

Night work, circadian rhythm, and cognitive performance: A field study with airport security screeners

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ABSTRACT

The effects of circadian rhythms and night work on performance have been extensively studied using standardized, non-work-related tasks in laboratory settings. However, field research on work performance is scarce in this domain. This study addresses this gap by analyzing four million behavioral responses from 1437 security officers at an international airport. We compared threat detection performance during the routine security screening of passengers' baggage X-ray images across night shifts (shift starting between 0:00 and 2:59), early morning shifts (starting between 3:00 and 5:59), and standard morning shifts (starting between 6:00 and 7:59). Processing times followed the circadian rhythm of attention found in laboratory studies, indicating that the rhythm affects real-life work performance. False alarm rates (i.e. false target present responses) were slightly higher during night and early morning shifts than during standard morning shifts, with no significant difference in the security-relevant hit rates (i.e. true target present responses). Furthermore, we found no performance differences between night work and early morning shifts, suggesting that both can disrupt employees' natural sleep patterns with implications on performance.

1. Introduction

Maintaining consistent attention over time is crucial for numerous work activities. For instance, if a radiologist investigating a potential cancer case overlooks a tumor in a medical image (e.g., X-ray, CT, ultrasound, or mammography) because of a lapse in attention, it could pose serious health risks. Conversely, false mammography-related alarms for breast cancer, for example, have been shown to lead to unnecessary medical procedures, unnecessary financial expenses, and patient anxiety with psychological harm, sometimes even years later (Brett et al., 2005; Brodersen and Siersma, 2013; Chubak et al., 2010; Ho et al., 2022; Nelson et al., 2016). Maintaining attention is also important in airport security, where security officers (referred to as screeners) visually inspect X-ray images of passenger bags for threat items (e.g., bombs, guns, and knives) and other prohibited items (Harris, 2002). Reduced attention from screeners when inspecting passenger bags could enable terrorists to bring a bomb or other prohibited articles onto an airplane to destroy or hijack it during flight. Laboratory studies have indicated that human attention follows a 24-h circadian rhythm with periods of

reduced attention (Horowitz et al., 2003; Valdez et al., 2005, 2010). However, it remains unclear whether this affects real-life job performance (Schmidt et al., 2007; Van Dongen and Dinges, 2003).

1.1. Circadian rhythm of attention

Summarizing relevant findings from laboratory studies, Valdez (2019) described the circadian rhythm of attention during a typical workday (Fig. 1) as follows: In the early day drowsiness phase (first 3 h after habitual wake-up time), individuals' attention levels are at their lowest. This phase is followed by the early day peak phase (hours four to seven after the habitual wake-up time), during which attention levels increase and have a first peak. During the post-midday (lunch) dip (hours eight to nine after the habitual wake-up time), attention levels drop. During the late-day peak (hours 10 to 15 after the habitual wake-up time), attention levels reach a second peak. From hours 16 to 21 after the habitual wake-up time, attention levels drop rapidly before people fall asleep.

The laboratory studies indicating the stated circadian rhythm of

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attention by Valdez (2019) required participants to adopt unnatural sleep–wake patterns to better detect circadian rhythms and their driving factors (e.g. Blatter and Cajochen, 2007; Schmidt et al., 2007; Valdez, 2019). Common laboratory methodologies involve keeping participants awake for extended durations or introducing sleep–wake cycles that deviate from the regular 24-h cycle (e.g., a 28-h one). However, given the divergence from typical sleep–wake cycles, the relevance of these findings for individuals maintaining regular sleep–wake cycles remains unclear from such studies (Van Dongen and Dinges, 2003). Efforts have been made to measure the circadian rhythm of performance in participants who maintain regular sleep–wake cycles. Although these studies suggest that performance on simple repetitive tasks, such as repetitive card sorting, follow a clear circadian rhythm (Colquhoun, 1971; Kleitman, 1987), studies regarding performance on more cognitively complex tasks, including visual search tasks, have yielded inconsistent and inconclusive results (see Carrier and Monk, 2000; Schmidt et al., 2007; Valdez, 2019). Valdez (2019) attributed the variability in results to insufficient sample sizes. Furthermore, some studies may have failed to detect circadian changes because they did not adequately control for external factors, such as lighting conditions and food intake. External factors can potentially disrupt and mask underlying rhythms (Blatter and Cajochen, 2007; Schmidt et al., 2007; Valdez, 2019). If external factors have a regular pattern during the day, they can result in wrong conclusions (Schmidt et al., 2007). For example, chefs usually serve more people and therefore face greater pressure to cook quickly during lunch time than during the late afternoon; therefore, more mistakes could potentially occur regularly during lunch time. However, this does not indicate an inherent circadian rhythm for cooking abilities. Similarly, in airport security lanes, task difficulty (baggage characteristics and task load) and other external factors (e.g., stress and lighting conditions) vary across the day and could falsely suggest a circadian rhythm for screening performance. For example, early in the morning, business passengers fly carrying lighter baggage than families flying on vacation later in the day. This could make baggage screening in the morning easier.

1.2. Nightwork: night and early morning shifts

Night shifts are common in numerous work domains, including airport security screening. Some airports operate for 24 h a day (e.g., Birmingham Airport and Beijing Capital International Airport), but even for those with a ban on night flights, screeners are often involved in early morning shifts requiring waking up in darkness, followed by partial night work (defined as work starting before 06:00). For example, they may start their shift at 04:00 to ensure that the aircraft is ready to depart as early as 05:00. Numerous studies have indicated that working at night can lead to more untoward incidents and impairments in vigilance, selective attention, and other cognitive functions (Dinges, 1995; Ferguson

et al., 2012; Ganesan et al., 2019; Krueger, 1989; Pilcher et al., 2000; Santhi et al., 2007; Williamson and Feyer, 2000). However, low performance levels during the night seem to primarily pertain to people following a diurnal sleep cycle and not to all night shift workers. Some shift workers operate according to schedules that include multiple consecutive night shifts. In such cases, performance has been indicated to recover (Chellappa et al., 2018; Lamond et al., 2004; Santhi et al., 2007). Performance can recover fully with regular night shifts in certain job environments (Hansen et al., 2010; Wilkinson, 1992). Most night work studies focus on night shifts and less studies focus on early morning shift (Ingre et al., 2004). That is, two studies have been found focusing on performance impairments due to early morning shifts, while one study found an effect (Haldar et al., 2013) the other did not (Kecklund et al., 1997). Another reason why the effects of circadian rhythms and night/early morning shifts on real-life job performance remain unclear is that previous studies have often relied on highly standardized, non-work tasks (Schmidt et al., 2007). For example, to measure the effects on selective attention, previous studies often used simple visual search tasks (e.g., searching for a “T” among “L” distractors).

1.3. The present study

In the present study, real-life behavioral responses were recorded during X-ray baggage screening at airports. The task entails screeners (airport security officers) searching for prohibited articles such as guns, knives, bombs and other prohibited articles in X-ray images. It is a visual inspection task that entails searching and decision-making (Koller et al., 2009; Wolfe and Van Wert, 2010). Baggage screening is more challenging than standardized visual search tasks, (for reviews see Biggs and Mitroff, 2015; Donnelly et al., 2019; Schwaninger, 2006), making it questionable whether the findings of standardized visual search tasks apply to baggage screening. In baggage screening, targets (e.g., threat items) are often more complex, ambiguous, and less noticeable (e.g. Biggs and Mitroff, 2015; Radvansky and Ashcraft, 2016). Detection becomes even harder when prohibited items are displayed from unusual viewpoints, are superimposed by other items, or are placed within complex baggage with many different items (Schwaninger et al., 2005, 2007). The impact of night work on X-ray baggage screening was investigated in one study with nonprofessional participants and simulated X-ray images in a laboratory setting (Basner et al., 2008). Participants did not miss more threat items during a simulated night shift compared with a regular shift but reported more false alarms. Interestingly, the reaction times were faster during the night shift. However, the results may not be directly applicable to real-life screening as they did not account for performance recovery in screeners working multiple night shifts. Furthermore, unlike participants in a laboratory setting, screeners in busy security lanes must maintain concentration for longer periods between noise and other distractions, requiring a high level of

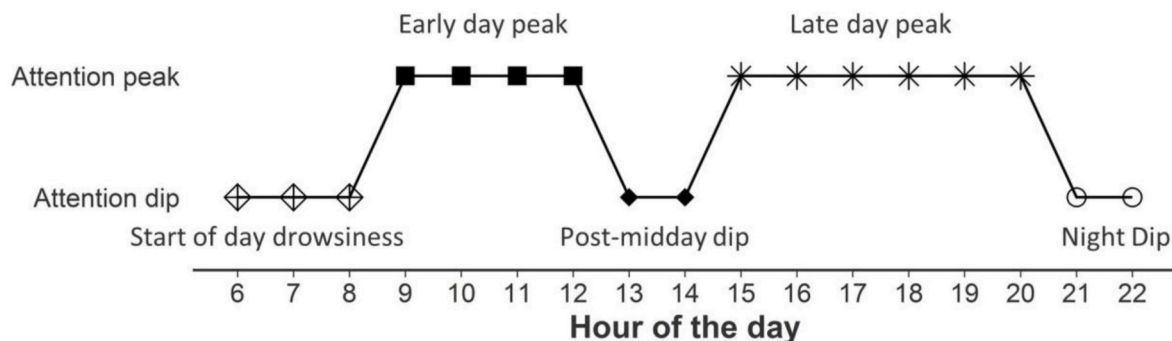


Fig. 1. Circadian rhythm of attention during a typical workday adapted from the description of Valdez (2019).

Note. This depiction applies to a person who usually wakes up at the sixth hour of the day (05:00–05:59) and goes to bed at the 20-s hour of the day (21:00–21:59). The depicted dichotomous course is a simplification, as the exact curve delineation has not been established.

vigilance (Buser et al., 2020; Speed et al., 2015). Real-life baggage screening is further complicated by the rarity of certain threat items (e. g., bombs) (Buser et al., 2020; Godwin et al., 2010; Wolfe et al., 2007).

The behavioral responses analyzed in the present study were recorded by the threat image projection (TIP) system of an international European airport that used single-view X-ray machines and matrix screening (Buser and Merks, 2020). The TIP system projects prerecorded threat items onto real passenger bag images (see Fig. 2) and stores data on the screener's detection performance. Many airports use a TIP system in which a fictional threat item (FTI) is projected onto real passenger baggage at the security lanes; this is known as FTI-TIP (Hofer and Schwaninger, 2005; Meuter and Lacherez, 2016; Skorupski and Uchroński, 2016). The airport that provided data for the current study uses an alternative TIP system in which FTIs are merged and projected onto bags beforehand to create combined threat images (CTIs) (Hofer and Schwaninger, 2005). This enables that only realistic-looking TIP images are used during operations, unlike in FTI-TIP, where images sometimes appear unrealistic (Riz à Porta et al., 2022). At the airport, on average one TIP image was displayed for every 50 bags. The analysis of real-life performance is challenging as large sample sizes are needed (Valdez, 2019); this is addressed in the present study by incorporating approximately four million behavioral responses from approximately one and a half thousand screeners. Furthermore, while analyzing real-life performance external factors cannot be controlled like in a laboratory setting; this is addressed by a strong emphasis on controlling confounding factors using state-of-the-art statistical methodologies.

1.4. Research questions and hypotheses

Screener performance (threat detection, false alarm rate, and processing time) was assessed during night shifts (starting from the first to the third hour of the day; or between 00:00 and 02:59), early morning shifts (starting from fourth and sixth hour of the day; or between 03:00 and 05:59), and standard morning shifts (starting from the seventh to the 8 h of the day; or between 06:00 and 07:59). Based on Valdez (2019), we tested three hypotheses regarding circadian rhythms: screeners perform better during the early day peak than during the early day drowsiness phase (H1a); screeners perform worse during the post-midday dip phase than during the early day peak (H1b); and screeners perform better during the late day peak than during the post-midday dip phase (H1c). We also tested three hypotheses regarding shift work: screeners performed worse during the night (H2a) compared with standard morning shifts; screeners performed worse during early morning shifts (H2b) compared with standard morning shifts; and the performance between night and early morning shifts was not statistically different (H2c), as screeners in both shift types were found to

experience sleep impairments in previous studies (Ingre et al., 2004; Kecklund et al., 1997; Sallinen and Kecklund, 2010).

2. Methods

2.1. Methodological approach

External factors that are correlated to the circadian rhythm can suggest a circadian rhythm that does not exist. In airport security lanes, task difficulty (baggage characteristics and task load) and other external factors (e.g., stress and lighting conditions) are different at certain hours of the day. For example, during certain hours (early morning and evening), business passengers fly carrying lighter baggage than families flying on vacation. Therefore, the hour of the day could bias the analysis of performance differences between different circadian stages (H1a, H1b, and H1c). However, at any given hour of the day, screeners in the night shift are at different circadian stages than those in the early morning shift (see Fig. 3A). Therefore, to control for the hour of the day, we compared the performances of screeners across the night and early morning shifts within each overlapping hour of the day.

Screeners in night shifts started, on average, at the third hour of the day (02:00–02:59), and screeners in the early morning shift started, on average, at the fifth hour of the day (04:00–04:59), as depicted in Fig. 3A. To derive the circadian phases, the screeners were assumed to be in their third hour after waking up at the beginning of their shift, based on a study (Roach et al., 2016) that suggests that people working in shifts starting between the second and 8 h of the day wake up approximately 2 h, on average, before they start their shifts. To compare night and early morning shifts, we analyzed the performance differences between early morning and standard morning shifts.

Regarding hypotheses H2a, H2b, and H2c, night and early morning shifts were expected to reduce performance over the entire duration of the shifts. To test these hypotheses, performance differences across the entire shift were investigated. In addition to the hour of the day, other external factors had to be controlled. The factors were determined by following guidelines from Hernán and Robins (2020), which are based on drawing directed acyclic graphs (Pearl et al., 2016) and are supposed to eliminate the shortcomings of earlier approaches (Shrier and Platt, 2008). Using this approach, the factors of season, checkpoint, and task load at the checkpoint were determined to be potentially confounding and were controlled for.

2.2. Sample

Anonymized behavioral responses from 1437 screeners at an international European airport were analyzed with 40,232 screening sessions

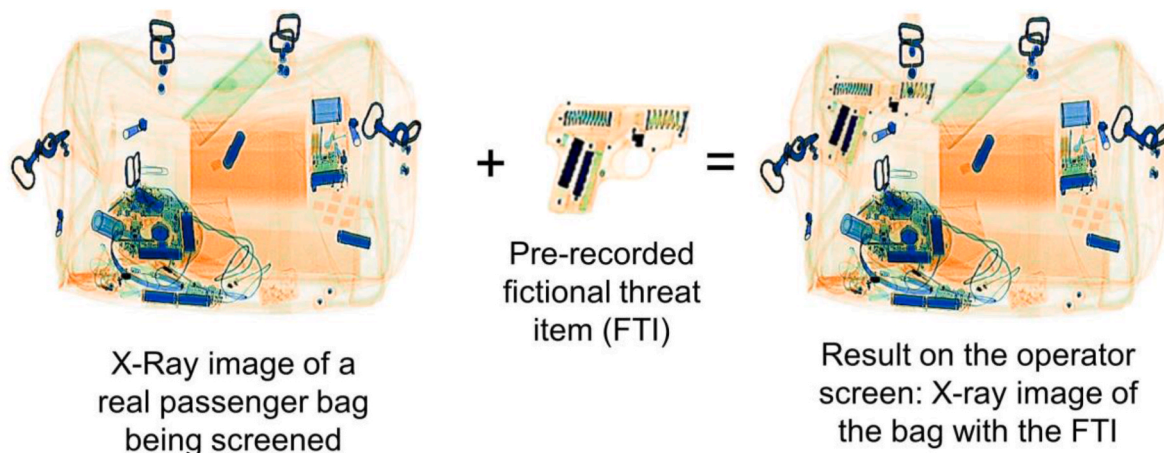


Fig. 2. Illustration of threat image projection functionality in cabin baggage screening using fictional threat items (FTI), adapted from Schwaninger (2006).

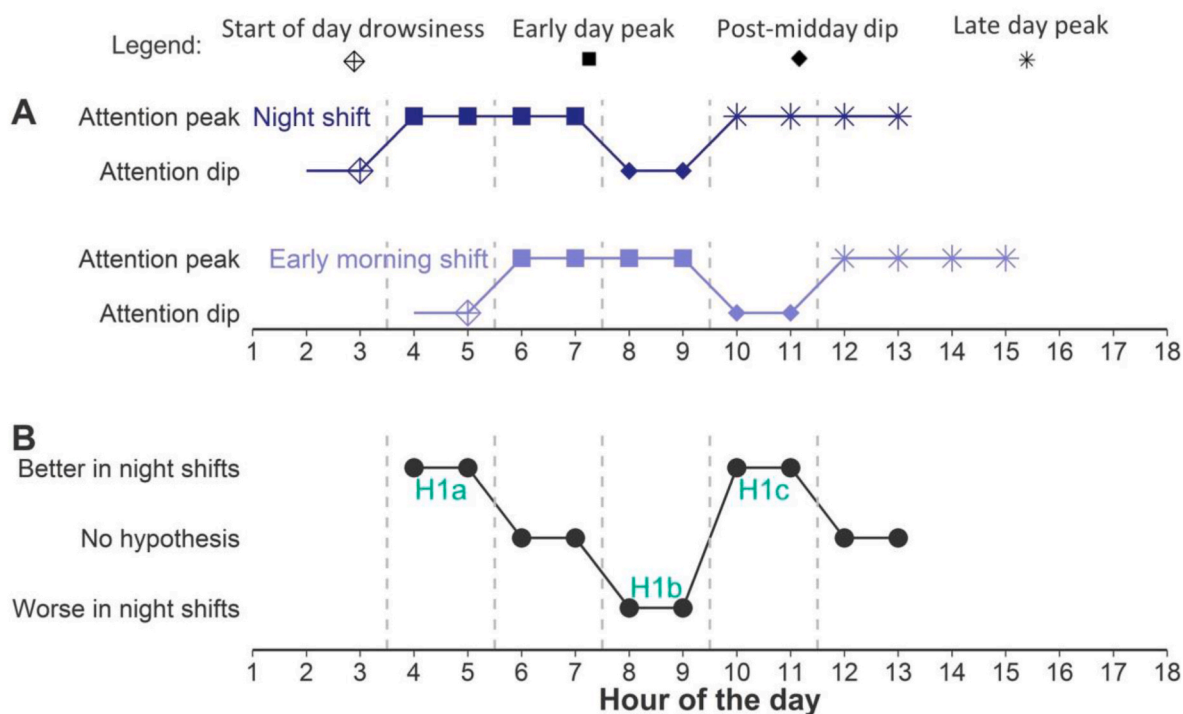


Fig. 3. Circadian rhythm of attention in night and early morning shifts according to Valdez (2019) (A) and hypothesized screening performance differences (B). *Note.* Hour of the day 1 pertains to 00:00–00:59 etc.; hypotheses: (H1a) screeners perform better during the early day peak compared with the early day drowsiness phase; (H1b) screeners perform worse during the post-midday dip phase compared with the early day peak; (H1c) screeners perform better during the late day peak compared with the post-midday dip phase.

(typically about 20 min, screeners rotated between different positions at the checkpoint (Michel et al., 2014)), 82,251 TIP events (responses to TIP image projections), and 3,953,519 baggage events (responses to regular X-ray images of baggage).

2.3. Data processing

The data were processed using R (R Core Team, 2020) and Spark, a large-scale data processing framework (Luraschi et al., 2021; Zaharia et al., 2016). As the airport was unable to share personal data on the screeners' shifts, their start and end times had to be inferred. They were approximated using the first and last screening activities within a time span of up to 11 h. Screening activities separated by more than 11 h were considered parts of different shifts; a break of at least 11 h was required between shifts. As the approximation of shift start and end only works well for screeners with screening activities close to the beginning and end of their shift, and the regular shift length (from shift start to shift end, including breaks) was 8 h, we only considered approximated shifts longer than 7 h. We also excluded 27 approximated shifts as they were considered outliers (longer than 11 h). Raw data from the selected period originally included 77,167 screening sessions with 161,274 TIP events and 7,781,412 baggage events from 1764 screeners. In the data processing and cleanup stages, data were excluded for the following reasons (see Fig. 5 for data flow): TIP and baggage events without corresponding sessions, sessions without TIP and baggage events, sessions shorter than 3 min or longer than 30 min, and TIP and baggage events with processing times longer than 21 s (which should not occur because the system was configured to automatically time-out and reject events after 21 s). We only compared the night, early morning, and standard morning shifts, the other shifts were excluded. As discussed in the introduction, the regularity of night work can be relevant for the effect on performance and can differ between jobs and organizations (Chellappa et al., 2018; Hansen et al., 2010; Lamond et al., 2004; Santhi et al., 2007; Wilkinson, 1992). At the airport examined in our study, the

shift work of the screeners involved individual start and end times considering their preferences and passenger volume; there was no standard shift pattern that was followed by most screeners. Regarding the shifts identified in our data, screeners often worked up to three similar night and early morning shifts in a row, the maximum allowed before a mandatory 48-h break, according to national regulation. For the subsample where screeners worked three consecutive calendar days, 82% of the night and 76% of the early morning shifts started at a similar time (± 2 h) as the shifts on the preceding two days (night shifts: $n = 55$; early morning shifts: $n = 215$). For the subsample where screeners worked two consecutive calendar days, 88% of the night shifts and 92% of the early morning shifts started at a similar time as the shift the day before (night shifts: $n = 294$; early morning shifts: $n = 1416$).

2.4. Measures

The independent variables were shift type (night, early morning, standard morning) and hour of day (1-h intervals from the first until the eighteenth hour of the day). *Threat item detection* (dichotomous) was a dependent variable indicating whether a TIP image was detected (1) or missed (0). *Mean processing time* (seconds) was another dependent variable that indicated a screener's average processing time across all baggage events in a session. *False alarm rate* (proportion) was the third dependent variable. The false alarm rate was approximated as the proportion of rejects in a session that were not confirmed in the resulting manual search of the baggage (in practice, many rejects are due to inappropriately divested liquids and large electronics) across all X-ray images presented in the session (typically, the false alarm rate refers to the proportion of rejects across only images that are confirmed not to include a prohibited item, however, such a confirmation is not possible in the field). The analyses also included *time of year* as a control variable (categorical, with October as the reference category). To control for *checkpoint*, a categorical variable was included that differentiated five checkpoints (departures and transit) in the data. To control for *task load*

at the checkpoint, a numeric variable was included that represented the number of baggage events at the checkpoint in a 15-min time interval.

2.5. Data analysis

The main analyses were based on mixed models. For processing time and false alarm rate, the average values per session were analyzed. As sessions often included only one or two TIP events, threat item detection was analyzed at the level of single TIP events. All the models included the screener as a random effect. The model for threat item detection also included the CTI—the CTI projected in a TIP event and the CTI library (the image pool from which the CTI was drawn)—as a random effect. Shift type was included as a categorical variable, with the early morning shift as the reference category. The model included the interaction between the checkpoint and task load at the checkpoint because the checkpoints differed in size, and the number of baggage events per time could therefore only serve as an indicator of the workload within a checkpoint. As the relationship between performance measures and task load is not necessarily linear, models with polynomials of increasing degree were compared, and for each performance measure, the task load was controlled based on the best-fitting polynomial. All analyses were performed using the R software (R Core Team, 2020). Threat item detection was modelled using binomial generalized linear mixed models with the lme4-package (Bates et al., 2015). Autocorrelation was found to be negligible (DW = 1.96; Durbin-Watson test) and not corrected for. The mean processing time and false alarm rate were modelled with linear mixed models using the nlme package (Pinheiro et al., 2020) with autocorrelation control (AR1).

For each of the three dependent variables, three models were calculated and compared based on likelihood ratio tests: a baseline model (see Eq. (1)) with the variable hour of the day, other control variables, and random effects; a main-effect model (see Eq. (2)), which additionally included the variable shift type (Eq. (2)); and an interaction

model (see Eq. (3)), which additionally included the main-effect model, which, in turn, included the interaction between shift type and hour of the day. To investigate whether performance differed among the three shift types across the entire shift, we evaluated whether the main-effects model explained the performance measures better than the null model without the shift type. If performance was affected by circadian rhythm, the differences between the different shift types would be expected to vary across the day, and the interaction model would outperform the main effect model. If a main effect or interaction was present for one of the dependent variables, one-sided tests were conducted based on the marginal effects estimated using the emmeans-package (Lenth, 2021) for the specific hypotheses illustrated in Figs. 3 and 4. In addition to these tests, we reported two-sided 95% confidence intervals (CIs) to provide better information about the estimated effect sizes.

$$\text{Screening performance} = \text{hour of day} + \text{control variables} + \text{random effects} \quad (1)$$

$$\text{Screening performance} = \text{shift type} + \text{hour of day} + \text{control variables} + \text{random effects} \quad (2)$$

$$\text{Screening performance} = \text{shift type} \times \text{hour of day} + \text{control variables} + \text{random effects} \quad (3)$$

3. Results

As a first step (Table 1), we determined whether TIP detection, false-alarm rate, and mean processing time were better explained by the main effect model of shift type (Eq. (2)) than by the null model (Eq. (1)), which would indicate general differences between night, early morning, and standard morning shifts (a summary of the model results is given in Table A1 in the Appendix). Furthermore, we determined whether they were better explained by the interaction model of shift type with hour of

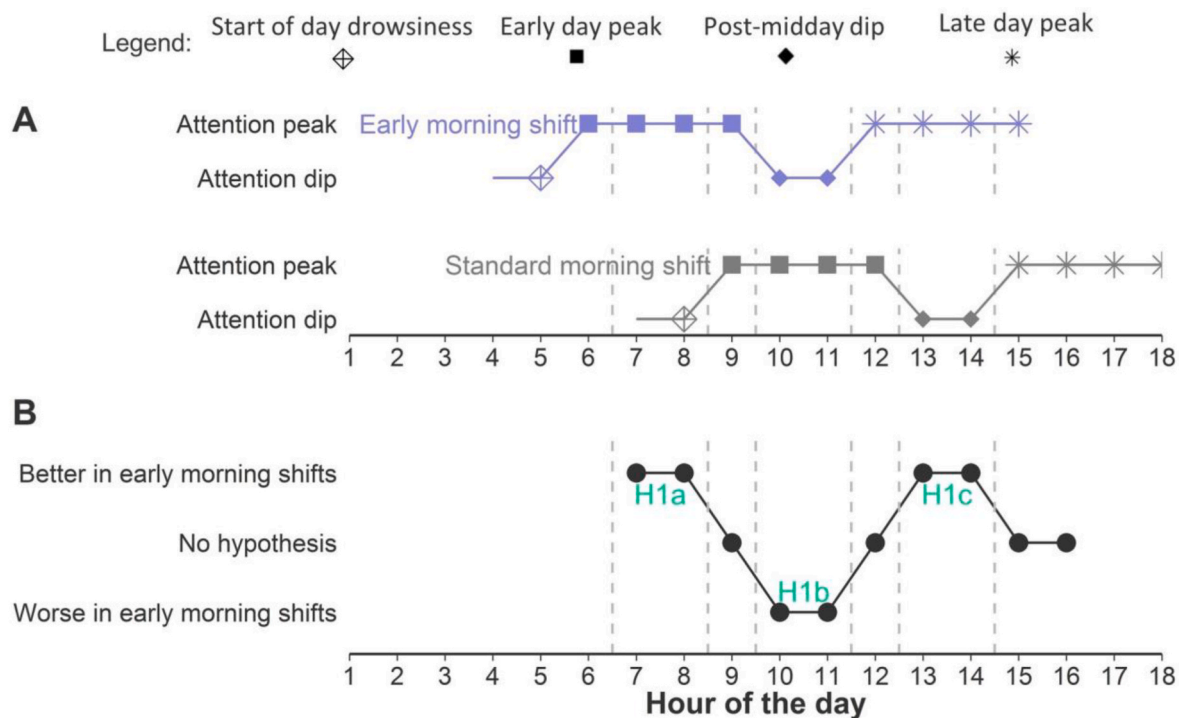


Fig. 4. Circadian rhythm of attention in early morning and standard morning shifts according to Valdez (2019) (A) and hypothesized screening performance differences (B).
 Note. Hour of the day 1 pertains to 00:00–00:59 etc.; hypotheses: (H1a) screeners perform better during the early day peak compared with the early day drowsiness phase; (H1b) screeners perform worse during the post-midday dip phase compared with the early day peak; (H1c) screeners perform better during the late day peak phase compared with the post-midday dip.

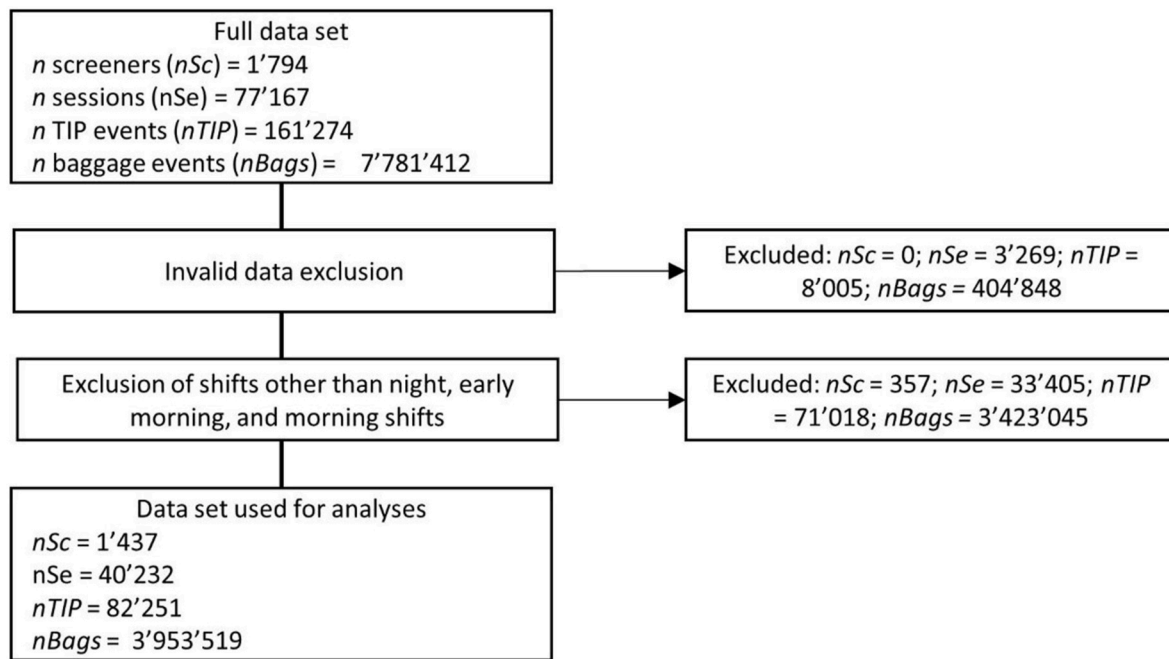


Fig. 5. Data flow during data processing.

Table 1

Model comparisons between the null (Eq. (1)), main-effect (Eq. (2)), and interaction-effect (Eq. (3)) models.

Model	TIP-detection				False-alarm rate				Mean processing time			
	AIC	X ²	df	p	AIC	X ²	df	p	AIC	X ²	df	p
Eq. 1	28592				-113231				128825			
Eq. 2	28594	2.22	2	0.329	-113247	20.42	2	<.001	128826	2.6	2	0.272
Eq. 3	28621	8.76	18	0.965	-113238	26.79	18	0.083	128772	90	18	<.001
Eq. 1 vs 3		10.98	20	0.947								

the day (Eq. (3)) which would indicate a circadian rhythm. If an effect of shift type or circadian rhythm was indicated, the effects were further analyzed.

Regarding TIP detection (95% hits and 5% misses), both the AIC and the likelihood ratio test suggested that, compared to the null model (Eq. 1), TIP detection was not better explained by either the main-effect model (Eq. 2) or the interaction-effect model (Eq. 3). In other words, TIP detection was not affected by the shift type and did not have a circadian rhythm. Therefore, TIP detection was not further examined in this study. Regarding the false-alarm rate ($M = .14$, $SD = .09$), the main-effect model (Eq. 2) showed a better fit than the null model (Eq. 1), indicating an effect of shift type; however, the interaction-effect model (Eq. 3) did not show an additional improvement, indicating the absence of a circadian rhythm. To further examine how false-alarm rates are affected by shift type, the difference between the three shift types was computed based on the main-effect model as marginal effects (see Section 2.4. Data Analysis). Screeners made 0.31 percentage points more false alarms in the night shifts than in the standard morning shifts ($p = .023$, 95% CI [0.0006, 0.0062]), which pertained to a 2% increase in false alarms, consistent with H2a, and approximately 0.45 percentage points more false alarms in the early morning shifts than in the standard morning shift ($p < .001$, 95% CI [0.0025, 0.0065]), which pertained to a 3% increase in false alarms, consistent with H2b. However, the false-alarm rate was not significantly different between the night and early morning shifts ($b = 0.0013$, $p = .322$, 95% CI [-0.0131, 0.0040]), consistent with H2c.

Regarding model comparisons for mean processing time ($M = 8.14s$, $SD = 2.65s$), the main-effect model (Eq. (2)) did not show an improved fit compared with the null model (Eq. (1)), indicating no main effect of

shift type, but the interaction-effect model (Eq. (3)) showed a better fit than the main-effect model (Eq. (2)), indicating the presence of a circadian rhythm. To further examine the circadian rhythm in processing time, the differences between night and early morning shifts were computed for each hour of the day (based on the interaction model). As depicted in Fig. 6, the significant differences generally corresponded to the hypotheses derived from the circadian rhythm of attention, as stated by Valdez (2019). The same is true for the hourly differences between the early morning and standard morning shifts (see Fig. 7). Screeners processed X-ray images significantly slower during early day drowsiness conditions than during the early day peak phase (H1a), faster during the early day peak than during the post-midday dip phase (H1b), and slower during the post-midday dip than during the late day peak phase (H1c).

4. Discussion

In this study, we examined four million real-life performance recordings from 1437 screeners to evaluate whether (H1) X-ray baggage screening performance follows the circadian rhythm of attention observed in laboratory studies (Valdez, 2019) and whether (H2) performance is negatively impacted by insufficient adaptation to night and early morning shifts. We assessed processing times, detection rates, and false alarm rates during night, early morning, and standard morning shifts, starting between 00:00 and 02:59, 03:00 and 05:59, and 06:00 and 07:59, respectively.

4.1. Circadian rhythm of screening performance (H1)

We hypothesized that screeners perform better during the early day

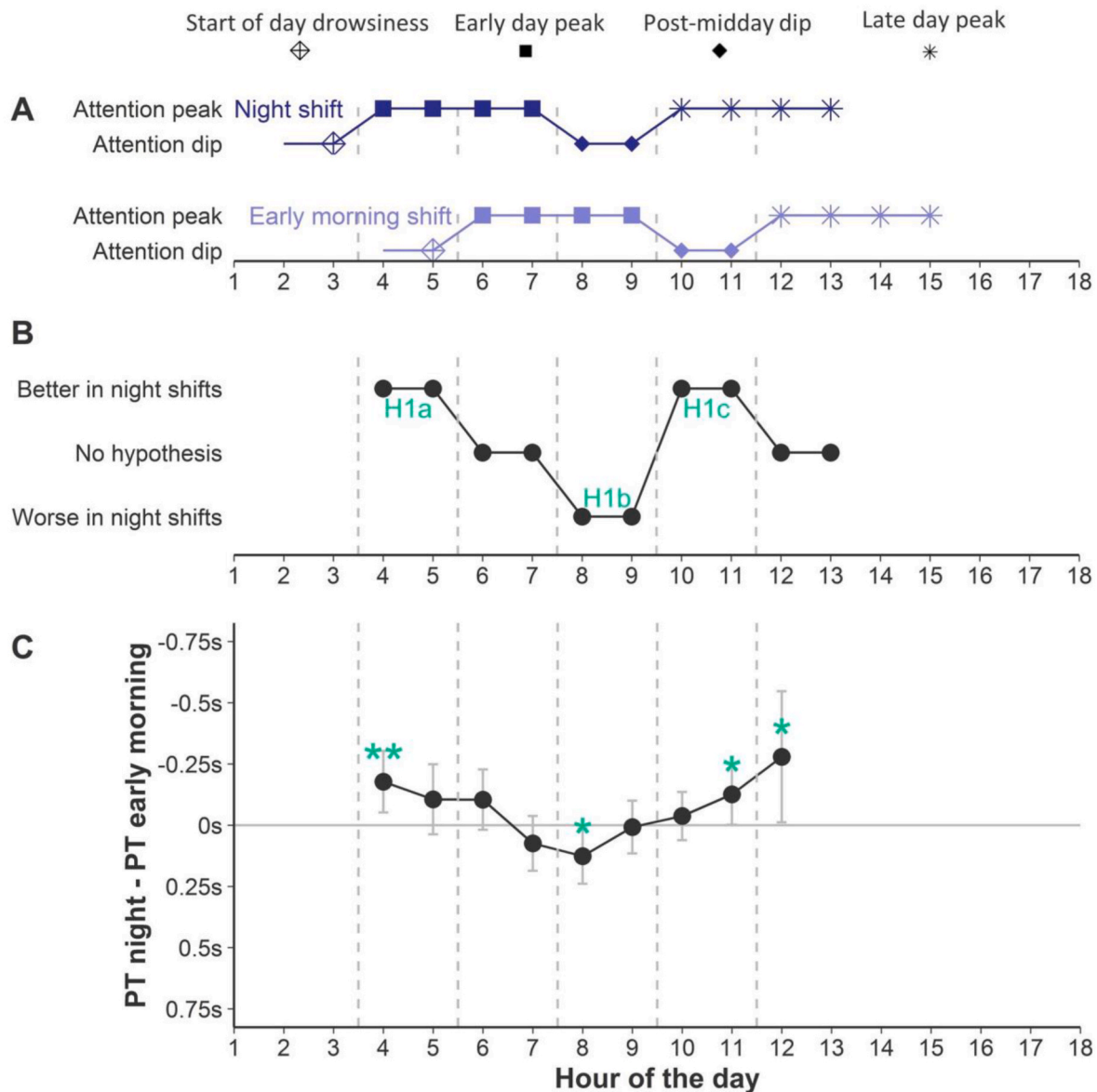


Fig. 6. Circadian rhythm of attention in night and early morning shifts according to Valdez (2019) (A), hypothesized screening performance differences (B), and the results for differences in processing time (processing time night shifts – processing time early morning shifts) for each overlapping hour-of-the-day (C). Note. Regarding results (C): * $p < .05$, ** $p < .01$, whiskers indicate a two-way 95% confidence interval, negative values indicate faster processing times in night shifts, and positive values indicate faster processing times in early morning shifts.

peak than during the early day drowsiness phase (H1a), worse during the post-midday dip phase than during the early day peak (H1b), and better during the late day peak than during the post-midday dip phase (H1c). In accordance with our hypotheses, screeners processed images quicker during the early day peak phase than during the early day drowsiness phase (H1a), slower during the post-lunch dip than during the early day improvement stage (H1b), and quicker during the late-day improvement stage than during the post-lunch dip (H1c). However, the hit and false alarm rates did not show statistically significant circadian variations.

The observed circadian variations in processing speed are consistent with findings from laboratory studies (Horowitz et al., 2003; Valdez et al., 2005, 2010) and provide evidence that the circadian rhythm of attention observed in laboratory studies can affect real-life work performance. Previous studies outside laboratory settings have not produced clear results regarding this, likely owing to small sample sizes and inadequate control of confounders (Schmidt et al., 2007; Valdez, 2019). We could not completely prevent the possibility of confounding factors

(i.e., no experimental setup). However, the results of our study are less likely to be confounded than previous studies because we controlled for external factors with a circadian rhythm (e.g., task load, lighting conditions) by controlling for hour of the day, which previous field studies have not done. We further controlled for additional factors by applying a state-of-the-art method to detect possible confounders and other biased factors (Hernán and Robins, 2020; Pearl et al., 2016). Additionally, prior research utilized highly standardized tasks (Schmidt et al., 2007), which were simpler than real-life job tasks, raising additional doubts about the generalizability of the previous results to real-world applications. Our study revealed that, while the circadian rhythm of attention affects screening efficiency, it does not seem to affect effectiveness and efficacy in terms of detection or false alarm rates.

4.2. Effect of night work shifts on screening performance (H2)

We hypothesized that screeners perform worse during night shifts (H2a) than during standard morning shifts, worse during early morning

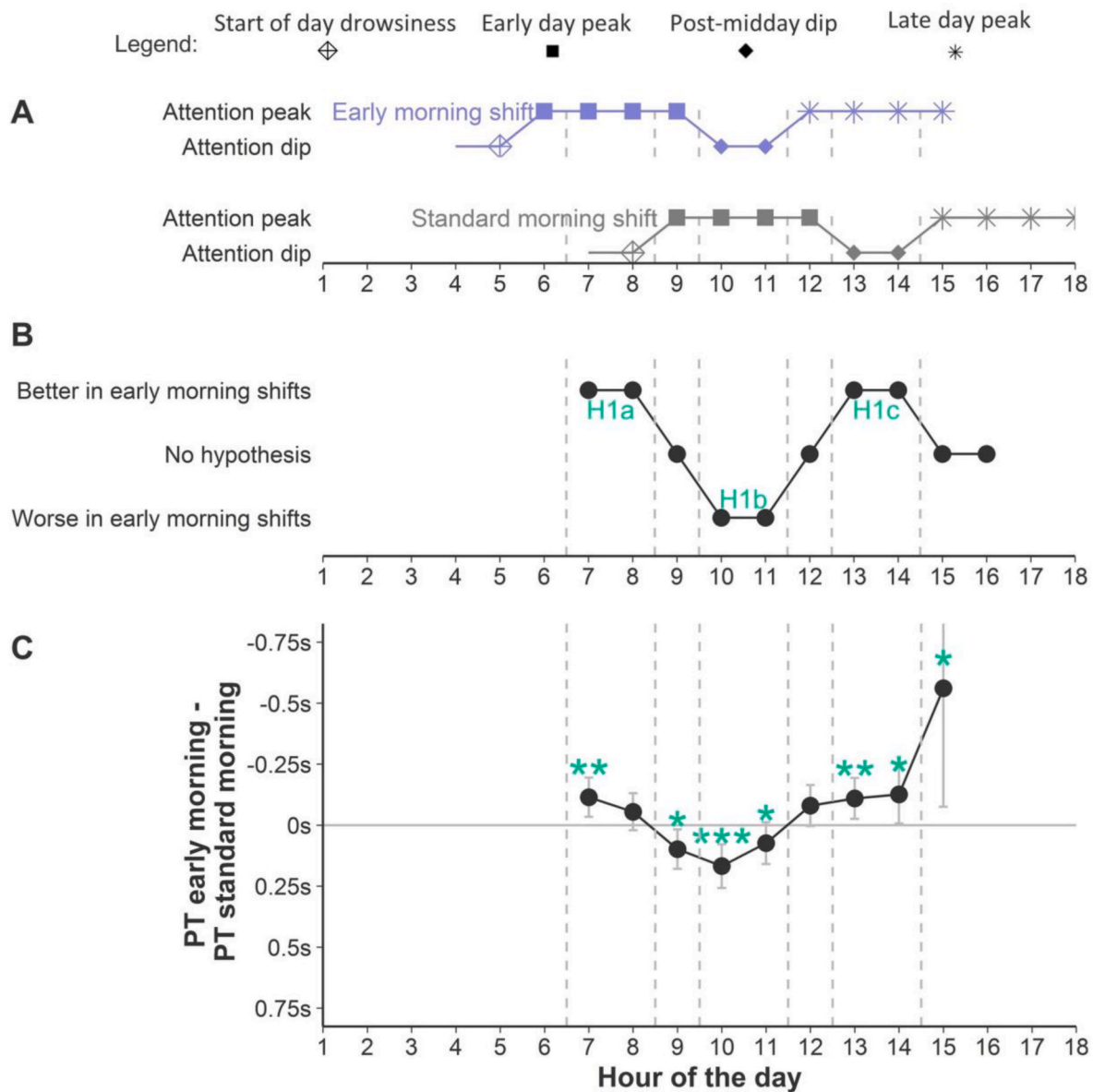


Fig. 7. Circadian rhythm of attention in night and early morning shifts according to Valdez (2019) (A), hypothesized screening performance differences (B), and the results for differences in processing time (processing time early morning shifts – processing time standard morning shifts) for each overlapping hour-of-the-day (C). *Note.* Regarding the results (C): * $p < .05$, ** $p < .01$, *** $p < .01$, whiskers indicate a two-way 95% confidence interval, negative values in (C) indicate faster processing times in early morning shifts, and positive values indicate faster processing times in standard morning shifts.

shifts (H2b) than during standard morning shifts, and that performance between night and early morning shifts is not statistically different (H2c). Screeners in the night and early morning shifts more often wrongly indicated that a threat item was present (higher false alarm rate) compared with the standard morning shifts, supporting H2a and H2b. No performance difference was found between the night and early morning shifts for any measure, supporting H2c. Our study confirms the results of field studies demonstrating that night work can affect job performance. The fact that false alarm rates, but not detection rates, were affected is consistent with a study that evaluated baggage screening in a laboratory setting (Basner et al., 2008). However, in that study, the increase in percentage in the false alarm rate (16%) was higher than in our study (2%). The lower increase in the false alarm rate in our study could be a result of a higher adaptation to a night-shift schedule, as screeners often had consecutive similar night shifts, in contrast to the laboratory study, where a single night shift was simulated. That single night shifts cause more impairment than consecutive

night shifts is supported by other studies (e.g. Chellappa et al., 2018; Lamond et al., 2004; Santhi et al., 2007). This coincides with adaptations of the biological clock to a night shift schedule (Hennig et al., 1998; Molzof et al., 2019). However, some earlier studies suggested that performance related to safety could decline with an increasing number of night shifts (Folkard and Tucker, 2003). Many studies have investigated night shifts, whereas early morning shifts have received little attention. Our study provides evidence that working early morning shifts can negatively affect performance. This is not surprising, as workers in early morning shifts, similar to those in night shifts, often have disrupted sleep patterns and shorter sleep durations (Ingre et al., 2004; Kecklund et al., 1997; Sallinen and Kecklund, 2010).

4.3. Practical implications

Our findings indicate that neither the circadian rhythm of screening performance nor night shifts pose a security risk as they do not seem to

impact threat detection (hit rates). Night and early morning shifts seem to increase the number of false alarms by a small margin. Therefore, they might affect the efficiency of baggage screening and could increase costs, given the increased need for manual searches of baggage when more false alarms are made. However, night and early morning shifts are operationally unavoidable if airports want to offer night and early morning flights, which seems to be of much greater business interest than avoiding a slight increase in false alarms. More concerning are the potential implications of false alarms in other areas. For example, in medical image interpretation, an increase in false alarms will cause further diagnostic measures, with unnecessary stress for patients, such as those wrongly diagnosed for a tumor, thus having negative implications for mental health (sometimes even long-term), further radiation exposure, and increased healthcare costs (Brett et al., 2005; Brodersen and Siersma, 2013; Chubak et al., 2010; Ho et al., 2022; Nelson et al., 2016). If an increase in false alarms would be present in domains with more negative implications, the 3-min psychomotor vigilance test developed by Basner and Rubinstein (2011) could be a solution to test fitness for duty. This test has been shown to predict performance variations in X-ray baggage screening in a simulated night shift and could also have predictive power in similar domains.

In addition to the results of our study, some issues should be mentioned that are relevant for practitioners. The impact of night shifts on health and social well-being has been a subject of considerable research and debate. Several studies demonstrated that night work can disrupt circadian rhythms, leading to adverse health outcomes such as fatigue, sleep disorders, cardiovascular diseases, metabolic disturbances, and compromised mental health (e.g. Bhuanantanondh et al., 2021; Chen et al., 2024; Costa, 1996; Guénel and Léger, 2023; Hsberg and Gamberale, 2000; Lecca et al., 2021) with consecutive night shifts being associated with insomnia (Sim et al., 2021). Moreover, night shifts often result in social isolation and strained family relationships due to misalignment with societal norms of daytime activity (Vitale et al., 2015), suggesting that the number of night shifts should be limited. Conversely, other studies found that extending the number of consecutive night shifts might enable workers to adapt their circadian rhythms to a nocturnal schedule (Hennig et al., 1998; Molzof et al., 2019), and improved sleep quality was reported (Lecca et al., 2021; Pilcher et al., 2000). Shift workers vary regarding their preference for the number of consecutive night shifts depending on chronotype, sleep patterns, and how demanding the night work is (Nabe-Nielsen et al., 2016). Considering workers' preferences for shift scheduling, like it was the case in our study, can be recommended. To help shift workers to recover from night shifts and prevent mental fatigue related issues, shorter shifts and more breaks have been proposed (Gurubhagavatula et al., 2021). Furthermore, previous research suggests that the direction in which the shifts are rotated is relevant, with many suggesting that forward rotation is recommended for better performance, sleep quality, and health (e.g. Di Muzio et al., 2021; Hakola et al., 2021; Hesselink et al., 2010).

4.4. Limitations and future research

While we controlled for external factors, we could not account for confounders associated with screeners' circadian behaviors, which may have contributed to the observed circadian rhythms in screening performance. For instance, previous studies have shown that a midday meal can contribute to post-midday cognitive performance dips (Craig et al., 1981; Smith and Miles, 1986). Thus, we cannot definitively attribute the found performance rhythm solely to an inherent rhythm. However, the presence of a similar rhythm in laboratory studies, with a high emphasis

on controlling confounders (e.g., controlled food intake), supports the notion that the inherent rhythm is a contributor. Finally, we approximated certain measures because of data constraints. Specifically, we lacked information on the exact start and end times of the shifts, which led us to approximate these factors. We also inferred the duration for which the screeners were awake before their shifts began. Future studies could provide a more precise understanding of the circadian rhythm in screening performance, potentially allowing for more precise curve delineation. With an increasing amount of data being collected, future studies could further directly measure performance across various job environments, pinpointing job-specific circadian rhythms and the effects of night work. Additionally, future studies could address the increase in false alarms observed during night and early morning shifts, which are particularly relevant in sectors such as medicine.

4.5. Conclusion

Although significant research has been conducted on circadian rhythms and the effects of night shifts in controlled studies, effects on real-life work performance has not been sufficiently established. Our study provides new insights, showing that a circadian rhythm can be observed in X-ray baggage screening performance and that night and early morning shifts can impact job performance. While this impact on baggage screening does not negatively impact security, the impact of more false alarms on night shifts in other areas (e.g., radiology and emergency medicine) could be significant.

Relevance to industry

The study showed that circadian rhythms and night shifts do not compromise airport security. However, a minor increase in false alarm rate during night shifts might reduce operational efficiency. This finding may have implications beyond airport security, including in healthcare domains like cancer screening, where the cost of false alarms is high.

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CRediT authorship contribution statement

Robin Riz à Porta: Writing – original draft, Visualization, Project administration, Methodology, Formal analysis, Data curation. **Stefan Michel:** Writing – review & editing, Methodology, Funding acquisition, Conceptualization. **Yanik Sterchi:** Writing – review & editing, Methodology, Formal analysis. **Juergen Sauer:** Writing – review & editing, Supervision, Methodology, Funding acquisition, Conceptualization. **Adrian Schwaninger:** Writing – review & editing, Supervision, Methodology, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

Appendix A

Table A1

Model summaries of the linear mixed effect models for threat image projection (TIP) detection, false-alarm rate, and mean processing time, as described in Eq. 5.

Predictors	TIP-Detection		False-alarm rate		Mean processing time	
	Odds Ratios	std. Error	Estimates	std. Error	Estimates	std. Error
(Intercept)	2.716	0.632	0.167	0.003	8.972	0.089
Night shift			-0.001	0.001	0.008	0.055
Normal shift			-0.004	0.001	-0.098	0.041
Night shift:Hour [3]					-0.185	0.08
Night shift:Hour [4]					-0.113	0.086
Night shift:Hour [5]					-0.112	0.075
Night shift:Hour [6]					0.067	0.071
Night shift:Hour [7]					0.119	0.072
Night shift:Hour [9]					-0.045	0.068
Night shift:Hour [10]					-0.134	0.078
Night shift:Hour [11]					-0.287	0.144
Night shift:Hour [12]					-0.519	1.062
Normal shift:Hour [6]					0.213	0.053
Normal shift:Hour [7]					0.153	0.052
Normal shift:Hour [9]					-0.07	0.057
Normal shift:Hour [10]					0.025	0.054
Normal shift:Hour [11]					0.179	0.054
Normal shift:Hour [12]					0.208	0.054
Normal shift:Hour [13]					0.224	0.07
Normal shift:Hour [14]					0.66	0.25
Normal shift:Hour [15]					0.518	0.539
Hour [0]	-0.184	1.53	0.045	0.015	-2.368	0.305
Hour [1]	0.264	0.464	-0.032	0.005	-1.482	0.114
Hour [2]	-0.145	0.21	-0.038	0.003	-0.896	0.07
Hour [3]	-0.133	0.152	-0.032	0.002	-0.44	0.043
Hour [4]	0.08	0.116	-0.021	0.001	-0.266	0.032
Hour [5]	-0.147	0.094	-0.017	0.001	-0.191	0.028
Hour [6]	-0.005	0.095	-0.011	0.001	-0.151	0.032
Hour [7]	-0.013	0.089	-0.005	0.001	-0.1	0.031
Hour [9]	0.01	0.089	0.008	0.001	0.067	0.031
Hour [10]	0.074	0.09	0.01	0.001	-0.012	0.029
Hour [11]	0.011	0.089	0.01	0.001	-0.094	0.027
Hour [12]	-0.06	0.091	0.007	0.001	-0.213	0.03
Hour [13]	0.081	0.111	0.003	0.002	-0.272	0.056
Hour [14]	0.019	0.132	0.005	0.002	-0.737	0.247
Hour [15]	0.11	0.162	0.001	0.003	-0.692	0.537
Hour [16]	-0.61	0.486	0.019	0.009	-0.235	0.18
Hour [17]	-1.173	1.074	-0.011	0.021	-0.615	0.402
Hour [18]	10.016	196.97				
Month [1]	-0.386	0.16	-0.012	0.002	-0.354	0.037
Month [2]	-0.334	0.161	-0.006	0.002	-0.233	0.037
Month [3]	-0.216	0.167	0	0.002	-0.081	0.037
Month [4]	0.179	0.197	0.009	0.002	0.072	0.035
Month [5]	0.44	0.198	0.01	0.002	0.183	0.034
Month [6]	0.636	0.202	0.015	0.002	0.379	0.038
Month [11]	-0.303	0.16	-0.005	0.002	-0.22	0.036
Month [12]	-0.502	0.162	-0.01	0.002	-0.315	0.037
Termil [1]	-1.051	0.827	0	0.01	2.878	2.321
Termil [2]	1.707	0.627	0.003	0.008	9.348	1.902
Termil [3]	1.194	0.867	-0.012	0.003	-0.218	0.057
Termil [4]	1.2	0.867	-0.006	0.002	-0.334	0.056
Termil [5]	0.668	0.866	-0.013	0.002	-0.24	0.039
Termil [1]:Task load (Std.)	-0.688	0.477	0.008	0.006	7.354	5.224
Termil [2]:Task load (Std.)	0.3	0.373	-0.004	0.005	23.653	4.304
Termil [3]:Task load (Std.)	0.064	0.092	-0.009	0.001	-0.161	0.064
Termil [4]:Task load (Std.)	0.053	0.105	-0.004	0.002	-0.033	0.068
Termil [5]:Task load (Std.)	0.006	0.096	0.001	0.001	0.105	0.067
Task load (Std.)	0.034	0.079	0.006	0.001	-0.108	0.06
Task load (Std.) ²					0.068	0.093
Task load (Std.) ³					0.081	0.04
Termil [1]:Task load (Std.) ²					5.491	3.777
Termil [2]:Task load (Std.) ²					18.905	3.152
Termil [3]:Task load (Std.) ²					-0.094	0.093
Termil [4]:Task load (Std.) ²					-0.049	0.096
Termil [5]:Task load (Std.) ²					-0.168	0.094
Termil [1]:Task load (Std.) ³					1.313	0.878
Termil [2]:Task load (Std.) ³					4.723	0.748
Termil [3]:Task load (Std.) ³					-0.033	0.04
Termil [4]:Task load (Std.) ³					-0.006	0.045
τ_{00}	4.70	CTH:Library	6.71	UserId	0.01	UserId

(continued on next page)

Table A1 (continued)

Predictors	TIP-Detection		False-alarm rate		Mean processing time	
	Odds Ratios	std. Error	Estimates	std. Error	Estimates	std. Error
N	0.64	UserId				
	1.09	Library				
	1437	UserId	1437	UserId	1437	UserId
	22009	CTI				
Observations	6	Library				
	82250		40232		40232	
Marginal R ² /Conditional R ²	0.026/0.46		0.014/0.834		0.032/0.625	

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