

Can apparent increases in muscle extensibility with regular stretch be explained by changes in tolerance to stretch?

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The aim of this study was to determine whether an intensive stretch program increases muscle extensibility or subjects' tolerance to an uncomfortable stretch sensation. Twenty healthy able-bodied individuals with limited hamstring muscle extensibility were recruited. A within-subjects design was used whereby one leg of each subject was randomly allocated to the experimental condition and the other leg was allocated to the control condition. The hamstring muscles of each subject's experimental leg were stretched for 20 minutes each weekday for four weeks. Hamstring muscle extensibility (angle of hip flexion corresponding with a standardised torque) and stretch tolerance (angle of hip flexion corresponding with maximal torque tolerated) were assessed on both legs at the beginning and end of the study. The intervention did not increase the extensibility of the hamstring muscles (mean change in hip flexion was -1 degree, 95% CI -4 to 3 degrees) but did increase subjects' tolerance to an uncomfortable stretch sensation (mean change in hip flexion was 8 degrees, 95% CI 5 to 12 degrees). These results highlight the importance of distinguishing between real and apparent increases in muscle extensibility when assessing the effectiveness of stretch, and indicate that whilst a four-week stretch program increases subjects' tolerance to an uncomfortable stretch sensation it does not increase hamstring muscle extensibility. [Folpp H, Deall S, Harvey LA and Gwinn T (2006): Can apparent changes in muscle extensibility with regular stretch be explained by changes in tolerance to stretch? *Australian Journal of Physiotherapy* 52: 45-50]

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Introduction

Limited muscle extensibility is a common problem that affects various patient populations as well as healthy able-bodied individuals (Ada and Canning 1990, Dalyan et al 1998, Leong 2002, Steffen and Mollinger 1995). If severe, limited muscle extensibility results in disabling and unsightly contractures (Ada and Canning 1990, Harvey and Herbert 2002). These are particularly common in patients with neurological disabilities, such as head injuries and spinal cord injuries. However, even slight loss of extensibility can have profound implications for both able-bodied and disabled people. For example, slight loss of extensibility in the hamstring muscles of people with quadriplegia can prevent sitting with the knees extended – a position essential for independent dressing (Harvey et al 2003b). In a similar way, slight loss of extensibility can limit the sporting and athletic achievements of able-bodied individuals. For instance, loss of extensibility can have important implications for high-jumpers, dancers and gymnasts. It is widely believed that limited muscle extensibility can be treated effectively with regular stretch (Ada and Canning 1990, Decoster et al 2005, Leong 2002). For this reason, stretch programs have become integral to sporting and rehabilitation programs for many patient and able-bodied populations.

There appears little doubt that stretch induces immediate increases in muscle extensibility. In isolated animal muscles this is demonstrated by an increase in muscle length with the application of constant tension. In vivo, the immediate effects of stretch are seen by an increase in joint angle with

a standardised torque. These effects are due to viscoelastic deformation and have been demonstrated in numerous pre-laboratory studies (Duong et al 2001, Magnusson et al 2000, Magnusson 1998, Magnusson et al 1995, Magnusson et al 1996c). However, viscous deformation is only transient and dissipates shortly after the removal of the stretch (Duong et al 2001, Magnusson et al 1996c).

In contrast to the transient effects of viscoelastic deformation, lasting effects of stretch involve underlying structural and biochemical adaptations. These adaptations are not readily reversible upon removal of the stretch. Animal studies have highlighted the highly adaptable nature of muscles and their ability to remodel structurally and biochemically in response to sustained stretch (Goldspink 1977, Goldspink 1978, Williams and Goldspink 1973). For instance, sustained stretch (as typically applied with serial casting) can increase the number of sarcomeres in series and change the concentration and arrangement of collagen within muscles (Goldspink et al 1974, Williams and Goldspink 1978, Witzmann et al 1982). These changes are accompanied by changes in a muscle's extensibility, so that notably less tension is required to stretch the muscle to a particular length.

The findings of animal studies line up with the strong anecdotal evidence suggesting that regular stretch induces lasting changes in muscle extensibility. A good example of anecdotal evidence can be found in the highly extensible muscles of ballerinas and gymnasts. The extensibility of these individuals is often attributed to their intensive

stretch programs. Numerous non-randomised studies in able-bodied and disabled populations have also reported the long-term beneficial effects of regular stretch on muscle extensibility (see reviews by Decoster et al 2005 and Leong 2002). However, few randomised studies have replicated these findings and fewer still have distinguished between the transient and lasting effects of stretch. A recent systematic review identified only thirteen randomised studies that had examined the lasting effects of stretch (defined as effects still evident 24 hours or more after the last stretch intervention; Harvey et al 2002). All 13 studies were in healthy able-bodied individuals where stretch was often applied for a few minutes a day over a 4–6 week period. The review reported an overall positive treatment effect (mean treatment effect 8 degrees, 95% CI 6 to 9 degrees) though the majority of studies had important methodological flaws. A second review conducted at about the same time searched for studies investigating the effects of stretch in people (including children) with various types of neurological conditions (Leong 2002). This review also failed to find any randomised studies that had examined the lasting effects of stretch in people with neurological disabilities. More recently a systematic review searched for studies that had specifically examined the effect of stretch on the extensibility of the hamstring muscles in able-bodied individuals (Decoster et al 2005). Twenty-eight studies were identified, though most were not randomised, did not distinguish between the immediate and lasting effects of stretch, and did not include a control (no-intervention) group. The authors concluded that stretch was beneficial, and that the treatment effect ranged from 5 to 33 degrees.

In more recent years, six randomised controlled trials have examined the lasting effects of stretch in patients with neurological disabilities (Ada et al 2005, Ben et al 2005, Harvey et al 2000, Harvey et al 2003b, Lannin et al 2003, Turton and Britton 2005). All but one (Ben et al 2005) have examined the effects of a four-week stretch intervention, and all but one (Ada et al 2005) indicate that stretch does not change muscle extensibility. These findings are unexpected particularly considering that in these studies the stretch was applied for considerably longer than is routinely applied in the clinical situation (i.e. studies applied stretch for between 20 and 30 minutes rather than 2–3 minutes).

One interpretation of the conflicting results of studies investigating the lasting effects of stretch, that we sought to explore in this study, is that stretch applied for only four weeks is insufficient to cause *real* changes in muscle extensibility and the positive results reported in the able-bodied literature (Decoster et al 2005, Harvey et al 2002) are primarily due to changes in subjects' tolerance to an uncomfortable stretch sensation. That is, regular stretch applied for four weeks leads to *apparent* but not *real* changes in muscle extensibility (Chan et al 2001, Magnusson et al 1996a). The distinction between *apparent* and *real* changes in muscle extensibility is important and can only be made if joint angle is measured passively with a standardised torque (Magnusson et al 1996a). If torque is not standardised and instead joint angle is determined by subjects' perceptions of discomfort, then changes in subjects' ability to tolerate uncomfortable stretch torques can result in corresponding increases in joint angle in the absence of underlying real changes in muscle extensibility. In the same way, if joint angle is measured actively, rather than passively, subjects can self-administer larger stretch torques as their tolerance to uncomfortable stretch increases. The majority of studies

and reviews on this topic that report lasting beneficial effects of stretch fail to make this distinction between real and apparent extensibility (Decoster et al 2005).

There is some evidence to suggest that regular stretch changes people's tolerance to uncomfortable stretch sensations (Halbertsma and Goeken 1994, Magnusson et al 1996, Chan et al 2001, Bjorklund et al 2001). Two of these studies are of particular interest and relevance. Halbertsma and Goeken (1994) found that two 10-minute hamstring stretches a day over a four-week period increased subjects' tolerance to stretch but had minimal effect on muscle extensibility. Magnusson et al (1996) reported a similar finding with a considerably shorter stretch intervention (five 45-second stretches, twice per day over 20 days).

People with spinal cord injury (SCI) provide a unique opportunity to distinguish between the real and apparent effects of stretch on muscle extensibility. These patients are insensate and paralysed. For these reasons the effects of stretch cannot be blurred by changes in stretch tolerance. The few studies that have examined this issue in people with SCI have found that regular stretch does not change muscle extensibility (mean treatment effect range = 0 to 4 degrees, 95% CI range -3 to 6 degrees; Ben et al 2005, Harvey et al 2000, Harvey et al 2003b). Of course it is possible that the muscles of people with SCI and other neurological disabilities do not respond to stretch in the same way as the muscles of able-bodied individuals. To explore this issue, this study replicated in healthy able-bodied individuals an earlier study performed in people with SCI (Harvey et al 2003b). Specifically, the aim of this study was to determine whether four weeks of regular stretch results in *real* or only *apparent* increases in hamstring muscle extensibility.

Method

Subjects Twenty subjects were recruited from the student and staff population of the University of Sydney. Eight were males and 12 females. Subjects were eligible for inclusion if they had limited hamstring muscle extensibility (assessed by subjects' ability to place their palms on the floor in a standard toe-touch test protocol; Gauvin et al 1990) but could achieve full pain-free knee extension. Subjects were excluded from the study if they had a history of back and/or hip pathology that was exacerbated by hamstring muscle stretches. The mean (SD) age, weight, height and toe touch scores (distance above the floor) were 24 years (SD 6.5), 66 kg (SD 14), 1.7 metres (SD 0.1) and 10.5 cm (SD 10).

A power calculation indicated that a sample size of 20 subjects would be sufficient to provide a 95% probability of detecting a 5 degree change in hip flexion, assuming a within group standard deviation of 5 degrees, alpha of 0.05 and loss to follow-up of 10%. The study received ethical approval from the University of Sydney's Human Rights and Ethics Committee, and informed consent was obtained from all subjects. All applicable institutional and governmental regulations concerning the ethical use of human volunteers were followed during the course of this research.

Outcome measures Two primary outcome measures were collected on both legs at the beginning and end of the four-week stretch period. One measure reflected *real* hamstring muscle extensibility and the other *apparent* hamstring muscle extensibility (tolerance to an uncomfortable stretch torque). Real hamstring muscle extensibility was determined by measuring passive hip flexion whilst the knee was maintained

Table 1. Mean (SD) hip flexion (degrees) before and after the four-week stretch intervention with the application of a standardised torque (real extensibility) and the highest torque each subject could tolerate (apparent extensibility). The mean (SD) highest torque (Nm) tolerated is also provided.

	Control			Experimental			Difference in changes
	Pre	Post	Change	Pre	Post	Change	
<i>Standardised torque</i>							
Hip flexion (degrees)	61 (13)	63 (11)	2 (5)	63 (14)	64 (13)	1(6)	-1 (7)
<i>Non-standardised torque</i>							
Hip flexion (degrees)	68 (12)	69 (14)	1 (7)	69 (14)	78 (17)	9 (8)	8 (8)
Torque (Nm)	56 (24)	55 (25)	-1 (13)	55 (25)	67 (27)	12 (15)	12 (13)

in extension with the application of a standardised torque. Apparent hamstring muscle extensibility was measured in the same way but with the application of the highest stretch torque subjects could tolerate. All testing was performed using a device specifically designed for the purpose and previously tested for reliability (ICC 0.98; Harvey et al 2003a).

The measurement device consisted of a wheel mounted to the side of an examination plinth (see Figure 1). Subjects lay supine on the plinth with the tested leg strapped into a knee-extension splint and the other leg and pelvis secured to the bed. The leg splint was attached to the wheel so that rotation of the wheel resulted in corresponding rotation of the leg splint and leg (i.e. hip flexion). The leg splint prevented knee flexion and hip abduction and rotation, and ensured that the leg rotated in a sagittal plane. The centre of rotation of the wheel was aligned with the subject's hip joint. A hip flexor torque was applied by weights that rotated the wheel. The weights were hung from a rope that circled around the wheel and was attached to the wheel's rim. The resultant hip flexor torque was calculated by multiplying the suspended mass multiplied by the radius of the wheel. The wheel acted to ensure that the moment arm of the hip flexor torque (namely the radius of the wheel) remained constant regardless of hip angle. The torque produced by the weight of the splint and subject's leg was eliminated by adjustable counterweights attached to a rod that extended proximally from the leg splint. The rod rotated as the hip flexed. Hip flexion angle was measured with a digital inclinometer attached to the long axis of the leg splint. Zero degrees indicated that the leg was horizontal.

Measurement procedure Subjects were tested on three occasions; twice at the beginning and once at the end of the study. The first test was performed one week prior to the commencement of the study, and was to familiarise subjects to the testing procedures. No data were collected during the familiarisation session. The second test was performed one or two days prior to the commencement of the study and the final test was performed at least 24 hours after the last stretch. A blinded therapist took all measurements and subjects were requested to refrain from participating in rigorous physical activity in the 48 hours prior to each assessment. Subjects were encouraged to completely relax throughout all tests.

Testing and the familiarisation session always followed the same format with the right leg measured before the left.

Initially, a 19 Nm torque was applied for three minutes. This torque was applied to ensure that the effects of viscoelastic deformation were standardised across control and experimental legs (Magnusson et al 1995, Magnusson et al 1996b). Once this initial torque was removed, testing commenced. Torque was incrementally increased by 6.3 Nm at 30-second intervals until subjects indicated they were unwilling to tolerate another 6.3 Nm increment. At this point, the torque was increased by smaller increments (1.4 Nm) though at a faster rate until subjects indicated that they had reached the maximal torque they were willing to tolerate. Hip flexion angle was measured at each 6.3 Nm increment and at the highest torque subjects were willing to tolerate. These measurements were taken with a digital inclinometer. The resultant torque-angle data were used to derive the two primary outcome measures. The extensibility of the hamstring muscles (i.e. *real* hamstring muscle extensibility) was reflected by the angle of hip flexion that corresponded with the highest torque each subject could tolerate for both legs at the pre and post assessments. In this way, the torque was the same for a particular subject but not across subjects.

Subjects' tolerance to an uncomfortable stretch sensation (i.e. *apparent* hamstring muscle extensibility) was reflected by the angle that corresponded with a non-standardised torque, namely the highest stretch torque subjects could tolerate on each leg at the time of each test. This torque differed for each subject's leg and differed between testing sessions.

Experimental protocol Following the completion of initial measurements, subjects' legs were randomly allocated to either an experimental group (stretch group) or control group (non-stretch group). The use of a randomised within-subjects design minimised effects due to between-subject differences in exercise and activity patterns. A person independent to the study generated a randomisation schedule with a computer. The randomisation schedule was placed in opaque, sequentially numbered envelopes. The envelopes were opened once the subject had been accepted into the study and after their initial measurements. Subjects were considered to have entered the study at this point.

Subjects were required to stretch five times a week. At least four (sometimes five) sessions were supervised. The fifth session was generally unsupervised and done in subjects' own time. Compliance with the unsupervised sessions was closely monitored with diaries. All stretches were static and

self-administered for 20 minutes. Subjects were instructed to apply the greatest stretch they could tolerate whilst sitting upright with the leg raised on a high stool or plinth. Attendance was marked at each supervised session and diary recordings of unsupervised sessions were reviewed at the end of each week.

Data reduction and analysis Mean changes from initial to final measures were calculated for both experimental (stretch) and control (non-stretch) legs for the two outcome measures (real and apparent extensibility). The t-distribution was used to estimate 95% confidence intervals for between-leg differences in change. Data were analysed by intention-to-treat (Pocock 1983). Increases in both real and apparent extensibility were indicated by a positive change.

Results

No subjects withdrew from the study. The trial protocol dictated that subjects receive 20 treatments to the experimental (stretch) leg over 28 days: a total of 400 minutes of stretch. There were some deviations from the study protocol; notably, one subject missed 8 stretch sessions. Overall however, subjects received a mean of 19.5 treatments (SD 1.8) over 28 days with a mean total stretch time of 390 minutes (SD 36). A mean of 16 sessions (SD 3) were supervised and three sessions (SD 1) were unsupervised per subject. Testing of all subjects was completed at least one and no more than two days after each subject's final stretch session.

The differences between the real extensibility of subjects' treated and non-treated hamstring muscles at the commencement of the study were small (Table 1). There was however variability in the extensibility of the hamstring muscles between subjects (median hip flexion with 19 Nm torque was 41 degrees, interquartile range was 35–48 degrees).

The mean change in hip angle with the standardised and non-standardised torque for treatment and control legs are depicted in Table 1. The stretch intervention did not increase *real* extensibility of the hamstring muscles (hip flexion with a standardised torque). The overall mean treatment effect with the standardised torque was -1 degree (95% CI -4 to 3 degrees). In contrast, the stretch intervention did increase subjects' tolerance to stretch (*apparent* hamstring muscle extensibility). The overall mean treatment effect with a non-standardised torque was 8 degrees (95% CI 5 to 12 degrees). This increase was reflected by a corresponding overall mean increase in the torque tolerated by subjects of 12 Nm (95% CI 7 to 18 Nm). The highest torques tolerated by each subject ranged from 19 Nm to 132 Nm (mean = 58 Nm). Thus, there was an *apparent* but not real increase in the extensibility of subjects' hamstring muscles.

Discussion

The results of this study indicate that an intensive four-week stretch program does not increase the extensibility of the hamstring muscles in able-bodied individuals. It does, however, increase subjects' tolerance to an uncomfortable stretch sensation. This altered stretch tolerance produced an *apparent* but not *real* increase in hamstring muscle extensibility.

Evidence about the effectiveness of stretch for inducing lasting changes in the real extensibility of muscles is

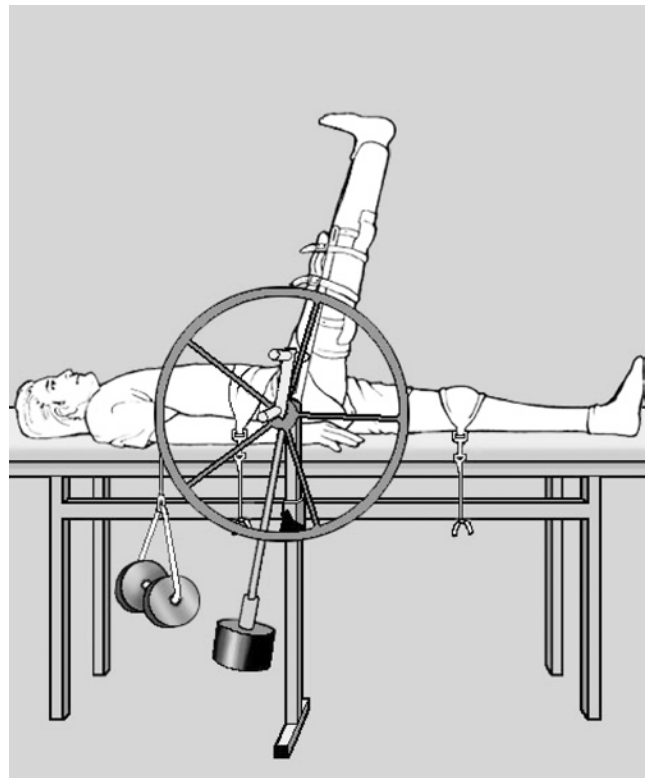


Figure 1. Device used to assess real and apparent hamstring muscle extensibility. (Image reproduced with permission from www.physiotherapyexercises.com)

conflicting. A number of trials in the disabled population have found no treatment effect (Ben et al 2005, Harvey et al 2000, Harvey et al 2003b, Lannin et al 2003, Turton and Britton 2005), despite high statistical power and despite the application of stretch for sustained periods of time (between 20 and 30 minutes a day). However, and in contrast, a meta-analysis of trials in the able-bodied population reported a beneficial effect from relatively short stretch interventions (primarily between 30 seconds and 3 minutes a day; Harvey et al 2002). Of course, one interpretation of these conflicting findings is that the muscles of able-bodied individuals are more responsive to stretch than those of their disabled counterparts. However, a more likely interpretation, and one that we sought to explore in this study, is that four weeks of stretch is insufficient to cause real changes in muscle extensibility and the previously reported beneficial effects of stretch in the able-bodied literature are primarily due to changes in subjects' tolerance to an uncomfortable stretch sensation (Magnusson et al 1996a). Interestingly in this study, the size of the treatment effect on stretch tolerance (8 degrees, 95% CI 5 to 12 degrees) mirrored the size of the treatment effect previously reported in the able-bodied literature (8 degrees, 95% CI 6 to 9 degrees; Harvey et al 2002).

It is not altogether surprising that stretch programs change people's tolerance to stretch. The underlying mechanism may be psychological. Subjects were not blinded and may have entered this study with a preconceived expectation that stretch would increase extensibility. Therefore, when tested at follow-up, they expected the stretch intervention to have improved hip flexion. Consequently they tolerated a greater

stretch torque on their experimental leg and there was a corresponding increase in passive hip flexion. Alternatively, it may be that regular stretch and familiarisation with the discomfort associated with stretch reduces perceptions of pain and discomfort. However, if this is the case, the effects are unilateral and specific to the muscle treated. That is, stretch on one leg does not also increase the stretch tolerance on the contralateral and untreated leg. Alternatively there may be a real underlying physiological mechanism contributing to subjects' altered stretch tolerance. For instance, the stretch intervention may change some characteristic of sensory neural pathways (Laessoe and Voigt 2003, Magnusson et al 1996a). Future studies that use a combination of within- and between-subjects design are required to explore some of these issues.

One possible explanation for the failure of the stretch intervention to cause real increases in hamstring muscle extensibility is not that stretch is ineffective but rather that stretch needs to be applied for more than four weeks and/or for more than 20 to 30 minutes a day. There is some evidence suggesting that both these factors may be important (Goldspink 1977, Williams 1990). It is also possible that stretch needs to be applied with a greater torque than that commonly tolerated. Clearly studies are now required that examine the effects of stretch applied in different dosages in both the able and disabled populations.

It could be argued that the underlying mechanisms explaining increases in hip flexion following stretch are irrelevant. That is, provided a greater range of hip flexion is attained, it is of little interest whether this is due to real or apparent changes in hamstring muscle extensibility. In some population groups this may be correct. For instance, in gymnasts the ability to touch the toes is of paramount importance but the underlying mechanism probably is not. Yet clearly there are examples where apparent changes in extensibility alone are not sufficient and that real underlying changes in tissue extensibility are clinically important. The most obvious example is in the area of disabilities where disfiguring deformities that result from loss of muscle extensibility cannot be treated by changes in stretch tolerance alone. In these patients stretch is only a worthwhile intervention if it can induce lasting structural adaptations within the muscle. The results of this study demonstrate that, contrary to expectations, four weeks of intensive stretch does not cause lasting changes in hamstring muscle extensibility and the only apparent effects are due to changes in subjects' willingness to tolerate uncomfortable stretch sensations.

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