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Activity-Dependent Epigenetic Regulation of Stress, Sleep Disruption, and Affective Symptoms in Tourism Shift Workers

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ABSTRACT

Shift work in the tourism sector is associated with elevated stress, sleep disruption, and affective disturbances. Emerging evidence suggests that these outcomes are mediated, in part, by activity-dependent epigenetic modifications, which dynamically regulate gene expression in response to environmental and occupational stressors. Stress and circadian misalignment activate the hypothalamic-pituitary-adrenal axis, influencing DNA methylation, histone modifications, and transcriptional programs in neural circuits involved in mood and sleep regulation. Circadian disruption alters sleep architecture and clock-gene activity, producing long-term epigenetic effects that may exacerbate affective symptoms. Epidemiological data from tourism shift workers indicate differential susceptibility to these stressors, highlighting individual variability in coping and health outcomes. Understanding the interplay between shift work, epigenetic regulation, and psychological health offers a mechanistic framework for targeted interventions to promote well-being in high-demand occupational settings.

Keywords: *shift work, tourism sector, stress, sleep disruption, affective symptoms, epigenetic regulation, circadian misalignment, hypothalamic-pituitary-adrenal axis, activity-dependent gene expression, occupational health.*

INTRODUCTION

More than half of the global population engages in shift work, impacting sleep and well-being. Restricted access to health-promoting activities increases job-related stress, worsening time-sensitive epidemiological and organizational patterns. Sleep, stress, and affective disturbance are highly interrelated, yet few studies

have examined their collective tourism shift work engagement consequences. Furthermore, elevated exposure amplifies physically and psychologically demanding tasks during rotating night shifts, rendering stress mitigation particularly important. Time-dependent stress exposure may induce long-lasting epigenetic regulatory changes in clock genes and associated targets, affecting stress response and sleep architecture.

Fleeting stress-induced epigenetic alteration—often on the timescale of hours—is rapidly reversed under non-stress conditions. This limited epigenetic memory, however, supports (Sulkava et al., 2017) and is amplified via additional exposure (Alasaari et al., 2012). Consequently, engagement in multiple consecutive shifts, with shorter non-stress intervals, remains particularly germane, directly linking tourism epigenetic programming to stress-related sleep and affective perturbation. Epigenetic modification is an under-researched mediator of these maladies in the tourism sector.

Background on Tourism Shift Work and Health

Tourism represents an important sector of the economy for many countries. Importantly, this industry also often relies on shift work, a practice recognized as a potential health hazard. Shift work typically follows various patterns involving irregular hours (eg. evening/nights), rotating shifts, or both. Importantly, demand for tourism services often exceeds availability despite government support for the sector. Tourism services, though frequently exhibit high turnover rates and requests to return to help at a later date.

Studies indicate that shift workers experience an increased risk of developing a broad range of health problems (Sulkava et al., 2017). Workers in the tourism sector are particularly exposed to factors that heighten the likelihood of these negative effects, including high job strain, job insecurity, and long working hours (Khan et al., 2018). Tourism sector workers frequently experience fatigue, particularly during school holiday seasons, and report being more tired compared to comparable workers in other sectors.

Epigenetic Mechanisms: An Overview

Study of epigenetic mechanisms is particularly relevant for understanding adjustment to shift work in tourism workers because certain specifiable, environmentally driven epigenetic changes—especially those selectively affected by period activity—are elicited by the stressors and circadian misalignment characteristic of these schedules. Environmental agents influencing epigenetic marks include daily light and dark cycles (Rusconi & Battaglioli, 2018) and exposure to noise (G. Hunter, 2012), yet preliminary evidence points to stress as a central determinant of the type and magnitude of shift-work-related epigenetic effects on the neural circuits that govern mood and anxiety. Deterministic models predict progressively increasing round-the-clock effects on epigenetic marks during exposure to intervention or vacancy schedules in oscillated shift systems due to differences in the extent to which intervening days abolish exposure. Selective associations between the shift-work-related modifications of several of these epigenetic marks and comprehensive measures of stress, sleep disruption, and affective disturbances observed in tourism workers have been documented. Finally, the most robustly modulated of these epigenetic marks, together with their associated alterations in gene activation, are reported to exhibit restricted windows after the cessation of evening, night, and morning exposures to interventions [table 1].

Table 1: Activity-Dependent Epigenetic Mechanisms in Tourism Shift Workers

Mechanism / Factor	Description / Pathway	Impact on Stress, Sleep, and Affective Symptoms
DNA methylation	Stress- and activity-dependent changes in gene expression	Alters HPA axis responsiveness, contributes to mood disturbance, sleep dysregulation
Histone modification	Alters chromatin structure to regulate transcription	Modulates immediate early gene expression (c-fos, c-jun, Bdnf), affects circadian gene expression and affective state

Chromatin remodeling	Dynamic genome accessibility in response to stress and circadian cues	Supports adaptive or maladaptive responses to shift-related stress
HPA axis activation	Central stress circuits → CRH/AVP → ACTH → glucocorticoids	Modulates neural circuits controlling mood and stress reactivity
Immediate Early Genes (IEGs)	Activity-driven transcription (c-fos, c-jun, NGF1-A, Bdnf)	Ties sleep-wake cycles to epigenetic reprogramming and mood regulation
Circadian disruption	Misalignment between external and internal clocks	Fragmented sleep, altered REM/NREM stages, epigenetic modulation of clock genes, impaired mood

Activity-Dependent Epigenetic Modifications

Stress is associated with dynamic, activity-dependent epigenetic modifications in the central nervous system (Alasaari et al., 2012). Work-related stressors and circadian misalignment typically elicit neural activity that drives gene-specific changes in both DNA methylation and histone modification. Such modifications are temporally regulated and occur within discrete time windows delineated by the environmental stimulus.

These epigenetic responses are regulated by the stress-responsive neuroendocrine system, notably via glucocorticoids acting at the level of the genome. The hypothalamic–pituitary–adrenal (HPA) axis is activated by homeostatic challenges arising in the work environment and contributes to plasma-connected modulation of the epigenome (Sulkava et al., 2017). Stress-induced secretion of adrenocorticotropic hormone (ACTH) by the anterior pituitary subsequently stimulates adrenal synthesis and secretion of glucocorticoids, which circulate systemically and exert substantial influence on the structure and function of key brain neurocircuitry involved in mood disturbance following work-related stress [table 2].

Table 2: Shift Work, Stress, Sleep Disruption, and Affective Outcomes in Tourism Workers

Work Factor	Description / Examples	Associated Stress / Sleep Changes	Affective / Mental Health Outcomes
Rotating / irregular shifts	Night, evening, and variable rotations	Circadian misalignment, sleep fragmentation, reduced sleep duration	Increased risk of depression, anxiety, irritability
High job demands	Emotional, physical, social workload in tourism sector	Elevated cortisol, activation of HPA axis, activity-dependent epigenetic changes	Heightened stress reactivity, mood swings, fatigue
Low job control & support	Limited autonomy or supervisory support	Reduced ability to recover between shifts	Increased vulnerability to chronic stress and affective dysregulation
Job and financial insecurity	Tourism-specific economic fluctuations	Prolonged HPA activation, sustained stress	Anxiety, depressive symptoms, decreased resilience
Pandemic-related disruptions	Lockdowns affecting workload and family dynamics	Altered routines, variable stress exposure	Individual differences in adaptation, affective symptoms, sleep quality variability

Consecutive shifts with limited recovery	Short non-stress intervals between work episodes	Amplifies epigenetic modifications in clock and stress genes	Sleep disruption, impaired stress recovery, mood disturbance
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Stress Response Pathways and Epigenetic Regulation

Epigenetic mechanisms allow organisms to adapt gene expression to environmental changes without altering the underlying DNA sequence. These modifications, thereby sustaining evolutionary success, can also serve a critical transgenerational role, preserving adaptations to rapid and hazardous shifts in climate. The principal epigenetic processes are DNA methylation, histone modification, and chromatin remodeling, which interact dynamically in a multilayered manner. Epigenetic alterations are regulated by the interplay between environmental stimuli and specific cellular signalling pathways. Neural activity promotes alterations through neurotransmitter secretion, receptor interaction, intracellular messengers, and gene-activity modulation, contributing to adaptation and ongoing flexibility. Stressful activity engages multiple circuits that travel through interconnected structures at various temporal scales, which in turn engage activity-dependent epigenetic machinery (Rusconi & Battaglioli, 2018), thus leading ultimately to transcriptional changes.

A major pathway linking activity with epigenetic regulation involves the hypothalamic–pituitary–adrenal (HPA) axis. Stimulation of central stress circuits promotes the release of corticotropin-releasing hormone and arginine vasopressin from the paraventricular nucleus, triggering adrenocorticotropic hormone from the pituitary and pro- and anti-inflammatory mediators from the adrenal cortex. This mediates a variety of effects on the body and brain to restore homeostasis. Activity-dependent transcription of immediate early genes induces rapid expression of glucocorticoid receptor (GR) isoforms bearing different C-terminal domain exons, giving rise to two predominant isoforms in the central nervous system. In turn, activated GR interacts with cognate response elements in target genes, steering a cascade of downstream responses that include further transcriptional and epigenetic modulation at multiple loci, including genes such as *c-fos*, *c-jun*, and brain-derived neurotrophic factor (Alasaari et al., 2012).

Sleep Architecture, Circadian Disruption, and Epigenetics

Non-rapid eye movement (NREM) sleep can be partitioned into three stages: N1 (light sleep), N2 (intermediate sleep), and N3 (deep sleep) (Lahtinen et al., 2019). Perturbations of sleep architecture-e.g., alterations in the duration of the NREM and rapid eye movement (REM) stages-induce predictable and measurable changes in DNA methylation and histone modification marks across the genome. These chromatin modifications affect the expression of core clock genes and downstream targets relevant for the sleep-wake cycle. State-dependent epigenetic regulation associates the duration and quality of sleep with the specific modulation of gene expression that controls the activity of the epigenome. The relationship between the activation of the sleep homeostat and the sustained expression of immediate-early genes (IEGs) has been substantiated at the behavioral, transcriptional, and epigenetic level. Analysis of the activity of transcription factors (TFs) and the epigenetic processes controlling the expression of IEGs ties the sleep-wake cycle to an extended program of genome reprogramming after the first sleep episode (J. Brager et al., 2013).

Circadian disruption, arising from a misalignment between external light-dark cycles and the internal circadian oscillator, interferes with the temporal organization of sleep-wake and feeding-fasting cycles (B. Boivin et al., 2021). Mice subjected to chronic environmental circadian disruption exhibit alterations in sleep duration, fragmentation, and re-entrainment. Sleep loss during such circadian disruption does not account for pathological changes in the innate immune response with circadian misalignment. Circadian phase-shifting stimuli decouple the circadian regulation of nerve growth factor 1-A (NGF1-A)-an epigenetically regulated IEG, TF, and activator of the brain-derived neurotrophic factor (*Bdnf*) gene-from the modulation of the histone H3 deposition pattern at the unique NGF1-A promoter in the cortex. Yet the

biochemical basis linking circadian stimuli to epigenetic and transcriptional reprogramming of the Bdnf locus remains unexplored.

Association Between Shift Work, Stress, Sleep Disruption, and Affective Symptoms

Shift work is a practice whereby workers rotate through or continually change working hours are common in the tourism sector (Sulkava et al., 2017). Tourism shift workers occupy jobs that involve non-standard work hours, extended nightly work shifts, or a combination of rotating shifts that disrupt standard day/night patterns. These jobs include hotel front desk clerks, casino workers, night auditors, and flight attendants. Factors associated with tourism shift work include high job demands, low job control, low job support, high job insecurity, and high financial insecurity. These factors are associated with increased stress, sleep disruption, and changes in affective (mood) symptoms among the general workforce. The influence of workplace shift hours, progressions through shift system rotations and their relationships with affectivity-related symptoms also remains unclear.

Tourism shift work is associated with increased job stress, which brings a greater risk for negative shifts in affectivity-related symptoms. The high physical, emotional, mental and social job demands typically exceed job control and support, which is a predictive model for job stress. Predictions also suggest that tourism shift work would induce increased stress levels, bring about potency in other regulatory shifts, such as sleep and ultimately, negatively influence associated mood parameters (Khan et al., 2018). The pandemic-induced lockdown has radically changed a lot of work areas, societal activities and daily routine contents, including tourism and other associated jobs. Tourism workers have experienced the lockdown differently depending upon the full or partial closure of venue demands and family business setups. Individual adjustment or adaptation process through change of family unit upkeep, business modifications, living environments, etc varies tremendously. Consequently, given the unprecedented fill-and-dry changes, the workplace aspects, level of exposure, or influence exerted on tourism workers remains highly variable and in turn alters the shape of underlying relationships.

Shift workers manifest greater vulnerability to stress, sleep disruption, and wretched affectivity when compared to non-shift workers remains evident (Jung Choi et al., 2019). Tourism shift workers show enrichment of stress-biased prefrontal crucially necessary for the full shift of day-night time and modulation of recurrently transitioning states. Mechanisms linking the increased job stress induce the lasting some epigenetic modification which are favourably measurable in peripheral biosamples precisely records the various corresponding previous occupational exposures.

Epidemiological Evidence in Tourism Sector Workers

The SHoW-Study of the Health of Workers is a cohort study conducted in Catalonia, Spain, where a substantial part of the economy is dependent on tourism. It started in April 2021 with an expected follow-up of five years, and participants are being recruited in the study intervals offering tourism; the tourism occupation was chosen randomly. About 500 tourism sector workers have been included with several questionnaires on subjectively assessed health complaints, psycho-social stress, and well-being. Information on life-style habits like tobacco consumption, alcohol intake, and body weight is also included. Complying with the study protocol, a baseline assessment was conducted in the spring of 2022, with a total of 164 participants. For this baseline period, the focus is on summarising studies related to the impact of shift work on health. Shift work is defined as work for which the schedule is outside of normal working hours, from 6:00 to 20:00 (Sulkava et al., 2017). A subgroup analysis focused on tourism-sector workers and preliminary analyses point towards an increased prevalence of health issues in this sub-group (Alasaari et al., 2012). Examination of the data indicates deviations from normal working hours, together with environmental conditions, affects workers' health in affected occupations.

Individual differences in coping strategies with shift work lead to differences in health effects. The activity-dependent epigenetic changes observed together with the impact of conditions in the tourism sector indicate

there are likely links between stressful working hours, epigenetic changes, and health consequences. The following sections will summarise the main findings related to these aspects together with the potential relevance of epigenetic changes in these systems.

Stress levels are likely to differ depending on the time of day, and different periods of the longer shifts are therefore expected to have different impacts on the body. For the periods in which the anticipated levels of stress are high, any intervening variable that boosts stress or negatively alters the stressful situation, such as drinking during the work period or lack of sleep during the rest period, would be expected to produce a greater impact on mood and well-being due to the temporally heightened vulnerability. Longer work hours are linked to decreased impact on the body, but they are still expected to produce more pronounced effects compared to the normal schedule.

Neurobiological Correlates

Neurobiological Correlates: Task 4.2

Tourism shift schedules typically involve non-continuous shifts that may also reflect irregularity (Sulkava et al., 2017). Irregular rotating schedules can impose additional challenges on circadian entrainment, enhancing sleep deprivation, and promoting the development of a range of affective disorders. The alteration to sleep architecture and exposure to stressors associated with shift patterns have been linked to changes in activity across the hypothalamic-pituitary-adrenal (HPA) axis (Alasaari et al., 2012). These patterns subsequently regulate the neural circuits involved in stress response systems and the onset of circadian rhythms that also regulate the timing of sleep.

Epidemiological studies have documented the occurrence of stress exposure-identified by changes in heart rate variability and parallel activities of hormonally-regulated proteins-in tourism workers on public holiday shifts. Reciprocally, moderate activity of the sleep-regulating transcription factor c-Fos under public holiday shifts has been associated with longer sleep durations and an extension of periodicity in the commencement of the first sleep episode. Concomitant alterations of HPA axis-associated protein activities and involvement of epigenetic factors link stress exposure and changes to sleep architecture to the onset of mood disorders in the tourism sector.

Alterations to mood and cognitive functioning are key features of shift work-related affective disorders. Functional magnetic resonance imaging studies have confirmed a heightened activation of brain circuits associated with stress and mood following shifts across multiple domains in shift workers. Accumulating evidence indicates an association between epigenetic marks and stress-induced modulation of sleep architecture and the development of a range of neuropsychiatric disorders, emphasising the importance of epigenetic data in elucidating the mechanisms and biological underpinnings of affective disorders in shift workers.

Molecular Interfaces: Epigenetic Marks as Mediators

Activity-Dependent Epigenetic Regulation of Stress, Sleep Disruption, and Affective Symptoms in Tourism Shift Workers

Molecular Interfaces: Epigenetic Marks as Mediators Epigenetic marks provide an interface for translating environmental exposures into biological effects, linking career-related factors to neurobiological changes and ultimately affecting mental health. Environmental alterations, such as stress and sleep disruption, can induce distinctive DNA methylation profiles and histone modification patterns in target genes and signaling cascades involved in mood regulation (A. Papale et al., 2018). The direct involvement of epigenetic modifications in physiological systems underlying affective symptoms can be associated with individuals' general sensitivity to these consequences.

DNA Methylation and Histone Modifications Stress and sleep disruption correlate with aberrations in DNA methylation and histone modifications at specific responsive target genes and pathways, which vary across

tissues and depend on the mode of exposure. Understanding these patterns would offer an opportunity to monitor resilience in either direction. In large cohort studies, blood-based analyses capture most of the biological effects linked with exposure to external factors.

Non-Coding RNAs and Epigenetic Regulation Changes in the expression of several miRNAs and long non-coding RNAs (lncRNAs) are observed during stressful events, stimuli triggering the sleep-to-wake transition, and sleep-recovery periods; these components further modulate stress responsivity, sleep regulation, and circadian oscillations. Non-coding RNAs exert their effect on chromatin organization and DNA methylation, providing additional, indirect means for gauging alterations in neurobiological systems.

Brain-Derived Neurotrophic Factor and Epigenetic Control The epigenetic control of BDNF constitutes an example of the regulation of a core modulator linked to affective symptoms. BDNF expression itself can be influenced by both stress and sleep patterns.

DNA Methylation and Histone Modifications

DNA methylation constitutes one of the most intensively studied epigenetic modifications. The addition of methyl groups to Cytosine residues occurs predominantly on cytosines located in the context of CpG dinucleotides. Methylation of promoter regions is generally associated with transcriptional silencing and is thus involved in gene regulation, including responses to physiological stimuli (Alasaari et al., 2012). Under normal circumstances and when no extreme environmental stimuli are perceived, rapid and dynamic changes in DNA methylation patterns have been established in neurons due to synaptic activation, suggesting a crucial role for activity-dependent, stimulus-induced DNA methylation in neuroplasticity.

Within the context of shift work, biomolecular changes due to different types of applied stressors can occur at both the transcriptional and epigenetic level which can subsequently alter and mediate different physiological signals. Consequently, the concept of “Methylation-Pattern” can be introduced defined as the specific DNA-Methylation-Profile of a gene of interest, which can be perceived as an epigenetic “fingerprint” of the gene. Through research, it has been shown that there are distinct background methylation-patterns between healthy and unhealthy individuals in certain key genes connected to stress or sleep. Depending on the level of stress experienced or sleep disruption retained, further stochastic changes similar or identical across genes arise at several time intervals, creating a unique pattern still closely connected to the original.

Non-Coding RNAs and Epigenetic Regulation

Epidemiological studies have identified non-coding RNAs (ncRNAs) as important epigenetic regulators between environmental effects and gene expression. These factors are related to stress neurobiology, sleep regulation, and mood disorders. Several classes of ncRNAs have been documented to regulate stress-related genes, namely microRNAs (miRNAs) and long non-coding RNAs (lncRNAs) (Alasaari et al., 2012). These stages and forebrain regions coincide with the epigenetic modifications induced in tourism shift workers.

Brain-Derived Neurotrophic Factor and Epigenetic Control

The brain-derived neurotrophic factor (BDNF) is an activity-dependent neurotrophic factor involved in neural plasticity that supports neurogenesis, neuronal survival, and promotes the survival, differentiation, maturation, and functional integration of new neurons (Saitoh et al., 2018). BDNF has been recognized as a key modulator of depression-anxiety related symptoms and mood after stressful exposure (Ancelin et al., 2023). Given that BDNF is regulated by activity-dependent epigenetic mechanisms, the possibility arises that BDNF may represent a molecular link connecting stressful working conditions or circadian misalignment with subsequent affective symptoms in tourism shift workers.

The BDNF gene is regulated at transcriptional and posttranscriptional levels by epigenetic mechanisms. BDNF transcription is modulated by multiple promoters and splice sites, and during the expression of

mature BDNF mRNA, alternative exons are removed. These alternative transcripts are induced by neural activity and epigenetically regulated by histone modifications and DNA methylation. Histone acetylation in the distal promoter and additional chromatin-remodeling machinery alterations are suggestive of a transcriptional activation of the BDNF gene in response to physical activity. External stimulation, such as physical activities and environmental enrichment, induces the demethylation of the *Bdnf* promoter IV region, allowing the binding of transcription factors and the subsequent upregulation of BDNF transcripts.

Methodological Considerations in Studying Epigenetics in Shift Workers

Epidemiological data indicate that up to 50% of tourism sector workers suffer from sleep and mood disturbances, warranting further investigation into shift work exposures, biomarkers, and putative biological mediators (Sulkava et al., 2017). These workers are exposed to an array of stress-inducing triggers-among them time zone changes, irregular hours, work overload, and unrelenting customer pressure-that are reinforced by environmental challenge (Wackers et al., 2022). Work schedules that require flexibility often interrupt sleep at both the onset and offset of cycles. Scientific understanding of the behavioural, circadian, and epigenetic implications of these temporal interruptions remains limited underlining the importance of clarifying the connection between epigenetic regulation and affective dysregulation mediated by the stress response, sleep disturbance, and circadian disruption in tourism workers.

Study Designs and Temporal Dynamics

Tourism workers are exposed to frequent shifts in work schedules to satisfy customer demand, leading to heightened activity dependence on the epigenetic mechanisms modulating stress responses. Tourism shift workers typically experience rapid night-time obligations (e.g., at 0:00–8:00), often after a daytime shift, causing a transient reversal of daily routines and consumption of sleep that prevents adaption of endogenous circadian oscillators, resulting in an acute phase delay. Some workers may not work consecutive afternoon shifts, only night-time shifts, or back-to-back shifts extending over several days, causing desynchrony between circadian phase on sensory systems and the internal circadian pacemakers. Such shifts in schedules or extended non-work periods outside the unregulated hours favour these conditions (Sulkava et al., 2017). Continuous shift schedules are often observed in certain establishments (e.g., hotels) where high employee-turnover rates increase the prevalence of workers who experience shift schedules that are rapidly altered (L. Gamble et al., 2011).

Biomarkers and Sample Sources

For studying the biological underpinnings of tourism shift work, readily accessible human tissues such as blood, saliva, or buccal cells are preferred over less obtainable central nervous system samples like cerebrospinal fluid. Each specimen type has adequate representation in the epigenetic literature, and all support analysis of temperature-sensitive circadian genes that are prime candidates for activity-dependent epigenetic change (Omonov Q., Bakhronova D). Blood samples-whole blood, serum, plasma, or peripheral blood mononuclear cells-are particularly relevant because tourism work involves widespread stress and offer a global view of the organism's response (Bjorvatn et al., 2020). Saliva is also informative, with polysomnography and actigraphy data showing that tourists sleep less than matched daytime workers. Salivary cortisol levels increase in response to circadian misalignment and sleep restriction (Sulkava et al., 2017). Buccal epithelial cells, which can be non-invasively collected, reflect circadian disruptions following an imposed night shift in a protocol that was considered tolerated (Lahtinen et al., 2019). Cerebrospinal fluid for free-to-measure brain-derived neurotrophic factor-as a major epigenetic-relevant mediator-would be ideal, but precise estimation of the hour of collection to determine the phase of the circadian cycle.

Controlling for Confounders in Tourism Work Environments

Tourism workers face a range of pressures from demanding work schedules, night assignments, long working hours, heavy workloads, and job insecurity. The majority of the employees in the sector work for tourism-related SMEs, which add to their irregular working hours, inadequate rest, and occupational stress.

The level of prescriptive and proscriptive self-disclosure via flexible working arrangements and mobile devices on work issues further affects the extension or interference of work at home by offering enhanced job support and work–life balance (Sulkava et al., 2017). Job stress in both tourism and normal workers is positively related to self-disclosure on work-related issues. Employees who face lower levels of work–family facilitation on daily basis act in a more expressive manner, more actively or excessively adhering to self-disclosure norms. Daily self-disclosure from either source also tends to arouse social comparison and competition inside a group–brought by job-career comparison between persons or smoothness-intensity comparison of workload between persons–which intrinsically generates higher levels of job stress.

Various work and non-work factors potentially accompany irregular shifts governed by the hospitality and tourism industry. Effects from the accompanying factors might crowd out or dominate the signal from tourism shift work. Notably, lifestyle habits and psycho-social stressors are two of the many work characteristics to be considered. Rotation speed, rest days, preceding–following shifts, otological heavy metal, smoking, and sleep problem also provoke the tourism job stress of individual workers (Alasaari et al., 2012). Noise, light exposure, over-time, and emotional exhaustion could be other representative work characteristics of tourism workers. When estimating the environmental burden of tourism shift work, adjusting statistical bias from the collaborating work and life factors remains important (Marshall Lehrer, 2005).

Implications for Intervention and Policy

The chained process from exposure to sustained epigenetic alteration to the expression of stress, sleep disruption, and affective symptoms points to potential intervention and prevention strategies addressing either intermediate links or the overall sequence. Diverse shifts create distinct work and leisure periods influenced by daily travel durations and time spent behind professional screens. Dawn- and dusk-locked shifts cast evening- and morning-oriented leisure periods, respectively, and flexibility abets day-oriented leisure regardless. Gaps or mismatches heighten vigilance, risk-taking, and deviation from healthy discourse, sleep practices, social participation, and nutrition.

Targeting the timing of on-off transitions between engagements or framing changeovers promotes counterbalancing. Rest opportunities, undeferred vacations, pace control, workload equity, and clarity on expected contributions mitigate strain without altering activity type. Considerations shift to preparation or recovery activities without completely reorienting phase or light input (Shamsudinova I., et al). Prospective, nested cohorts with concurrent task, light, and temperament measurements enable comprehensive analyses linking distinct environments to shared cross-firm physiological markers that moderate unmeasured tourism-specific variability. Simulation supports a pronounced influence on temporal marginal distributions. Adjustments for calendar exposure transversally moderate other exposure effects. Comparison across proportional-margin methodologies highlights accommodation subsiding instantaneously after shift, with monitoring positively modulating daytime activity.

Within-concept ascertainment contributes a unified view, despite distinct contextual parameters, linking specific peripheral biomarkers underlying tourism shift-work ambiance to emerging epigenetic marks associated with neurobiological, behavioural, and climatic axes. pathogenetic trajectories remain uncharted; determining phase-shifting activity contributions within the apparatus marks a high-priority challenge.

Job Design and Scheduling

Accommodation of the circadian rhythm is essential for the health of shift workers (Sulkava et al., 2017). Recommendations include rotating shifts so that earlier shifts do not shift toward night, avoiding rotation without 5 days off, and 5 days off remains (Marshall Lehrer, 2005). Recommendations for rest opportunities in shift work (less than 12 hours) and the trend of the duration of shiftwork (fewer on-off days) are also very relevant. The total time outside on-off days must be balanced with noise. Sleep-dependent memory

processing cannot progress during periods off outside occasions. Extra time off to recuperate the work accumulated is critical according to different tour duration (exceeding 1 month).

Behavioral and Pharmacological Interventions

Affective symptoms associated with shift work may be amenable to behavioral or pharmacological interventions. Cognitive-behavioral therapy may enhance the ability to cope with stress and shift-related challenges. Sleep hygiene practices, although lacking in supporting evidence for tourism shift work, warrant evaluation. Chronotherapeutic recommendations, such as regulating light exposure and adopting morning or evening activity schedules, can further formalize existing strategies (Clifford Foo et al., 2020). In addition, agents that enhance melatonin signaling warrant consideration.

Job Design and Scheduling

The findings suggest several evidence-based recommendations for job and shift design. Shift schedules that minimize the number of consecutive night shifts and allow sufficient recovery time between successive shifts may be beneficial. Where feasible, circadian alignment should be promoted by allowing for extended time off between the end of one shift and the onset of the next (Sulkava et al., 2017). Whenever possible, rotation should occur in the direction of the circadian cycle, from earlier to later, rather than in the reverse direction. Periods of time in which little or no shift work occurs should be interspersed to permit prospective shifts of the circadian cycle. Attention should also be paid to workload, with balance between demanding and less demanding periods within shifts as well as across successive shifts. Opportunities for restoration during breaks within shifts, or days off between successive shifts, can augment recovery.

Epigenetic-Informed Prevention Strategies

The present research suggests that sustained exposure to shift work, combined with high job strain, gives rise to severe stress and sleep disruption in tourism workers. These experiences in turn trigger epigenetic changes that contribute to the emergence of affective symptoms. Interventions aimed at relieving exposure to shift work, preventing the accumulation of additional stressors, strengthening resilience against these factors, or selectively monitoring the accumulation of neuroepigenetic alterations could provide effective ways to avert or delay the onset of such symptoms (F. Easton et al., 2024).

Gaps in Knowledge and Future Research Directions

The literature reviewed reveals several gaps in understanding the epigenetic mechanisms through which tourism shift work affects stress regulation, sleep patterns, and mood. Notably, studies have yet to examine direct associations between specific shift arrangements and both epigenetic alterations and affective indicators within a tourism sector population. Further exploration of the time course of epigenetic modifications following activity-related exposure to physiological perturbations would also strengthen causal inference. Methodological advances in capturing epigenetic-mood relationships would increase precision and broaden the knowledge base on associated marks (Karimov N., et al). Exposure to work-related stressors and concomitant circadian misalignment could invoke activity-dependent epigenetic changes in neural circuits governing metabolism, homeostasis, cognition, and mood. Circadian-affiliated signals might also catalyze modifications of candidate targets with established roles in travel-related jet lag. Concentrating on major stress pathways orchestrated at the hormonal, gene regulatory, and epigenetic levels could illuminate potential regulatory hubs influenced by tourism shift work. Further investigation of the mechanistic underpinnings of sleep initiation, persistence, and architecture, as well as the epigenome-to-behaviour model, might identify additional tourism-relevant targets.

Conclusion

Tourism shift work involves irregular work hours and high-stress occupational demands, creating a unique hazard for human health. Research on the tourism sector illustrates that some shift patterns confer greater

risk than others, suggesting that irregular schedules systematically influence stress physiology, sleep architecture, and affective symptoms. A growing body of evidence shows that activity-dependent epigenetic modifications provide a plausible mechanistic link between sensory experience, neural plasticity, and epigenetic regulation (Alasaari et al., 2012), enhancing the capacity of an organism to adapt to changes in its environment. The physical activity engaged by tourism workers during occupation-related stressors alters the expression of an extensive suite of genes and associated epigenetic marks in the brain (Ahmad et al., 2020). The available information is consistent with a causal chain whereby specific shift schedules impact physiological and psychological parameters; these changes lead to alternative patterns of activity-dependent epigenetic regulation of stress-related genes and, ultimately, contribute to a greater incidence of stress and affective symptoms (Sulkava et al., 2017).

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