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Combined Effects of Noise and Shift Work on Fatigue as a Function of Age

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The study was conducted to analyse possible interactions between noise and shift work on fatigue as a function of age. In a large questionnaire survey, we assessed personal and environmental risk factors related to fatigue. Noise exposure at work ($L_{Aeq,\ 8hr}$) was measured with personal noise dosimetry. The sample included 254 day and shift workers, and was divided into 2 age groups (<40- and >40-year-olds). Noise exposure had a main effect on fatigue. The highest noise exposure resulted in an increase in the fatigue level of older shift workers. The quantity of sleep mainly depended on the type of shift and age. Our data suggest that the most important factor generating fatigue could be related to industrial noise exposure, a factor which seems to aggravate work-related fatigue generated in a synergic manner by shift work and ageing. Senior workers should be prevented from cumulating those occupational stressors.

noise exposure shift work ageing sleep general fatigue

1. INTRODUCTION

Noise is one of the most common physical stressors to which industrial workers are exposed [1, 2]. There is good evidence that occupational noise exposure impairs performance [3]. Even if this effect is not necessarily observed immediately during exposure [4], it changes the structure of subsequent sleep [5]. Kjellberg, Muhr and Sköldström conducted a series of studies about noise effect on work-related fatigue [6]. They showed that reaction time was increased and complaints about fatigue were more common among workers exposed to noise. Melamed and Bruhis reported a study on textile workers exposed to noise with or without hearing protectors [7]. They found subjective effects such as fatigue and irritability after working without hearing protectors.

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Shift work is also well documented to be an important cause of work-related fatigue [8, 9, 10, 11]. An essential component in the link between shift work and fatigue is related to insufficient sleep. Shift work, particularly night work, presents a challenge to the human circadian system since shift workers, and especially night workers, are often required to have optimal performance when their biological and psychological functions are at their lowest level [11]. Likewise, sleep during the day, when individuals are biologically driven to be awake, tends to be shorter and of decreased quality [12]. As a result, shift workers may accumulate a significant sleep debt even in one week, contributing to long-term exhaustion [13].

Moreover, there is good evidence that ageing is also an important factor that affects performance, sleep and fatigue. Not only do older subjects have more difficulty in sleeping and, therefore, obtain less sleep [14, 15], but ageing potentializes the adverse effects of shift work on health [16, 17]. Older shift workers seem to be less able to adjust to shift work [14] and, therefore, if possible, they give up [10]. Glazner [18] suggested four hypotheses to explain this effect: cumulative adverse effects of shift work, a general decline in the worker's health and ability to cope with stressors, flattening of the circadian rhythm and a tendency towards sleep fragility and morningness.

All together, those findings suggest that work-related noise, shift work and ageing could represent three potential contributors to enhanced fatigue at work. However, while many studies investigated the effects of only one, or at best a combination of two of risk factors, to our knowledge, our study is the first attempt to assess the combined effects of all three factors concomitantly. Therefore, we examined the hypothesis that industrial noise exposure produces fatigue that might be potentialized under the condition of shift work, and this fatigue would be stronger in older workers.

2. MATERIAL AND METHODS

2.1. Subjects

The study was carried out in a chemical plant in the north-east of France. Work consisted of supervision in control rooms as well as physical work (managing operative disturbances, loading and unloading cargo, etc.). The selection of subjects was based on their job titles to ensure a rather equal workload over the sample. Thus, all employees whose job descriptions and/or shift schedules were different from that of the majority were excluded from the study. Finally, 254 blue-collar workers including day and shift workers were selected for the study. Their age ranged from 21 to 57 years (M = 38.6 ± 9.4). They were all permanently employed. None worked overtime or had an extra job. Periodic medical examinations showed no diseases or medication use attributed to fatigue.

2.2. Work Schedules

Participants included both day (n = 66) and shift workers (n = 188). The usual work hours for day workers were 8:00–16:30 or 9:00–17:30. Shift workers worked in a regularly forward rapid rotating shift with two mornings (4:00–12:00), two afternoons (12:00–20:00) and two nights (20:00–4:00) followed by 4 days off.

The employment history in the present work schedule was more than 3 years for 86% of shift workers (n = 162), while 62% of them (n = 117) worked for more than 10 years in the same work schedule (Table 1).

TABLE 1. Employment History in the Present Work Schedule for Day and Shift Workers

	Seniority (years)			
Schedule	<3	3–10	>10	Total
Day workers	2	13	51	66
Shift workers	26	45	117	188

2.3. Questionnaire

A questionnaire was designed to collect workplace and off-the-job variables mainly recognized to produce fatigue [5, 7, 8, 15, 19, 20, 21, 22, 23, 24]. It consisted of four parts: (a) demographic data (age, gender, weight, height, etc.); (b) well-being at home (number and age of children, commuting time, sleep comfort, etc.); (c) professional data including seniority, type of job, working time and schedules, rotation and direction of shift systems, usual quality and amount of sleep related to each shift. Information on physical (noise, vibration, light, temperature), chemical, ergonomic and psychosocial factors as well as the use of personal protection devices was also collected; (d) subjective assessments of fatigue. General fatigue (tired, bushed, exhausted), rated on a 7-point scale, was used as the dependent variable [22].

Except for those concerning the subject's characteristics, all the questions on the studied variables were presented on a 7-point scale from *not at all* (1) to *extremely* (7).

The questionnaires were filled out directly at the workplace during working time from 9:00 to 16:00 when shift workers were always on the morning or afternoon shifts. To ensure the results of the survey were as reliable as possible, respondents were informed that this was an anonymous survey. However, they were not aware of the scope of the study. The experimenters were always present to respond to possible questions and avoid misunderstandings.

2.4. Noise Exposure

Noise exposure was measured with personal noise dosimetry with a Brüel & Kjær BA 4436 (Denmark). The equivalent continuous *A*-weighted sound pressure level for 8 hrs ($L_{Aeq,\ 8hr}$) was calculated for each worker. The subjects were then divided into three categories on the basis of $L_{Aeq,\ 8hr}$ (<80, 80–85, >85 dB) (Table 2).

TABLE 2. Number of Day and Shift Workers in Each Age Group as a Function of Noise Exposure at Work

	Noise Exposure ($L_{Aeq,\ 8hr}$) (dB)		
Age (years)	**<80**	**80–85**	**>85**
Day workers (*n* = 66)			
20–40	21	3	4
41–60	15	10	13
Shift workers (*n* = 188)			
20–40	33	54	19
41–60	30	32	20

2.5. Statistical Analyses

A three-factor analysis of variance (ANOVA) was performed with three between-subject variables: age (<40 and >40 years old), work schedule (shift/day work) and noise exposure (<80, 80–85, >85 dB). A two-way ANOVA with one between- (age) and one within-subject (morning, afternoon and night shifts) variable was applied on sleep quantity of shift workers only. When analyses reached significance ($p < .05$), post-hoc comparisons were performed with the LSD Fisher test. Chi-square analysis was performed to compare sleep quality between the different shifts. Associations between personal and work-related parameters with fatigue were evaluated using Pearson correlations.

3. RESULTS

3.1. Interaction Between Noise Exposure, Age and Shift Work on Fatigue

ANOVA showed that noise exposure had a significant effect on fatigue; $F(2, 233) = 9.6$, $p = .0001$. Fatigue increased as noise exposure increased. A significant interaction was observed between age and noise exposure ($F(2, 233) = 5.7$, $p = .003$) suggesting that older workers experienced the same level of fatigue whatever the level of noise exposure, while younger workers showed a dose dependent increase in fatigue as a function of noise exposure (<85 versus 80–85 dB, $p = .002$; <85 versus >85 dB, $p < .0001$; 80–85 versus >85 dB, $p = .05$). The 2 × 2 comparison showed no difference between age groups under the two higher noise conditions (80–85 and >85 dB), but in the low noise condition (<80 dB), older workers considered themselves more tired than their younger counterparts ($p = .02$) (Figure 1).

There was no main effect of age and shift work on fatigue. However, age and shift work interacted on fatigue; $F(1, 233) = 2.9$, $p = .04$. Younger shift workers were less tired than day workers of the same age group ($p = .008$), while older shift workers felt more fatigue than older day workers ($p < .01$) (Figure 2).

A significant interaction was also found between age, noise and shift work on fatigue; $F(2, 233) = 4.5$, $p = .01$. This interaction showed that older shift workers who were exposed to the highest noise load (>85 dB) were more fatigued than older day workers exposed to the same noise level ($p = .01$) and older shift workers exposed to the two lowest noise levels ($p = .03$ for both comparisons).

3.2. Effects of Sleep Characteristics on Fatigue in Shift Workers

Sleep characteristics were analysed for shift workers only ($n = 188$) to compare the effects of different shifts on sleep. There were no age-related differences in sleep characteristics, except for a main effect of age on difficulty to stay asleep; $F(1, 184) = 4.5$, $p = .03$. Older shift

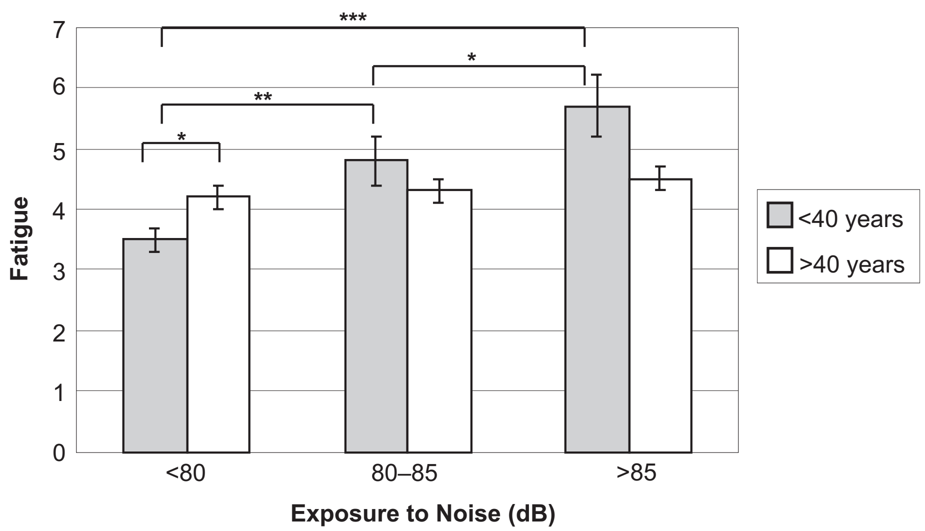

Figure 1. Interaction of age and exposure to noise on fatigue. Mean level of fatigue (±*SEM*) for different noise level groups in younger (grey bars) and older (white bars) workers. *Notes.* *$p \leq .05$, **$p < .01$, ***$p < .0001$.

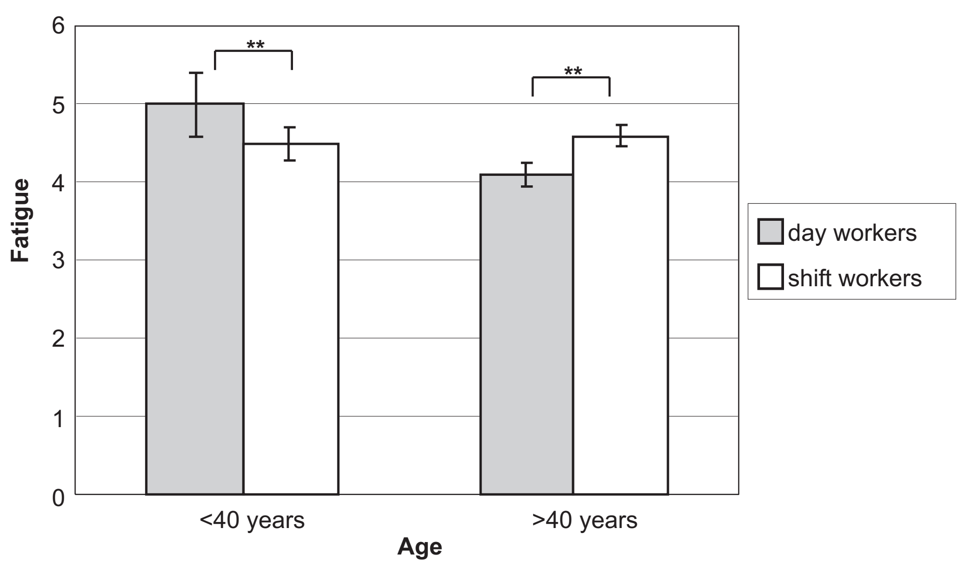

Figure 2. Interaction of age and shift work on fatigue. Mean level of fatigue (±*SEM*) for 2 age groups (<40- and >40-year-olds) in day (grey bars) and shift workers (white bars). *Notes.* **$p < .01$.

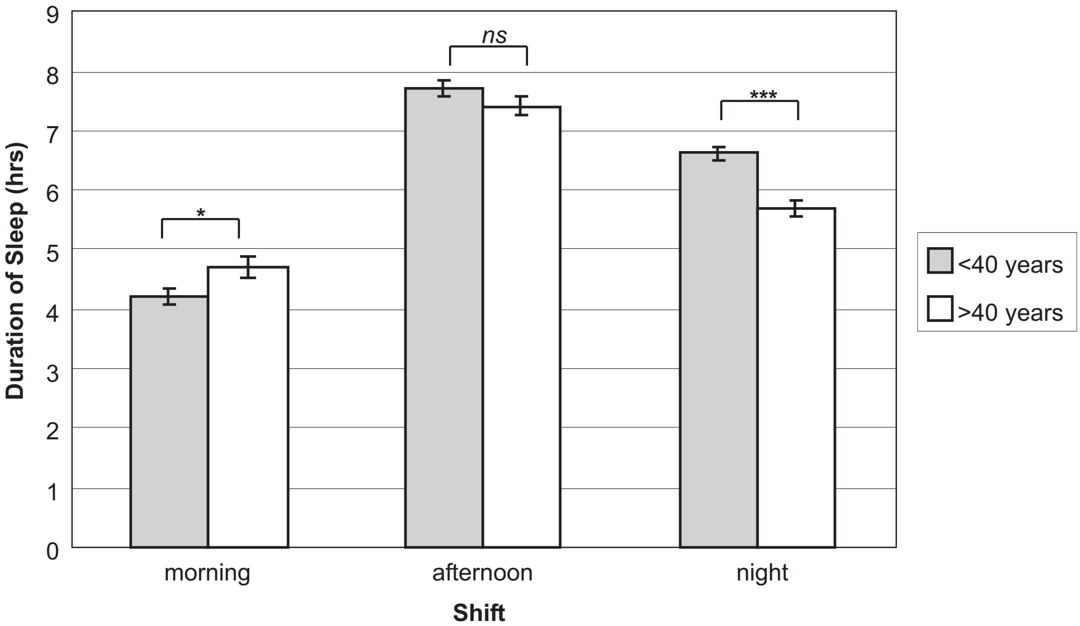

Figure 3. Sleep quantity as a function of age and type of shift. Average duration of sleep (±*SEM*) after 3 types of shift (morning, afternoon, night) for younger (grey bars) and older (white bars) workers. *Notes*. $^{*}p = .05$, $^{***}p < .0001$.

workers (>40 years) found it more difficult to stay asleep compared to the under-40 group.

Concerning shift preference, 80% of all shift workers preferred the afternoon shift, 14% the night shift and 6% the morning shift.

The average of sleep quantity was 7.54 ± 1.27 hrs after the afternoon shift, 6.23 ± 1.20 hrs after the night shift and 4.40 ± 1.30 hrs after the morning shift. The effect of shifts on sleep duration was significant; $F(2, 364) = 298.5$, $p < .0001$. Sleep duration was maximal after the afternoon shift and minimal after the morning shift, the night shift being intermediate ($p < .0001$ for all comparisons). However, an age × shift interaction on sleep duration ($F(2, 364) = 13.9$, $p < .0001$) revealed that shift workers over 40 years old slept more in the morning shift ($p = .05$), and less in the night shift ($p < .0001$) compared to their younger counterparts. No age-related difference was found for the afternoon shift (Figure 3). Compared to the quantity of sleep in the different shifts, fatigue was found to be inversely correlated with sleep duration after the night shift ($r = –.2$; $p = .007$); however, this was not so for the morning and afternoons shifts.

3.3. Correlation Between Other Parameters and Fatigue

None of the demographic, home- or work-related variables were associated with fatigue, except for self-estimated noise exposure at work; $r = .45$, $p < .0001$. Age and seniority at work were positively correlated ($r = .7$, $p < .0001$), but none of those two factors were associated with fatigue. No age-related difference was found in using hearing protection devices.

4. DISCUSSION

The present study reveals a complex interaction between noise, shift work and age. Our results suggest an interaction between factors such as shift work and age, which could be aggravated by exposure to high industrial noise. In agreement with previous studies [4, 6, 7], our data showed that occupational noise exposure produced fatigue. Noise level at work had a critical effect on fatigue in all workers whatever their work schedules or their age. However, our hypothesis was that noise load would interact with age leading to a more deleterious effect of noise on fatigue in older workers. In fact, depending on the age group and noise load, respondents did not report the same level of fatigue. While older workers reported approximately the same fatigue rate whatever the noise load, the younger group showed a dose-dependent increase in fatigue from the lowest to the highest noise level. Accordingly, the expected age-related increase in fatigue was only found in the lowest noise condition with a significant higher rate of fatigue in the senior group, whereas in the two highest noise levels, no more difference was found between age groups. Since the physical workload was approximately the same in all the workers included in this study (essentially blue-collar workers), this factor cannot explain the observed age-related difference. Moreover, we showed that neither environmental risk factors (temperature, posture, light or chemical agents) nor home conditions (comfort in the sleeping environment, children, commuting time, etc.) were significantly related to fatigue. Neither can this be explained by a differential use of hearing protection devices as suggested by a similar reported application rate between the two age groups. Indeed, in this factory, hearing protection devices were strongly recommended in the two highest noise conditions. It could be, therefore, that in the lowest noise condition, where most workers did not wear hearing protectors, seniors were less tolerant to ambient noise. This result would be in agreement with Leventhall, who also reported greater complaints about moderate ambient noise in middle-aged persons [25]. However, one should consider that in the present context the lowest noise condition still included exposure to quite high noise load. Anyway, this could not explain why in the two highest noise conditions, the fatigue rate of the senior group remained stable.

The best explanation for this apparent all-or-none sensitivity to noise-related fatigue observed in older workers could be the result of an adaptation to noise over the years of work leading to an underestimation of fatigue produced by noise. According to Gitanjali and Dhamodharan the negative effects of permanent exposure to loud occupational noise were significantly reduced with seniority at work [26]. If so, older workers always had a similar perception of noise load because they got used to it over time, unlike younger workers who did not show this habituation effect (yet?).

However, older workers, due to age-related hearing loss, might be less able to differentiate between the two higher noise levels (i.e., 80–85 and >85 dB). Therefore, they would not perceive the difference between 80 and 85 dB as a different level of fatigue. This explanation is, however, unlikely in this study, since a gradual increase in fatigue level was found with noise load in older shift workers, suggesting that older workers had an adequate noise perception to consider themselves more tired when exposed to higher noise levels. In other words, if older workers had attenuated noise perception because of age-related hearing loss, they would not consider themselves more tired under the combined condition of shift work and high noise exposure.

In any case, noise is certainly not the only factor involved in fatigue, as suggested by the interaction between age and shift work. Older shift workers experienced more fatigue than day workers of the same age. According to Glazner, enhanced difficulty to adjust to shift work with age could be due to modifications in the circadian rhythms and a general decline in the worker's health and ability to cope with stressors [18]. Härmä, Hakola, Åkerstedt, et al. also reported increased inability of older workers to tolerate shift work [14]. Moreover, the significant interaction of noise, age and shift work clearly confirms that the highest occupational noise exposure could aggravate the aforementioned negative effects of age and shift work on fatigue.

All together, these data suggest that a key factor could be related to age even though there was no main effect of age on fatigue. Therefore, our hypothesis is that the common pathway between loud noise exposure, shift work and age could be related to sleep characteristics. The flattening of circadian rhythms with age is associated with sleep–wake fragmentation and it is well known that old workers (either day or shift workers) usually experience decreased restorative sleep due to sleep fragmentation, sleep maintenance difficulty, or a drastic decrease in deep sleep. Many studies have reported modifications in sleep structure over the life span, with specific deficits due to age [13, 15]. As a matter of fact, in this study, older workers complained about difficulty in maintaining sleep. Moreover, sleep duration was strongly related to the shift, suggesting that shift work and age could have cumulative effects on sleep quality and/or quantity, a result which could, at least partly, account for increased fatigue during the day for older shift workers. Therefore, it is likely that reduced sleep and/or decreased restorative power of sleep could not only disadvantage older workers compared to younger ones, shift workers compared to day workers, but also older workers exposed to high ambient noise load, thus leading to a complex interaction between those three factors in generating enhanced fatigue.

However, these results should be taken cautiously since fatigue by itself is a complex and multidimensional concept, which includes different aspects such as physical and mental fatigue, reduced motivation, etc. In the current study, fatigue was defined very broadly as tiredness, which usually reflects general fatigue [21, 27], and it is not certain that all the aspects of fatigue would be affected in the same way.

In conclusion, the present study suggests that when age, noise and shift work interact, age could be an important factor potentialized by noise and shift work to produce fatigue at work. This complex interaction could, at least partly, be sustained by the sleep deficits due to (a) ageing, (b) the deleterious effects of shift work and (c) delayed effects of noise on sleep structure (a factor which was not investigated here). Efforts should be made to avoid as far as possible employing seniors in such conditions. Since this was a field study, many other factors could have interfered. However, the major limitation of our study is the lack of specific information on sleep characteristics and this could be the next step to provide more insight into the interaction between age, noise and shift work on work-related fatigue.

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