REFLEX RESPONSES TO LOCAL SOLEUS MUSCLE VIBRATION

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The aims of the present work was i. to investigate the acute effects of prolonged vibratory stimulation on short-latency stretch reflexes (SLR) of soleus muscle, ii. to assess effects of vibration on parameters of the H-reflex and M-wave stimulus-response curves. There were no changes in the EMG of SLR. During vibration H-reflex amplitudes decreased but H-reflex threshold current increased. None of the H-reflex parameters showed time-dependent changes. In contrast, maximum M-wave magnitude (M_{MAX}) decreased after 30min of sustained vibration. The analysis suggests differential effects of presynaptic inhibition on α-motoneurons. The vibration parameters have no effect on excitability of afferent and efferent fibers. The depression of the M_{MAX} after vibratory stimulation may be related to neuromuscular transmission failure and/or reduced sarcolemmal excitability.

KEY WORDS: Presynaptic inhibition, SLR, H-Reflex, M-Wave

INTRODUCTION: Vibration is a powerful tool for activating muscle receptors. High-frequency vibrations are used to preferentially stimulate spindle primary endings (Roll et al., 1989) and to elicit the tonic vibration reflex (Eklund & Hagbarth, 1966; De Gail et al., 1966). Local vibration has received a good deal of attention in literature concerning physiology of muscle spindle (Bianconi & Van der Meulen, 1963), pathology of neuromuscular disorders (Hagbarth & Eklund, 1968), proprioception (Jones, 1988) and sensorimotor integration (Forner-Cordero et al., 2008). Recently, the use of local vibration has emerged in a broad range of training (Brunetti et al., 2012; Cochrane, 2016) and rehabilitation settings (Murillo et al., 2014). There is increasing evidence that acute vibratory stimulation can improve joint range of motion in both healthy (Sands et al., 2006) and spastic populations (Noma et al., 2012). Resetting of muscle tone is thought to occur as a result of the excessive proprioceptive activity induced by the vibration (Atha and Wheatly, 1976). However, there is a limited knowledge regarding the involved neural mechanisms. Thus the purpose of the present work was i. to investigate the acute effects of vibratory stimulation on SLR of soleus muscle, ii. to assess its effects on parameters of the stimulus-response curves of the H-reflex and M-wave.

METHODS: Twelve healthy subjects (age 21.9 ± 2.2 years; height 1.78 ± 0.07 m; body mass 70.0 ± 11.7 kg) volunteered for the study. Stretch reflex without muscle activation and recruitment curves of the H-reflex and M-wave were registered. Maximal voluntary isometric torque of the ankle plantar flexors (MVT) of the left leg was determined for each subject before beginning with the experimental procedure. Analog signals were collected at a sampling frequency of 5 kHz. Surface EMG activity was recorded from soleus and tibialis anterior. Transcutaneous electrical stimulation was delivered to the posterior tibial nerve by a constant current stimulator using a unipolar stimulation technique. A custom-made vibration stimulation device was used to deliver the vibratory stimulation with a frequency of about 150Hz at ~1.6g to the soleus muscle on 5 selected sites of the muscle (for complete setup see figure 1.) Measurements were taken before (pretreatment), directly after the start, after 30 minutes of vibration and again 10 minutes after the termination of it.

RESULTS: There was a significant effect of treatment on the maximum peak-to-peak amplitude of H-reflex (F (1.74, 19.137) = 21.79, p < .001). The mean value of H_{MAX} decreased significantly directly after applying the vibration (2.34 ± 1.23 mV, p = .007) and remained almost at the same level during the prolonged vibration (2.30 ± 1.13 mV, p < .001), while recovered to baseline (3.14 ± 1.06 mV) in about 10 min after the end of the vibration (3.03 ± 1.06 mV, p = 1.00). There was no significant difference between short-term and prolonged conditions (p = 1.00), whereas both were significantly lower than the aftereffects condition (p = .005 and p < .001).

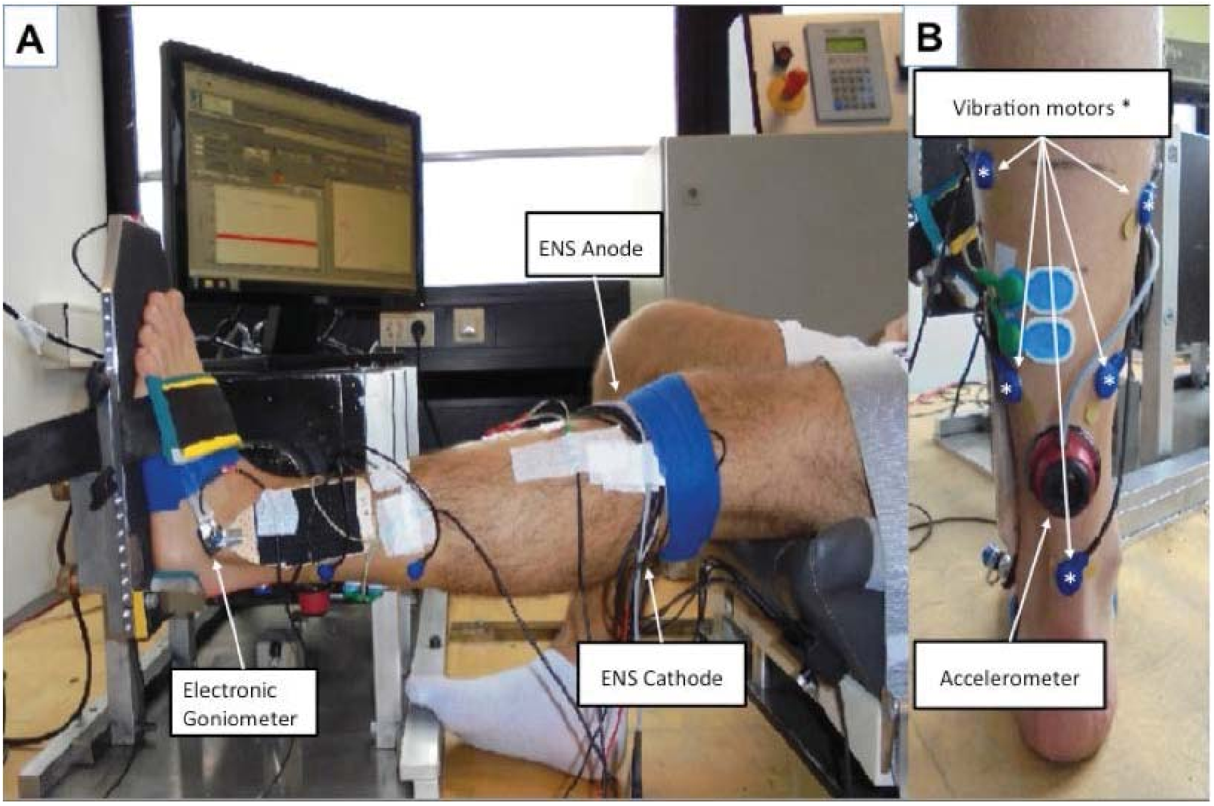

Figure 1: Experimental setup (A) and placement of the accelerometer and vibration motors (B) ENS = electrical nerve stimulation

The maximum peak-to-peak amplitude of the M-wave showed also significant changes during the intervention (F (1.31, 14.45) = 6.29, p = .018). The mean value of M_{MAX} was significantly lower during the prolonged condition (5.31 ± 1.40mV) as compared to the aftereffects condition (5.63 ± 1.50mV, p = .001), while being markedly lower than during pretreatment (5.79 ± 1.48mV) and short-term conditions (5.63 ± 1.48 mV) (p = .059 and .083) (figure 2A and B). The mean value of H_{SLPD} was significantly lower in the prolonged condition (-4.55 ± 2.06 mV/M_{THR}) than in pretreatment (-7.54 ± 3.14mV/M_{THR}, p = .016) and aftereffects conditions (-6.68 ± 2.44 mV/M_{THR}, p < .001). The mean value of H_{SLPD} was also significantly lower in the short-term condition (-5.24 ± 2.89 mV/M_{THR}) than in aftereffects condition (p = .038) (figure 2B). There were no significant differences between the mean values of the maximum slope of the M-wave recruitment curve of the different test conditions (F (3, 33) = 2.38, p = .087). (figure 2C and D) There was also a significant main effect of treatment on the relative H-reflex threshold current (F (1.95, 21.45) = 6.57, p < .006), its main value of the short-term condition (0.70 ± 0.18M_{Thr}) being significantly lower than that of the aftereffects condition (0.63 ± 0.16M_{Thr}, p = .022), while the main value of the prolonged condition (0.72 ± 0.16M_{Thr}) was significantly lower than the pretreatment condition (0.59 ± 0.08M_{Thr}, p = .012)
There was no significant main effect of treatment on peak-to-peak amplitude of SLR (F (3, 33) = 1.14, p = .346), while muscle activation had a significant effect (F (1, 11) = 6.71, p = .025. The mean value of the SLR amplitude was significantly higher in the active conditions (0.87 **±** 0.79mV) than in passive conditions (0.68 ± 0.78mV, p = .025). It was, however, noticeable that SLR latency tended to increase in short-term conditions (40.31 ± 2.66ms) in contrast to aftereffects conditions (39.62 ± 2.86ms).
The analysis of the ascending limb of the H-reflex recruitment curve demonstrated a strong negative correlation between the mean percentage decrease in H-reflex amplitudes after the vibration and the current intensity (r = -.985, p < .001). Since motoneurons are recruited in

the H-reflex from smallest to largest with the increasing current intensities (Zehr, 2002), the finding of this study suggests that the smallest motoneurons are more affected by the presynaptic inhibition than the largest ones

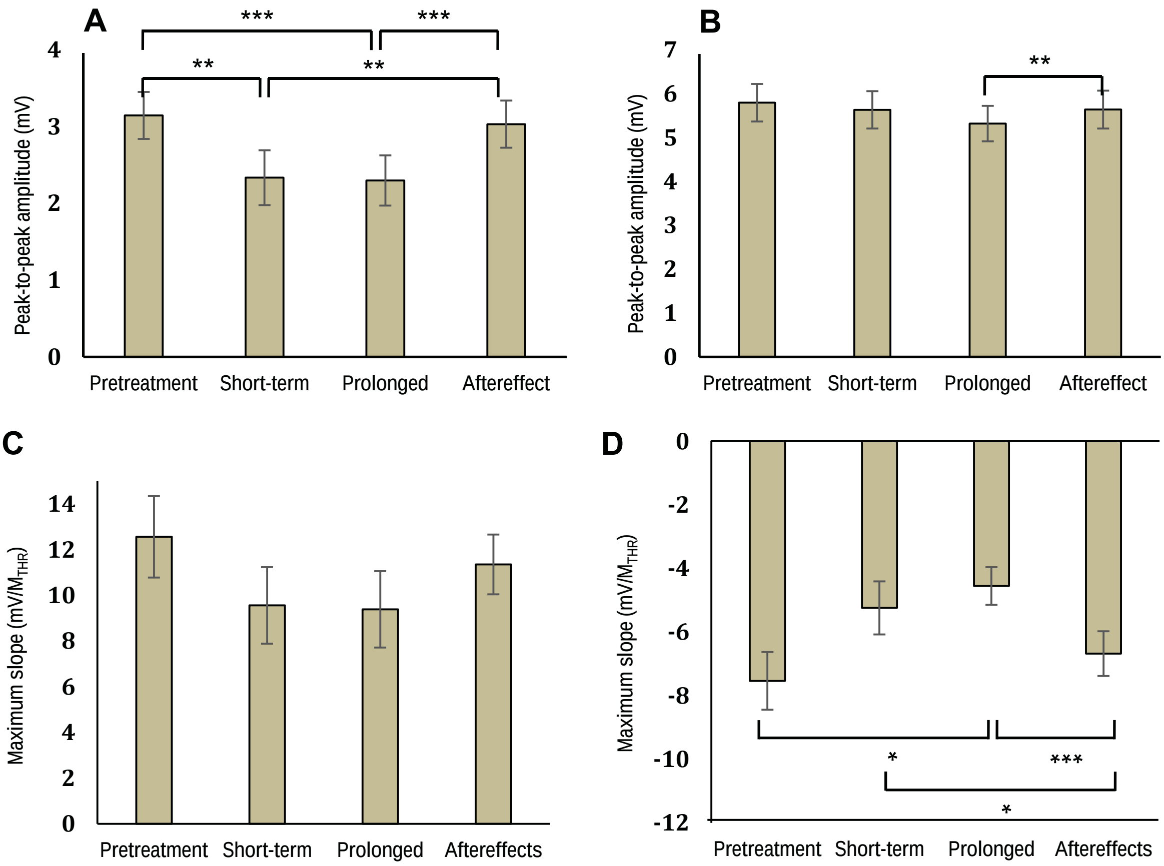

Figure 2: Peak-to-peak amplitudes of the H_{MAX} (A) and M_{MAX} (B) during the test conditions. and maximum slope of the ascending (C) and descending (D) limbs of the H-reflex recruitment curve. Error bars are the standard error (SE) of the mean (* $p < .05$; ** $p < .01$; *** $p < .001$)

DISCUSSION: The primary aim of this study was to investigate the effect of prolonged vibratory stimulation on the SLR of the soleus muscle. It was hypothesized that prolonged vibratory stimulation can induce intrafusal muscle fatigue, leading to decrease in stretch reflex sensitivity. To address the working hypothesis, an average of eight stretch reflexes were elicited in the passive and active soleus muscle during each test condition. Unfortunately, the results of the stretch reflexes were not promising. Both active and passive stretch reflexes showed a great intra-individual variability during all test conditions. On the contrary, peak-to-peak amplitudes of the largest 10 H-reflexes showed an acceptable variability (Mean ± 95% CI, 5 ± 3%) during the test conditions. The difference in variability between stretch reflexes and H-reflexes can be attributed to neurophysiological differences between the two reflexes and/or methodological considerations. Electrical nerve stimulation produces a single synchronous volley in group Ia- and Ib-afferent fibers (Burke et al., 1983), and provide a constant stimulating electrode - mixed nerve relationship; a certain stimulus intensity is assumed to recruit a constant population of afferent fibers, thus generating a relatively stable composite EPSP and H-reflex response. The results of this study revealed that the myoelectric amplitudes of SLRs of the soleus muscle were higher during muscle activation than during passive conditions. The increase in SLR responses during muscle activation can be attributed to increased spindle dynamic sensitivity due to α-γ-coactivation and decreased presynaptic inhibition (Hultborn et al., 1987; Person, 1994).

CONCLUSION: The analysis suggests differential effects of presynaptic inhibition on α-motoneurons with the smallest motoneurons being more affected than the largest. To our knowledge no study has shown presynaptic inhibition effects on the basis of transcutaneous electrical nerv stimulation and surface EMG parameters yet. The findings also suggest that the utilized vibration parameters have no effect on the electrical thresholds of afferent and efferent fibers. The depression of the M_{MAX} after prolonged vibratory stimulation may be related to neuromuscular transmission failure and/or reduced sarcolemmal excitability radiating on therapeutical and training issues.

LIMITATIONS: It was not possible to routinely check the myoelectric activity of the prime antagonist tibialis anterior to determine the presence of voluntary muscle activation during eliciting the stretch reflexes of the soleus muscle which might have influenced the excitability of the agonist muscle via reciprocal inhibitory pathways. Moreover, stretch reflexes were elicited in the soleus muscle while the knee was fully extended. Thus the hamstring muscle was elongated to a great degree. This might have increased the sensitivity of muscle spindles so that the applied mechanical perturbation might have simultaneously elicited reflex responses in the hamstring muscle.

REFERENCES:

Atha J, Wheatley DW. Joint mobility changes due to low frequency vibration and stretching exercise. *Br J Sports Med.* 1976; 10(1): 26 – 34

Bianconi R, Van der Meulen J. The response to vibration of the end organs of mammalian muscle spindles. *J Neurophysiol*. 1963; 26: 177-190

Brunetti O, Botti FM, Roscini M, Brunetti A, Panichi R, Filippi GM, Biscarini A, Pettorossi VE. Focal vibration of quadriceps muscle enhances leg power and decrease knee joint laxity in female volleyball players. *J Sports Med Phys Fitness*. 2012; 52: 596-605

Burke D, Gandevia SC, McKeon B. The afferent volleys responsible for spinal proprioceptive reflexes in man. *J Physiol*. 1983; 339: 535-52

Cochrane DJ. The Acute Effect of Direct Vibration on Muscular Power Performance in Master Athletes. *Int J Sports Med*. 2016; 37(2): 144–148

De Gail P, Lance JW, Neilson PD. Differential effects on tonic and phasic reflex mechanisms produced by vibration of muscles in man. *J Neurol Neurosurg Psychiatry*. 1966; 29(1): 1–11

Eklund G, Hagbarth KE. Normal variability of tonic vibration reflexes in man. *Exp Neurol*. 1966; 16(1): 80-92

Forner-Cordero A, Steyvers M, Levin O, Alaerts K, Swinnen SP. Changes in corticomotor excitability following prolonged muscle tendon vibration. *Behav Brain Res*. 2008; 190(1): 41-49

Hagbarth KE, Eklund G. The effects of muscle vibration in spasticity, rigidity, and cerebellar disorders. *J Neurol Neurosurg Psychiatry*. 1968; 31(3):207-13

Hultborn H, Meunier S, Pierrot-Deseilligny E, and Shindo M. Changes in presynaptic inhibition of Ia fibres at the onset of voluntary contraction in man. J Physiol. 1987; 389: 757–772

Jones LA. Motor illusions: what do they reveal about proprioception?. *Psychol Bull*. 1988; 103(1):72-86.

Issurin VB. Vibrations and their applications in sport. A review. *J Sports Med Phys Fitness*. 2005; 45(3): 324-336

Murillo N, Valls-Sole J, Vidal J, Opisso E, Medina J, Kumru H. Focal vibration in neurorehabilitation. *Eur J Phys Rehabil Med*. 2014; 50(2): 231-242

Noma T, Matsumoto S, Shimodozono M, Etoh S, Kawahira K. Anti-spastic effects of the direct application of vibratory stimuli to the spastic muscles of hemiplegic limbs in post-stroke patients: a proof-of-principle study. *J Rehabil Med*. 2012; 44(4):325-330.

Person RS. Presynaptic control of the monosynaptic reflex from Ia afferents: Studies in Humans. Neurophysiology. 1994; 26(5): 323 – 326

Roll JP, Vedel JP, Ribot E. Alteration of proprioceptive messages induced by tendon vibration in man: a microneurographic study. *Exp Brain Res*. 1989; 76(1): 213-222

Sands WA, McNeal JR, Stine MH, Russell EM, Jemni M. Flexibility Enhancement with Vibration: Acute and Long-Term. *Med Sci Sports Exerc*. 2006; 38(4): 720 - 725

Zehr P. Considerations for use of the Hoffmann reflex in exercise studies. Eur J Appl Physiol. 2002; 86(6): 455–468