Effect of simulated vibration and noise exposure on human contrast sensitivity function

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Abstract. In occupational environments that involve mobile machinery, operators are often subjected to vibration and acoustic noise. These risk factors can cause short-term performance degradation, which may increase the chance of occupational hazards. Prior studies focused on visual acuity (VA), which is inadequate in characterizing all aspects of human visual function. For real-world scenarios, contrast sensitivity (CS) was shown to be capable of characterizing human ability in object detection. Therefore, we developed a controlled experiment as an exploratory step to investigate the effects of vibration and noise on CS. We developed a computerized test and measured how the CS of participants (N=24) altered under exposure to vibration and noise. Significant CS losses were observed for vibrations of 5 Hz and 12 Hz. Further findings and implications are discussed.

Keywords: contrast sensitivity, vibration, noise, occupational safety

1. Introduction

Employees who work in environments that involve mobile machines and vehicles are often exposed to different kinds of ergonomic risk factors. Two prevalent factors tightly associated with running machines are the transmitted vibration to the human body and the noise emitted by the machine's moving parts. Isolated or combined exposure to noise and vibration can negatively impact workers' health and lead to headaches, eyestrain (Hashiguchi et al. 2021), hearing loss (Turcot et al. 2015), and compromised reaction time (Newell & Mansfield 2008). It is crucial to understand how human is affected by these risk factors to promote occupational safety.

Human visual acuity (VA) has been widely used as a defining measure to assess a person's vision. So naturally, previous studies investigated the effect of noise and vibration on the VA. For instance, exposure to whole-body vibration was shown to negatively impact visual acuity and cause blurred vision (Kjellberg 1990).

However, the VA cannot characterize the entire spectrum of human visual performance. By contrast, the contrast sensitivity function (CSF) can access aspects of human vision that are more closely related to daily life (Ginsburg 2003). The CSF can measure visual performances under real-life conditions, such as determining the least amount of contrast needed to detect a visual stimulus, yielding a complete quantization of human visual capabilities (Jindra & Zemon 1989). Other studies confirmed that CS could predict pilots' visual performance in aircraft simulators (Ginsburg et al. 1982). Combining previously mentioned evidence, we conclude that considering CS alongside VA when accessing human visual performance may provide a more holistic picture in understanding the real-world demands in occupational fields.

To our knowledge, no research has attempted to study the combined effects of both stressors on human CSF over a wide range of spatial frequencies. Therefore, we explore how human CS changes in response to selected combinations of spatial frequencies, vibrations, and noises. We hypothesized that noise and vibration negatively could cause losses in contrast sensitivity.

2. Method

We designed a controlled experiment to evaluate the effect of different combinations of vibration and acoustic noise on human CSF. A computerized CS testing application was developed using Unity (2020.3.19f1 LTS) to record participants' input.

2.1 Participants and exclusion criteria

We recruited by distributing flyers physically and virtually on social media. The participants were aged between 18 and 60 years old and required to wear their daily corrections during the entire experiment. We used the Rodenstock Binoptometer II to administer quick VA screening, and those who had a binocular VA below 0.8 were excluded. In addition, Lang's Stereo Test was also used to exclude participants with poor stereopsis. These exclusion criteria were to minimize effects caused by stereoscopic dysfunction or severe refractive errors. Those who finished all measurements were compensated with 20 CHF for their time and participation.

2.2 Instrumentation

We chose to use Snellen's E as the visual stimuli for the CS tests, as they are less susceptible to the spurious resolution and spatial aliasing that can occur on a monitor with periodic stimuli such as gratings (Herse & Bedell 1989; McAnany & Alexander 2006). According to the definition (Wesemann et al. 2010), the stroke width of this optotype was 1/5 the letter width, and there were 2.5 cycles per letter (cpl).

Since decimal visual acuity of 1.0 (20/20 Snellen or 0.0 log MAR equivalent) corresponds to 30 cycles per degree (cpd) (Regan et al. 1981), the SF of the optotype can be estimated as 30 * decimal visual acuity. Therefore, we will hereafter interchangeably use VA in decimal to represent the SF and the size of the optotype. We chose to use a Snellen's E with a stroke width of 2 pixels for the visus 1.0. To avoid aliasing, the optotype's width and height were set to be integer multiples of 2 pixels. In total, seven spatial frequencies (2, 3, 5, 7.5,15, 20, 30 cpd) were included.

To change the contrast, we displayed the optotype as an image and modified its alpha component on the screen. An image's alpha is a color component representing the degree of transparency (or opacity) of the displayed color. The value ranges from 0 (fully transparent) to 1 (fully opaque). It is updated with a variable update frequency and a constant step of 1/255. Calibration was performed with a photometer (LMT1003, Krochmann GmbH) to create a lookup table for the final calculation of the CS.

During pretest trials, participants needed way higher contrast to recognize small optotypes, especially at higher vibration frequencies. Consequently, we decided to double the update frequency of the contrast every second optotype size until a maximum of 4Hz is reached.

The visual stimuli were displayed in the center of an LCD monitor (AOC 27G2SU 27) with a white background of constant luminance (263 cd/m2). Given the stroke width of the optotype, the required viewing distance of 2.13 meters to the monitor can then be calculated based on the minimal stroke width (2 pixels), the monitor size (27 inches), and its resolution (1080p). A dim backlight with a small luminance of 3 cd/m2 illuminated the surrounding.

2.3 Generation of the stimuli

In our setup, the vibration was simulated through software by shifting the pixels on the monitor. The shift followed a sinusoidal function in time. We focused on vibration in the vertical direction, which is prominent in occupational situations and has been shown to significantly influence human performance (Griefahn et al. 2000; Hashiguchi et al. 2021). Further research concluded that vibrations lower than 4 Hz did not significantly affect the CSF (Adams 1992). To limit the scope of the study, we used a fixed amplitude of 10 pixels. Consequently, we included 0Hz, 5Hz, and 12Hz to represent baseline, moderate and intensive vibrations.

We used two types of auditory stimuli, which were generic white noise and a recording taken in the cabin of an operating excavator (Vidar steinsland 2020). For the measurements where the noise was included, the corresponding audio clip of 45 dB (A) was presented through noise-canceling headphones (Bose QC 25) concurrent with the onset of the visual stimulus. A sound level meter (Voltcraft VL-10) was used to calibrate the sound level pressure at the location of the ear.

2.4 Psychophysical method to measure contrast sensitivity

The contrast sensitivity function is typically obtained by measuring contrast thresholds over a range of spatial frequencies (SF). Standardized methods, such as the Pelli-Robson chart, are favored for their efficiency in clinical measurements (Pelli & Bex 2013) but cover a limited range of spatial frequencies.

Our approach was a computerized modification of the method of limits (Gescheider 2013) on PC. Once started, a Snellen's E with one of four possible facing directions (left, right, up, down) would be displayed on a white background in the center of the screen. When the test scene was first initiated, both the optotype and the background were of the same contrast. The application then gradually increased the contrast by decreasing the optotype's luminance. The participants were required to input the facing direction of the optotype as soon as the optotype became visible to them. Logically, the response may lead to two outcomes: Upon correct response, the current contrast level would be recorded for this measurement. The contrast sensitivity was then calculated as the logarithm of the Weber contrast reciprocal, also referred to as logCS (Bach et al. 2017). Each measurement always started at the largest optotype size, and the next optotype of one size smaller was loaded with a randomized orientation after the logCS was recorded. Upon a wrong answer, the direction of the optotype would be randomized, and the measurement would start from zero contrast. The number of wrong answers was also recorded. Whenever the stimulus changed, the screen switched back to white for one second to wash out the visual memory.

Such a single measurement corresponds to a single point on the CSF. After pretests, we concluded that recording the CS at seven SFs struck a good balance between the total experiment duration and the covered SF range. To increase the robustness against outliers, each CS was measured four times, and the measurements' median was used as the final result.

2.5 Controlled experiment and variable

We included two dependent variables, the CS and the error count (EC). The entire experiment can be separated into two parts based on the exposure condition. In the first part, we included the spatial frequency (SF)(7 levels), the vibration frequency (VF)(3 levels), and the noise level (NL)(2 levels) as independent variables. To study the sequence effect, we partitioned participants into two equal groups that started with different NL. The two-level between-subject variable was named "sequence."

The second part (Part 2) attempted to recreate an experience closer to occupational conditions. Therefore, a combination of 5Hz vibration and occupational noise recorded in the driver cabin of a construction machine was applied.

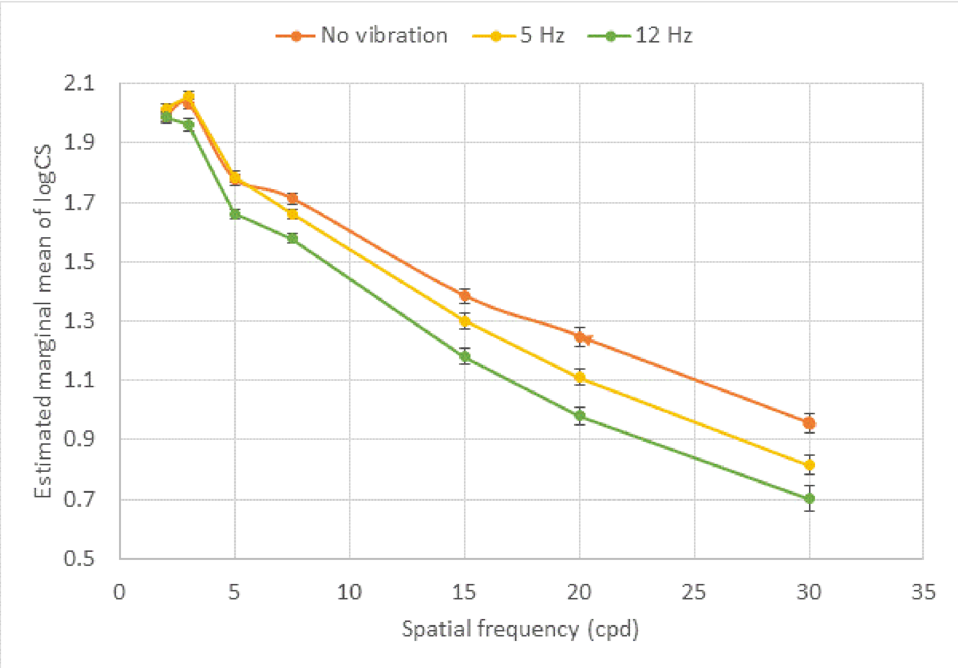

Figure 1. *Estimated marginal means of logCS from experiment part 1*

3. Results

Limited by the scope of the short manuscript, we will not cover the second part of the experiment and any analysis of the error count. The ANOVA for part 1 revealed that SF and VF significantly affected the dependent variable CS, while the NL and the between-subject factor did not. The CS was significantly affected by the SF with $F(1) = 245.7$, $p < 0.001$, partial $\eta 2 = 0.925$, and by the VF with $F(1) = 1357.1$, $p < 0.001$, partial $\eta 2 = 0.985$. Fig. 1 plots the estimated marginal means of CS against the SF. A follow-up simple effects test for the estimated marginal means of SF and VF confirmed no significant differences for the first level of SF (2 cpd) across all VFs.

4. Discussion

Our major finding was the negative effect of the vibration on the human CSF. A closer inspection of Fig. 2 TPDP and a follow-up study of the simple main effects reveals further details about the combined effect of SF and VF: It is evident that for measurements at 2 cpd, neither VF affected the CS. After that, vibrations of 5Hz only started to cause the drop of CS starting from the 7.5 cpd. By contrast, significant CS losses were already detectable, starting from 3 cpd for vibrations with 12 Hz.

Moreover, we found that the magnitude of CS losses increased with increasing SF, which matches a prior study (Moseley & Griffin 1987). These findings imply that the degradation of CS depends on both SF and VF. Large target objects of smaller spatial frequencies and coarse patterns, such as zebra markings on the ground, are less prone to vibrations. By comparison, fine-detailed small objects of higher spatial frequencies (such as signs and partly occluded human body viewed from a distance) that are relatively demanding to detect even in static conditions could be heavily influenced by the CS loss and may thus require more contrast than under normal circumstances. Since the between-subject variable was not significant and the duration of the experiment was short, we ruled out fatigue as a possible reason for the drop.

A vexing problem for CS-related studies is the difficulty of comparing measured results across studies, as different methods target different ranges of SF. Even CS measured at the same SF may have large discrepancies depending on the methods applied, which makes a direct comparison difficult (Bühren et al., 2006; Kollbaum et al. 2014). Judging from the general trend, our baseline CSF exhibits a monotonically decrease starting from 3 cpd, just like measurements obtained with the Vistech table (cf. El-Gohary & Siam 2009)). Though the measured CS differed in magnitude, our CSF had the same peak at around three cpd.

Due to human's complex response to vibrations, the simulated vibration in our study is not entirely equivalent to exposure to whole-body vibration. Operators of mobile machines may face whole-body vibration, vibration transmitted to human eyes and vibrating displays, and the interaction between vibration and CS may be more complex and intertwined. Therefore, one should take this study as a first exploratory step toward a complex problem and not over-interpret the results.

To conclude, we conducted an exploratory experiment and obtained data on how human CSF changes under vibration and noise exposure. We could measure human CS at a wide range of SF within a short time with a computerized method. Our major finding was that the vibration of target objects displayed on a monitor screen significantly reduced CS, especially at higher spatial frequencies, which could make the identification and detection of fine-detailed objects on display more demanding than it already was.

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