Local vibration inhibits H-reflex but does not compromise manual dexterity and does not increase tremor

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ABSTRACT

The present work aimed at investigating the effects of local vibration on upper limb postural and kinetic tremor, on manual dexterity and on spinal reflex excitability. Previous studies have demonstrated a decrease in spinal reflex excitability and in force fluctuations in the lower limb but an increase in force fluctuation in the upper limbs. As hand steadiness is of vital importance in many daily-based tasks, and local vibration may also be applied in movement disorders, we decided to further explore this phenomenon. Ten healthy volunteers (26±3 years) were tested for H reflex, postural and kinetic tremor and manual dexterity through a Purdue test. EMG was recorded from flexor carpi radialis (FCR) and extensor digitorum communis (EDC). Measurements were repeated at baseline, after a control period during which no vibration was delivered and after vibration. Intervention consisted in holding for two minutes a vibrating handle (frequency 75Hz, displacement ~7mm), control consisted in holding for two minutes the same handle powered off. Reflex excitability decreased after vibration whilst postural tremor and manual dexterity were not affected. Peak kinetic tremor frequency increased from baseline to control measurements (P=.002). Co-activation EDC/FCR increased from control to vibration (P=.021). These results show that two minutes local vibration lead to a decrease in spinal excitability, did not compromise manual dexterity and did not increase tremor; however, in contrast with expectations, tremor did not decrease. It is suggested that vibration activated several mechanisms with opposite effects, which resulted in a neutral outcome on postural and kinetic tremor.

Key words: Vibration, H-reflex, Tremor, Manual dexterity, Steadiness

1) INTRODUCTION

Any static or dynamic muscle contraction shows involuntary irregularities, which, if they tend towards rhythmical oscillations are referred to as physiological tremor (Marshall & Walsh, 1956). To date a number of both mechanical and neural mechanisms have been listed as elements contributing to this complex phenomenon (for review (McAuley & Marsden, 2000)). Among the neural mechanisms are reflex loop resonances (Durbaba, Taylor, Manu, & Buonajuti, 2005; Lippold, 1970) and motor units discharge properties (Elble & Randall, 1976; Taylor, Christou, & Enoka, 2003). Both of these are related to Ia afferent activity. For this reason it could be argued that muscle vibration, as it depresses Ia afferents (Burke, Hagbarth, Löfstedt, & Wallin, 1976) with subsequent effects on reflex excitability (Fry & Folland, 2014; Ritzmann, Kramer, Gollhofer, & Taube, 2013) and on motor unit recruitment (Pollock, Woledge, Martin, & Newham, 2012; Romaiguère, Vedel, & Pagni, 1993), could also influence force fluctuations during muscle contractions.

Indeed, prolonged muscle vibration was demonstrated to reduce the normal increase in tremor during sustained fatiguing isometric plantar flexions at 30% of maximal voluntary contraction (MVC) (Cresswell & Löscher, 2000) and a decrease in the standard deviation (SD) of force during isometric plantar flexions performed at 2.5 and 10% MVC (Yoshitake, Shinohara, Kouzaki, & Fukunaga, 2004). By applying the same vibration though, Saito et al. (2016) reported neither changes in coefficient of variation (CoV) of the force nor changes in the power spectra analysis within any frequency band, during isometric knee extensions at 2.5, 10 and 30% MVC. Opposite results were obtained during isometric elbow flexions at 15% MVC following five seconds of vibration (+40% in CoV (Harwood, Cornett, Edwards, Brown, & Jakobi, 2014)), and during isometric contraction of the first dorsal interosseous at ~5% MVC following 30 minutes of tendon vibration (+21% SD of force signal (Shinohara, Moritz, Pascoe, & Enoka, 2005)). Specificity of the muscle group tested, in terms of muscle spindle density and sensitivity, was proposed as one possible explanation for the diverse findings (Saito et al., 2016; Shinohara et al., 2005). This justification is legitimate and further supported by the evidence that muscle spindle afferents inputs are unevenly distributed among motor units (MUs) of synergistic muscles and even among MUs of the homonymous muscle (Hamm, Koehler, Stuart, & Vanden Noven, 1985; Lucas, Cope, & Binder, 1984). Nevertheless, the 29% increase in force steadiness reported by Yoshitake and colleagues during plantar flexion (Yoshitake et al., 2004) is a remarkable result worth to be further investigated on upper body muscles.

Shinohara and colleagues (2005) reported a 21% increase in force fluctuations during first dorsal interosseous contractions as result of 30 minutes of vibration and hypothesised that this outcome could be attributed to the prolonged activation of the tonic vibration reflex (TVR). Activation of the TVR was suggested to induce a failure in the excitation-contraction coupling (Martin & Park, 1997) due to the onset of vibration-induced muscle fatigue (Park & Martin, 1993). In support of this argument, Mottram et al. (Mottram, Maluf, Stephenson, Anderson, & Enoka, 2006) showed that the time to task failure during a sustained fatiguing elbow flexion contraction was shorter when vibration at supra threshold TVR was applied during the effort compared to when the vibration was sub threshold or was not applied. Accordingly, Shinohara and colleagues (2005) described the reduced maximal force capacity of the muscle after vibration as something similar to what is observed as consequence of muscular fatigue produced by prolonged low intensity effort (Kouzaki, Shinohara, Masani, & Fukunaga, 2004). Further similarities between the effects of fatigue and vibration can also be found in relation to MUs recruitment. In this regard, it was reported an increased recruitment threshold of lower threshold MUs and a decreased recruitment threshold of higher threshold MUs both following vibration (Pollock et al., 2012) and during muscle fatigue (Carpentier, Duchateau, & Hainaut, 2001). Taking together these evidences, it seems reasonable to embrace Shinohara and colleagues´ (2005) hypothesis that the decreased steadiness following vibration could be attributed to muscle fatigue induced by prolonged activation of the TVR. Other elements acknowledged by the authors (Shinohara et al., 2005) as potential limitations include the location of the vibration and the lack of H reflex measurements.

The purpose of the present work was therefore to further investigate the effects of vibration on hand steadiness trying to overcome some of the methodological limitations highlighted by Shinohara and colleagues (2005). Firstly, shorter vibration time was used in order to avoid a failure in the excitation-contraction coupling. Second, postural and kinetic tasks were measured instead of isometric contractions. In fact, muscle spindles discharge frequency decays with time if the contraction is sustained beyond 10 seconds (Macefield, Hagbarth, Gorman, Gandevia, & Burke, 1991) and this aspect would influence the results in a not easily predictable way. H reflex from the flexor carpi radialis (FCR) was measured. Vibration was applied through a vibrating handle (local vibration). As local vibration decreases rate and amplitude of Pacini´s organs responses (Ilyinsky, 1965) which are fundamental for tactile perception (for review (Bell, Bolanowski, & Holmes, 1994)), these issues were addressed by testing the effects on fine fingertip dexterity through a standard Purdue test.

We expected a decrease in postural and kinetic tremor and H reflex due to an inhibited activity of the Ia afferents, and a decrease in the Purdue test score due to a decreased sensitivity in the hand and fingers.

2) MATERIALS AND METHODS

2.1) Participants

Ten male individuals (age 26.2±3 years, body mass 68.9±6.1 kg, stature 1.76±0.1 m) with no history of neurological disorders participated in the experiment. Volunteers were required to abstain from caffeine, nicotine and alcohol on the testing day. The study was approved by the local research ethics board in accord with the Helsinki Declaration of 1975 and written informed consent was obtained from all volunteers before the onset of the experimental procedures.

2.2) Experimental design

The participants were requested to attend the laboratory for one single experimental session. Before starting data collection, the volunteers were prepared for EMG recording and completed five familiarization trials for the Purdue task and five for the kinetic tremor task (details in the following sections). The experiment consisted in the measurement of: H reflex, postural and kinetic tremor and standard 30 second one hand Purdue test. Each assessment was performed two times in random order and was repeated at: baseline, after a control period and after local vibration. Local vibration was delivered by holding a vibrating handle for 120 seconds (more details in the “Vibration” section). The control period consisted in holding the same vibration device powered off for 120 seconds. Vibration was repeated twice: a first time immediately before H reflex measurements and a second time immediately before tremor and manual dexterity assessments. The vibration sequence was always performed after the control sequence to avoid any possible long lasting effect induced by the vibration.

The testing sessions were therefore structured in seven parts as shown in Fig1:

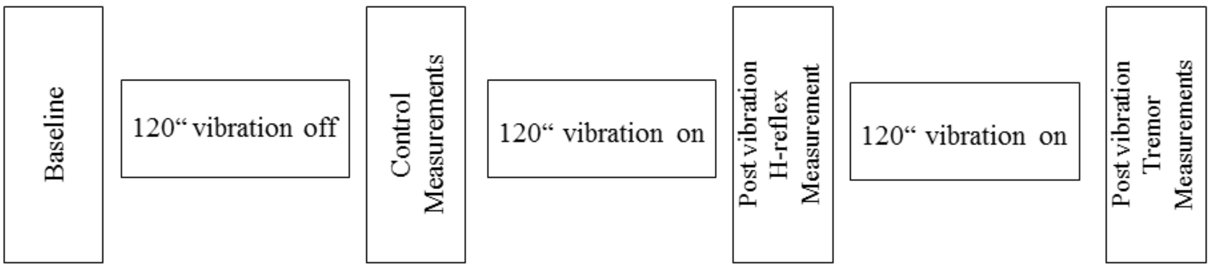

Fig1: Experiment flow chart.

2.3) Postural task assessment

Postural tasks were performed at both hand and arm levels as described in a previous work (Budini, Lowery, Hutchinson, et al., 2014). For the hand, the volunteers seated on a chair with their forearm supported on the armrest and the wrist joint aligned to its edge with the hand horizontal (palm down) and the fingers loosely extended. Tremor was recorded for 20 seconds using a 3-axis accelerometer fixed to the dorsal aspect of the hand with the y axis aligned along the length of the third metacarpal bone. Postural recording of tremor was also performed with the arm outstretched at shoulder level. Volunteers were instructed to gaze upon a fix point at 2 meter distance and exert only the effort necessary to keep the outstretched arm parallel to the floor. EMG signal from the extensor digitorum communis (EDC) and from the flexor carpi radialis (FCR) was recorded during the postural tasks.

2.4) Kinetic task assessment

Kinetic tremor was recorded with the accelerometer fixed in the same arrangement as for the postural tremor task. The participants stood in front of a 0.5 m long wire comprising 5 bends of the same size and shape (half circle ~5cm diameter) while holding a 20 g wand with a 2 cm diameter metal loop at its extremity (Fig2). The volunteers were instructed to follow the bent wire shape with the wand loop engaged in the circuit and complete the circuit from left to right and return trying not to touch it (Budini, Lowery, Hutchinson, et al., 2014). For this task the volunteers had five familiarisation trials before the beginning of the testing session. During the familiarisation trials the volunteers were invited to find a comfortable posture and a suitable distance from the circuit that would have allowed the performance of the task without moving the feet. Familiarisation sessions were timed and the volunteers were asked to try to complete each trial in about the same time. During the test no restrictions about the execution speed were given although the volunteers were invited to complete the task in approximately the same time they completed it during the familiarisations, execution time was measured but no feedback about it was provided and the task was always self-paced.

2.5) Purdue Test

The Purdue Pegboard test measures the ability to make rapid, controlled manipulation of small objects involving both fingertip dexterity and goal-directed arm-hand movements. The Purdue Pegboard is a rectangular board (30X60 cm) with 2 centre rows each having 25 small holes (1/8 inch in diameter) drilled into them (Desai, Kene, Doshi, More, & Desai, 2006). At the top of the board there is a container with 50 pins in it. For the standard 30 seconds one hand test, the volunteer is required to pick up one pin at a time with the right hand starting with the top-hole, placing each pin in the right hand row. The number of pins successfully inserted in holes within 30 seconds represents the score for this task.

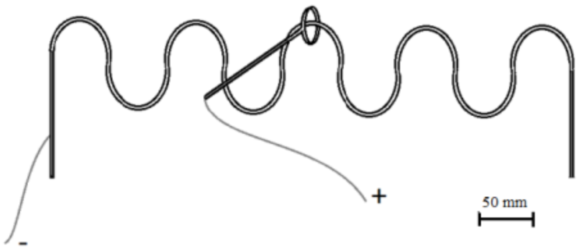

Fig2: The buzzwire circuit.

2.6) Electromyography

After appropriate skin preparation, surface electromyography was recorded from the EDC and from the FCR by Silver/silver chloride bipolar electrodes placed at an interelectrode distance of 20 mm. A ground bracelet was placed distally on the forearm at wrist level. EMG signals were pre amplified (500) band-pass filtered (3-900 Hz) and A-D converted at a sampling rate of 2048 Hz.

2.7) H reflex

The electrodes placed over the belly of the FCR at about one-third of the distance between the medial epicondyle and the radial styloid (Jabre, 1981) were used for recording H reflex as well as for assessing co-contraction between FCR and EDC. The median nerve was stimulated (Digitimer, model DS7A) at the elbow using bipolar surface electrodes with the subject comfortably seating in semi recumbent position and the elbow slightly flexed. A rectangular pulse of 1.0 ms duration at a random frequency not exceeding 0.2 pulses per second was delivered with increasing current strengths. Two complete ramps (from H onset to the 120% stimulation intensity needed to elicit an M max) were collected at each protocol step (baseline, control, vibration). Additional stimuli were delivered around the intensity at which the H-wave appeared maximal. On average 20 stimuli were delivered per ramp. It was possible to obtain an H reflex in 90% of the participant.

2.8) Vibration

The vibration device used consisted in a rigid plastic handle containing an internal motor with an eccentric mass attached to its shaft. The motor rotation generated an oscillation frequency of 75Hz and a displacement of ~7mm. The volunteers were instructed not to squeeze the handle, but to exert only the strength needed to hold it. For describing handle position and vibration direction in a 3D Cartesian plane: the "z" axis was aligned with 3rd metacarpal bone and arm parallel to the floor, the longitudinal axis passing through the handle was aligned to the "y" axis perpendicular to the floor, and vibration occurred around the "y" axis inducing a circular displacement involving both "x" and "z" axes.

2.9) Data analysis

The acceleration, force and electromyography were synchronized and digitized with a sampling frequency of 2048 Hz, stored on a PC and analysed using custom algorithms developed in Matlab (7.8.0.347 R2009a).

Postural steadiness was quantified by examining the SD of the low pass-filtered (30 Hz) acceleration signal averaged for the 3 axes and calculated over the last 15 seconds of each postural task. Kinetic data were similarly analysed after additional high pass filtering at 1Hz to eliminate the fluctuations related to voluntary prono-supination movements (Budini, Lowery, Hutchinson, et al., 2014).

Since tremor is mostly represented by its main frequency component, for tremor quantification the analysis focused on the characteristics of its dominant peak (position and amplitude) within the range of 7-13 Hz in the power spectra of the accelerometer signals. Further, the power spectra (2048-point, hamming window fast Fourier transform) of the acceleration signal, were plotted on a linear amplitude scale and the integral of the power was calculated for each participant in the range ±0.5 Hz about the tremor frequency, which was identified as the frequency at which the maximum value of the acceleration power spectrum occurred (Budini, Lowery, Durbaba, & De Vito, 2014).

Manual dexterity was quantified as the contact time in milliseconds between the wand and the bent wire (Fig2) during the kinetic task. Additionally, we used the score in the standard 30 second, single hand, Purdue Pegboard.

Root mean square (RMS) of the FCR and EDC electromyographic signals was calculated for each postural task within the same 15-second interval used for the acceleration analysis. The percentage ratio of FCR\EDC RMS EMG was also calculated as an index of co-contraction.

Reflex excitability was measured in terms of: H_{max} peak-to-peak, H_{max}/M_{max} ratio, intensity of stimulation (expressed as peak to peak of the M wave) used for obtaining a H_{max} (M_H) (Hwang, 2002). Average values of all H waves within ≤20% of the Mmax (Crone et al., 1990; Laudani, Wood, Casabona, Giuffrida, & De Vito, 2009) were considered to evaluate whether there was a shift in the ascending limb of the recruitment curve.

2.10) Statistical analysis

All measurements were repeated twice at each protocol step (baseline, control, vibration) and the average value of each step was used for comparisons. Shapiro-Wilk test was used to check for distribution normality.

Individual pairs were compared by either an ANOVA for repeated measures and Bonferroni post-hoc when assumption of normality was satisfied or by Friedman test with follow-up Wilcoxon signed ranks tests and Bonferroni adjustment when data showed a skewed distribution.

All statistical analysis was completed using PAWS Statistic 18.0.0 adopting an α level of .05.

3) RESULTS

Table 1 reports the results of the Shapiro-Wilk test and either ANOVA (Shapiro-Wilk $P>.05$) or Friedman test (Shapiro-Wilk $P<.05$) for each parameter considered in relation to postural and kinetic assessments. Most of the results showed a skewed distribution.

During both postural exercises, the level of co-contraction between agonists and antagonists showed a tendency to decrease from baseline to control condition and increased from control to vibrationHowever, significant results were not reached for the hand task (P=.067) whilst for the arm (P=.016) the Wilcoxon tests, post Bonferroni adjustment, reveal that co-contraction increased from control to vibration (P=.021). Figure 3 shows both group average and individual values of co-contraction between baseline-control and control-vibration for the arm task; an increase in co-contraction from control to vibration is consistent in 9 out of 10 subjects.

Significant differences were found for tremor frequency during kinetic tasks (Table1). The Bonferroni post hoc revealed an increase in the main tremor peak frequency from baseline (9.9±1 Hz) to control condition (10.4±1.3 Hz) (P=.002), and not in baseline vs vibration

(10±1.1 Hz) (P=.409) or control vs vibration (P=.089). None of the remaining tested parameters related to muscle postural and kinetic assessments resulted in significant changes (Table 1).

Manual dexterity was not affected by the vibration. There were no significant differences in contact time during the kinetic task at baseline (290±120 ms), control (170±70 ms) and post vibration measurements (240±60 ms). The time spent by the volunteers to complete the kinetic task also did not change (33.8±0.5, 32.6±0.8 and 32.3±0.6 seconds respectively). Similarly, there were no differences in the Purdue test scores between baseline, control and post vibration with a group average of 17.3±1.5, 18±1.6 and 17.3±1.2 pin successfully inserted in 30 s, respectively.

Table 1: P values for the kinetic and postural tasks assessments

Parameter assessed	Postural arm tremor			Postural hand tremor			Kinetic tremor		
	Shapiro-Wilk	ANOVA	Friedman	Shapiro-Wilk	ANOVA	Friedman	Shapiro-Wilk	ANOVA	Friedman
SD	**.000**		.407	.301	.791		.512	.114	
Peak	**.000**		.741	.065	.130		**.013**		.273
Tremor_Fr	.179	.873		**.008**		.784	.598	.027*	
Area_Peak	**.000**		.497	**.000**		.150	**.008**		.202
RMS_Ext	.160	.230		**.007**		.407			
RMS_Flex	**.000**		.067	**.001**		.122			
Co_contr	**.043**		.016*	**.006**		.067			

Data not normally distributed are highlighted in bold. Significant data are underlined. *P<.05. SD = Standard Deviation

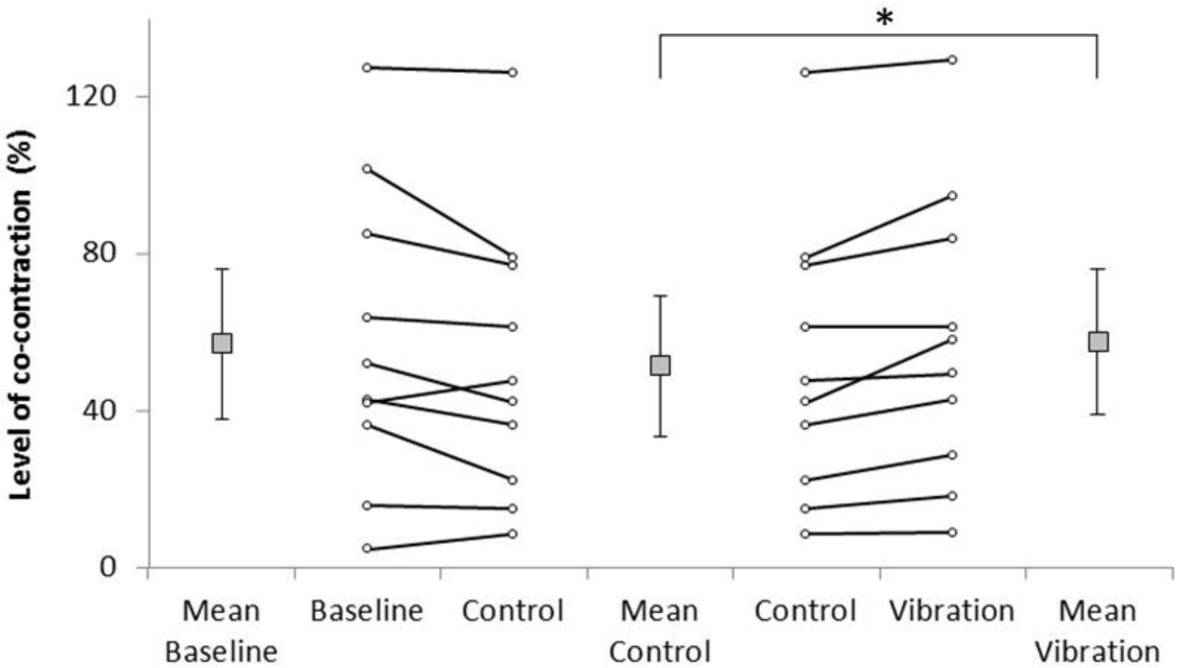

Fig3: Co-contraction during arm postural tasks. Group average (dots) ±SD and individual values (small connected dots) for levels of co-contraction FCR/ EDC at Baseline, Control and Vibration. *=P<.05

Although Hmax, Hmax/Mmax ratio and M_H did not show differences between the measurements, an inhibition of reflex excitability was evident when analysing the entire recruitment curve as shown for a single subject in Fig4. Average values of all H waves recorded within a stimulation intensity ≤20% of the M_{max}, measurements after vibration resulted lower than those collected at both baseline (P=.011) and control (P=.015) conditions, whilst baseline and control conditions did not differ from each other (P=.314) (Fig5).

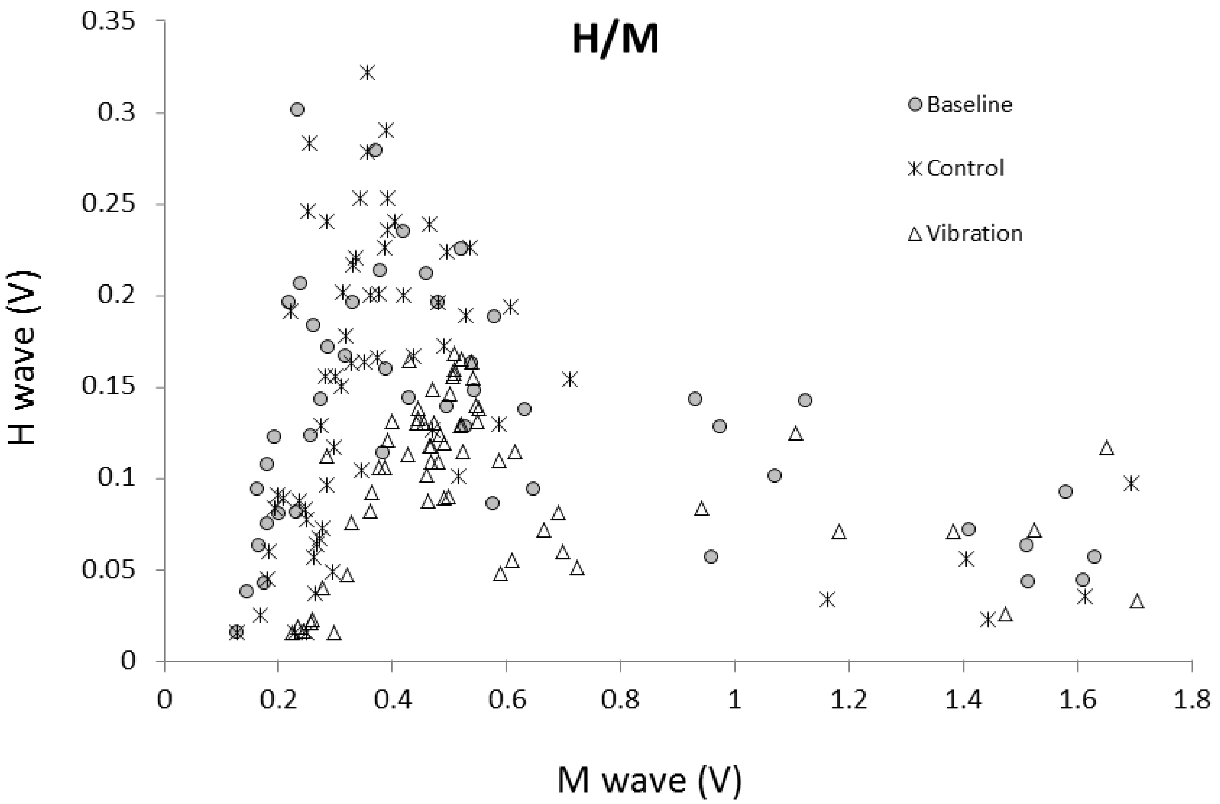

Fig4: Complete H-M recruitment curves in a representative subject. H waves are plotted against corresponding M waves for each condition.

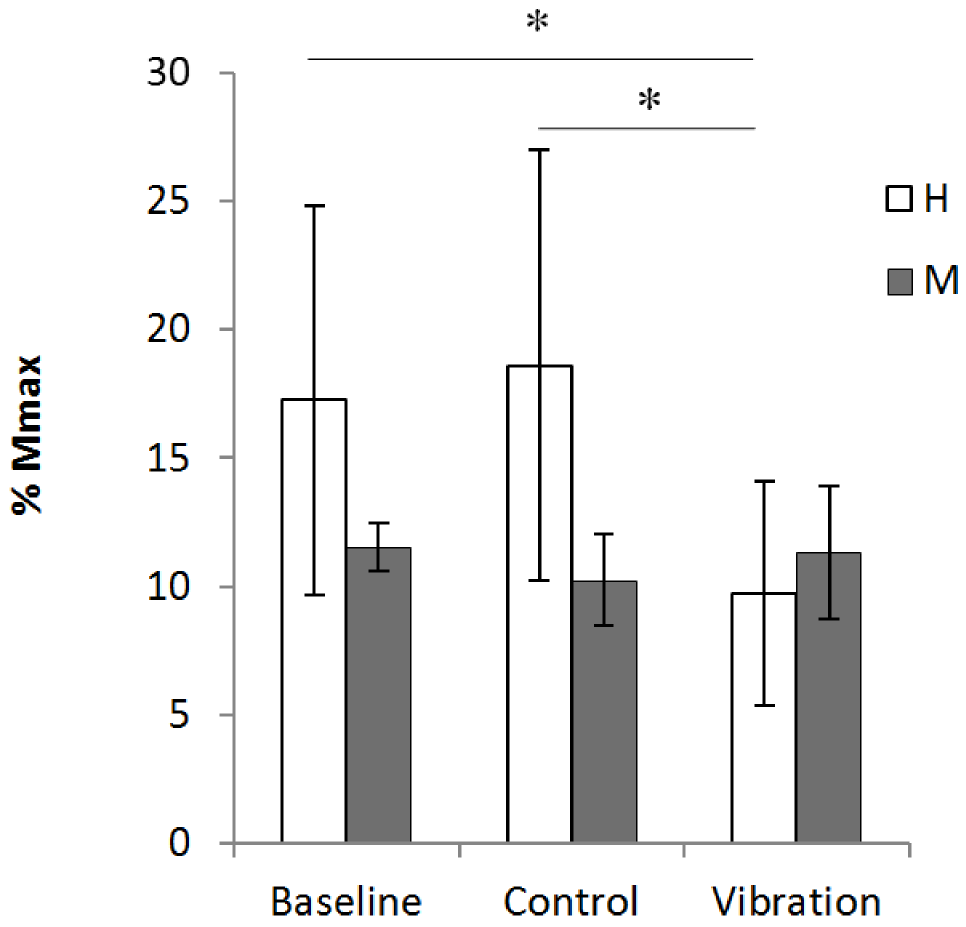

Fig5: Bars represent H (white bars) and M (grey bars) reported as the group means and SD at baseline, control and vibration conditions. Responses are normalized to the Mmax   *=P<.05

4) DISCUSSION

The main finding of this study was that vibration applied at subthreshold intensity for TVR induced an inhibition in the H reflex without compromising manual dexterity and without increasing force fluctuations.

Depression of H reflex amplitude in response to vibration is a commonly reported result that has been already extensively discussed (Fry & Folland, 2014; Ritzmann et al., 2013) and our findings in this regard (Fig. 5) are in line with previous studies.

Shinohara and colleagues (2005) hypothesised that this vibration mediated depression in Ia afferent activity would have also decreased force fluctuations, thus increasing muscle steadiness. Contrary to the authors´ expectations though, force steadiness decreased by 21% and other authors reported similar results (40% decrease in force steadiness (Harwood et al., 2014)). By addressing the methodological aspects that we thought could have accounted for the previous outcomes, we managed to prevent an increase in force fluctuations. However, in our study, we were also expecting that the depression in the Ia afferent activity would have decreased muscle tremor but this did not occur. Several explanations are possible: a) the Ia afferent inhibition achieved was not sufficient to be mirrored into actual tremor or steadiness, possibly due, as already suggested by others (Saito et al., 2016; Shinohara et al., 2005), to specificity in muscle spindle density, sensitivity and responses to vibration. b) There is no direct correlation between H reflex amplitude and tremor. c) Other sensory receptors or neuromuscular mechanisms activated by the vibration might have influenced the final outcome. Specifically, vibration influences motor unit recruitment (Pollock et al., 2012; Romaiguère et al., 1993) by increasing small and decreasing big MUs recruitment threshold (Pollock et al., 2012). As result, at the same contraction intensity, a simultaneous increase in the activation of large diameter MUs and decrease of small diameter MUs could be hypothesised. As large diameter MUs are stronger (Carpentier et al., 2001), it is reasonable to assume that a given force target will be achieved by recruiting a smaller number of MUs with related increased difficulty in producing steady contractions (Dideriksen, Negro, Enoka, & Farina, 2012). The final output of vibration on muscle tremor could therefore be the result of these two opposite effects. We speculate that in our study, the effects of vibration-induced decrease in the number of MUs recruited were counterbalanced by the effects of vibration-induced decrease of muscle spindles afferents contribution.

Mottram and colleagues (2006) showed that while holding a load with the elbow flexors, the standard deviation of the upper limb acceleration was greater when the contraction was performed simultaneously to vibration inducing TVR than during vibration at subthreshold intensity for TVR and during a contraction without vibration. It could therefore be argued that simply, if TVR is not activated, steadiness is not compromised. However, the tasks in the present study involved unloaded postural and kinetic contractions and both muscle group tested and vibration applied were different making direct comparisons rather complicated.

Quite unexpectedly, after the control period during which the participants were simply holding the powered off vibrator in their hand for two minutes, the main tremor frequency peak during the kinetic assessment increased. It is known that during low force tasks, as those that would involve holding our vibrator powered off, motor unit firing rate changes, with some authors reporting a gradual increase (Kuchinad, Ivanova, & Garland, 2004) whilst others a decrease (Garland, Griffin, & Ivanova, 1997). However, it has to be considered that the frequency of muscle tremor is not the direct consequence of MUs firing rate as it is known that tremor frequency remains unchanged with increasing contraction intensity, whilst MUs firing rate increases (Allum, Dietz, & Freund, 1978). Moreover, this result was observed for the kinetic and not for the postural tasks. It is therefore complicated to speculate on this effect and probably further investigations would be necessary to clarify.

The level of co-contraction between agonist and antagonist muscles increased from control to vibration (Fig3). By co-activating antagonist muscles our body stiffened the joints. While stiffening the joints may be useful for increasing stability and precision (Gribble, Mullin, Cothros, & Mattar, 2003; Osu & Gomi, 1999), other studies reported that increased co-contraction was associated with an increase in tremor (J. Keogh, Morrison, & Barrett, 2004; Morrison & Newell, 2000). Strength training also resulted in significant reductions in both co-contraction and tremor in older adults (J. W. Keogh, Morrison, & Barrett, 2010). Our central nervous system is able to decrease co-contraction when learning a new motor task (Osu et al., 2002; Thoroughman & Shadmehr, 1999), however in our study the motor task consisted simply in holding the arm outstretched at shoulder level and it is hard to believe that any learning process was involved or anyhow influenced this result. The increase in co-contraction following vibration could be attributed to fatigue (Psek & Cafarelli, 1993; Weir, Keefe, Eaton, Augustine, & Tobin, 1998), although fatigue, as known from over a century, would have very likely be mirrored in an increase in muscle tremor (Herringham, 1890).

Finally, it is quite surprising that neither manual dexterity assessed through the Purdue test nor fine movement control assessed by measuring the contact time between the wand and the circuit in the kinetic tremor task (Fig2) were affected by vibration. Although we did not directly assess it, we have reasons to assume that our vibration protocol induced a decrease in rate and amplitude of Pacini´s organs responses (Ilyinsky, 1965). As the activity of these organs is fundamental for tactile perception (for review (Bell et al., 1994)), we were expecting that after vibration the volunteers would have experienced substantial impairment in performing the Purdue test as well as precisely holding the wand used in the kinetic tremor assessment. Indeed, the subjects reported a sensation of numbness, but the location of this was mainly in the hand palm rather than in the fingers. It would be interesting to investigate whether a different outcome could result by applying the vibratory stimulus directly on the fingers.

5) CONCLUSIONS

In conclusion, this study suggests that manual dexterity is not compromised by local vibration when this is applied in a form of vibrating handle. Our methodology was effective in inhibiting reflex excitability without increasing force fluctuations but not effective enough for decreasing muscle tremor. This work represents a step forward in understanding some of the neurophysiological mechanisms underlying the relationship between vibration and tremor and suggests that by further improving the methodology, a decrease in tremor and an increase in manual dexterity may be obtained.

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