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Muscular forearm activation in hand-grip tasks with superimposition of mechanical vibrations

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ABSTRACT

The purpose of this paper is to evaluate the muscular activation of the forearm, with or without vibration stimuli at different frequencies while performing a grip tasks of 45 s at various level of exerted force. In 16 individuals, 9 females and 7 males, the surface electromyogram (EMG) of extensor carpi radialis longus and the flexor carpi ulnari muscles were assessed. At a short latency from onset EMG, RMS and the level of MU synchronization were assessed to evaluate the muscular adaptations. Whilst a trend of decay of EMG Median frequency (MDF_d) was employed as an index of muscular fatigue. Muscular tasks consists of the grip of an instrumented handle at a force level of 20%, 30%, 40%, 60% of the maximum voluntary force. Vibration was supplied by a shaker to the hand in mono-frequential waves at 20, 30, 33 and 40 Hz. In relation to EMG, RMS and MU synchronization, the muscular activation does not seem to change with the superimposition of the mechanical vibrations, on the contrary a lower MDF_d was observed at 33 Hz than in absence of vibration. This suggests an early muscular fatigue induced by vibration due to the fact that 33 Hz is a resonance frequency for the hand-arm system.

1. Introduction

The influence of Mechanical Vibration (MV) on a neuromuscular system has been widely studied in several fields of applied physiology (sport, occupational, rehabilitation).

Even if MV are at low levels, in occupational studies a long period of exposure to MV have been proved to induce disorders called hand-arm vibration (HAV) syndrome on the hand-arm system (HAS) (Bovenzi, 2006). Mainly, chronic effects regards joint and vessels while acute ones involves HAS muscles and sensory subsystems. Chronic effects weigh on the subject's quality of life, whereas acute effects have a relative significance on the subject's professional performance and safety.

The study of MV stimulation on electric muscular activity began with the work of Hagbarth et al. who investigated the vibration stretch reflex (Hagbarth et al., 1976), which is related to tonic vibration reflex (TVR). Some authors assessed the TVR influence on local muscular activation and found that the stimulus can induce an early fatigue (Park and Martin, 1993; Martin and Park, 1997). Moreover, in literature several papers described how MV may be used to induce an increase of muscular performance (Abercromby et al., 2007; Bosco et al., 1999a,b; Fattorini et al., 2006).

However, the influence of MV on a neuromuscular system is far from being clear. One of the reason could be the lack of a defined connection between MV and muscular response as this could depend on multiple physiological and physical factors. First and foremost there are the MV physical characteristics: as widely documented the MV frequency and power have an evident influence on energy transmissibility (Pyykkö et al., 1976; Sörensson and Lundström, 1992). Moreover, the amplitude of the MV displacement may affect the stretch reflex. However, with regards to frequency, the lower it is, the longer MV will travel along the HAS (Griffin, 1990; Sörensson and Lundström, 1992) involving different anatomic structures. Secondarily, the central role of the coupling between mechanical and biological compartments must be taken into account. This coupling is performed by muscles of the hand by actions named "Grip"; these actions are the clamp-like forces exerted by the two halves of the operator's hand that clutches the handle (ISO 15230:2007). The grip changes the mechanical characteristic of the articular stiffness of the joints (Pyykkö et al., 1976; Reynolds and Angevine, 1977). Several authors reported a general response function of the biological system when exposed to MV (Kihlberg, 1995; Sörensson and Burström, 1997; Sakakibara et al.,

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1986), but the studies are not wholly comparable because the coupling parameters are not homogenously defined.

Martin and Park studied the neuromuscular response from the point of view of the amount of motor units (MU) synchronized and unsynchronized with the external MV vibration cycle (Martin and Park, 1997). In the same paper the authors suggested that TVR could influence the motor control, because the imposed MU synchronization over the physiological motor drive, changes the recruitment pattern during exposure.

Under the mechanical point of view, the transmission of MV along the HAS shows a non-linear relationship with the frequency (Kihlberg, 1995), in the range of 20–40 Hz and this is due to the HAS mechanical resonance that is determined by the forearm stiffness (Dong et al., 2008c; Marchetti et al., 2007; Kihlberg, 1995). The stiffness change is related to grip force and posture. Evidently, mechanical and biological compartments coupling changes are due to interaction between biological and mechanical properties of the forearm via joint stiffness. This in turn is affected by grip force exerted during the motor tasks.

Finally, the study of muscular fatigue is of particular interest from the point of view of occupational hygiene, given the prolonged exposure of people to low level vibration, typical of occupational circumstances. The muscular fatigue can also affect the motor task performance of workers that, in turn, can affect personal safety. The exploration of fatigue requires a longer motor task than the mere TVR investigation. Martin and Park worked on a signal of 45 s, in order to assess muscular fatigue. This paper was designed to evaluate the HAS neuromuscular adaptation and fatigue to the mechanical vibration related to grip level and stimulus frequencies. The MV studied frequencies were chosen within a narrow range around the main HAS resonance using a set of frequencies as well as one adopted in a recent paper that are of interest from an hygenistic point of view (Marchetti et al., 2007).

2. Materials and methods

2.1. Experimental design

The experimental setup was designed to assess the muscular activity when the subject was exposed to mechanical vibration while executing a motor task, which required the standardization of multiple aspects of the setup. Hereafter all these aspects will be examined in detail.

For each subject all measurements were performed on the same day. The study was conducted according to the declaration of Helsinky and followed the guidelines established by the ethics committee of the University of Roma Sapienza.

Table 1
Experimental anthropometric subject's characteristics.

	Age (y)	Body mass (kg)	Height (m)
Male ($N = 7$)	38.3 ± 11.1	76.3 ± 5.3	1.78 ± 0.05
Female ($N = 9$)	29.4 ± 7.1	55.2 ± 3.4	1.68 ± 0.07
All subjects	32.8 ± 9.2	63.1 ± 3.3	1.72 ± 0.08

2.2. Subjects

Sixteen experimental subjects (Table 1) were selected between healthy volunteers: 9 females and 7 males. None of the subjects had a history of muscular or bone injuries, diseases, or previous professional exposure to vibration. All of them were informed previously and gave their consent to the experiment.

2.3. Vibration signals

Mechanical vibration on the handle was elicited by an electrodynamic shaker (RMS SW 1508, Germany, EU) driven by a controller (Vibration Research VR 7500-2, Germany, EU) at 20, 30, 33 and 40 Hz, from here on called SV20, SV30, SV33 and SV40 respectively. The control loop was closed by a monoaxial accelerometer (PCB, 353M197, NY, USA) on the handle. The signal was constant with a velocity amplitude of $27 \cdot 10^{-3}$ m s^{-1}. The sequence of the vibration imposed to the handle, included a control condition of the shaker switched off (SV0), was randomly administered to each subject.

2.4. Motor task

The motor task consisted in holding the handle with the dominant hand (subjects declaration) at pre-established force values for 45 s. This task was performed on a steel handle (first resonant frequency at 800 Hz) instrumented with strain gauges for grip force measurement (Fig. 1) connected to the vibration generator. In order to measure both components of grip force (i.e. push and pull) the handle was separated into two halves, connected by bridged strain gauges. The latter configuration allowed zeroing the Wheatstone bridge before every measurement, as temperature and humidity conditions having great influence over strain gauge response.

The grip force (GF) exerted was expressed in terms of Maximum Voluntary Contraction (MVC). The MVC was the maximal force exerted on the handle over three repetitions, each lasting 5 s. The MVC value adopted was the highest of these reiterations. The force values requested during the motor tasks were 20–30–40–60 percent of MVC, from here on called GF20, GF30, GF40 and GF60 respectively. Both components of grip force were continuously recorded and displayed to the subject by an oscilloscope

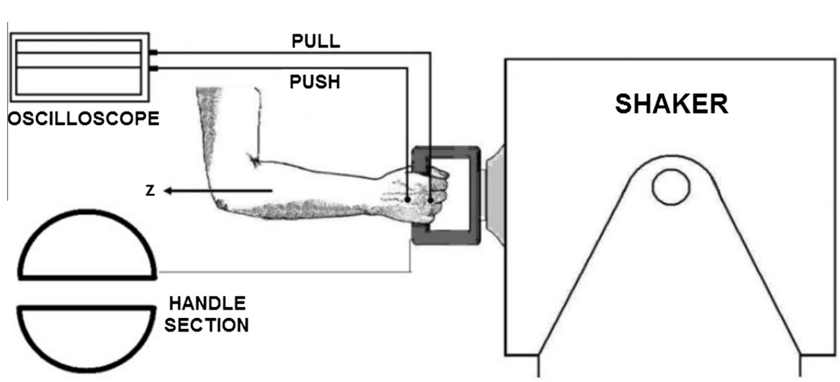

Fig. 1. Experimental setup.