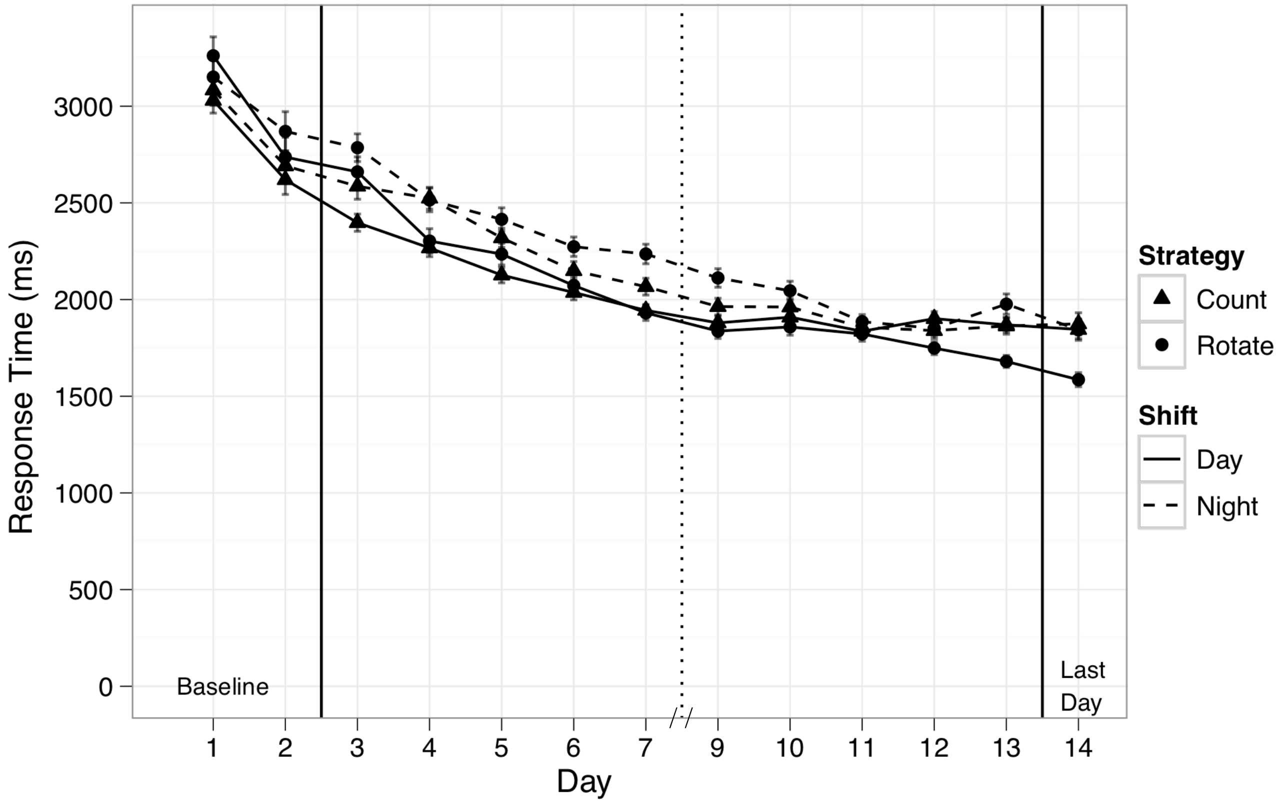


Figure 2. Reaction time as a function of strategy trained, work shift, and day in study. Data from days 1 and 2 (baseline) prior to work shift and day 14 (last day) after work shift are shown for reference, but were not included in the primary analysis. The sleep schedule was interrupted by a simulated weekend on day eight (dotted line), which was not included in the analysis or shown here. Error bars indicate ±1 standard error.

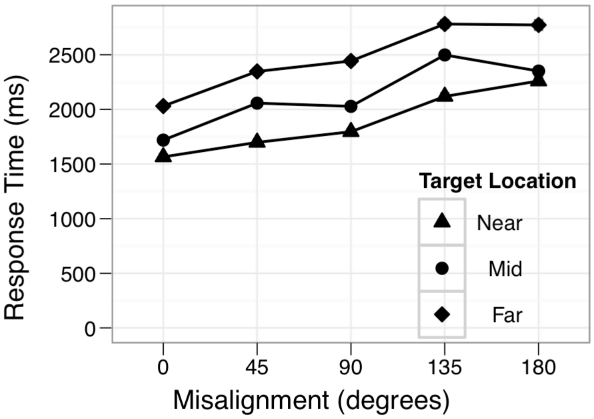


Figure 3. Response time as a function of misalignment and target location. Error bars are too small to be visible.

22) = 0.12, *p* = .73, nor their interaction, F(1, 22) = 0.04, p = .85, were significant, indicating that the groups were roughly equivalent in their performance at the start.

Discussion

All of the participants gained extensive expertise in the task by performing the task multiple times per day over a two-week period. Still, the strategy the participants trained on and the work shift to which they were assigned had a significant impact on performance.

During the first two days of the experiment (i.e., baseline days), performance was not significantly different across work shift conditions, which supports the conclusion that differences seen in the subsequent weeks were real and not a result of selection bias. Differences seen in the baseline condition with respect to strategy are consistent with previous research using this task (Gunzelmann et al., 2004). As seen in Figure 2, participants trained to use the counting strategy initially performed slightly better (but not significantly better) than participants trained to use the rotation strategy, and, as shown in Figure 3, misalignment angle and target location interacted, both of which are in line with those previous results.

Participants on the night shift tended to perform worse than those on the day shift. Previous research has shown that performance on a variety of tasks tends to be worse at night (e.g., Van Dongen & Dinges, 2005) and a number of commercial and industrial disasters have been attributed to degraded cognitive functioning associated with such shift work (Caldwell, 2003; Dinges, 1995). Further, within each shift condition, participants using the rotation strategy tended to perform worse than those using the counting strategy. As with the baseline data, this was expected, as it is consistent with previous research (Gunzelmann et al., 2004). However, the results also suggest that, although initially more difficult, the rotation strategy may be a more efficient approach to the task by the end of the experiment (at least in the day shift condition).

Asymptotic performance appears to have been reached earlier when the counting strategy was used. Further, asymptotic performance appears to have been the same for day and night shift when the counting strategy was used. When the rotation strategy was used, the rate of performance improvement was reduced. However, on the night shift, performance using the rotation strategy was eventually equivalent to performance using the counting strategy. Moreover, on the day shift, performance with the rotation strategy continued to improve through the end of the protocol, and was eventually better than the performance in all other conditions. These results suggest that (a) learning occurs faster for the counting strategy than for the rotation strategy, (b) the task is learned equally well when the counting strategy is used whether performed during the day or night, (c) the task is not learned as well at night when the rotation strategy is used, and (d) the rotation strategy may ultimately display the greatest amount of learning, when performed during the day.

So what could cause this interaction of strategy and shift? One possibility is the familiarity of the knowledge and transformations needed for the two strategies. The counting strategy relies heavily on well-known facts: the order of integers. That familiarity may have limited the impact of lower alertness and allowed participants on the night shift to arrive at a level of performance comparable to those on the day shift by the second half of the experiment.

In contrast, the rotation strategy may rely on knowledge that is less well practiced, thus requiring more cognitive or perceptual learning. Mental rotation is often associated with the visual perceptual system (e.g., Kosslyn, Thompson, & Ganis, 2006). While mental rotation is a well-practiced process, it may be stimulus or task specific. For instance, research has shown that the rate of rotation varies with stimulus complexity (Bethell-Fox & Shepard, 1988). While the stimuli in this task are relatively simple, the angle to be rotated by the participants is defined only by the end points, which may have added to the difficulty in maintaining an accurate visualization. Results of this imaginal visualization may be more difficult to learn or recall with a lower level of alertness, thus resulting in slower performance for participants on the night shift.

With practice, specific angles and rotations may be consolidated and stored in declarative memory. Within a session, the same combination of target and misalignment angle was never repeated. However, trials were repeated across sessions. This may have allowed participants to learn the results of mental rotations over days.

In addition, the rotation strategy may allow for more optimization of the procedural knowledge than does the counting strategy. Perhaps because mental rotations require more effort than counting, there was more pressure for additional optimization in the rotation strategy. Initially, the task takes longer to execute using the rotation strategy. This extra time may work as additional pressure to optimize (either explicitly or implicitly) the procedural knowledge brought to bear on the task. Further, variations in alertness may affect the pressure to optimize or the results of the optimization.

If the rotation strategy involves more learning throughout the task, either through declarative or procedural knowledge processes, then this may explain why participants using that strategy on the night shift performed more poorly. It is possible that one effect of decreased alertness is to decrease the effectiveness of learning. Specifically, fluctuations in alertness may affect the encoding, consolidation, or retrieval of declarative knowledge gained through effortful processes, like mental rotations, or interfere with the optimization of procedural knowledge (Jackson & Van Dongen, in press).

Importantly, performance on the last day of the experiment, when all participants performed the task during the day, does not support the argument that memory retrieval was the cause of slowed performance at night. Performance continued to improve only for participants using the rotation strategy on the day shift, but remained fairly consistent with the previous three days for all other participants. If retrieval processes, rather than learning or encoding, were causally involved, we would expect performance for night shift participants using the rotation strategy to improve noticeably on the last day. Additional research is required to determine if declarative knowledge, procedural knowledge, or both are affected by decreased alertness when performing orientation tasks at night.

Conclusion

Performance differences based on strategy and sleep patterns have both real-world and theoretical importance. The results have implications for task training and performance in real-world contexts, and also illustrate how different cognitive processes may be affected differently by circadian rhythms.

This study shows that training must be evaluated in context. The time of day in which the task will be performed and the time allowed for training need to be considered, among other things. If the choice of strategy were based upon the best day shift performance alone, the preferred strategy in this task may be rotation. However, shift alone is only part of the story. The rotation strategy resulted in performance improvements over the counting strategy only near the end of the two-week experiment. If the training period were short or if consistent performance across shifts were an important criterion, a strategy that uses familiar knowledge, as the count strategy does, may be more beneficial.

Choosing the correct strategy for the task environment can help reduce the effects of night shift decrements in alertness. Even small differences in performance can have drastic effects on some tasks. Orientation tasks are commonly performed in parallel with many time-critical tasks, such as driving or flying. Distractions from the primary tasks of even a couple hundreds of milliseconds can have unwanted consequences, especially when magnified in more complex tasks and environments. This is true in many situations, in addition to orientation tasks, where delays and errors can have severe consequences.

This research also reveals ways in which different components of cognitive functioning, utilized by different strategies, are differentially affected by circadian rhythms. The performance of individuals using the counting strategy did not vary significantly between those on a day shift schedule and those on a night shift schedule. This robustness was likely the result of using familiar knowledge in the strategy, leading to similar learning trends regardless of shift assignment.

In contrast, there was a significant impact of shift on performance for those using the rotation strategy, suggesting that the cognitive processes involved may be less robust to degradations in alertness at night. This vulnerability may be due to a greater reliance on the learning of visual perceptual information (i.e., angles and rotations), which appeared to be hindered by lower alertness.

In conclusion, the findings presented here speak to both the need for considering the strategy set used in a task and the potential for decrements in learning caused by decreased alertness. In other words, when evaluating the effects of cognitive moderators, such as alertness, it is critical to consider the strategy people use to complete tasks.

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