A Comparison of the Effect of Muscle Energy Technique (Chaitow Method) and Passive Stretching on Hamstring Extensibility

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ABSTRACT

This study compared the effects of the Chaitow Muscle Energy Technique (MET), with passive stretching for increasing hamstring muscle extensibility both immediately and after 30 minutes. Fifty nine asymptomatic participants (mean age = 21.78 years, SD = 2.34) were measured for hamstring length using active knee extension (AKE). AKE was recorded using digital photography, and values were calculated using computer software. After the initial measurement, participants were randomly allocated to either a passive stretch or MET intervention group. Immediately after the treatment, post-intervention measurements of AKE were recorded, and this was repeated 30 minutes later. There was a mean increase of 4.38 (SD = 4.49) degrees recorded in the MET group, whereas passive stretching produced a mean increase of 2.24 (SD = 4.33) degrees. Using a split-plot ANOVA, a significant change over time in the AKE values was found ($F_{1.71\,,\,97.28} = 30.94$, $p = 0.00$), however, there were no significant differences between groups ($F_{1\,,\,57} = 0.22$, $p = 0.64$). Although the measurement procedure was determined to be repeatable, modifications to the AKE methodology may have resulted in under-estimation of the error range, and raises major concerns about the validity of the measurement procedure. In view of this methodological flaw, no conclusions can be made regarding the effectiveness of the two manual techniques. Future studies are recommended using the accepted AKE methodology and measurement analysis.

INTRODUCTION

Muscle Energy Technique (MET) is a manual technique that involves precise contraction of a subject's muscle, and is claimed to increase muscle extensibility and joint motion (Chaitow 1996). MET is claimed to address both the soft tissue and articular component of somatic dysfunction, and is commonly advocated by authors of manual therapy (Greenman 1996, Chaitow 1996). These techniques are a part of the evolution from relatively forceful techniques such as high velocity low amplitude thrusts, towards gentler techniques (Chaitow 1996). Several studies have shown that both passive/static stretching and isometric stretching (such as MET) are effective in increasing muscle flexibility, however there are varying results as to the most effective technique (Magnusson et al 1996c, Ballantyne et al 2003, Gribble et al 1999). Furthermore, different authors of MET have advocated different methods in applying the technique, with differences in the force and duration of the passive stretch component and even in the direction of the isometric contraction (Greenman 1996, Chaitow 1996). Therefore, further research into which techniques are the most effective is warranted to assist manual therapists to providing the most efficacious treatments.

MET differs from static stretching as it involves an active isometric contraction of the muscle under stretch from the patient against the resistance of the practitioner in addition to passive/static stretching. When applied for the purpose of increasing muscle extensibility, there are similarities between MET and isometric techniques, such as contract relax (CR) and proprioceptive neuromuscular facilitation (PNF) techniques, used in other manual therapy disciplines.

Within the field of osteopathy, various authors have suggested different ways of applying MET, by altering the force, duration of contraction, direction of isometric contraction and length of post-contraction stretch (Chaitow 1996, Greenman 1996, Bandy et al 1998). However, there has been no investigation of the most effective application of MET, nor has there been research into the effectiveness of the Chaitow technique. For the application of MET to increase hamstring muscle extensibility, Chaitow (1996) recommended passive stretching of the hamstring muscles to a sense of tension, followed by an active, moderate force isometric contraction of the hamstrings against operator resistance, and then an active contraction of the quadriceps muscles by the subject to reach increased range of motion, and finally 30 seconds of passive stretching. In contrast, other authors of MET texts advocate more gentle contraction forces, without the agonist (quadriceps) contraction, and a lesser duration of passive stretch (Greenman 1996).

The effect of Chaitow MET on hamstring extensibility has not specifically been examined, although several studies have investigated various muscle flexibility treatments on joint ROM (Magnusson et al 1996c, Ballantyne et al 2003, Gribble et al 1999). These studies have established that static stretching and MET are both effective in improving joint flexibility in comparison to control groups. However, there is still some conjecture about which is the most effective method to be used by practitioners (Gribble et al 1999, Magnusson et al 1996c, Bandy et al 1998).

Some researchers have found no difference between the effectiveness of isometric stretching techniques and passive stretching on hamstring muscle extensibility. Gribble et al (1999) compared the effects of static stretching with hold relax stretching on the hamstring muscles flexibility measured using Straight Leg Raise (SLR), and active knee extension (AKE). Gribble et al concluded that both of these techniques improved flexibility, however, no significant differences between the effectiveness of these techniques were found (Gribble et al 1999). Similarly Feland et al (2001) measured the effects of contract relax (CR) stretching, static stretch and no stretching on hamstring flexibility and found that all groups increased in flexibility from pre-test to post-test, however the increase was greater for the two treatment groups. The median difference in flexibility was one degree in the control group, five degrees in the CR stretching group and four degrees in the static group. Therefore the benefits in flexibility between CR stretching and static stretch were similar.

In several studies, MET and PNF stretching have shown to produce greater joint ROM and hamstring extensibility in comparison with passive and static stretching (Sady et al 1982, Wallin et al 1985, Osternig et al 1990, Magnusson et al 1996c). Sady et al (1982) investigated the effects of stretching techniques on the flexibility of the shoulder, trunk and hamstring muscles. Subjects were randomly assigned to either a control, ballistic, static or PNF group. Post hoc analysis showed that only the PNF group had flexibility increases (10.6 degrees) greater than the control (3.4 degrees). Wallin et al (1985) compared the methods of CR and ballistic stretching for improving muscle flexibility, finding that the CR method achieved significantly greater improvement.

Magnusson et al (1996c) conducted a study using ten male volunteers to examine the electromyographic (EMG) activity, passive torque, and stretch perception during static stretch and CR stretch techniques. By using a dynamometer the passive torque (Nm) measured the resistance to stretch offered by the hamstring muscle group during passive knee extension (PKE) (Magnusson et al 1996c). This study concluded that the maximum tolerated joint angle and passive torque were greater in CR stretch techniques, compared with the static stretch. Similarly Ballantyne et al (2003) found that MET produced greater hamstring extensibility when stretched to tolerance.

Several studies have found that agonist contract relax (ACR) techniques are more effective than CR at increasing joint ROM (Osternig et al 1990, Ferber et al 2002a, Ferber et al 2002b). Osternig et al (1990) compared stretch-relax (SR), CR, and ACR techniques on hamstring muscle activation and knee ROM. ACR involves passive muscle stretching, active contraction of the quadriceps muscles to further increase ROM, followed by additional passive stretching, with similarities to the MET method advocated by Chaitow (1996). The results revealed that ACR produced a 9 to 13% greater increase in knee joint ROM when compared to CR and SR, respectively. Ferber et al (2002a) tested the effects of PNF stretching on joint ROM in older adults and determined that the ACR technique produced 4 to 6 degrees more ROM than SS (Static Stretch) and CR techniques. In a similar study Ferber et al (2002b) examined the effects of PNF stretching techniques on knee flexor muscles in older adults. Three PNF stretch techniques SS, CR, ACR were applied to 24 older adults aged 50–75 years (Ferber et al 2002b). The results indicated that ACR produced 29 to 34% more ROM than CR and SS, respectively (Ferber et al 2002b). It can therefore be concluded that several studies determined that ACR techniques are more effective at increasing joint ROM than SR, SS and CR techniques.

Neurophysiological and biomechanical mechanisms may underlie changes to both ROM and muscle stiffness following the application of MET (Magnusson et al 1996c). The neurophysiological component is explained by inhibition of the motor activity of muscles exposed to stretch. The object of stretching is therefore to minimise muscle activity to reduce resistance to stretching (Magnusson et al 1996c). The visco-elastic response is the response that a tissue undergoes after a load is applied to the muscle. Elasticity is the ability of the tissue to return to their original state after the load is applied, whereas the viscosity is related to the fluid change occurring after the muscular load (Chaitow 1996). These visco-elastic components are responsible for the changes in extensibility available at a muscle. When a muscle under tensile stress is held at an unchanging length, the tensile strain will be reduced over time.

There have been several studies investigating the visco-elastic changes that both MET and static stretching produce during the relative techniques (Magnusson et al 1996b, Magnusson et al 1996a, Ballantyne et al 2003). Magnusson et al (1996b) found that the muscle changes measured were a temporary visco-elastic stress relaxation, and unrelated to EMG activity. Ballantyne et al (2003) tested the effect of MET on hamstring extensibility and the results suggested a significant increase in knee ROM after MET treatment. If there was a significant increase in the joint angle at the pre-test load, following MET, then a change in the tissue property may explain this enlargement (Ballantyne et al 2003). Because this did not occur, it appeared that there were no visco-elastic changes occurring during the MET treatment (Ballantyne et al 2003). Magnusson et al (1996a) also investigated the effects of long-term stretching on the stretch tolerance of human skeletal muscles and the tissue property changes. The results showed no changes in EMG activity after stretching, and it was therefore concluded that EMG activity had no effect on the ROM available at the knee. The increased ROM was therefore due to increased stretch tolerance rather than changes in mechanical or visco-elastic properties (Magnusson et al 1996a).

There has been limited research into the optimal time for either isometric muscular contraction or post-contraction stretching when applying MET and PNF techniques. Bandy et al (1998) suggested that the optimal time a stretch should be held for is 30 seconds, once a day. The duration of muscle contraction needed to produce significant results varies between authors. Greenman (1996) advocates MET involving 3 to7 seconds of resisted contraction, whereas Ferber et al (2002a) recommends 20 seconds of contraction.

Researchers have previously measured knee joint ROM and hamstring muscle flexibility changes using AKE (Spernoga et al 2001, Gribble et al 1999). Cameron et al (1993) examined the validity of AKE in measuring hamstring ROM changes by comparing AKE and active straight leg raise (ASLR). These researchers concluded that the AKE test may be a useful alternative to the straight leg raise test for providing an indication of hamstring muscle length. AKE is simple to perform, reliable, and many researchers have demonstrated changes to hamstring length following manual treatment using this measurement (Handel et al 1997, Gribble et al 1999, Spernoga et al 2001, Funk et al 2003). The aim of this study was to investigate the effects of MET, as described by Chaitow (1996), on hamstring extensibility using AKE, and to compare the effectiveness of this technique with passive stretching.

MATERIALS AND METHODS

Participants

The participants were recruited from students and staff at Victoria University, Flinders Lane City Campus, Melbourne. The study involved 59 participants (37 females, 22 males), aged between 18 and 33 years of age (mean age = 21.78 years, SD = 2.34). The participants were all asymptomatic, with no current symptoms of musculoskeletal dysfunction in their hamstrings or lower back.

Participants of the main study were excluded if they were able to perform greater than 170 degrees of AKE, because the AKE changes were difficult to accurately measure beyond 170 degrees in these flexible individuals. One hundred and five participants were initially measured, with forty-six participants being excluded because they achieved greater than 170 degrees of AKE pre-testing.

The Human Research Ethics Committee of Victoria University approved the study. Participants gave written consent before participating in the research, and were able to withdraw from the study at any time.

Measures

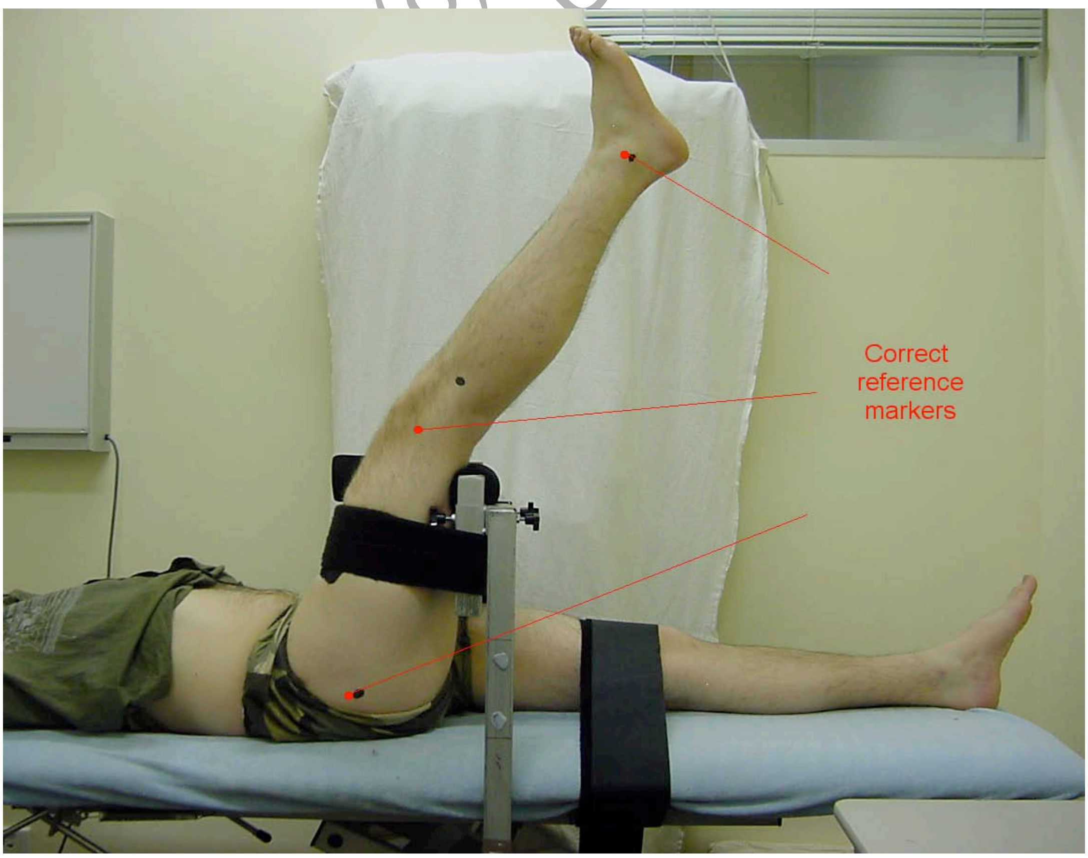
AKE was chosen as the method of measurement for the present study because it is simple to perform, reliable (Cameron et al 1993), and many researchers have demonstrated changes to hamstring length following manual treatment using this measurement (Handel et al 1997, Gribble et al 1999, Spernoga et al 2001, Funk et al 2003).

AKE measurements were achieved by marking on bony landmarks of the greater trochanter, fibula head and lateral malleolus (Figure 1). These landmarks were later identified as being inaccurate as the midpoint of the lateral femoral condyle should have been used as the reference marker for the vertical vector, rather than the fibula head (Ballantyne et al 2003).This error in landmarks used would result in miscalculation and under-estimation of movement.

Participants lay supine on the testing table, with their thigh flexed at the hip and firmly fixed into this position. The stabilising bar was found to be easily moved by the extension effort of the participant, and so the technique was modified by placing the bar on the posterior surface of the thigh, which appeared to improve the stability of the thigh (Figure 1). This modification affected the angle of the thigh and resulted in a serious flaw in the validity of the procedure, which will be discussed later.

Participants had their opposite leg firmly fixed to the table in order to decrease the amount of rotation of the pelvis during testing. The participants were required to actively straighten their knee until the point of maximum stretch tolerance, at which point a photograph was taken. This was performed three times and was recorded using a digital camera. The camera was set up parallel to the participant's leg and the treatment table, in order to decrease the chance of miscalculations regarding the angle being recorded. The digital photos were later analysed using SiliconCOACH Pro Software to calculate the AKE angle.

Figure 1- AKE measurements



Pilot reliability study

Twenty participants were measured using AKE on two occasions, five minutes apart, to determine the repeatability of the AKE measurement and calculations. These participants were recruited from students and staff at Victoria University, and were invited to return to be involved in the treatment study. Participants were unfastened from the table and left the room between measurements. They were asked not to participate in any exerting physical activity during the five minute interval.

Treatment interventions

Muscle Energy Technique (Chaitow Method)

The participants assigned to the MET group were asked to relax and lie on the treatment table while the practitioner flexed their hip and extended their knee until the point of maximum stretch tolerance of their hamstring muscle. The procedure involved seven seconds of isometric contraction against the resistance of the practitioner, followed by three seconds of relaxation. The participant was encouraged to reach the new barrier by actively contracting the knee extensors (Chaitow 1996). This was then followed by thirty seconds of passive stretching at the point of maximum stretch tolerance of their hamstring muscle. This process was performed four times (Figure 2).

Passive stretching

The participants were asked to relax, and the practitioner flexed the participant's hip and extended their knee until the point of maximum stretch tolerance of their hamstring muscle. This was held for thirty seconds and then placed back into a neutral position.

Figure 2- Muscle Energy Technique

Procedure

The study was a controlled-blinded experimental design. Participants were initially measured for hamstring extensibility using active knee extension (AKEpre). Participants were then moved into a separate room and were randomly assigned to either stretch (n = 32; Female = 23, Male = 9) or MET groups (n = 27; Female = 14, Male = 13). Random allocation of treatment groups was achieved by placing twenty pieces of paper labelled with either stretch or MET into a container. Subjects then closed their eyes and picked one piece of paper, read it out and placed it back into the container. The researcher taking photos of the AKE and calculating the angles was blinded to the group allocation of the participants. Participants where then treated with either the passive stretching technique or MET. Participants then returned to the first room for AKE re-measurement immediately after the treatment (AKEpost1) and again 30 minutes after the treatment (AKEpost2). During the 30 minute interval between measurements participants were asked not to be involved in any exerting physical activity.

Statistical Analysis

Pilot reliability

The Pilot reliability study involved measuring the Intraclass Correlation Coefficient (ICC) for the two AKE readings.

Treatment Intervention

To examine the differences between groups and the effect over time AKE data was analysed using a SPANOVA. The between group effect size was calculated using Eta squared. Eta squared can be defined as small (0.01), medium (0.06) or large (0.14). Data was then reported using both tables and graphs.

RESULTS

During the collection of data there were several major flaws, which have been detailed in the discussion section. Therefore due to the problems with the validity of the testing methods the results can not be discussed as being significant.

Pilot reliability study

In the reliability study, the average measure Intraclass Correlation Coefficient (ICC) for the two AKE readings was calculated as 0.98, which demonstrated that the calculation procedure was highly repeatable. The error range between the first and second measurements (mean difference + standard deviation of the mean difference) was calculated (0.45 + 2.48) as 2.93 degrees.

Table 1: Results for Pilot reliability study

	Mean	Std. Deviation	N
AKE pre	172.35	10.37	20
AKE post	172.80	10.67	20
Difference scores	0.45	2.48	

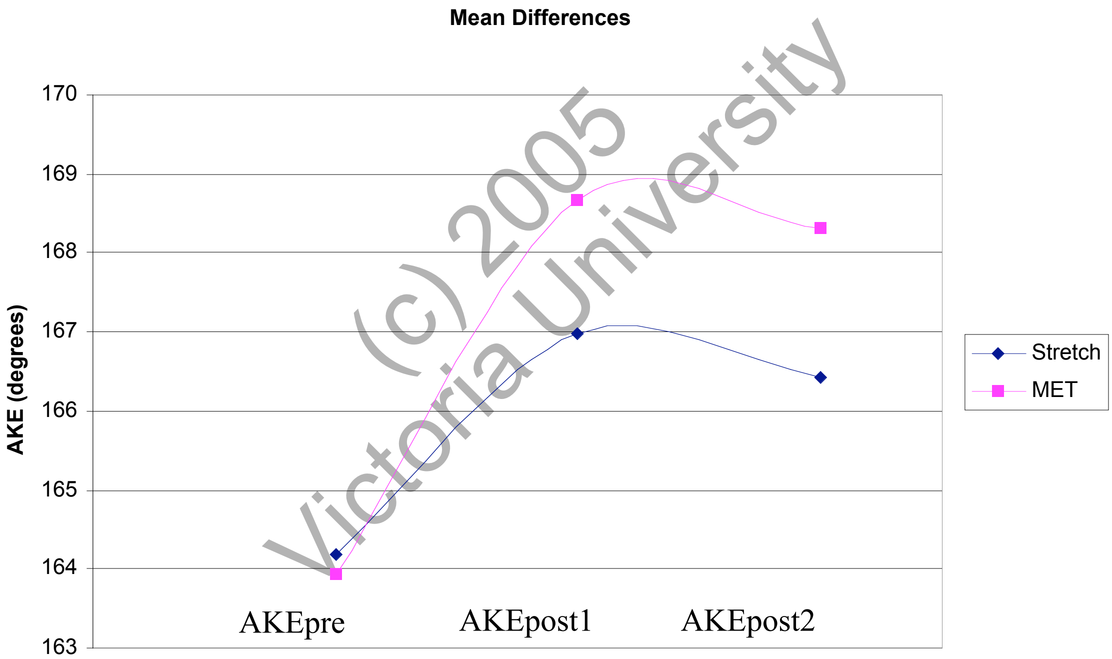
Treatment Intervention

The mean difference between AKE pre and AKE post2 (30 minutes post treatment) in the Chaitow treatment group was 4.38 degrees, whereas the mean difference in the stretching group was 2.24 degrees (Table 2). The data was analysed using a split plot ANOVA (SPANOVA). Mauchly's Test of Sphericity was significant (p = 0.01), so the degrees of freedom were adjusted using Greenhouse-Geisser (Coakes & Steed 2000). The results demonstrated a change over time ($F_{1.71\ ,\ 97.28} = 30.94$, $p = 0.00$), however, there were no significant differences between groups over time ($F_{1\ ,\ 57} = 0.22$, $p = 0.64$). The partial Eta squared value for between-subjects effects was small (0.004). These data show that 0.4 % of the variance in hamstring extensibility is due to group membership (i.e. treatment type).

Table 2: Descriptive statistics for Chaitow and Stretch Techniques (Degrees)

	AKEpre	AKEpost1	AKEpost2
MET	163.94 (9.29)	168.67 (7.45)	168.32 (7.22)
Stretch	164.18 (11.01)	166.97 (9.61)	166.42 (10.47)

Figure 3: AKE pre, post1 and post2 mean angles (Degrees)



DISCUSSION

Data analysed in the current study suggested that there was an increase in hamstring extensibility following both the Chaitow MET technique and the 30-second passive stretch when compared to pre-treatment measurements, but no differences were evident between the techniques. However, since the collection of data, the authors of this study have become aware of serious methodological flaws in the measurement of AKE in this study. In view of these flaws, no conclusions can be made concerning the relative effectiveness of these two manual techniques.

One of the major flaws in the methodology of this research project resulted from the modification of the AKE measurement procedure. AKE has previously been effective in measuring joint ROM, and is normally measured with the stabilisation bar on the anterior surface of the thigh and the thigh flexed to 90 degrees (Gribble et al 1999, Ballantyne et al 2003). The researchers in the present study were concerned about the movement occurring at the bar during active extension, and moved this bar behind the thigh to provide better stability. On reflection, this was a major mistake, because it resulted in the thigh being no longer maintained at 90 degrees of hip flexion and would have resulted in the under-estimation of change in AKE. Additionally, the midpoint of the lateral femoral condyle should have been used as the reference marker for the vertical vector, rather than the fibula, and this would also result in miscalculation and under-estimation of movement. Ballantyne et al (2003) measured knee extension from points on the greater trochanter, lateral femoral condyle and lateral malleolus. The current study however measured the angle from the greater trochanter, fibula head and lateral malleolus. This measurement used in the current study would therefore result in the angles measured at the knee joint under-estimating the change in joint ROM.

It is also possible that the pressure on the hamstring muscle from the stabilisation bar may also influence muscle extensibility. In order to prevent excess movement while the patient was fixed onto the treatment table, the patient's thigh was fixed with the apparatus against the posterior thigh. It was considered during the testing procedure that this would allow for greater accuracy during testing as the thigh could not move from the original position during the knee extension movement. However since the testing, it has been considered that the hamstring muscle contact with the stabilising bar may have affected the extensibility of this muscle, and therefore the validity of the testing procedure. This procedure was determined to be highly repeatable after completing the pilot study, however the methodology flaws would have lead to an under-estimation of the error in the reliability study, and so this method cannot be considered reliable or valid. In view of these issues, no conclusion can be inferred from the results of this study.

Magnusson et al (1996c) and Osternig et al (1990) compared the effects of CR techniques with static stretching by measuring changes in joint ROM using passive knee extension (PKE). Ballantyne et al (2003) also researched the effect of MET on hamstring extensibility using PKE rather than AKE. PKE may be useful in further studies as it can be used to specifically measure stretch tolerance occurring after the techniques. The advantage of PKE torque measurements is that it gives information about possible changes in the muscles visco-elastic properties, as opposed to the likely change in stretch tolerance. Further research comparing AKE and PKE measurements may be useful in determining the best method for testing the effectiveness of CR and static stretching techniques.

A limitation of this current study was the fact that participants were osteopathic students, who were familiar with MET and passive stretching, and therefore were not blinded to the types of techniques being performed. The students may have been more likely to favour MET, because students were familiar with this technique. They may have tried harder to produce greater knee extension by exerting more than the pre-test measurements, as studies emphasise the effectiveness MET rather than stretching techniques. However, this bias was not evident from the results in this study, but future studies should aim to use a more naïve group of subjects.

Another limitation of the current study was the lack of a control group. Although it has been well established that passive stretching may produce an increase in hamstring extensibility (Bandy et al 1998, Gribble et al 1999, Feland et al 2001), in order to be certain that the increase in extensibility was due to treatment intervention, AKE gains should be compared to a control group. This may be important for future researchers to consider, because it reduces the chances of the increase in hamstring extensibility being due to repeated testing rather than the effectiveness of the technique.

Future researchers may need to consider other important variables in regards to determining the effectiveness of stretching techniques. The differences between treatment interventions may be more likely to occur when examining symptomatic patients as participants. It is possible that symptomatic patients may respond to MET more than asymptomatic subjects, because minor tissue damage may have produced tissue contracture and stretch tolerance may be also altered in these subjects, which could be more receptive to change following treatment. It is therefore important for further studies to test and compare both symptomatic and asymptomatic patients. Symptomatic patients could include those with a history of hamstring tightness. Inclusion criteria of participants may involve those with decreased AKE measurements, or a history of hamstring hypertonicity. A study with a greater number of participants would have more power to yield significant results.

It has been suggested that a greater number of stretching treatments over a period of time may yield a significant difference between techniques. Gribble et al (1999) compared hold-relax techniques to static stretches four times a week over a six-week period. This study demonstrated the effects of treatment on flexibility after one treatment in comparison to successive stretching. The study concluded static and hold-relax stretching were both equally effective in improving hamstring ROM. It was also determined that participants continued to improve in flexibility each week, but reached a flexibility plateau between weeks 4 and 5. Therefore a significant difference between techniques may be obtained by using several treatments over a 4 week period, as would occur in the clinic setting. Further studies may also consider the addition of other techniques together with the Chaitow MET stretch, which would be consistent with osteopathic management in private practice.

After completing this minor thesis project, I believe that it is important for researchers to reflect on any flawed methodology, and to also understand why this occurred and how to avoid similar mistakes in the future. For a new researcher, the process of research, regardless of the outcome, involves learning to apply a solution to a given problem and reflect on the process, and this is especially true when an aspect of the process is found to be flawed.

CONCLUSION

During the current study there were several flaws in the method used to measure hamstring extensibility. These results suggested that a single application of MET (Chaitow technique) was no more effective at increasing hamstring muscle extensibility, but these findings are not valid given the problems with data collection. It is recommended that future studies use methods that have been previously determined to be reliable and valid, and that researchers further investigate the most efficacious method for increasing hamstring extensibility.

REFERENCES

Ballantyne F, Fryer G, McLaughlin P 2003 The effect of muscle energy technique on hamstring extensibility: the mechanism of altered flexibility Journal of Osteopathic Medicine 6 (2):59-63

Bandy WD, Irion JM, Briggler M. 1998 The Effect of Static Stretch and Dynamic Range of Motion Training on the Flexibility of the Hamstring Muscles Journal of Orthopedic Sports Physical Therapy 27 (4): 295-300

Cameron DM, Bohannon RW 1993 Relationship between active knee extension and active straight leg raise test measurements The Journal of orthopaedic and sports physical therapy17 (5):257-260

Chaitow L. 1996 Muscle Energy Techniques Churchill Livingstone Edinburgh.

Coakes SJ, Steed LG 2000 SPSS – Analysis without Anguish - Version 10.0 for Windows John Wiley & Sons Australia Ltd Queensland.

Feland BJ, Myrer JW, Merrill RM 2001 Acute changes in hamstring flexibility: PNF versus static stretch in senior athletes Physical Therapy in Sport 2 (4): 186-193

Ferber R, Gravelle DC, Osternig LR. 2002a Effect of proprioceptive neuromuscular facilitation stretch techniques on trained and untrained older adults Journal of Aging and Physical Activity 10:132-142

Ferber R, Osternig LR, Gravelle DC 2002b Effect of PNF stretch techniques on knee flexor muscle EMG activity in older adults Journal of Electromyography and Kinesiology 12:391-397

Funk DC, Swank AM, Mikla BM, et al 2003 Impact of prior exercise on hamstring flexibility: a comparison of proprioceptive neuromuscular facilitation and static stretching. Journal of Strength & Conditioning Research 17(3):489-492

Greenman PE. 1996 Principles of Manual Medicine - 2nd Edition. Williams and Wilkins Maryland

Gribble PA, Guskiewicz KM, Prentice WE, Shields EW 1999 Effects of Static and Hold-Relax Stretching on Hamstring Range of Motion Using the FlexAbility LE1000 Journal of Sport Rehabilitation 8:195-208

Handel M, Horstmann T, Dickhuth HH, et al 1997 Effects of contract-relax stretching training on muscle performance in athletes. European Journal Applied Physiology 76(5):400-408

Magnusson SP, Simonsen EB, Aagaard P, Sorensen H, Kjaer M 1996a A mechanism for altered flexibility in human skeletal muscle Journal of Physiology 497 (1): 291-298

Magnusson SP, Simonsen EB, Dyhre-Poulsen P, Aagaard P, Mohr T, Kjaer M 1996b Viscoelastic stress relaxation during static stretch in human skeletal muscle in the absence of EMG activity Scandinavian Journal of Medicine and Science in Sports 6:323-328

Magnusson SP, Simonsen EB, Aagaard P, Dyhre-Poulsen P, McHugh MP, Kjaer M 1996c Mechanical and Physiological Responses to Stretching With and Without Preisometric Contraction in Human Skeletal Muscle Archives of Physical Medicine and Rehabilitation 77:373-378

Osternig LR, Robertson RN, Troxel RK, Hansen P 1990 Differential responses to proprioceptive neuromuscular facilitation (PNF) stretch techniques Medicine & Science in Sports and Exercise 22 (1):106-111

Sady SP, Wortman M, Blanke D 1982 Flexibility Training: Ballistic, Static or Proprioceptive Neuromuscular Facilitation? Archives of Physical Medicine & Rehabilitation 63 (6):261-263

Spernoga SG, Uhl TL, Arnold BL, Gansneder BM 2001 Duration of maintained hamstring flexibility after a one-time, modified hold-relax stretching protocol Journal of Athletic Training 36 (1):44-48

Wallin D, Ekblom B, Grahn R, Nordenborg T 1985 Improvement of muscle flexibility. A comparison between two techniques The American Journal of Sports Medicine 13 (4):263-268