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Review Article

Working Time Society consensus statements: Individual differences in shift work tolerance and recommendations for research and practice

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Abstract: There is no standard definition of shift work universally, and no validated report of complete biological adjustment to shift work in workers. Similarly, the evidence for shift work tolerance is limited due to a small number of studies and a narrow range of outcome measures. This paper discusses evidence to date regarding individual differences in shift work tolerance and highlights areas for future research and recommendations for workplace practice. The few factors that are consistently associated with perceived or actual shift work tolerance are young age, low scores of morningness or being a late chronotype, low scores of languidity and neuroticism, high scores on extraversion, internal locus of control and flexibility and male sex. An important first step is to differentiate between factors that are potentially modifiable, such as those that are determined by lifestyle choices, and those factors specific to the working time arrangement. Identifying determinants of shift work tolerance and the ability to adjust to shift work, whether they are innate and/or acquired mechanisms, is important so workers who are less likely to tolerate shift work well can be self-identified and supported with appropriate harm/risk minimization strategies. This paper also identifies important areas for future research with the goal of increasing the evidence base on which we can develop evidence-based harm mitigation strategies for shift workers.

Key words: Shift work, Health, Sleep, Adjustment, Tolerance, Workplace policy

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Consensus Statements

1) Individuals vary in their sleep requirements and preferences with regard to both duration and timing (e.g. observable as different chronotypes). They also vary considerably in the impact of sleep loss and circadian misalignment on their alertness and cognitive functioning. Long-term health consequences and risks associated with shift work vary among individuals as well.
2) Employers should consider flexibility in individuals' work hours where operationally feasible. Employers should work with experts, regulators, worker representation, and employees to develop flexible work schedules, specific to occupation or workplace.
3) Consideration should be given to allowing employees to take a nap in the workplace if they need it (sanctioned napping). And if naps are deemed appropriate, adequate facilities and worker guidance should be provided.
4) Caffeine is useful as a fatigue countermeasure and may positively impact alertness, although it also has the potential to disturb both nighttime and daytime sleep. Workers should be made aware that caffeine's effects depend on the dose and timing of administration, and that sensitivity to caffeine varies considerably among individuals.
5) Individuals vary considerably in their ability to adapt to shift work. Healthy eating patterns and physical activity may help to promote shift work adaptation and improve long-term health outcomes. Employers should consider providing shift workers with healthy food options at all times of day/night and opportunities to get physical activity/exercise.
6) Workers differ in the work and home demands on their time and attention, and the optimal state of work-life balance. Workers should be encouraged to discuss their individual work-life balance needs with their employers, and employers should be encouraged to make accommodations where possible.
7) Shift work operations tend to interfere with normal social support systems (family, friends, colleagues, etc.). To help shift workers cope, support groups and events could be organized to promote social support, reduce feelings of isolation, and reduce conflicts between work and home demands.
8) Light is a key modulator of shift worker alertness, well-being and health, and a useful fatigue countermeasure, and workers should be educated on the effects of light. Individuals differ profoundly in their responses to light and darkness, making it difficult at present to design individualized lighting solutions for shift workers.

Consensus statements review expert panel: Hans VAN DONGEN[1](Chair), John CALDWELL[2], Debra SKENE[3]

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Full consensus among panel members on all statements.

Introduction

The Oxford dictionary defines 'tolerance' as the "capacity to endure continued subjection to something such as a drug or environmental condition without adverse reaction" and provides the following example: "The desert camel shows the greatest tolerance to dehydration". For the camel, the definition of tolerance appears clear: the ability to withstand dehydration under adverse environmental conditions. However, to apply the same concept of tolerance to shift workers may be more complicated. One reason, is the lack of understanding about the conditions defining shift work tolerance[1–3]. This includes our current lack of understanding of whether shift work (in-) tolerance is grounded in physiological factors at the level of the individual worker (e.g. the inability of a specific individual to adequately recover when sleeping during the biological day) versus individual psychological factors (e.g. an individual's increased use of inappropriate coping strategies such as increased caffeine, alcohol or tobacco consumption to mediate 'sleepiness and alertness' or voluntary sleep restriction to accommodate family and social obliga-

tions). If physiological factors predominate, this would point towards individuals inherently unsuited to shift work. If the problem is inherently biological, coping strategies may provide little benefit to the individual and the harm may be unavoidable. On the other hand, if the role of (in-) appropriate coping strategies predominates, then shift work tolerance could be improved—especially for those about to start with shift work—through the development of guidance materials addressing the appropriate behavior and lifestyle changes required for harm minimisation. In practice, it is likely that physiological predispositions and coping behaviors interact which, unfortunately, further complicates the search for ways to minimize shift work intolerance.

This manuscript is part of a series of consensus papers developed by the Working Time Society, as commissioned by the International Commission on Occupational Health. The goal of this series is to provide guidance for a broad, international audience of researchers, industry representatives, workers, labor representatives, policy makers, and other stakeholders on managing fatigue associated with non-standard working hours and ensuring worker health and safety. Collectively, the papers provide overviews of the current state of research, identify health and safety risks, make recommendations for effective interventions, and suggest future research directions. Each paper presents a number of consensus statements, developed through the procedures outlined in Wong *et al.*[4], and describes the background information on which the consensus statements are based. This paper presents an overview of the current evidence on the relation to individual differences in shift work tolerance. We conclude our paper with recommendations for future research and the workplace practice.

Definition of Shift Work Tolerance

The definition of shift work tolerance was first introduced by Andlauer *et al.*, and was described as the ability of an individual to adapt to shift work without adverse consequences[5]. Following on from this initial definition, researchers have tried to understand what determines this 'ability' and have deconstructed shift work tolerance into measures of the individual physiological and behavioral differences in adapting to shift work[6, 7]. More recently this has been further expanded to include psychological and social problems also thought to mediate shift work tolerance[8–10]. It is now generally considered that shift work tolerance is a complex phenomenon that includes a range of factors and is both physiologically and psychologically determined.

A recent exploratory study supports the use of the wider definition of shift work tolerance[9]. In that study, a principal component analysis conducted on Norwegian nurses (n=1,529) identified two main factors that were associated with shift work tolerance; psychological health or well-being (this factor loaded on measures of insomnia, mental health and well-being, fatigue and anxiety) and physical health (including measures of physical health determined by well-validated general health questionnaires)[9]. This was the first time that the definition of shift work tolerance was conceptualized using an empirical, rather than theoretical, approach on a large sample size. While there are limitations of this definition that still need to be addressed, this finding warrants the view that shift work tolerance is a multi-factorial construct that combines individual physical, psychological, social and behavioral differences.

Historically, the assessment of shift work tolerance has been inconsistent due to the lack of definitional consensus and the fact that different measures have been used across different studies. Not surprisingly this had made comparisons between studies difficult. As yet, there is no consensus on how to best define or measure shift work tolerance. If we look across the extant literature, the most common measures include subjective evaluations by the individual about their perceived tolerance of shift work related problems, including subjective measures of sleep (e.g. sleep quality, sleep problems, fatigue), chronotype (early or late sleepers), and subjective health status[6, 7]. In terms of social factors, standardized questionnaires are typically used to measure work-life conflict, work-family conflict, family and social disruption[6, 9]. Psychological questionnaires are used that measure job strain, work satisfaction, and personality factors[6, 7, 11]. Objective measures typically focus on sleep, circadian disruption and cognitive impairment and include measures such as sleep actigraphy, core body temperature, saliva, blood, and urine samples for hormones used to measure circadian parameters such as period, phase and amplitude (e.g. melatonin, cortisol), and computerized measures of cognitive or neurobehavioral task performance, e.g. PVT)[6, 7].

Individual Differences of Shift Work Tolerance

Although studies on shift work tolerance are relatively scarce, and are limited in scope as per above, several factors have been identified that are potentially associated

with better adaptation to shift work: young age, low scores of morningness or being a late chronotype, low scores of languidity and neuroticism, high scores on extraversion, internal locus of control and flexibility and male sex[7, 12, 13]. Other than age and sex *per se*, all parameters on this list vary intraindividually, mainly with lifestyle choices, leaving these at the present stage as rather unreliable predictors for shift work tolerance across time. Cultural and socio-economic class differences between countries might also be factors that can influence shift work tolerance. To the best of our knowledge, there are no studies exploring the relationship between shift work tolerance in different cultural and socioeconomic settings, highlighting the need for additional studies addressing this issue. Due to methodological differences in shift work studies, it remains difficult to draw conclusions about the determinants of shift work tolerance. Saksvik *et al.* argued that "More longitudinal studies, especially concerning personality, are needed to make conclusions about the predictive power of individual differences for shift work tolerance"[7]. Next, we will discuss individual differences in shift work tolerance for a variety of factors, including age, sex, trait vulnerability to sleep loss, circadian rhythms, psychological determinants, social and behavioral determinants, and occupational schedules and demands.

Age

Research on the relationship between shift work tolerance and age has produced mixed results. Many studies suggest that a younger age is related to a better tolerance of shift work[7, 14–16], with indications that the critical age for reduced tolerance to shift work is between 40 to 50 yrs of age[17, 18]. However, other studies have found contrasting results, where shift work tolerance may increase with age, or produce a U-shaped association[7, 16, 19, 20]. While the evidence is unclear regarding age and shift work tolerance, there is biologic plausibility for poorer shift work tolerance at older age. Age is principally a plausible factor since virtually all health and sleep problems become more severe with ageing. One might hypothesize that shift workers age at a quicker pace, since shift workers do not suffer from unique shift work related health and sleep problems, but from common aging related epidemiological health and sleep problems at an earlier age. This hypothesis, of course, requires large scale longitudinal studies for confirmation.

One likely explanation for the published differences in the relation between age and shift work tolerance can be the healthy (shift) worker effect, a form of selection bias[21]. Older workers who have stayed in shift work for many years represent a cohort of workers who overall are healthier, and because of their good health they still are employed in shift work (and might appear as "survivors")[21]. There is also evidence that there is self-selection into shift work based on traits such as sleep[22], which likely interacts with the healthy shift worker effect and age. In addition, the healthy worker effect is associated with other risk mediators like gender or sex, race, age at hire, occupational class, and length of employment, which may influence shift work tolerance[3, 23]. However, more knowledge can be gained from investigating other traits that are related to workers who stay in shift work, and those who select out of shift work.

Sex

The evidence linking sex with differences in shift work tolerance suggests that shift work tolerance is more common among male workers, while some studies show no sex relationship[6, 7]. Some studies report that women have greater susceptibility to shift work adaptation in terms of sleep-related problems and fatigue, higher risk of diseases such as metabolic syndrome, higher risk of poor mental health outcomes, and work injuries[24–29]. Not all studies support this relationship though, suggesting sex differences in adaptation to shift work could be related to only some measures of shift work tolerance[7]. Further, for some diseases, particularly mental health, it is hard to disentangle whether these sex differences in susceptibility to the health impacts of shift work are due to underlying sex differences in disease etiology or differences in the ability to adapt to shift work. The current evidence suggests that more research is needed to investigate sex differences in shift work tolerance, and suggests that future interventions and policies should recognize that women may be more susceptible to the health impact of shift work.

Some reasons for sex differences in shift work tolerance are suggested in terms of both behavioral and physiological function. In terms of physiological differences, there is evidence that men and women might differ in terms of sleep behaviors and sleep-wake patterns[30]. New evidence indicates there might be biological differences in the circadian regulation of sleep between sexes, making women more vulnerable to the impact of working nights[31, 32]. Sex differences in chronotype and susceptibility to mental health problems are also likely to play a role[33, 34]. In terms of behavioral factors, women may be additionally challenged in their shift work tolerance due to family and domestic duties[6]. Shift working women with children have

a greater risk for work injury than shift working women without children, especially during extended working hours and rotating shift work[24]. This suggests that the probability of a work injury might also be influenced by social factors, such as family and childcare responsibilities, that lead women to work longer hours and to sleep less on days off than men or women without children[6]. However, more research on sex-specific differences with respect to domestic duties on shift work tolerance is needed to better understand these relationships.

Trait vulnerability to sleep loss

Shift workers are at an increased risk for developing chronic sleep disturbances, such as insomnia, shortened sleep duration, fatigue, and poorer sleep quality[35]. There is evidence that some shift workers are more vulnerable to insufficient sleep than others. Observational and laboratory studies show that there are high interindividual differences in adapting to shift work after sleep restriction, as evident in cognitive impairment and work performance[36, 37]. However, it is still unclear why some shift workers are more resilient to the impact of sleep restriction; multiple factors, including personality, genetics, and chronotype, are likely to play a role[35, 38]. Shift workers who report higher feelings of work satisfaction and have more flexibility in sleep habits show higher shift work tolerance after sleep restriction[39, 40]. Traits such as lower scores of languidigy (i.e. difficulties overcoming drowsiness and lethargy following a reduction in sleep), morningness, neuroticism, low scores on extraversion, and long sleep need are linked to poor shift work tolerance[7, 41]. Individual differences in sleepability (i.e. the ability to fall asleep easily), unrelated to sleepiness, has also been suggested as an individual sleep trait[38]. However, it is still unclear how this trait may relate to shift work tolerance. Polymorphisms related to homeostatic sleep processes and circadian rhythms are also associated with individual differences in sleep pressure, fatigue, and performance, including CLOCK, PER1, PER3, and MTNR1A[42–44]. Further, individual differences in chronotype are associated with resiliency to sleep loss, which will be discussed further below.

Circadian rhythms

Overall, it is still unclear why circadian misalignment occurs differently for individual shift workers, with evidence showing individuals adapt differently to shift work[45–47]. Different work schedules, differences in light exposure (especially at night), forced sleep timing, age, and the health status of shift workers likely affect their degree of circadian entrainment[46]. While complete circadian adaptation to shift work would correct for the misalignment between daily rhythms and the environment, it might only be desirable on some but not all circumstances. Evidence from simulated shift-work research suggests this is unlikely to occur. It has been reported that a complete adaptation of the circadian system to night shift work only occurs in a minority (<3%) of workers, even when working a fixed night shift schedule[48], whereas a partial entrainment to night work occurs in <21% of workers. A study of 15 patrol officers (mean ± SD, 29.8 ± 6.5 yr) showed that more than 40% were adapted to their night shifts, possibly because of the organization of night shifts within their work roster[45, 47]. Other observational studies of melatonin as a biomarker for circadian adjustment show changes in the pattern and timing of peak production among healthcare employees working alternating days and nights[49, 50], suggesting shift work may impact circadian physiology, and thus also shift work tolerance. Similar changes in pattern have also been reported for cortisol, another suggested circadian biomarker[51, 52] as well as for the majority of rhythmic transcripts of the human genome[53].

While complete circadian adaptation is unlikely, some studies suggest that certain work conditions may promote adaptation to night work to some degree. Studies suggest that forward rotating shift schedules, shift lengths of under 10 h, napping during night shifts, and use of light-dimming glasses at night or during commute home may promote adaptation to shift work[54–58]. However, few studies have assessed the effectiveness of these conditions outside of experimental settings, and how it may relate to better health outcomes over time. This highlights the need for well-designed randomized interventions to assess the effectiveness and feasibility of these strategies in the workplace. Whether and how circadian disruption can lead to individual vulnerability to shift work and the health disturbances associated with it remains largely unknown and will require further research.

Another factor that impacts circadian adaptation to shift work is chronotype. However, chronotype (a behavioral marker based on preferred sleep timing) also varies with sex and age[54], and therefore should be monitored regularly. Studies suggest that individuals with an evening-oriented chronotype exhibit less rigid sleep timing and higher shift work tolerance compared to morning-oriented chronotypes; late and flexible sleepers appear to suffer less from night shifts, and late sleepers are more challenged by morning shifts[59, 60]. This is supported by studies that show shift workers with an evening-oriented chronotype

have lower levels of drowsiness and sleepiness, and lower sleep-quality but longer sleep duration in comparison to workers with a morning-oriented chronotype[7, 61]. In addition, morning-oriented chronotypes show higher levels of social jet lag during night shifts in comparison to evening-oriented chronotypes[61]. Morning-oriented types, in turn, are less challenged by morning shifts[61]. This evidence suggests that late chronotypes may be less challenged by circadian misalignment due to shift work, and suggests that consideration of chronotype is important when developing healthy work policies, interventions and work schedules.

While an evening-oriented chronotype may be beneficial in terms of sleep quality, it has also been linked to adverse health effects in some shift workers. A recent study found that shift workers who have evening-oriented chronotypes are more susceptible to the adverse affects of light at night, as evident through reduced melatonin[49]. There is additional evidence that shift workers with evening chronotypes may have a higher risk of obesity and breast cancer[62, 63]. These findings highlight the importance of continuing to study chronotype differences in the adjustment to shift work, especially when considering future disease risk. Further, while there is evidence suggesting chronotype is relatively stable during adulthood[64], it is unclear whether chronotype could be altered to promote adaptation. More research is needed to examine the stability of this trait, and its potential effect on shift work tolerance.

Psychological determinants

Most studies investigating personality traits and shift work tolerance have found that internal locus of control, flexibility (i.e. ability to sleep and work at odd times of the day), hardiness, extraversion, and self-esteem are positively related to shift work tolerance[7, 41, 65, 66]. In contrast, higher scores of neuroticism, negative mood, and low positive affect are associated with shift work intolerance[7]. However, it is difficult to assess the temporality of these effects, since shift work could also induce personality changes[7]. In addition, it is still unclear if certain personality traits in shift workers are linked to a reduced risk of chronic health outcomes later in life; it could be that personality traits may be linked only with better self-reported adaptation to shift work. These findings and uncertainties highlight the need for longitudinal studies, especially when considering future health outcomes.

In recent years, the link between shift work and mental health has gained interest. Shift workers report poorer mental health, higher job strain, higher occupational stress, and are at higher risk for disorders such as anxiety and depression[11, 28, 67, 68]. However, it is still unclear if individual differences in mental health are causally related to shift work tolerance. It could be that certain personality factors allow for better adaptation to shift work, and a lower risk of mental health outcomes[65]. Another explanation is that individual differences in self-perceived work stress could be related to shift work tolerance. In a recent meta-analysis of eleven papers, psychological factors attributed to the work environment, such as job strain, low decision latitude, high psychological demands, and high job insecurity predicted mental disorders such as anxiety and depression[11]. This finding was significant despite the heterogeneity between studies, and response bias was ruled out as a possible explanation[11]. Overall, the pathway linking individual differences in psychological factors to shift work tolerance is still unclear, especially when considering mental health outcomes. More research is needed to investigate how personality factors and perceived stress may relate to shift work tolerance over many years, and how this relates to the development of mental health outcomes.

Social and behavioral determinants

Research investigating differences in behavioral factors and shift work adaptation is limited. Shift work has been associated with changes in behavior including work performance, changes in eating patterns, and physical activity[69–71]. Some researchers state that behavioral factors may be related to shift work tolerance through coping strategies[6]. It could be that shift workers who have favorable coping strategies that include healthier eating patterns and regular physical activity can adapt better to shift work. In contrast, individuals who have better shift work tolerance may develop healthier behaviors than shift workers with poorer tolerance. Thus, it is unclear how individual behavioral factors (and coping strategies) relate to shift work tolerance. In addition, future research warrants the consideration of psychological traits when considering behaviors, since these are likely to be influenced strongly by personality traits.

In addition, there is evidence that having social support determines shift work tolerance. This includes social support from partners/spouses, family, co-workers, and supervisors and employers[6, 65, 72]. There is also evidence that having children and domestic obligations are related to poor shift work tolerance, for both men and women[6, 73]. As mentioned previously, women with children and domestic obligations are more vulnerable to poor shift work

adaptation, which could be explained by sex differences in domestic and family roles[24]. While social support and family determinants have been thoroughly investigated, there is limited evidence on the link between individual differences in cultural and socioeconomic determinants in shift work tolerance. It is still unclear how lower (or higher) socioeconomic class, and differing cultural views of shift work affect adaptation to a shift work schedule. Future research should address these research gaps, which could help identify vulnerable groups and populations to the health impacts of shift work. Future research should also consider how employers and organizational support within the workplace may promote adaptation to shift work, with consideration of aspects such as provision of meals, transportation, childcare, and more.

Occupational schedule and demands

It is important to highlight that occupation (or actually which tasks are performed) itself likely plays a role in shift work tolerance. Most research has currently focused on how shift work schedule (i.e. shift work type, years of shift work, and intensity of shift work) may contribute to poorer health outcomes. Evidence suggests that permanent night shifts, rotating shifts, longer years of shift duration (in as little as 5-yrs), and higher shift work intensity increase the risk of a multitude of health outcomes, including cancer, cardiovascular disease (CVD), diabetes, and disrupted sleep and circadian rhythms[49, 74–78]. There is also evidence that quitting shift work may decrease the risk of poorer health outcomes. In comparison to current shift workers, former shift workers have a lower risk of adverse health outcomes such as cardiometabolic indices, poor cognition, CVD, disrupted sleep, and disrupted circadian rhythms; however, studies also suggest that former shift workers are still at a higher risk of these poorer health impacts in comparison to never-shift workers[79–83]. In addition, evidence suggests that longer time since quitting shift work may decrease risk of poorer health outcomes, such as CVD[80]. Nonetheless, it is important to highlight that most studies have assessed these associations cross-sectionally, and factors such as confounding by age and selection bias cannot be ruled out completely.

Although both permanent night and rotating shift work has been linked to poor shift work adaptation, studies indicate that permanent night workers do not adapt better to permanent shift schedules in comparison to rotating schedules[48, 84]. Few studies have assessed this prospectively, making it difficult to rule out biases such as the healthy shift worker effect or an incomplete consideration of confounding factors. Further, due to the lack of longitudinal data on shift work tolerance, it is unclear how duration of shift work may relate to shift work tolerance, outside of factors such as the healthy shift worker effect and age. Finally, studies suggest that a rapid forward rotation schedule may be the most beneficial for shift work tolerance[55, 58]. Again, only few studies have investigated this schedule long-term, leaving it unclear how the schedule may impact shift work tolerance.

Overall, while the evidence has linked certain shift work types, higher intensity of shifts, and longer shift work duration to poorer health outcomes, it is still unclear how these factors may influence tolerance to shift work. While studies suggest that rapid forward rotating shift work schedules may be the most beneficial in terms of adaptation, it is important to further investigate shift work types and duration more at the individual level in order to better understand how shift work interacts with tolerance to shift work, and inform future workplace policies. In particular, longitudinal studies are needed to more clearly assess the impact of different shift work schedules on adaptation.

Occupational demands likely also contribute to shift work tolerance; however, research is lacking on how different types of occupations and occupational conditions may influence shift work tolerance. It is uncertain how different types of occupations, (e.g. healthcare, first-responders, airline pilots), and different occupational conditions (e.g. active vs. sedentary jobs, exposures to various chemicals and hazards, job strain), may affect tolerance to shift work. In addition, self-selection into certain occupations and maybe even shift schedules likely contributes to adaptation to shift work, although little research has investigated this. More research is needed to identify how occupation itself plays a role in shift work tolerance.

Discussion

Our understanding of the individual differences of shift work tolerance appears impeded by a lack of clear definitions, different research methodologies, potential for the healthy (shift) worker bias, scarcely scrutinized concepts, and a limited number of variables investigated regarding the issue of shift work tolerance. The mere emergence of diseases and endpoints (as points in time when e.g. medical help would likely occur too late) in shift workers does not tell us much about shift work tolerance, unless there is a solid understanding about the causal pathway leading to these endpoints.

Ideally, we want to know whether a certain disease state,

e.g. cancer or metabolic syndrome, is related to a range of issues, from the specific aspects of shift work to certain coping strategies, or their biologic interaction. To improve our understanding about this complex causal situation, detailed prospective and long-term studies across at least 20 to 30 yrs are needed. This research design would help to overcome risk stratification (e.g. by age, sex, or chronotype) issues, which also are a matter of debate. In addition, the lack of clear definition for shift work makes it difficult to compare studies. Studies frequently only focus on type of shift work (i.e. rotating vs. night only shifts), without consideration for intensity (i.e. number consecutive shifts in a row) or duration (i.e. length of shifts)[85]. In the future, studies should consider defining shift work in terms of type, duration, and intensity to grasp the complete picture of shift work, as different parameters of shift work likely influence shift work tolerance differently. Further, social, psychological, and cultural factors (and their interaction) should be considered important factors in determinating the limits of tolerance and intolerance to shift work.

When interpretating findings, researchers should consider the possible bias imposed by these factors to disentangle and help explain the mixed associations between age, sex, and shift work problems pointed out here. Ideally, one would follow populations of shift workers and non-shift workers (as the control group) over time (years to decades) and quantify the specific effects of age, seniority, sex, and their potential interaction. The healthy (shift) worker effect can by itself become a research opportunity if expressed as a survival rate of shift work. With high quality long-term prospective studies, one can explore what factors affect survival and attrition rates. This would address the question of tolerance in the context of duration of exposure (i.e. past shift work experience), since also time being employed, beyond the age effect *per se*, should be assessed[23].

It is a prevailing view that restorative sleep and good health rely on regular exposure to light and darkness to keep the circadian system synchronized with the natural environment[86–88]. Shift work disturbs this process[1, 89] and thus also leads to atypical sleep schedules. Even though, sleep timing might be disrupted, sleep homeostasis might be preserved by the strategic planning of naps. To our knowledge, there are no studies on the long-term effects of sleeping on an atypical schedule. To date, there is no evidence to support that humans are or can become fully tolerant—with respect to the adjustment of their sleep and circadian system—towards the effects of shift work, especially where it includes work at night.

Overall, this paper highlights the lack of understanding of individual differences in shift work tolerance. There is a general understanding of how sleep, circadian rhythms, chronotype and personality impact shift work tolerance. However, it is still not completely clear how differences in culture, socioeconomic condition, mental health, genetics, occupational conditions, age and sex contribute to shift work tolerance. It is important that future research addresses these research gaps, for many reasons. Further research into individual differences will help to identify specific groups and populations that are vulnerable to the health impacts of shift work. Knowledge of these individual factors would allow for the development of effective and evidence-based interventions, healthy workplace policies, and work schedules to improve adaptation of shift work. The consideration of these individual differences are therefore crucial not only for future disease risk, but also in terms of workplace safety and performance, and the psychological and social well-being of shift workers.

In conclusion, there is no evidence that workers better adapt across their shift work career, and full tolerance to working shifts has not been described in the literature. Intolerance to shift work could, theoretically, be defined by the amount of time spent outside the range of an individual's endurance capacity, in turn defined by the endurance to live at atypical circadian phases and/or to resist sleep deprivation and restriction. From this definition, it then follows to elucidate the effects of age, sex, and years of enduring exposure to shift and night work. The details provided in this consensus paper, we hope, inform researchers, employers, and policy makers to broaden their view of aspects that should be taken into account when investigating the impact of shift work on human sleep and health. We emphasize that this paper does not allow us to draw strict conclusions about which individuals should or should not be selected into shift work. Further knowledge about shift work tolerance is needed to better adjust the work conditions to the individual shift worker, as recommended in the following section.

Recommendations

Our recommendations aim to strengthen the awareness and understanding of the interaction between individual differences and shift work tolerance, including differences in sleep, physical and mental health, performance and an individual's biology. This includes recommendations for future research and workplace practice.

Based on the evidence presented in this consensus

paper, we recommend researchers consider the following factors to study the physical and psychosocial health in shift workers:

• Definition of shift work exposure, especially in terms of type, duration, and intensity;

• Chronotype differences in the adjustment process to shift work;

• Sleeping and napping behavior;

• Effects of age between populations with different histories of shift work exposure;

• Consideration of the healthy (shift) worker effect;

• Effects of sex and gender in the context of domestic, familial, and biological factors;

• Cultural and socioeconomic class differences between countries;

• Work stress levels.

We also highlight the need for more research in the following areas:

1) Studies assessing the complex interaction between work, sleep, light exposure, health, performance and an individual's biology (e.g. circadian rhythm);

2) Studies assessing determinants of tolerance to sleep deprivation (acute and chronic), of living at adverse circadian phases (including assessments of melatonin and other markers of the circadian system), and of circadian readjustment to atypical work schedules;

3) The role of genetics and polymorphisms in shift work tolerance, especially those involved with homeostatic processes, circadian rhythms, and sleep;

4) Prospective studies to assess individual differences in shift work tolerance (particulary individual differences in age and personality factors), and the long-term health impacts of shift work;

5) Studies assessing the relationship between individual differences in health behaviors and coping strategies on shift work tolerance; and,

6) Implementation and assessment of the effect of interventions to mitigate workers intolerance (e.g. using tailored light exposure/hiding schemes).

7) Studies assessing the impact of employer and organizational support within the workplace on shift work tolerance, with consideration of aspects such as provision of meals, transportation, and childcare as well as education and training.

Additional comments regarding consensus statements provided by the Deutsche Gesetzliche Unfallversicherung (DGUV), an umbrella association of the accident insurance institutions for the industrial and public sectors in Germany, can be found at https://www.dguv.de/medien/inhalt/praevention/fachbereiche_dguv/fb-gib/beschaeftigung/stellungnahme.pdf (accessed January 22, 2019).

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