The human body exposed to vibration may be thought of as a series suspended elements (head, thorax, pelvis) linked by shock absorber systems (ligaments, muscles, intervertebral discs).

The physiological and psychological effects of vibrations on humans are caused by significant relative deformation and displacement undergone by organs and tissues at certain frequencies.

The frequency of the sinusoidal movement of a freely oscillating system if it is subject to impetus and not damped is known as the eigenfrequency. The eigenfrequency of the organ corresponds to the maximum transmission of movement applied to it, if the organ is considered to be an undamped system. If the system is damped (which is generally the case in the human body), maximum transmission of movement occurs at a particular frequency which is known as the resonant frequency. By definition, the resonant frequency is lower than the eigenfrequency, but there is generally only a small difference between the two, as the organs of the human body generally are not heavily damped.

Some resonant frequencies for a subject who is exposed to vertical vibrations:

- Head: 20-30 Hz. Visual disturbance is also observed between 60 and 90 Hz, which can be explained by resonance of the eyeballs.
- Thorax: 3-7 Hz. This explains the respiratory problems that are observed at such frequencies.
- Heart: 4-8 Hz. Chest pains have been described, which could correspond to heart-related pain.
- Abdominal and thoracic organs: 4 to 9 Hz
- Spine: 2-6 Hz (5 Hz)
- Pelvis: 4-9 Hz

At frequencies of less than 2 Hz, the body reacts like a single mass. In a seated human body, the first resonant frequencies occur between 3 and 6 Hz; in a standing human, there are two maximum values, at 5-6 Hz and 12 Hz [Subashi²].

Resonance occurs when transverse or front-to-back vibration occurs at frequencies of around 2 Hz. It is caused by flexion in the lumbar and thoracic spine, in the hip joints and by curvature of the head.

The perception threshold for vibration is around 0.01 m/s².

Vibration perception depends on:

- the region and surface area of the body that is in contact with the source of excitation;
- the intensity, frequency and direction of the vibration;
- the subject’s sensitivity;
- the position and posture of the subject and whether he/she is tense or relaxed;
- the dynamic interaction between the body and the structure through which the vibration is transmitted to the human body;
- the distribution, mass and dynamic properties of any clothes and equipment the subject may be wearing/carrying;
- the environment: noise, temperature, lighting, vision;
- the activity engaged in (physical, mental, visual, oral);
- psychological influences.

It is considered that there are three types of condition under which people are exposed to vibration:

- Vibration transmitted to the whole body in all directions;
- Vibration transmitted to the trunk via the lower limbs of a standing person, the pelvis of a seated person or the bed in the case of someone who is lying down. This is the situation that is encountered on board ships.
- Vibration via the extremities, such as the hands, arms or head.

A change in posture can alter distribution of body mass and resonance linked to vibration. This can also mean that vibration transmission shifts to another part of the body. The effects may, for example, be different for someone who is standing than for someone who is sitting. Muscular activity can modify the effects of vibration on the organism [Huang and Griffin3].

As well as being a cause of seasickness, Haward et al.15 have shown that fatigue and sleeping problems are strongly correlated with movement along all three axes, and the strongest correlation is with sleep quality. Hours spent asleep were negatively correlated with amplitude of movement.

Lower back pain is also associated with an increase in amplitude of ship movement. Törner et al.16, 17 have reported that vertical acceleration of ±0.4m/s² and rolling of ±8 degrees on board trawlers is associated with an increase in cerebrospinal fluid pressure. Hoogendoorn’s18 work suggests that twisting movements of the spine are an independent factor responsible for lower back pain. Such movement is common on board as individuals seek to keep their balance as the ship moves, particularly on small vessels. However, Törner has shown that knee movement acts as a buffer. In spite of this, compression forces may be increased while carrying materials on board, because of increased contraction when attempting to stabilize [Barzgari19]. Several authors [Törner17, Wertheim20] have shown that oxygen consumption was increased in subjects standing on board ships while undertaking a lifting task, but that oxygen exchange was reduced, because of overall muscular tension, which increases fatigue.
levels. Conversely, Drerup\textsuperscript{21} found no abnormalities in intervertebral discs in subjects exposed to whole-body vibration, in comparison with a control group.

At frequencies of between 2 and 20 Hz, the body no longer acts as a single mass, but as a system of suspended masses. At such levels of vibration, the labyrinth is no longer sensitive.

On board ships, vibration of between 2 and 20 Hz is found, and as we have seen this is linked to the propulsion system and propellers. The intensity of this vibration is generally quite low. Depending on the RPM of the engine, this vibration can be amplified and, if this occurs, inconvenience is caused to those trying to write or read. This can also cause partitions to resonate, and can generate unpleasant noise which will increase general fatigue and exacerbate concentration problems. Many authors have attempted to quantify the reduction in performance experienced by people exposed to periodic and random vibration. Vibration makes a task more difficult and cumbersome. Vibration hampers precise movement and accurateprehension with hands and fingers.

Vibration also leads to an increase in reaction time, requiring greater concentration on the task in hand at the expense of attention to secondary tasks, which means that vigilance is reduced.

In a subject who is exposed to this type of vibration, shifting body mass and maintaining posture (particularly in the case of random vibration such as whipping and springing jerks) leads to stimulation of muscular activity which compensates for the effects of vibration. If there are major jerks (acceleration greater than 2 m/s\textsuperscript{2}), there can be trauma to the lower back, in the form of fractures or compression injuries, particularly to L3-L4 [Ayari\textsuperscript{22}].

Holmlund \textit{et al.}\textsuperscript{23} have shown that impedance increases as a function of frequency, up to an initial maximum in the 4-6 Hz range, which particularly affects the spine. There is a second and third impedance maximum in frequency ranges 8-12 and 50-70 Hz.

Subjects exposed to medium-frequency whole-body vibration have been shown to have a higher incidence of lower back pain [Burdorf\textsuperscript{24}].

Vibration can lead to microscopic trauma of the spine, particularly the lumbar spine, which are particularly troublesome because the spinal column is unbalanced. On board ships, particularly fishing vessels and fast craft, vibration is a factor that exacerbates problems caused by postural constraints and the difficulty of keeping one’s balance in a moving vessel, as we have seen. The most significant responses were in the 5-8 Hz range.

Low-frequency vibrations, particularly between 4 and 12 Hz, tend to increase respiratory parameters: respiratory frequency, ventilation rate and oxygen uptake [Maikala\textsuperscript{25}]. These increases seem to be linked to general muscular tension caused by vibration: at 10 Hz, there is very significant tension in the muscles in the lower back, chest, abdomen and back.

An increase in heart rate is often observed. Between 4 and 11 Hz, when vibration is of significant intensity, disturbances to heart rhythms have been observed, in the form of extrasystoles and at times tachycardia.
Occasional cases of myocardial infarction in young people with no history of arteriosclerosis or coronary artery disease, have been linked to vibration.

Digestive tract and urinary tract problems have also been observed, which are partly due to changes in peristalsis in visceral smooth muscle.

This all has an effect on general levels of fatigue, which are already raised by various causes (noise, very low frequency vibration, stress etc).

High-frequency vibrations, above 20 Hz, have a purely local impact. The most commonly studied example of this is vibrating tools. Some seafarers (engineers or deck crew members) are likely to use such tools, for rust removal, sanding and cutting. Upper limb conditions arising from such vibration are well-known. High-frequency vibration can cause angioneurotic problems in the hands and fingers, arthritis in the elbows and finger joints, bone disease in the carpal bones (necrosis of the lunate bone or Kienböck’s disease). These diseases are rare in seafarers, but it is nonetheless essential that the field of maritime medicine gain familiarity with them in order to diagnose and prevent them.

19.3 Effects of Ship Vibration on Humans
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