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Interference of Vibration Exposure in the Force Production of the Hand–Arm System †

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Abstract: The authors evaluated the short-term neuromuscular effects on the assessment of mechanical hand—arm systems induced by vibrating tools to investigate the relationship between the force exerted and the vibration exposure. The motor task consisted of holding the instrumented handle with the dominant hand at predetermined grip force values. Five subjects took part in the tests. The tests were developed in the absence of vibration and in the presence of vibration at 5 m/s^2, 7.5 m/s^2 and 10 m/s^2. The push and pull force values were calculated in the tests on the five subjects.

Keywords: tonic vibration reflex; mechanical vibrations; exhaustive motor task; push–pull force control

1. Introduction

The active behavior of the tonic vibration reflex (TVR) in the assessment of vibration exposure in the mechanical hand–arm system (HAS) is well-known [1–3]. The interaction between vibration and muscular contraction may generate disturbance in motor tasks and force development. This paper aimed to assess the force parameters during exhaustive grip force tasks with and without vibration. The hypothesis is that vibration exposure can induce early fatigue and unbalanced motor control during a motor task.

2. Material and Methods

The authors evaluated the short-term neuromuscular effects on the HAS induced by vibrating tools to investigate the relationship between forces exerted and vibration exposure [1]. The tests were performed at 30 Hz at different accelerations with a grip force of 30% of the maximum voluntary contraction (MVC), as explained below. The selected frequency represents the frequency inducing maximal hand–arm energy transmission, as reported in Fattorini et al. [2,3].

2.1. Subjects

Five subjects took part in the tests (Table 1). Each volunteer underwent the MVC measurement, exerting grip force with the dominant hand on the handle of the shaker, switched off, three times. The average of the measurements offered the MVC value of each subject. The grip force values depend on the average value [2].

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Table 1. Characteristics of Subjects and MVC values.

	Subject				
Subject	**A**	**B**	**C**	**D**	**E**
Height [cm]	170	167	170	184	181
Weight [kg]	103	72	65	93	88
Gender	M	M	M	M	M
MVC 1 [N]	470	400	380	470	330
MVC 2 [N]	490	430	360	460	310
MVC 3 [N]	490	400	350	450	330
MVC 30% [N]	140	120	110	140	100

2.2. Motor Task

The motor task consisted of holding the instrumented handle with the dominant hand at predetermined grip force values. The handle had two strain gauges, measuring push and pull forces, and the subject had to maintain the target force value for as long as possible (Table 1). To measure both components of gripping force (i.e., push and pull) the handle was divided into two halves, as described in Fattorini et al. [2]. The deformation of the handle resulted in a strain gauge response. This configuration allowed for continuous control of push and pull forces on an oscilloscope positioned in front of the operator. Temperature and humidity were maintained by an air conditioner to stabilize the strain gauges' transfer function. Before the tests, MVC was evaluated as the maximal force between three trials of maximal gripping. During this evaluation, the subject's posture was that described in Fattorini et al. [2]. The subject stood on an elevated platform to adjust the forearm and handle axes. The subject was instructed to balance push and pull force to attain pure grip force, without any possible component from the shoulder. Both components of grip force were continuously recorded and displayed to the subject by an oscilloscope (Hewlett & Packard, 54603B, Palo Alto, CA, USA) to help maintain a fixed level of force and balance between push and pull. The test consisted of exerting grip force at the level defined in Table 1 for as long as possible, with and without vibration. Different percentages of MVC tests on the same subject were randomized to avoid hysteresis (Table 1). Performing the grip action on the instrumented handle can induce HAS fatigue, which can yield a set of changes in the HAS's regulation systems. Therefore, the minimum rest period between successive tests was 60 min. The rest period could increase with the value of the intensity of the gripping force exerted on the handle [4].

3. Results

The coordinate system adopted was the biodynamic one of UNI EN ISO 5349-1 [5]. The experiment was along the direction of the z axis. The coordinates were measured concerning the human hand while holding a cylindrical handle. The acquisition system eliminated sample aliasing effects during the digitization of the acquired signals using an analog-to-digital converter (ADC). Push and pull forces represent a complex mechanism in the presence of mechanical vibrations on the HAS. The experimental investigations considered three sinusoidal signals at 30 Hz with an r.m.s. acceleration of 5 m/s^2, 7.5 m/s^2 and 10 m/s^2. Subjects developed a pull and push strength level of 30% of their *MVC* value. The difference between the pull and push force was assessed by the following relationship:

$$\Delta G = \left[\frac{(Mean\ Push\ Force - Mean\ Pull\ Force)}{MVC\ 30\%} \right] \quad (1)$$

The difference ΔG between the pull and push force is lower in the test with a vibration level of 5 m/s^2 than in tests with a vibration level of 7.5 m/s^2 or 10 m/s^2 (Figure 1). The ΔG value and the standard deviation assume lower values with the vibration level of

5 m/s^2 than with the vibration levels of 7.5 m/s^2 and 10 m/s^2 (Figure 2). The handle endurance times on the shaker are shown in Table 2.

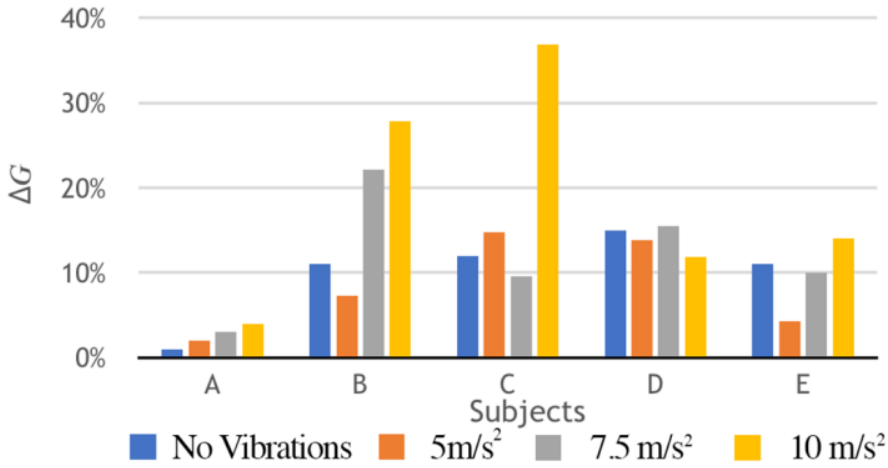

Figure 1. Values of ΔG evaluated on 5 subjects in the absence of vibration and in the presence of vibration with accelerations at 5 m/s^2, 7.5 m/s^2 and 10 m/s^2.

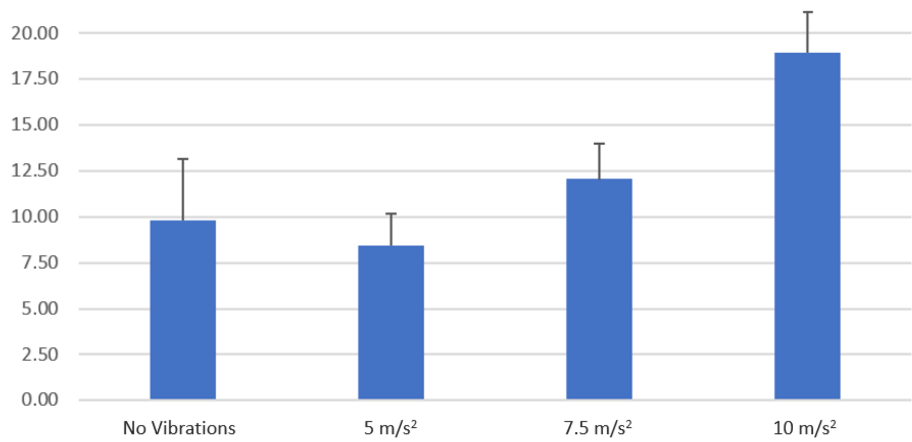

Figure 2. The ΔG value and the standard deviation evaluated in the absence and presence of vibration with accelerations of 5 m/s^2, 7.5 m/s^2 and 10 m/s^2.

Table 2. Time of gripping maintenance without and with vibration.

Subject	No	Vibrations		
	Vibrations	5.0 [m/s^2]	7.5 [m/s^2]	10.0 [m/s^2]
		Time [s]		
A	205	146	140	145
B	264	312	242	213
C	288	204	202	280
D	275	307	286	307
E	303	305	302	295

4. Discussion

In humans, force production is a complex task involving the nervous and muscular systems. The former sends a command, i.e., the motor drive, to the muscular apparatus, which responds with the contraction. In the presence of any external factor, the proprioceptive apparatus, input via the nervous system, reveals this occurrence, and the motor drive is rearranged. This paper aimed to evaluate the influence of the vibration, as an external factor, on force parameters, fatigue and the push–pull balance in a controlled grip task. The present fatigue results did not show evidence of changes in the time of force exertion with vibration. Indeed, as reported in Table 2, the time duration before fatigue is quite unchanged with vibration compared to without vibration. These findings are likely due to the neuromuscular system's capacity to modulate muscular contractions to always perform the gripping task, even in different working conditions. In this regard, it must be considered that the gripping task involves a great number of muscles belonging to different anatomical districts, such as the hand, forearm, arm and shoulder, other than the anti-gravitational ones. It is conceivable that the nervous system can modulate the force of every muscle involved to obtain always the target output force, and while maintenance endurance time is unchanged, the muscle interplay is probably changed. The change in muscle interplay could be observed by measuring the push and pull force in the gripping task. In Figure 2, these measurements in the different experimental conditions are shown. It is quite evident from the figure that the vibration must be considered a sort of noise for the nervous system. The nervous system can perform the target task in all conditions but with different muscular interplay engagement. In particular, it is possible to affirm a different behavior, an unbalance, of the forearm muscles being responsible for the production of push and pull forces. Moreover, the unbalance is related to the vibration's acceleration. This finding was expected because more acceleration corresponds to greater input and, in turn, more noise.

Finally, our findings show a lower level of coordination between the two components of grip force: push and pull.

5. Conclusions

Force production parameters, fatigue and push and pull force values were assessed with and without vibration on five subjects. Vibration does not seem to influence the fatigue phenomenon because of a neuromuscular rearrangement. These changes were recognized by ΔG values representing the push and pull balance during the gripping task. These findings show a clear relationship with vibration acceleration. Present data confirm the neuromuscular plasticity involved in adapting the force production in interfering conditions at the dispense of fine muscle control. The loss of fine muscle control should be better investigated to monitor muscular integrity.

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