The Effects of Two Different Stretching Programs on Balance Control and Motor Neuron Excitability

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Abstract

We examined the effects of training (4d/wk for 6 wks) with static stretching (SS) or contract-relax proprioceptive neuromuscular facilitation (PNF) on static balance time and motor neuron excitability. Static balance time, H_{max}/M_{max} ratios and H-reflex recovery curves (HRRC) were measured in 28 healthy subjects (SS: n=10, PNF: n=9, control: n=9) before and after training. SS improved static balance time with a trend observed for PNF. Post training, during 150-200-250 msec interstimulus intervals, we observed a reduction in facilitation, but during 500-700-900 msec interstimulus interval; there was an increase in H2/H1 ratio in the PNF group only. Both stretching techniques improved static balance. The Ia afferent inhibitions during the acute exercises were not found after the SS and PNF training programmes. It was concluded that training with contract-relax proprioceptive neuromuscular facilitation may cause some augmentation in supraspinal and postsynaptic inhibition on the motoneuron pool.

Keywords: static stretching, contract-relax PNF stretching, static balance, Hoffmann-reflex

1. Introduction

Flexibility and balance are considered to be important for health and physical fitness. Flexibility affects muscular performance (e.g. Ferreira, Teixeira-Salmela, & Guimarães, 2007). It was shown that subjects with bilaterally shortened hamstrings improved muscle performance and range of motion (ROM) with a static stretching intervention (Ferreira et al., 2007). Effects of static stretching on ROM have been well established in other studies as well (e.g. Marek et al., 2005). However, other stretching techniques, such as proprioceptive neuromuscular facilitation (PNF) stretching which inhibits tonic reflex activity as a limiting factor during stretches, increases the ROM more markedly (Etnyre & Abraham, 1986; Guissard, Duchateau, & Hainaut, 1988). Both mechanical and neural adaptation mechanisms have been proposed to be responsible for ROM changes from stretching (Guissard & Duchateau, 2004; Youdas et al., 2010). In addition, PNF induces a larger reduction of motor neuron excitation by pre and post-synaptic inhibitory mechanisms (Guissard et al., 1988; Guissard, Duchateau, & Hainaut, 2001). This was shown by analysis of the H-waves from α-motoneuron excitability which was reduced during but not after stretch of the soleus muscle (Etnyre & Abraham, 1986; Guissard et al., 1988).

The Hoffmann reflex (H-reflex), and associated H-waves, is an established measure of motoneuron excitability. The H-reflex serves as a summative measure of excitability in the motoneuron pool in terms of reflecting influences of postsynaptic inhibition (Trimble & Koceja, 2001). The H-reflex has been instrumental in research investigating the production of purposeful movement. Interpretation of the H-reflex is complex as it is influenced by supraspinal, homonymous, and heteronymous modulation, as well as intrinsic motoneuronal properties. In addition, the H-reflex is influenced by the state of the physiologic system, with inhibition induced by factors such as joint position, muscle activity, and phase of movement (Trimble, Brunt, & Thompson, 2000).

It has been suggested that both static and PNF stretching techniques cause an increase in musculotendinous compliance, which allows for a greater pain-free muscle stretching (Marek et al., 2005). The enhanced efficiency of PNF techniques

has been related to a larger reduction of motoneuron excitation, which results from pre- and postsynaptic inhibitory mechanisms (Guissard et al., 1988; Guissard et al., 2001), assuming that greater motor pool inhibition reduces muscle contractibility and therefore allows more muscle compliance. Thus, PNF methods which involve reciprocal activation may provide the greatest potential for muscle lengthening (Etnyre & Abraham, 1986; Sharman, Cresswell, & Riek, 2006; McArdle, Katch, & Katch, 2010).

Recently, many studies focus on falls and poor balance control of elderly subjects and on the effectiveness of exercise programs to reduce the risks for falls and to improve balance (for a review see Gardner, Robertson, & Camphell, 2000). It is known that some exercises, which include stretching, are beneficial for postural balance control of the elderly (Carlson et al., 1999; Bird, Hill, Ball, & Williams, 2009). Balance control necessitates optimal muscle strength and flexibility as well as accurate visual, vestibular and proprioceptive inputs. Improvement in at least one of these factors may result in better balance control not only for the elderly but also for younger subjects. However, despite studies demonstrating the acute effects of stretching exercise on balance (Costa, Graves, Whitehurst, Jacobs, 2009; Behm, Bambury, Cahill, & Power, 2004; Lim, Nam, & Jung, 2014), the chronic effects of a consistent stretching exercise programmes on balance have not been addressed.

The aim of the present study was to investigate the chronic effects of 24 sessions of static stretching and contract-relax PNF stretching on balance control and motor neuron excitability to the hamstring and triceps surae muscles. To this end, the changes in the soleus muscle H-reflex responses, H_{max}/M_{max} ratio and H-reflex recovery curves were recorded. We also analyzed the changes in static balance control by measurement of single leg time. Knowledge on the chronic effects of stretching exercises on balance control, and motor neuron excitability may have implications for targeted interventions on individuals with impaired balance.

2. Method

Twenty-eight healthy male volunteers participated in the study. Subjects were all accustomed to the experimental procedures and had no signs of any neurological or orthopedic disorder. All subjects were informed about the experimental procedures, the risks involved in this study and provided informed consent (Declaration of Helsinki). Approval for the study was obtained from the Abant Izzet Baysal University's Faculty of Medicine Ethics Committee. Subjects were randomized into three groups; a static stretching group (n =10, age 22±2 yrs, height 174±5 cm, mass 75.5±4.5 kg), a contract-relax PNF stretch group (n = 9, age 22±2 yrs, height 180±7 cm, mass 72.0±7.0 kg) and a control group (n = 9, age 22±2 yrs, height 175±6 cm, mass 70.1±8.2 kg).

All measurements were performed on the dominant leg before and after stretching interventions. Leg dominance was determined by asking to take a step forward, the preferred leg was taken as dominant leg. Investigators were blind to the treatment group of the subjects. All groups were tested before and after a 6-wk period.

Static balance time was measured with a manual chronometer (Casio) to the nearest 0.1 seconds. All subjects were instructed to focus on a target approximately three meters away at eye level. For all trials, subjects placed hands on their hips and the non-dominant foot on the knee of the dominant leg. Subsequently, subjects raised themselves upon their toes and balance time started with the elevation of the heel from the floor and stopped at loss of balance. Loss of balance included removal of one hand from the hip, removal of the foot from the knee, touching the floor with the heel, or movement of the weight-bearing foot from its original position on the floor. The trial was repeated twice and the longest time was taken as balance time.

2.1 Electrophysiological Measures and Soleus Muscle H-Reflex Studies

Initially, tibial nerve motor conduction, tibial nerve F-waves and sural nerve sensory conduction were measured and observed to be normal in all subjects. A Nicolet Viking 4 channel EMG-EP machine was used for electrophysiological assessments. Subjects were familiarized for all procedures. For H-reflex recordings, subjects were lying prone with the head in a neutral midline position and their feet resting freely over the edge of the table in a quiet room. Monopolar stimulation electrodes made of silver-silver chloride were used; the cathode was attached over the popliteal fossa superposing the tibial nerve and the anode was placed over the patella. The soleus H-reflexes were recorded with surface electrodes applied on the skin approximately 4 cm distal to the musculotendinous junction of the gastrocnemius muscle. A metal ground electrode with a diameter of 2 cm was placed between the stimulating and the recording electrodes. All electrodes were fixed tightly with a surrounding bandage. The responses were recorded using a gain of 1000-5000 μV and a filter of 10 Hz to 10 kHz. The duration of the stimulus was one ms. Peak-to-peak H-waves were measured and recorded. Electrode locations were recorded for each subject to provide similar stimulation and recording conditions for pre- and post training testing sessions.

Initially, the amplitude of the maximal M-wave (M_{max}) and the H-reflex (H_{max}) were measured and pre- and post training M_{max}/H_{max} ratios were calculated. H-reflex recovery cycle (HRRC) was established by recording double stimuli

of equal intensity applied with varying interstimulus intervals ranging from 50 to 1000 msec (50-70-100-150-200-250-300-400-500-700-900-1000 msec). Four separate recordings were obtained at each interstimulus interval and the averages were calculated from the ratios (H2/H1) for each subject at each interstimulus interval. Ratios were expressed as percentages.

2.2 Training Program

All subject received before the start of the training program instructions on the performance of the stretching techniques. Static stretching or contract-relax PNF stretching exercises were performed four times per week for six weeks, a total of 24 sessions. The control group did not participate in any exercise program. The volume of the training programmes of the two stretching groups was similar.

2.2.1 Static Stretching Training

During the static stretching exercises, subjects lay in a supine position on the floor. For stretching of the hamstrings, the knee joint was extended with the hip held 90^0 of flexion while simultaneously flexing the ankle joint to 90^0 (neutral ankle dorsiflexion) to stretch the triceps surae for 30 seconds. Stretching was performed at the maximum range tolerated by the subjects. For each leg, the stretching was repeated four times with a rest period of 10 sec between stretches.

2.2.2 Contract-Relax PNF Stretching Training

The contract- relax PNF procedure consisted of three stages. In the first stage, with the subject lying in a supine position, the knee joint was extended with the hip held at 90^0 of flexion while simultaneously flexing the ankle joint to 90^0 (neutral ankle dorsiflexion) for 10 sec. In the second stage, hip extension and ankle plantarflexion against a force executed by the investigator was performed for five seconds. Following the subject's five seconds voluntary contraction, the subject relaxed for five seconds followed by the investigator applying hip- and dorsi-flexion stretching forces for an additional 15 sec. After a 5 sec relaxation period, passive hip flexion and ankle dorsiflexion were performed again for 15 sec. For each leg, the stretching was repeated four times with a rest period of 10 sec between each procedure.

2.3 Statistical Analysis

For each parameter, mean, standard deviation and effect sizes were calculated. Differences in change scores in pre and post training period at each group were assessed using paired t-tests. Further, in H-reflex recovery curve evaluation, repeated measures of analysis of variance procedures were performed with checks for sphericity. The sphericity assumption was not met so the Greenhouse-Geisser correction was applied. If there was a significant F ratio, *post hoc* comparisons were performed using paired t-tests with a Bonferroni adjustment of the alpha level (.05). The level of significance was determined as p<0.05 at the beginning of the survey and analyses were done by the program SPSS 20.0 for Windows.

3. Results

While the static balance time was significantly increased in SS group from pretest to posttest, a trend was observed in the PNF group with no change for in the control group (SS: $t_{(9)}$=-3.064, p=.013, η^2=.51, PNF: $t_{(8)}$=-2.020, p=.078, η^2=.34, Control: $t_{(8)}$=.175, p=.865, η^2=.00) (Table 1).

In the groups, pre- and post training values of H_{max}/M_{max} ratios indicated a trend for the SS group but no differences for the PNF and control groups (SS: $t_{(9)}$=-1.930, p=.086, η^2=.29, PNF: $t_{(8)}$=-.048, p=.963, η^2=.00, Control: $t_{(8)}$=.495, p=.634, η^2=.03) (Table 1).

Pre-training, H2/H1 ratios were not different in the groups [$F_{(2,25)}$=.233, p=.794, η^2=.02]. In addition, post training, H2/H1 ratios were not significantly different among groups [$F_{(2,25)}$=.471, p=.630, η^2=.04] (Figure 1).

Table1. Static balance time and H_{max}/M_{max} for all three groups. Data are mean (SD)

	Balance (sec)		Hmax/Mmax	
	pretest	posttest	pretest	posttest
Static	15.72 (9.47)	24.48 (17.51)*	0.39 (0.24)	0.50 (0.18)
PNF	18.10 (14.02)	26.14 (11.97)**	0.43 (0.23)	0.44 (0.18)
Control	15.2 9(13.16)	14.98 (11.50)	0.46 (0.15)	0.43 (0.18)

*significant difference from pre to post program (p<0.05). ** indicates a trend from pre to post program (p=0.078).
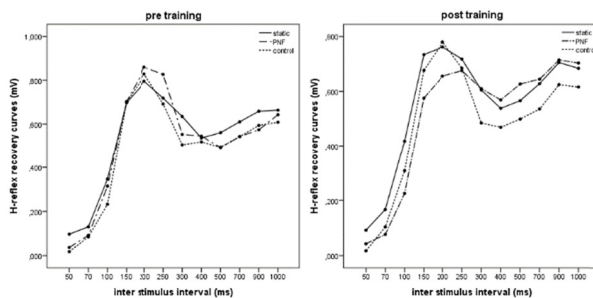
Figure 1. H-reflex recovery curves pre and post training for all three groups. Values are means (SD). This graph shows the H-reflex recovery curves of control and two stretching groups in pre and post training periods are similar (p>0.05)

In the groups, no differences in HRRC curves were observed in pre- and post training (for SS $F_{(1,18)}$=.036, p=.852, η^2=.00, for PNF $F_{(1,16)}$=.004, p=.951, η^2=.00, for Control $F_{(1,16)}$=.001, p=.973, η^2=.00) (Figure 2, 3, 4).

However, there was a significant interaction between pre and post training periods in PNF group [$F_{(11,176)}$=2.168, p=.018, η^2=.12], in the "post training" period, during 150-200 and 250 ms interstimulus intervals, we observed a reduction in facilitation but then during 500-700 and 900 ms interstimulus intervals, there was an increase between interstimulus intervals in HRRC curves (Figure 2).
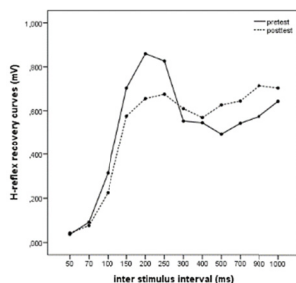

Figure 2. This graph shows the PNF group's H-reflex recovery curves obtained at two different periods Values are means (SD). There was a reduction in facilitation during 150-200 and 250 ms interstimulus intervals, then during 500-700 and 900 ms interstimulus intervals, there was an increase in HRRC curves.
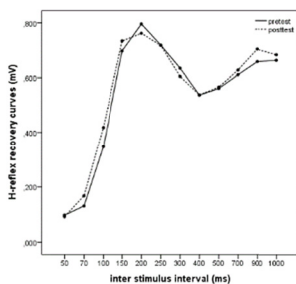

Figure 3. Static group's H-reflex recovery curves obtained at two different periods. Values are means (SD).

This graph shows the static group's H-reflex recovery curves in pre and post-training period are similar (p>0.05).
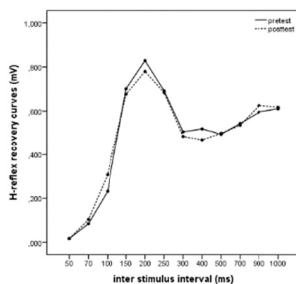

Figure 4. Control group's H-reflex recovery curves obtained at two different periods. Values are means (SD). This graph shows the static group's H-reflex recovery curves in pre and post-training period are similar (p>0.05).

4. Discussion

The current study was designed to assess the prolonged effects of two different stretching programs, performed for four times per week for six weeks, on static balance and the H-reflex activity. Despite the lack of a significant effect of PNF stretching, which may have been due to a lack of power, our results seem to indicate that that both the SS and PNF stretching exercises improved static balance, and PNF also induced some changes in HRRC curves.

The functions of the intrafusal (includes stretch receptors) muscle fibers, Golgi tendon organs and other proprioceptors is to aid in the maintenance of balance and detection of the position of the body in space (proprioception). Also, balance involves the interaction of automatic postural and voluntary motor commands of both the trunk and limb musculature (Behm et al., 2004). The results in studies regarding the effects of acute static stretching sessions on balance are conflicting. While some studies observed a worsening balance after stretch (Behm et al., 2004; La Torre et al., 2010), another study reported that longer-duration stretching protocols may not adversely affect balance (Costa et al., 2009). Behm et al. (2004) have suggested that a more compliant musculotendinous unit has more slack on the connective tissue, hence affecting muscle activation, consequently affecting balance and stability, or the proprioception of a limb.

Additionally, repeated and prolonged passive stretching has been shown to decrease reflex activity resulting from reduced sensitivity of the muscle spindles to repeated stretch (Avela, Kyrolainen, & Komi, 1999), which may partly explain the effects of stretching on balance. Again, a moderate stretching protocol may avoid possibly unfavorable reflex activity decrements. Moreover, static stretching has been shown to improve joint position sense, which investigators believe could be an increased proprioceptive feedback (Costa et al., 2009). This improvement in proprioception could be a mechanism that might, consequently, improve balance.

In the literature, Gehlsen and Whaley (1990) reported that balance, strength, and flexibility might be factors contributing to falls for the elderly. A well-designed stretching program will lessen the decline of flexibility of the elderly adults (Swank, Funk, Durham, & Roberts, 2003). It is known that some exercises, which include stretching, are beneficial for postural balance control of the elderly (Celebi, Zergeroglu, & Ergen, 2003; Marigold et al., 2005; Means, Rodell, & O' Sullivan, 2005). In a report by Celebi et al. (2003), it was shown that loss of balance control was small in a group of the elderly subjects who performed stretching exercises. They suggested that the muscle spindles become more sensitive to muscle lengthening, thus the strength and the velocity of voluntary and reflexive muscle contractions improves leading to an amelioration in balance control (Celebi et al., 2003). Another explanation is likely to increase in muscle strength as a result of the stretching exercises. It has been suggested that muscle hypertrophy might occur as a result of chronic stretching (Stone et al., 2006). Increase in muscle strength will improve the balance control (Garrett & Kirkendall, 2000). Furthermore, it was emphasized that the stretching duration and the frequency should be sufficient to see the effects of the stretching techniques on the balance (Lim et al., 2014).

In the current study, the subjects were all young and active and had no ocular or vestibular dysfunction. Although statistically significant differences were not detected from the PNF technique, may be due to lack of power as stated above, our results indicate an improvement from pre-test to post-test in static balance by both stretching programmes (Table 1).

In a report by Nielsen, Crone and Hultborn (1993), H-reflexes were of proportionally lesser amplitude in ballet dancers than in athletes. In another report by Guissard and Duchateau (2004), a training program involved 30 sessions consisting of a total of 10 minutes passive static stretching performed five times a week for 6 weeks in 12 subjects. After the 10th session, they found that muscle viscoelastic properties have progressed and after the 30th session, there have been also some neuronal changes leading to a decrease in H max and T max amplitudes. They also showed that these neuronal changes had returned to the control values more rapidly than the mechanical changes. They suggested that the decrease in H-reflex amplitudes have resulted from the reduction of the synaptic transmission from the Ia afferents to the motoneuron pool and also the more pronounced decrease in T reflex amplitude than H-reflex could be related to reduced sensitivity of the muscle spindle (Guissard & Duchateau, 2004). Guissard et al. (1988) also showed that for small amplitude passive muscle stretching, the H-reflex was reduced without any change in the T reflex amplitude but for a larger stretching amplitude both the H and the T reflexes and also the MEP response amplitudes have decreased. They proposed that decreased reflex loop activity during small-amplitude stretching should be related primarily to presynaptic inhibition on Ia afferents, and the other changes observed during large amplitude stretching were related to postsynaptic inhibition (Guissard et al., 1988). In our study, although balance improved, we did not find any changes in H-reflex amplitudes; this finding may indicate that the flexibility exercises must be performed for longer periods and more intensively than our program.

H-reflex recovery curve consists of four phases: primary inhibition phase with an initial complete depression within several tens of milliseconds (up to 50 msec); beginning of the recovery at 50-100 msec; secondary facilitation phase with an early recovery attaining an initial peak at 200-300 msec and, later secondary inhibition phase with a gradual recovery at 350-500 msec (Kagamihara et al., 1998). Previous studies reported that the secondary facilitation period of HRRC was possibly the result of input from cutaneous afferents, Ia afferent discharge, or contributions from supraspinal

influences (Crayton & Reud, 1981; Panizza, Lelli, Nilsson, Hallet, 1990; Spaulding, Hayes, & Harburn, 1987). In the current study, there seemed to be a reduction in the secondary facilitation phase of HRRC in the PNF group. It is possible that this reduction was due to the increase of supraspinal and postsynaptic inhibition, and that the presynaptic inhibition was excluded by the unchanged H_{max}/M_{max} ratios. Furthermore, the HRRC seemed to be greater in the post training period than in the pre training period during the 500-700-900 msec intervals in the PNF group. This may be explained by a different adaptation mechanism resulting from supraspinal influences and interneuronal mechanisms of spinal cord or may be a rebound phenomenon with a rapid recovery reaction following the secondary inhibition phase.

5. Conclusion

In conclusion, the Ia afferent inhibition occurring during the acute exercises has not been found after our long-term training programs with either static stretching or PNF. Finally, PNF may cause some augmentation in supraspinal and postsynaptic inhibition on the human motoneuron pool.

Acknowledgments

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