"EFFECTS OF DYNAMIC AND STATIC STRETCHING PROTOCOLS WITHIN ACTIVITY SPECIFIC AND GENERAL WARM UPS"

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"Effects of dynamic and static stretching protocols within activity specific and general warm ups"

by

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I dedicate this thesis to my family, Andrea Lewis and our son Todd. I would not have been able to accomplish this goal would their patience, support, and love.

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List of Acronyms

GDS – General warm-up with dynamic stretching.

GSDS – General + specific warm-up with dynamic stretching.

GSS –General warm-up with static stretch.

GSSS – General + specific warm-up with static stretch.

MT - Movement Time.

CM – Countermovement Jump.

SRF – Sir and reach flexibility.

PAP – Post activation potentiation.

PNF – Proprioceptive Neuromuscular Facilitation.

ROM – Range of Motion.

MVC – Maximal Voluntary Contraction.

RFD – Rate of Force Development.

Review of Literature

Abstract

The stretching and warm-up literature has examined to varying extent the effect of static, dynamic and proprioceptive neuromuscular facilitation (PNF) stretching routines, along with general and sport specific warm-ups on subsequent performance. Common methods of measurement in the current stretch literature include measures of electromyography (EMG) and mechanomyography (MMG) (Herda et al. 2008), peak torque (Nelson et al. 2000, Yamaguchi et al. 2007), jump height (Bradley et al. 2007, Holt et al, 2008, Unick et al. 2005), agility (McMillian et al. 2006) and sprint performance (Chaouachi et al. 2010, Fletcher et al. 2007). Stretching protocols of various time frames range from 2-3 sets of 15-30 seconds to routines lasting up to 20 minutes (Behm et al. 2001). Many of the studies have used an athletic population. Often the studies incorporate a 5 minute general warm-up routines of running or stationary bike rather than sport specific activities.

The findings in the literature mostly point to a decrease in performance on power, strength and speed measures following bouts of static stretching. Static stretching was previously a mainstay in pre-training and competition warm-ups at all levels of sport. Similar findings have also been noted in studies which included PNF routines (Streepey and Jefferson. 2010, Young et al. 2001). However, performance indices generally increased or experienced no change following dynamic stretch protocols (Chaouachi et al. 2010, Sim et al. 2009, Yamaguchi et al. 2005). The trend within current literature demonstrates that static stretching routines, previously used as a common component of the pre-training and pre-competition warm up, may be counterproductive to performance.

Introduction

Research regarding the effects of pre training warm-ups on subsequent performance in the recent literature has led many athletes, coaches, and trainers to change their approach to warming up prior to training and competition. This review will discuss both the composition of a warm up including, aerobic activity, static, dynamic, and PNF stretching, and activity specific tasks. A better understanding of the various components of warm up and stretching routines and the mechanisms by which they affect performance may lead to better design of such routines, resulting in greater performance and reduced risk of injury.

It has been the belief for many years, that prior to activity one should warm-up initially via jogging or riding a stationary bike followed by repeated bouts of static stretches. Past issues of popular fitness magazines, physical education text books, and coaching manuals all promoted pre-exercise static stretching as the cornerstone to the warm-up for injury prevention and enhancing performance (Ingraham, 2003.). Desmedt (1983) Stated, "It appears today that static stretching is a better approach, as compared to repetitive dynamic lengthening, because it avoids the reflex activity of the stretched muscles". Moore and Hutton, (1980) stated "It is well known today that muscle stretching performed by slow mobilization of the joint (often called static stretching) is more effective than stretching the muscle by rapid and repetitive movements". Such recommendations were often made although "no scientifically based prescription for flexibility training and no conclusive statements can be made about the relationship of flexibility to athletic injury" (Gleim et al. 1997). The results from more recent studies however, illustrate the many associated performance decrements of static stretching (Costa et al. 2009, Kokkonen et al. 1998, Fowles et al. 2000, Young and Behm. 2002, Power et al. 2004, Young and Elliot. 2001, Cornwall et al. 2002, Behm et al. 2004, Behm et al. 2001, Guissard et al. 2001, Samuel et al. 2008, William and Stauber. 2004, Cramer et al. 2004, Nelson et al. 2000). Such evidence of stretch induced decrement to both the mechanical and neural properties of the muscle following static stretch has lead to a paradigm shift on optimal stretching types.

Recent research however is pointing to possible performance decrements associated with the use of static stretching immediately before competition and training (Behm et al. 2001, Di Cagno et al. 2010, Holt et al, 2008, Kokkonen et al. 1998, Power et al. 2004, Sayers, et al. 2008, Sim et al. 2009) and also examining possible performance enhancement (Curry et al, 2009, Little et al. 2006, Yamaguchi et al. 2007) as well as injury reduction via dynamic stretching protocols. A review by Behm and Chaouachi, (2011) reveals some conflicting results among studies; more recent studies on static stretching have reported no impairment in performance associated with static stretch. These results may be associated with reduced stretch time, less intense stretch position, and the use of elite and trained middle aged athletes as subjects (Behm and Chaouachi, 2011, Handrakis et al, 2010). Despite the conflicting findings there are still far more publications demonstrating performance impairment associated with static stretch than those that show no change or performance enhancement. Further research is warranted to determine optimal pre competition warm-up and stretching protocols. Such research will allow for a better understanding of the mechanical and physiological mechanisms responsible for increased range of motion and maintenance of maximal strength.

Systemic Warm-up Component

Components generally included in a warm-up would include; a passive warm up and / or an active aerobic component of 5-10 minutes (Emiliano et al. 2008) of slow jogging or riding on a stationary bike, which both function to increase core and peripheral muscle temperature (Behm et al. 2001, Young et al. 2001), heart rate, blood flow, and to decrease joint fluid viscosity (Holcombe. 1998). A recent meta-analysis (Fradkin et al. 2010) found improved performance following a warm-up in 79% of the examined studies. Studies using aerobic based warm ups have been shown to allow muscles to stretch more before tensile failure and produce increased force (Crosier, 2004) and improve neuromuscular function (Young et al. 2001). It has also been suggested that, where active muscle stiffness rather than passive muscle stiffness is more related to injury, increased muscle temperature via sub-maximal exercise would be more effective than stretching for decreasing the incidence of soft tissue injury (Young and Behm, 2002). Further, it is proposed that passively warming the muscle by external means could be used experimentally to determine if many of the performance changes seen following a warm-up are primarily temperature dependent. Although this type of warm-up may not be practical for most athletes it would result in the conservation of energy substrate (Bishop, 2003).

Passive Warm-ups

Studies using superficial, deep heat and active means of warming have been examined produced interesting results; Knight et al. (2001) observed ankle dorsiflexion following 5 stretching protocols, including; no stretch control, stretch only, superficial warming + stretch, ultrasound + stretch, active warming + stretch. The results in this study concluded an increase in both active and passive range of motion for all experimental groups with the ultrasound + stretch group yielding the greatest ROM increases. Emiliano et al. (2008) found that passive warm up did not show any increase in performance despite the same increase in skin temperature as the active warm-up condition. The author suggests that lack of metabolic activity in the passive group would account for this.

Many authors recognize massage as an effective component of an athlete's warm-up which aids to increase joint range of motion, decrease muscle stiffness, increase blood flow, and help to prevent and recover from muscle injuries. (Boone et al. 1991, Cafarelli and Flint. 1993, Drust et al. 2003, Tiidus and Shoemaker. 1995, Wiktorsson-Möller et al. 1983). McKecknie et al. (2008) studied the acute effects of two massage techniques on ankle joint flexibility and power of the plantar flexors. The results showed a significant increase in ankle joint angle similar to those found after bouts of static stretching with no significant increase in plantar flexion power. This suggests that a massage may increase flexibility without altering power output, a finding not noted in many recent stretch studies. (Behm and Kibele. 2007, Behm et al. 2001, 2004, 2006, Power et al. 2004, Young and Behm. 2002).

Static Stretching

Following a active warm-up, the next step until recently in the overall warm-up plan would be a routine of static stretching. Stretching within a warm-up is to induce a short term increase in the range of motion – (ROM) of a joint and to decrease the stiffness of the muscle-tendon unit (Behm et al. 2004, Young et al. 2001). Performing static stretchingas part of the warm up was believed to promote better performance and reduce risk of injury (Nelson et al. 2001). Static stretching is a slow constant stretch with the end position held for an average of 30 seconds (Bandy et al. 1994, Bandy et al. 1997), Thirty seconds is also the recommendation of the NSCA (Unick et al, 2005), with the intent to relax and elongate the stretched muscle . The American College of Sport Medicine (ACSM) recommends holding a stretch for 10-30 seconds for 3-4 repetitions. Recent studies, however, have shown static stretch induced decrements in performance (Kistler et al. 2010, Winchester et al. 2008) including factors such as power (Young et al. 2001), strength (Bacurau et al. 2009, Behm et al. 2004, Behm et al. 2001) stability, proprioception, reaction time, and movement time. (Cramer et al. 2004, Croisier. 2004, Fowles et al. 2000, Guisard et al. 1988, Kokkonen et al. 1998, Nelson et al. 2001, Power et al. 2004, Willems et al. 2001, Wilson et al. 1994). Fowles et al. (2000) showed reduced strength in plantar flexors following a routine of passive stretching which resulted in a total of 30 minutes time under stretch, although the prolonged stretching in this study was said by the author to likely have little application in sport stretching.

A review by Young and Behm, (2002) however, suggested that in more realistic warm-ups as seen in training and competition settings static stretching for as little as 2 minutes per muscle group can result in power decrements. Findings by Power et al, (2004) support this suggestion as their finding of significant decreases in MVC (lasting 120min) following 2 bouts of 45 second static stretching of the quadriceps suggesting that such stretching should be avoided for up to 120 minutes prior to activities requiring maximal force output. Young and Simon. (2001) produced a significant decrease in drop jump performance following 3 repeated bouts of 15 second static stretch, which is typical with what is generally seen in a general athletic warm-up routine. Kokkonen et al. (1998) used 5 static stretches to stretch all major muscles involved in knee flexion and extension following 3 sets of 15 seconds with an equal rest time and found that both 1RM knee flexion and extension were decreased following this acute bout of stretching.

It has been suggested that decrements to peak force and torque may be velocity specific, Nelson et al. (2001) showed decreases in peak torque at 60°/sand 90°/s, but showed no such decreases at150°/s, 210°/s, or 270°/s following acute static stretching. However, Cramer et al (2004) conducted a similar study which resulted in decrements in peak torque at low 60°/s and high 240°/s velocity.

Mechanisms

Much of the recent research support two plausible mechanisms for the demonstrated stretch reduced decreases in force (Avela et al. 1999, Behm et al. 2001, Fowles et al. 2000, Kokkonen et al. 1998, Nelson et al. 2001, Nelson et al. 1996, Nelson, Guillory, and Cornwall. 2001, Nelson and Kokkonen. 2001, Young and Elliot, 2001). It has been proposed that increased muscle compliance affects the muscle length tension relationship thus increasing the time for force to act on the bone. Such a change in length tension relationship may be related to an increase in joint angle at peak torque (Cramer et al. 2004). Fowles et al. 2000 and Nelson et al. 2001, both noted increased joint angle at maximal isometric torque following static stretch. No such change in joint angle at peak torque was reported during a maximal concentric isokinetic leg extension varying from 60° to 270 (Nelson et al. 2001).

The effects of static stretching on other related performance factors have been investigated. These factors may include altered reflex sensitivity and muscle activation. Behm et al. (2004) proposed that acute effects of static stretch on muscle – tendon unit length, stiffness, force output, and muscle activation may be related to a decreased afferent and efferent detection and response to stimuli. Such impairment may translate to decreased balance, stability, proprioception, reaction time, and movement time (Behm et al. 2004). This study showed reverse trends for balance, reaction time, and movement time between the control and stretch group. The stretch group repeated three 45 second bouts of stretching on the quadriceps, hamstrings, and plantar flexors in random order with 15 seconds recovery between bouts. The control group showed significantly faster reaction time and movement time. The authors attribute this finding to the possible increase in nerve conduction velocity related to the increase in temperature or the effect of post activation potentiation, while the stretch group showed non-significant decrements in performance. Although statistically non - significant, it should be noted that both groups underwent the same protocol except for the stretching. The stretching routine removed any warm-up related improvements and slightly decreased posttest performance. This finding is of importance across a range of populations, ranging from the elite athletes whose performance is often measured to very finite levels at which even small decrements can have large impacts on results. Also, the development of rehabilitation programs for those of all ages especially the elderly whose risk of serious injury could be greatly increased with small reductions in balance and proprioception.

Other studies examined the role of stretching in injury prevention (Croisier. 2004, Reiwald. 2004, Young and Behm. 2002), the general research question was, "Does an increase range of motion (ROM) via static stretch decrease risk of muscle tear?" Much of the recent evidence suggests that there is no decrease in all- injury risk. (Knudson et al. 1999, Pope et al 2000, Shrier et al. 1999). However, Gleim and McHugh. (1997) and Small et al. (2007) report significant reduction in musculotendonious injury despite non-significant reduction in all injury risk. Pope et al. (2000) found no significant decrease in the risk of injury through the use of static stretch without a warm-up preceding high intensity training of army recruits. It is suggested that warm-up does offer injury prevention mechanisms, through reduction of active rather than passive muscle stiffness or increased ROM and through increased muscle temperature which has been shown to decrease the risk of a muscle tear via reduction in active muscle stiffness (Behm and Young, 2002).

It must also be considered that not only mechanical muscle properties are affected by static stretching, but that enhanced flexibility following stretching may be due to neural adaptations (McHugh et al. 1992). Reduction of Hoffman (H) – reflex amplitude during stretch suggests that such neural adaptations to stretch contribute to muscle compliance via reduced excitability of the afferent input to the motoneurone pool (Guissard et al 1988, 2001). Similarly, Thigpen et al.(1985) reported depressed H reflex following a sustained stretch of the tricep surae. The findings suggest that the stretching may induce autogenic inhibition and compromise force production. However, Guissard et al. (1988) findings suggest that autogenic inhibition would be limited to the time which the stretch is held. Since dynamic stretching tends to excite the motoneuron, dynamic stretching may be more appropriate for a warm-up.

Dynamic Stretching

Along with observed performance decrements in studies examining the effects of static stretching there has been concurrent observations of the associated effects of dynamic stretch routines. Subsequent performance improvements observed following warm-up activities involving dynamic stretch modalities are often coupled with prior sub-maximal sport specific activities (Behm. 2004, Chaouachi et al. 2010, Fletcher and Jones. 2004). Static stretch decreases and dynamic stretch increases in performance were demonstrated by Fletcher and Jones, (2004). They reported significantly faster 20m sprint time when subjects (trained rugby players) utilized an active dynamic stretching routine whereas both active and passive static stretch routines resulted in significantly slower sprint times. In a more recent study Fletcher and Jones, (2007) examined the effects of three different stretch protocols which included; active dynamic stretch (ADS), static dynamic stretch combined with active dynamic (DADS), and static passive combined with active dynamic (SADS). The results concluded that when static stretch was removed from the warm-up protocols, fifty meter sprint time was significantly decreased in both men and women. Mean decreases of 0.16 and 0.11 seconds for men and 0.1 and .09 seconds for women were observed following the ADS and SADS protocols respectively. Little and

Williams, (2006) compared similar stretching protocols on performance of 10 meter static start and 20 meter flying start sprints in professional soccer players. Observations in this study included significantly faster 10m times for dynamic stretch (1.83 ± .08) compared to no- stretch (1.87 ± .09), while both dynamic (2.37 ± 0.13) and static stretch (2.37 ± 0.12) yielded significantly faster 20m sprint times than no stretch (2.41 ± 0.13). A significant difference was observed between static (5.22 ± 0.18) and dynamic (5.14 ± 0.17) stretching during a zig-zag agility test, and no significant difference was noted on vertical jump performance between conditions. The author suggests that dynamic stretching is the optimal choice when preparing for subsequent high speed performance.

Most studies have concentrated on lower limb ROM when comparing static and dynamic stretching protocols and reported decrements in performance following static stretch only. Torres et al. (2008) however examined the effects of 4 stretching protocols on upper body muscular performance. The protocols included, no stretch, static, dynamic and static plus dynamic stretch. Subjects were tested on 30% of maximum bench press throw, isometric bench press, over head medicine ball throw and lateral medicine ball throw to test power, force, acceleration / velocity and displacement respectively. The only significant difference was lateral medicine ball displacement where the static + dynamic were significantly larger than static alone. Although no effect of upper body stretching was observed on upper body muscular performance the authors suggested using dynamic rather than static stretch prior to activities requiring upper body strength and power due to the evidence provided in many previous similar studies involving the lower body. McMillian et al. (2006) provides a similar suggestion to reassess the use of static stretch warm-up protocols. Their study resulted in significantly superior performance on t-shuttle run, underhand medicine ball throw and a 5 step jump following dynamic as opposed to static stretch. Similar results are seen in training studies where subjects are elite level athletes. Results from Herman and Smith. (2008) support these suggestions following their study of a 4 week dynamic stretch program in NCAA division 1 wrestlers. When compared to a similar 4 week static stretch program, the athletes who performed the dynamic stretch program had several performance improvements, including increases in quadriceps peak torque (11%), broad jump (4%), underhand medicine ball throw (4%), sit-ups (11%), and push-ups (3%). Decrease in the average times on 300-yd shuttle (-2%) and the 600-m run (-2.4%), suggesting enhanced muscular strength, endurance, agility, and anaerobic capacity; these markers show improvements in both upper and lower body performance.

Aside from static and dynamic stretching, other methods of stretching are used frequently in order to elicit greater changes ROM. One such method that has become quite popular is proprioceptive neuromuscular facilitation (PNF).

Proprioceptive neuromuscular facilitation

Until recently proprioceptive Neuromuscular Facilitation (PNF) stretching has received less attention in the literature than the more common methods of stretching (Young and Elliot. 2001). Proprioceptive neuromuscular facilitation stretching utilizes isometric contractions of agonist and sometimes antagonist muscles to theoretically cause reflexive relaxations in the target muscle, allowing a greater stretch response (Sharman et al. 2006). The two most common methods being contract relax (CR), which involves an isometric contraction of the agonist muscle following a passive static stretch and contract relax agonist contract (CRAC) which is similar to the CR technique however utilizes a second isometric contraction, of the antagonist muscle. When studied by Young and Elliot (2001) no significant differences regarding concentric muscle contraction performance or stretch shortening cycle were reported when compared to static stretching. It is suggested that PNF stretching may decrease musculotendonous stiffness in similar ways as static stretching and as such have negative effects on explosive force. PNF stretching did yield non-statistically significant decreases in performance (Moore and Hutton, 1980). Moore and Hutton. (1980) believe that the contraction phase of the PNF stretch could act to counter the effects of the reduced stiffness due to the stretch. Young and Elliot. (2001) suggest this may be the reason their non-significant findings. A more recent study (Bradley et al. 2007) demonstrated a significant decrease in jump performance following 10 minutes bouts of either static or PNF stretching, however decrements in performance subsided following 15 minutes of recovery. These findings support recommendations to avoid static and PNF stretching immediately prior to explosive athletic performance. There is evidence however to suggest that the use of PNF style stretching may promote long term performance enhancement. Handel et al. (1997) demonstrated up 21.6% increase in peak torque under eccentric load conditions following an 8 week unilateral contract relax stretching program. The author suggests that torque increase is likely due to the heavy isometric loading which occurs during the contract relax protocol. It is important to note that the Handel et al. (1997) studied the long term training adaptations to stretching and not acute effects.

Sport Specific Warm-Up Activities

Sport specific warm-up activities may have further beneficial physiological effects as opposed to general warm up activities on subsequent performance. Vetter, (2007) looked at 6 different warm-up protocols and their effects on counter movement jump and sprint performance. The walk run and walk run + dynamic stretch and jumping activities yielded greater performance in countermovement jump when compared to static stretch, however when jumping activities were used with the static stretch no significant difference was observed when compared to the dynamic stretch + jumping activities protocol. It is suggested that the activity specific task of jumping may negate the expected decrement of the static stretch routine and post activation potentiation may have a positive effect on performance. Meanwhile, Needman et al, (2009) observed that when 8 front squats were added to a dynamic stretch protocol that there was a significant increase in countermovement jump performance. Batista et al. (2007) investigated the presence of PAP following intermittent exercise, where 10 near maximal isometric knee extensions were used and PAP was seen up to 12 minutes follow the knee extension condition. The author suggests more "real world" approaches to verify applications to a warm-up routine. Such activity specific tasks within a warm-up could have a potentiating affect. This observed effect on performance when adding activity specific tasks to either type of stretching protocol may allow for warm-up protocols with further performance benefits. To assess the benefits of such protocols it is important to understand post activation potentiation.

Post Activation Potentiation (PAP)

Post activation potentiation (PAP) is the phenomenon in which there is an increased contractile capability of the muscle following maximal and near maximal forces (Esformes et al. 2010, Scott and Docherty. 2004, Hamada et al. 1999). PAP has been attributed to phosphorylation of myosin regulatory light chains, causing actin and myosin to become more sensitive to Ca+. Increases in alpha motor neuron excitability reflected in changes in the H-reflex have also been considered as a contributor to the potentiated state. (Hodgson et al, 2005). Such studies, have led to the premise of complex training which involves the use of explosive movements preceded by heavy resistance exercise (HRE) (Robbins. 2005, Hodgson et al. 2005) when movements have generally been of similar biomechanical characteristics. The consideration that contractile activity produces both fatigue and PAP (Esfomes et al. 2010, Hamada et al. 2003, Robbins. 2005) would mean that we need to consider the rate of dissipation of both fatigue and PAP in order to determine a timeline of optimal net potentiation. Knowledge of such a timeline would allow for the design of programs (complex training) which would allow the manipulation of PAP and fatigue in order to produce a greater increase in performance. Optimal performance occurs when fatigue has dissipated and potentiation still exists. (Hodgson et al. 2005). In the case of trained athletes knowledge of a net potentiation timeline could be of great benefit to their training. Hamada et al, (1999) noted that the enhanced fatigue resistance of the muscles of endurance trained athletes may allow for the effects of potentiation to be greater than the effects of fatigue due to increased fatigue resistance, thus yielding a greater net potentiation.

The existence of PAP has been shown in twitch stimulation studies, in-vivo studies, in-vitro skinned mammalian muscle tissue studies and in athletic performance studies (Robbins. 2005, Metzger et al. 1989). Metzger et al. (1989) examined skinned mammalian muscle tissue in which twitch potentiation was observed and concluded it was result of myosin light chain (MLC) phosphorylation. Observation by Houston et al. (1985) suggests that MLC kinase activity is mainly associated with fast twitch muscle fibers. This was suggested, as the time to twitch potentiation followed a similar timeline to that of phosphate incorporation into the light chain of fast myosin. Conversely there was no observation of phosphate into slow myosin light chains. A study of mouse fast twitch muscle fiber by Grange et al. (1995) showed a potentiation of both maximum isometric twitch force and rate of force development following two studies using both isometric and muscle shortening techniques. This is consistent with reports from Sweeny and Stull (1993) of an increase in the rate constant of the transition of cross bridges from non force producing to force producing states following regulatory light chain (RLC) phosphorylation (Grange et al. 1995). Findings by Vanderboom and Houston (1996) suggest that such effects may only be present while RLC is phosphorylated above resting values for fatigued muscles.

Phosphorylation of the myosin regulatory light chain is a mechanism of potentiation which causes an increased sensitivity of actin – myosin to Ca2+ that is released from the sacroplasmic reticulum (Sweeney et al. 1993, Hamada et al. 1999, Sale. 2003). When MLC kinase phosphorylates the myosin head, this phosphate binding leads to a structural change in the myosin molecule which subsequently decreases the time to form a myosin cross bridge. Voluntary and evoked stimuli show varying effects, with low frequency tetanic contraction resulting in increased force and rate of force development (RFD) while high frequency tetanic stimulation have only been shown to increase RFD and have no effect on force. Voluntary contractions' effect on potentiation is related to the intensity and duration of contraction. Potentiation is greatest following contraction of approximately 10 seconds while longer duration show suppression of potentiated state via fatigue. It is also noted that voluntary contraction of less than 75% maximum voluntary contraction (MVC) resulted in little to no potentiation. Therefore, contraction near or at MVC lasting close to 10 seconds would cause the greatest potentiation. Such results were found to be greater in fast type 2 fibers (Hodgson et al. 2005). Chaouachi et al. (2011) examined the literature and found that a large variety of maximal and submaximal exercises done with traditional weights where 70% or more of the 1 repetition maximum was used. The study reported a >75% likelihood of increasing peak power, force, and velocity when 5 x 70% of 1 repetition maximum and 3 x 85% of 1 repetition maximum were used. This finding supports the use of heavy resistance exercise protocols to elicit potentiation and performance enhancement in training sessions. Turki et al. (2011) however observed that 10 minutes of dynamic stretching without the use of sub-maximal or maximal resistance exercises was sufficient to potentiate vertical jump performance. This result would suggest that near maximal resistance is not the only factor of contractile history affecting potentiation.

In studies involving heavy resistance training exercise, results show that trained athletes are likely to benefit from PAP significantly more than recreationally trained individuals (Chiu et al. 2003). Findings that athletically trained would benefit more than recreationally trained athlete were observed by Chiu et al. (2003) who performed rebound and concentric only squat jump of 30%, 50%, and 70 % MVC, 5 and 18.5 minutes post heavy load warm-up of 5 sets of 1 rep at 90 % of 1 rep maximum. Conversely, Scott and Docherty. (2004) found no significant effect on vertical or horizontal jump following a 5RM back squat. Fewer researchers have examined the effects of prior plyometric type exercise on heavy resistance exercise performance. One such study of (Masamoto et al, 2003) pointed to enhanced 1RM squat ability 30 seconds following performance of 2 depth jumps. It was noted in this study that subjects were experienced strength trained athletes and all had prior experience with plyometrics. Also Chiu et al, (2003) who performed heavy resistance exercise prior to explosive squats jumps found that only athletically trained individuals experienced a significant increase in performance.

Reaction time is also affected by contractile history. Etnyre et al (2001) found that a 3 second isometric contraction of the knee extensors yielded an increase in reaction time (RT), pre-motor time (PmT), and motor time (MT) to a pre contraction auditory stimulus, concluding that RT, PmT, and MT could be significantly reduced when preceded by an isometric contraction.

When examining practical applications of PAP, twitch potentiation increases in rate of force production and theoretically should increase peak power and velocity during dynamic muscle action (Hodgson et al, 2005). Further research however may indicate what combination of intensity and duration at prior activities will result in an optimal PAP: fatigue ratio. (Sale, 2002). Some studies suggest that longer recovery periods (3 minutes) are most likely to yield such an optimal ratio (Gilbert et al. 2001, Guilich et al. 1995, Young et al. 1998) Sale (2002) suggested that other effects of contractile history need to be considered in future studies such as increased muscle temperature which would increase rate of force production thus increasing power performance synergistically with PAP. However while an increase in muscle temperature would shorten twitch duration positively affecting contraction velocity, it could have detrimental effects on endurance performance.

The benefits of PAP seem to be most profound when the mechanism (activity) used to elicit potentiation is biomechanically similar (task specific) to testing protocol. (Chui et al. 2003, Masamoto et al. 2003, Robbins. 2005, Sale. 2003). Masamoto et al. (2003) demonstrated a significant (3.5%) increase in 1RM squat performance following 2 drop jumps 30 seconds prior to the 1RM attempt. Subjects in this study had strength training with plyometric training experience. The plyometric exercise within the study was kept at a low volume to prevent fatigue. A study which used an opposite approach where heavy squats where performed prior to plyometric exercise yielded similar performance increases. Young et al (1998) showed a 2.8% improvement in countermovement jump following one set of squats at 5RM. Further studies have also investigated the use of resistance via weighted vests to stimulate greater post activation potentiation (PAP) in subjects during dynamic stretch and sport specific warm-up protocols (Faigenbaum et al. 2006, Thompson et al. 2006). In the Faigenbaum study, subjects performed static stretch, dynamic stretch and weighted dynamic stretch protocols at 2% and 6% body mass added weight. There were significant increases in performance for the dynamic stretch and dynamic weighted 2% body mass group over the static stretch group. The author believes the 6% body mass weight may have been too fatiguing for the young high school aged subjects due to lack of mature muscular development. It was suggested that this fatigue effect could be limited if extended recovery periods were given. Similar studies using weighted vests within their experimental design with older more muscularly mature subjects have yielded improved performance results using resistance up to 10% body mass. (Burkett et al. 2005, Thompson et al. 2006)

Little information is available in the literature though that examines the performance effects of low to no resistance activity specific tasks. Perez et al. (2007) showed a significant increase in the ability of subjects to perform stable co contractions of the plantar and dorsiflexors following 30 min of co contraction task training. This amount of time may not be practical in a typical warm-up however.

Another measurement tool used to study the effects of contractile history on neuromuscular response is the Hoffman reflex (H-reflex) (Hoffman. 1910). Studies involving sub maximal concentric-eccentric (Trimble and Harp 1998), and maximal isometric contractions (Gullich and Schmidtbleicher. 1996) have shown immediate H reflex depression generally lasting from 10-60 (Enoka et al. 1980, Crone et al 1989) seconds. Following this depression there is a period of H- reflex potentiation lasting from 4-11 minutes (Gullich and Schmidtbleicher. 1996). Trimble and Harp, (1998) reported an h-reflex potentiation in subjects who were speed-strength trained and found no such potentiation effect in untrained subjects. Studies of static stretching where H-reflex is used as a measure have shown decreases in motor neuron excitability (Condon and Hutton. 1987, Guisard et al. 1988). It is unclear if this decrease remains once the stretch has been ceased. There are studies that show a decrease in H-reflex directly following stretch (Avela et al. 1999, Thigpen et al. 1985). While others that do not (Guisard et al. 1988, Vujnovich and Dawson. 1994). Among those studies that did provide evidence of H-reflex depression following a stretch condition, neither Avela et al.(1999) nor Thigpen et al. (1985) demonstrated that this effect would be sufficiently prolonged. Avela et al. (1999) showed a near complete recovery in H-reflex after 4 minutes while Thigpen et al. failed to report the time between stretch condition and post stretch measurements. Nelson et al. (2001) suggested that recovery times may have been less if more realistic stretching protocols were used. The Avela et al. (1999) and Thigpen et al. (1985) studies used prolonged bouts of repeated passive stretching for 1 hour on the triceps surae. Fowles and Sale. (1997), however, reported a plantar flexion torque decrement up to 60 minutes post stretch, while motor unit activation had returned to pre-stretch level following 30 minutes recovery. Nelson et al. (2001) suggests that H-reflex depression is not likely to be the dominant mechanism in the post stretch strength decrement seen in many studies.

Conclusion

With all factors considered, the paradigm shift towards pre event dynamic stretching coupled with more sport specific warm up movement patterns as opposed to the traditional general warm up and static stretch model is quickly gaining support. Much recent research demonstrates a decrease in force, power, balance, reaction time, and movement time following static stretch routines (Behm et al. 2001, 2004, 2006, Chaouachi et al. 2010, Kokkonen et al. 1998, Young and Behm 2002). Studies lend support to the aforementioned performance impairments with decrements in reflex responses and muscle activity. (Cornwell et al. 2001, Fowles et al.1999). Research on pre event warm-up and stretching is constantly examining alternative means by which to increase muscle range of motion, such as, PNF stretching

(Decicco et al. 2005), dynamic stretching (Yamaguchi et al. 2007), heat (Usuba et al. 2006), and added weight (Swank et al. 2003), while decreasing risk of injury (Hasselman et al. 1995, Reiwald, 2004) and minimizing decrements to performance (Behm et al. 2001, Di Cango et al. 2010, Holt et al. 2008,Nelson et al. 2001, Power et al. 2004).

Investigations still need to be performed to determine optimal warm up and stretching protocols for athletes. The current literature continues to use dynamic stretching protocols. Further research should be performed to provide further information toward optimizing stretching and warm-up programs. Some researcher's contest that such optimized programs will be sport dependent to reflect the variety of ROM requirements across sports (Gleim et al. 1997) and training status and age of the athlete (Behm and Chaouachi, 2011). Supporting a need for more sport specific studies utilizing subjects from a, cross section of training status, age groups, and activities.

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"Effects of dynamic and static stretching within general and activity specific warm-up protocols"

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Abstract

The purpose of the current study was to determine the effects of static and dynamic stretching protocols within general and activity specific warm-ups. Nine male and 10 female subjects were tested under four warm-up conditions including a general warm-up with static stretching, a general warm-up with dynamic stretching, a general + specific warm-up with static stretching and a general + specific warm-up with dynamic stretching. Following all conditions subjects were test for performance on Movement time, Countermovement jump, sit and reach flexibility and repeated sprints. Results indicated that when a sport specific warm-up is used, there is an increase ($p=.0013$) of 0.8% in 20 meter sprint time in both the dynamic and static stretch groups. No such difference in sprint performance between dynamic and static stretch groups existed in absence of the sport specific warm-up. The static stretch condition performed significantly ($p=0.0083$) better than the dynamic condition in the sit and reach test. Such results would support the use of static stretching within an activity specific warm-up to ensure maximal ROM along with an enhancement in sprint performance. However, when enhance ROM is not of particular value a protocol of activity specific warm up and dynamic stretching may be as good or a choice.

Introduction

Stretching is a common component of warm-up routines in physical activity, exercise, and sport. Both static and dynamic stretching are commonly used and often preceded by a warm-up intended to increase the blood flow and temperature of the target muscle to make it more compliant and at less of a risk for injury. Research regarding the effects of pre training warm-ups on subsequent performance in the recent literature has led many athletes, coaches, and trainers to change their approach to warming up prior to training and competition. This review will discuss both the composition of a warm up including, aerobic activity, static, dynamic, and PNF stretching, and activity specific tasks. A better understanding of the various components of warm up and stretching routines and the mechanisms by which they affect performance may lead to better design of such routines, resulting in greater performance and reduced risk of injury.

It has been the belief for many years, that prior to activity one should warm-up initially via jogging or riding a stationary bike followed by repeated bouts of static stretches. Past issues of popular fitness magazines, physical education text books, and coaching manuals all promoted pre-exercise static stretching as the cornerstone to the warm-up for injury prevention and enhancing performance (Ingraham, 2003.). Desmedt (1983) Stated, "It appears today that static stretching is a better approach, as compared to repetitive dynamic lengthening, because it avoids the reflex activity of the stretched muscles". Moore and Hutton, (1980) stated "It is well known today that muscle stretching performed by slow mobilization of the joint (often called static stretching) is more effective than stretching the muscle by rapid and repetitive movements". Such recommendations were often made although "no scientifically based prescription for flexibility training and no conclusive statements can be made about the relationship of flexibility to athletic injury" (Gleim et al. 1997). The results from more recent studies however, illustrate the many associated performance decrements of static stretching (Costa et al. 2009, Kokkonen et al. 1998, Fowles et al. 2000, Young and Behm. 2002, Power et al. 2004, Young and Elliot. 2001, Cornwall et al. 2002, Behm et al. 2004, Behm et al. 2001, Guissard et al. 2001, Samuel et al. 2008, William and Stauber. 2004, Cramer et al. 2004, Nelson et al. 2000). Such evidence of stretch induced decrement to both the mechanical and neural properties of the muscle following static stretch has lead to a paradigm shift on optimal stretching types.

Recent research however is pointing to possible performance decrements associated with the use of static stretching immediately before competition and training (Behm et al. 2001, Di Cagno et al. 2010, Holt et al, 2008, Kokkonen et al. 1998, Power et al. 2004, Sayers, et al. 2008, Sim et al. 2009) and also examining possible performance enhancement (Curry et al, 2009, Little et al. 2006, Yamaguchi et al. 2007) as well as injury reduction via dynamic stretching protocols. A review by Behm and Chaouachi, (2011) reveals some conflicting results among studies; more recent studies on static stretching have reported no impairment in performance associated with static stretch. These results may be associated with reduced stretch time, less intense stretch position, and the use of elite and trained middle aged athletes as subjects (Behm and Chaouachi, 2011, Handrakis et al, 2010). Despite the conflicting findings there are still far more publications demonstrating performance impairment associated with static stretch than those that show no change or performance enhancement. Further research is warranted to determine optimal pre competition warm-up and stretching protocols. Such research will allow for a better understanding of the mechanical and physiological mechanisms responsible for increased range of motion and maintenance of maximal strength.

The present study examined the effect of static and dynamic stretching protocols when used within warm-up routines involving either general warm-up activity alone and general warm-up with the addition of an activity specific warm-up. The purpose of the present experiment was to contrast the effects of static and dynamic stretching on subsequent performance following both general and activity specific warm ups to help determine possible mechanism associated with enhanced or decreased performance. The experimental protocol was designed to be similar to practical warm-up protocols which would be used in real world training conditions. This was to ensure that any findings would have practical implications.

Methods

Subjects

Nine male and 10 female university students and staff volunteered for the experiment (Table 3). All participants were trained and actively involved in recreational or competitive sports. They were verbally informed of the protocol, read and signed a consent form. Each participant also read and signed a Physical Activity Participation Questionnaire (PAR-Q: Canadian Society for Exercise Physiology) to ensure their health status was adequate for participation in the study. The study was sanctioned by the Memorial University of Newfoundland Human Investigations Committee.

Independent variables

Participants were required to complete four warm-up (WU) conditions. The order of the conditions was randomized.

1. General warm-up / Dynamic Stretch

    This condition had participants run around a 200 meter track for 5 minutes obtaining a heart rate of 70% of the individuals predicted maximal heart rate. Heart rate was monitored with a heart rate monitor (Polar A1 heart rate monitor; Woodbury NY) secured around the participants chest at the level of the ziphoid process Participants were also informed and monitored by the investigator to ensure a light sweat was achieved at the completion of the run. This represented a increase in core temperature. The dynamic stretching included 3 repetitions lasting 30 seconds each of (1) Hip extension / flexion (2) Adduction / Abduction (3) trunk circles (4) Passive ankle rotation. All stretches were performed dynamically to full ROM at a medium speed such that there was continuous motion, but without enough speed to force the stretch beyond normal ROM.

2. General Warm-up & Specific warm-up / Dynamic Stretch

   This condition followed the same protocol as condition 1, however there was an addition of a sport specific warm-up which included 3 sprint specific exercise performed in random order. These exercise included (1) high knee skipping, (2) high knee running, and (3) butt kick running. Each task was performed over a 20 metre distance and repeated twice before moving on to the next task.

3. General warm-up / Static Stretch

   This condition followed the same guideline for general warm-up as the previous 2 conditions however there were no specific task and a static stretching protocol was used. Following the general warm-up participants were put through a series of static stretches in randomized order including (1) supine partner assisted hamstring stretch, (2) Kneeling partner assisted quadriceps stretch, (3) seated partner assisted low back stretch, and (4) Standing wall supported calf stretch, rear leg in dorsiflexion. All stretches were repeated for 3 sets of 30 seconds held at the point of mild discomfort.

4. General Warm-up & Specific Warm-up / Static Stretch

   This condition followed the general warm-up outlined in all 3 previous conditions followed by the specific warm-up used in condition 2 and the static stretching from condition 4.

Dependent Variables

The order of testing began with movement time (MT) follow by countermovement jump, sit and reach flexibility and concluded with repeated sprints.

1. Movement time (MT): Movement time was measured with a contact mat and light gate apparatus. The subject was to activate the timer by touching their foot to the contact mat and then immediately flex the hip with maximal acceleration in a kicking motion through a light gate set at 0.5 meters from the mat. Data was collected using the Innervations © Kinematic Measurement System, v. 2004.2.0 on a laptop computer. This process was repeated 3 times.
2. Countermovement Jump (CMJ): Jump height was measured using a contact mat Data was collected using the Innervations © Kinematic Measurement System, v. 2004.2.0 on a laptop computer. Participants were instructed to jump as high as they could immediately following a semi squat counter movement. During the countermovement participants were allowed to swing the arms to full flexion and instructed to squat no lower than thighs parallel to the floor. During the jump phase the arms were allowed full extension over head. (Behm et al. 2004, Kean et al. 2006, Power et al. 2004)
3. Sit and Reach Flexibility (SRF): Using a sit and reach testing device (Acuflex 1, Novel products Inc., USA), participants sat with leg straight and feet flat against the sit and reach device. They exhaled and stretched forward as far as possible with one hand over the other and finger tips in line and held the end point for 2 seconds. This is the protocol prescribed by the Canadian Society for Exercise Physiology (CSEP) to determine flexibility. The same protocol was used by Behm et al. (2006), and Power et al. (2004).

4. Repeated 20m sprints: Participant ran six 20 metre repeated sprints with 30 seconds recovery between each sprint. Sprint time was measured via switch mat and light gate apparatus. Timing was from the first stride on to the mat until passing through the light gate 20 metres away. Data was collected using the Innervations © Kinematic Measurement System, v. 2004.2.0 on a laptop computer.

Statistical Analysis

A 2 way repeated measures ANOVA (4x2) with factors being 1) conditions (Dynamic stretch, Static Stretch, Dynamic stretch with specific warm-up, and Static stretch with specific warm-up) and 2) time was performed to determine if significant differences existed between the warm-up conditions. (GB Stat Dynamic Microsystems, Silver Springs Maryland USA). An alpha level of $P<0.05$ was considered statistically significant. If significant difference were detected, a Tukeys –Kramer procedure was used to identify the significant main effects and interactions. All data are reported as means and standard deviations.

Results

There were no significant main effects or interactions involving the experimental conditions for movement time and countermovement jump.

Sprint Time

There was a significant main effect for gender, condition and sprint factors. A main effect for gender ($p<0.0001$) indicated that males (3.1± 0.17) were 19.4% faster than the females (3.7s ± 0.2). (Figure 1) A main effect for condition ($p=0.0013$) indicated that the warm-ups involving a specific warm-up component resulted in a 0.8% improvement versus the warm-ups involving only a general warm-up (Figure 2). A main effect for sprint time (P=0.007) showed that the fifth sprint was 1.2% significantly slower than the second sprint. (Table1) (Figure 3)

A significant (p=0.0002) gender x sprint interaction illustrated a 1.3% increase in sprint time from the second to the fifth sprint for males (figure 4) (Table 2). A near significant (p= 0.07) gender x sprint trend with a 1.7% increase in sprint time from the first to fifth sprint in females. (Figure 5) (Table2)

Sit and Reach

There was a significant main effects for conditions (p=.0083) with all static stretch conditions providing greater mean sit and reach score than conditions involving dynamic stretch (Figure 6)

Movement Time

A trend was observed for gender. Males (0.19± 0.02) were (p = 0.002) faster than females (0.21± 0.02) (Figure 7)

Counter Movement Jump

A significant main effect was discovered for gender (p<0.0001) indicating that males (40.7± 6.8) jumped 58% higher than females (25.7± 3.9). (Figure 8)

Discussion

The most important findings of the present study are the, addition of activity specific warm-up enhanced sprint performance and that static stretching protocol resulted in a greater sit and reach score than dynamic stretching.

Whether the activity specific warm-up protocol was implemented with static or dynamic stretching there was a significant improvement in sprint time. A similar intervention was used by Rosenbaum et al. (1995) who reported a decreased time to peak force following a tendon tap of the triceps surae following static stretch and treadmill running warm-up and an increased time to peak force when measured after static stretching alone. It seems that the addition of a warm-up helps to negate the performance decrements of static stretch alone. Skof and Strojnik (2007) found that the addition of sprinting and bounding to a warm-up consisting of slow running and stretching resulted in an increase in muscle activation when compared to slow running and stretching alone. However Young and Behm, (2002) reported that the addition of static stretching to a warm-up yielded a decrease in performance results. The Young and Behm study though does indicated that many of the stretching protocols used in earlier studies utilized prolonged static stretching outside of the range of typical stretching protocols used by athletes. The present study had participants stretch the target muscle for 3 sets of 30 seconds where as Young and Behm describe protocols of 15 minutes or more of sustained stretch, often without no aerobic warm up or pre-stretch submaximal exercise. Zakas et al. (2006) observed no change in peak torque following 30 seconds of static stretching compared to significant ($p < 0.001$) decreases in peak torque after static stretching volume of 480 seconds. The activity specific warm-up in the present study may have offset the impairments thought to be caused by static stretching. Furthermore, the shortened time under stretch may have not caused any impairment. A review by Kay and Blazevich (2011) supports this statement with their conclusion that the detrimental effects of static stretching are mainly limited to stretch times of 60 seconds or greater.

The results of the present study indicate increase performance capacity following the addition of the activity specific warm up. This may be attributed to many physiological factors. The additional warm up time may have lead to a further increase in muscle temperature, nerve conduction velocity, and muscle enzymatic cycling, along with a decrease in viscosity (Bishop 2003). Also, as indicated by Behm and Chaouachi (2011) and Turki et al. (2011) post activation potentiation can be seen following lower intensity dynamic movements. This potentiation could increase cross bridge cycling via increased myosin phosphorylation of the regulatory light chains (Tillin and Bishop, 2009). There may also be neural potentiation resulting in a decrease of the fast twitch motor unit threshold, and increase in motor unit recruitment and firing frequency (Layec et al. 2009). The increased firing frequency would be related to an increase rate of force development. (Miller et al. 1981)

Significant differences were not found during for the countermovement jump (CMJ) test. This is consistent with results from similar studies (Knudson et al. 2001, Power et al. 2004, Unick et al. 2005) While Bradley et al. (2007) noted a decrease in vertical jump performance following static stretching condition and a less significant decrease in performance following ballistic stretching. Perrier et al. (2011) found that dynamic stretch yielded significantly ($p=0.004$) greater CMJ results than static stretching, although static stretching was not significantly different from the no stretch protocol. The warm-up protocols in the present study had no effect on CMJ performance, however it should be noted that a no stretch group was not used in the present study. This lack of change in CMJ height may be due to a change in jump strategy as the musculotendonous unit (MTU) becomes more compliant (McNeal et al. 2010). McNeal et al. who studied the effects of 60 seconds of continuous countermovement jumps concluded subject altered jumping technique in response to a fatiguing task. Power et al. (2004)

concluded that a more compliant MTU might be more beneficial when higher forces are involved. The Power et al study did not report any countermovement jump impairment following static stretching but did report an increase in contact time. Conversely, Holt and Lambourne, (2008) observed a decrease in vertical jump performance when static stretch was used following a general warm-up. Similarly Needham et al. (2009) observed superior sprint and jump performance when dynamic stretching was used in warm-up protocols. The Needham et al. study however used 10 minutes of static stretching where as the current study used 3 repetitions of 30 seconds. This significant time difference may account for the difference in performance results.

When static stretching was implemented within the testing conditions, sit and reach scores exceeded scores attained by conditions using dynamic stretching. The warm-up protocol implemented in the present study had no effect on sit and reach results. These results concur with (Bandy et al. 1994, Beedle et al. 2007, Covert et al. 2010, O'Sullivan et al. 2009, Power et al. 2004). However some findings (Amiri – Khorasani et al. 2011, Mandy et al. 2006, Perrier et al. 2011, SamuKawa et al. 2011) have indicated that dynamic stretching can produce equal or greater results in dynamic and static range of motion tests. Perrier et al. (2011) compared the effects of static and dynamic stretching on factors including sit and reach flexibility and unlike the present study found no difference in sit and reach score between static and dynamic treatments. Static stretching is known to increase muscle compliance to stretch as well as decrease muscle stiffness and viscosity. Magnusson et al. (1996) indicates that increased flexibility can be primarily attributed to an increase in stretching tolerance. Neural effects may also play a role as Avela (1999) reported a decreased H-Reflex and subsequent muscle relaxation due to decrease reflex activity. Test specificity may also play a role, as the static stretching protocol more closely resembles the sit and reach test.

Gender differences in performance found in the present study are consisted with common findings in the literature. (Deschenes and Kraemer. 2002, Terzis et al. 2009) In the current study males recorded faster sprint and movement times along with higher countermovement jump heights. These results are consistent with known physiological differences in muscle mass, fat free mass and absolute strength and power between males and females. (Gursoy 2010, Zuniga et al. 2011)

Conclusion

Overall the present study has demonstrated that the use of activity specific warm-up may be useful to enhance sprint performance regardless of the stretching protocol. Further research may support the argument that such activity specific warm-ups could negate the performance decrements of static stretching previously report. Interestingly the study has also shown that static stretching will yield greater results in the static ROM Sit and reach test. Such results would support the use of static stretching within an activity specific warm-up to ensure maximal ROM along with an enhancement to sprint performance.

List of tables

Table 1: Asterisk (*) indicates a significant difference ($p=0.007$) in mean sprint time (seconds) between sprint 2 and 5.

Table 2: Asterisk (*) indicates a significant difference ($p=0.0002$) in the mean sprint time (seconds) of males between sprint 2 and 5. The number symbol (#) indicates a trend ($P=0.07$) towards an increase in sprint time between sprint 1 and 5 in females.

Table 3: Description of participants.

List of figures

Figure 1: Figure illustrates a significant ($p<0.0001$) main effect for gender. Columns and bars represent means and SD respectively. Arrows indicate a significant difference between male and female sprint times.

Figure 2: Figure illustrates a significant ($p=0.0013$) main effect for condition. Column and bars represent mean and SD respectively. Arrows indicate a significantly decreased sprint time.

Figure 3: Figure illustrates a significant ($p=0.007$) main effect for sprints. Columns and bars represent means and SD respectively. Arrows indicate significant differences between the second and fifth sprint.

Figure 4: Figure illustrates a significant ($p=0.0002$) gender x sprint interaction. Columns and bars represent means and SD respectively. Arrows indicate significant differences between the second and fifth sprint for males.

Figure 5: Figure illustrates a near significant ($p= 0.07$) gender x sprint trend. Columns and bars represent means and SD respectively. Arrows indicate trend of increasing sprint time between the first and fifth sprint in females

Figure 6: Figure illustrates a significant ($P=0.0083$) main interaction for condition. Columns and bars represent means and SD respectively. Arrows indicate the significantly greater sit and reach score.

Figure 7: Figure illustrates significant ($p=0.002$) main interaction for gender. Columns and bars represent means and SD respectively. Arrows indicate a significant difference in movement time.

Figure 8: Figure illustrates significant ($p<0.0001$) main interaction for gender. Columns and bars represent means and SD respectively. Arrows indicate a significant difference in countermovement jump height.

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Appendices

Appendix 1: Tables

Table 1: Mean sprint times collapsed over gender.

Sprint	Males and Females combined averages
1	3.40 ± 0.35
2	3.39 ± 0.36 *
3	3.40 ± 0.38
4	3.42 ± 0.37
5	3.44 ± 0.38 *
6	3.41 ± 0.36

Table 2: Male and Female Mean Sprint Times

Sprint	Males	Females
1	3.11 ± 0.16	3.67 ± 0.22 #
2	3.07 ± 0.11 *	3.69 ± 0.21
3	3.09 ± 0.16	3.70 ± 0.25
4	3.10 ± 0.16	3.71 ± 0.23
5	3.12 ± 0.17 *	3.73 ± 0.25 #
6	3.11 ± 0.16	3.70 ± 0.22

Table 3: Description of participants.

Sex	Mean Age in Years	Mean Weight in kg	Mean Height in cm
Males	27.8 ± 8.4	90.6 ± 11.1	178.6 ± 5.7
Females	22.2 ± 3.3	55.8 ± 5.2	164.6 ± 7.7

Appendix 2 : Figures

Figure 1: Figure illustrates a significant (p<0.0001) main effect for gender. Columns and bars represent means and SD respectively. Arrows indicate a significant difference between male and female sprint times.

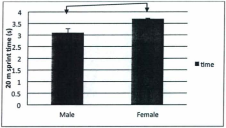


Figure 2: Figure illustrates a significant (p=0.0013) main effect for condition. Column and bars represent mean and SD respectively. Arrows indicate a significantly decreased sprint time.

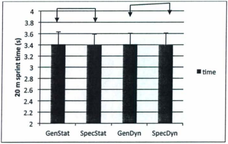


Figure 3: Figure illustrates a significant (p=0.007) main effect for sprints. Columns and bars represent means and SD respectively. Arrows indicate significant differences between the second and fifth sprint.

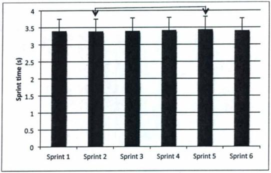


Figure 4: Figure illustrates a significant (p=0.0002) gender x sprint interaction. Columns and bars represent means and SD respectively. Arrows indicate significant differences between the second and fifth sprint for males.

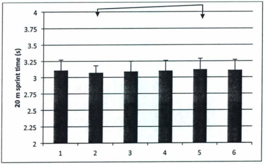


Figure 5: Figure illustrates a near significant (p= 0.07) gender x sprint trend. Columns and bars represent means and SD respectively. Arrows indicate trend of increasing sprint time between the first and fifth sprint in females.

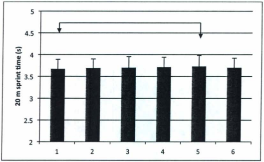


Figure 6: Figure illustrates a significant (P=0.0083) main interaction for condition. Columns and bars represent means and SD respectively. Arrows indicate the significantly greater sit and reach score.

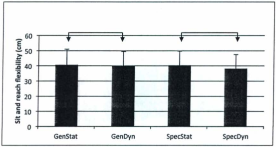


Figure 7: Figure illustrates significant (p=0.002) main interaction for gender. Columns and bars represent means and SD respectively. Star indicates a significant difference in movement time.

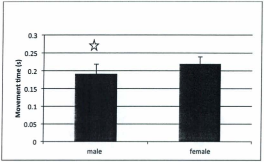
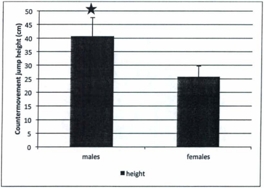


Figure 8: Figure illustrates significant (p<0.0001) main interaction for gender. Columns and bars represent means and SD respectively. Star indicates a significant difference in countermovement jump height.



Appendix 3 : Raw Data.

Key

F1, 2, 3,... – Female subject 1, 2, 3...

M1- Male Subject 2

GDS – General warm-up with dynamic stretching.

GSDS – General + specific warm-up with dynamic stretching.

GSS –General warm-up with static stretch.

GSSS – General + specific warm-up with static stretch.

MT - Movement Time.

CM – Countermovement Jump.

SRF – Sir and reach flexibility.

Female subjects scores during all trials and testing conditions.

Subject females	Sprint1	sprint2	sprint3	sprint4	sprint5	sprint6	mean sprint
F1gds	3.976	4.145	4.018	3.912	4.091	3.969	4.0185
F1gsds	4.1	4.018	4.103	4.074	4.111	4.136	4.090333333
F1gss	3.917	3.994	3.983	3.867	3.801	3.81	3.895333333
F1gsss	3.752	3.865	3.936	3.902	3.811	3.87	3.856
F2gds	3.41	3.474	3.34	3.534	3.44	3.535	3.4555
F2gsds	3.401	3.52	3.539	3.659	3.565	3.514	3.533
F2gss	3.456	3.488	3.435	3.473	3.434	3.444	3.455
F2gsss	3.456	3.614	3.642	3.536	3.528	3.524	3.55
F3gds	3.891	3.71	3.863	3.86	3.9	3.718	3.823666667
F3gsds	3.686	3.758	3.734	3.792	3.877	3.83	3.7795
F3gss	3.879	3.801	3.847	4	3.848	3.859	3.872333333
F3gsss	3.869	3.838	4.046	3.872	3.948	3.842	3.9025
F4gds	3.687	3.605	3.678	3.564	3.668	3.578	3.63
F4gsds	3.534	3.566	3.59	3.501	3.563	3.616	3.561666667
F4gss	3.699	3.698	3.657	3.731	3.787	3.714	3.714333333
F4gsss	3.701	3.623	3.699	3.673	3.719	3.728	3.6905
F5gds	3.774	3.736	3.736	3.772	3.693	3.703	3.735666667
F5gsds	3.872	3.769	3.864	3.831	3.777	3.794	3.817833333
F5gss	3.747	3.858	3.927	3.752	4.005	3.837	3.854333333
F5gsss	3.885	3.843	3.914	3.795	3.847	3.788	3.845333333

F6gds	3.744	3.636	3.732	3.698	3.788	3.731	3.7215
F6gsds	3.633	3.69	3.718	3.649	3.613	3.629	3.655333333
F6gss	3.671	3.56	3.689	3.657	3.636	3.719	3.655333333
F6gsss	3.846	3.731	3.685	3.697	3.789	3.919	3.777833333
F7gds	3.536	3.474	3.435	3.426	3.473	3.502	3.474333333
F7gsds	3.491	3.424	3.401	3.491	3.506	3.499	3.468666667
F7gss	3.473	3.529	3.53	3.605	3.559	3.6	3.549333333
F7gsss	3.41	3.456	3.54	3.578	3.601	3.558	3.523833333
F8gds	3.896	4.045	3.053	3.85	4.016	3.903	3.793833333
F8gsds	4.029	4.116	4.118	4.133	4.242	4.189	4.137833333
F8gss	3.912	3.928	4.157	4.31	4.34	4.099	4.124333333
F8gsss	3.99	3.996	3.969	4.141	4.217	3.953	4.044333333
F9gds	3.547	3.669	3.816	3.613	3.549	3.631	3.6375
F9gsds	3.572	3.661	3.587	3.535	3.617	3.598	3.595
F9gss	3.556	3.644	3.706	3.771	3.824	3.713	3.702333333
F9gsss	3.503	3.769	3.806	3.751	3.765	3.653	3.707833333
F10gds	3.42	3.369	3.318	3.293	3.294	3.29	3.330666667
F10gsds	3.381	3.376	3.311	3.208	3.268	3.221	3.294166667
F10gss	3.245	3.307	3.314	3.362	3.403	3.257	3.314666667
F10gsss	3.29	3.36	3.454	3.412	3.395	3.402	3.3855

MT1	MT2	MT3	meanMT	CM1	CM2	CM3	meanCM
0.251	0.234	0.218	0.234333	21.8	20.2	20.2	20.73333
0.215	0.213	0.217	0.215	20.7	20.7	20.2	20.53333
0.224	0.209	0.208	0.213667	21.4	22.8	20.6	21.6
0.222	0.231	0.2	0.217667	21.5	21.1	21	21.2
0.205	0.189	0.194	0.196	29	28.3	29.2	28.83333
0.192	0.183	0.196	0.190333	29.2	31.3	28.5	29.66667
0.191	0.21	0.191	0.197333	30.8	30	29.9	30.23333
0.237	0.196	0.19	0.207667	28.8	24.5	28.1	27.13333
0.209	0.185	0.218	0.204	22.1	22.5	22	22.2
0.236	0.251	0.248	0.245	27	26.6	25.1	26.23333
0.284	0.268	0.242	0.264667	18.3	20.7	26.9	21.96667
0.24	0.232	0.215	0.229	23.6	25.3	24.4	24.43333
0.262	0.26	0.223	0.248333	28.7	29.4	31.1	29.73333
0.217	0.212	0.2	0.209667	30.3	29	28.8	29.36667
0.232	0.227	0.201	0.22	28.7	28	29.5	28.73333
0.217	0.211	0.213	0.213667	30	29.8	27	28.93333
0.253	0.256	0.214	0.241	23.3	24.2	22.1	23.2
0.229	0.227	0.263	0.239667	21.8	21.9	20.6	21.43333
0.235	0.206	0.234	0.225	21.9	18.7	20.3	20.3
0.202	0.204	0.215	0.207	21.3	20.2	22.5	21.33333
0.219	0.24	0.223	0.227333	25.5	22	23.2	23.56667
0.208	0.261	0.226	0.231667	26.5	24.5	23	24.66667
0.242	0.156	0.219	0.205667	23.7	23.8	23.2	23.56667

0.246	0.16	0.217	0.207667	23.7	28.5	24	25.4
0.192	0.14	0.224	0.185333	24.9	24.9	25.3	25.03333
0.191	0.194	0.195	0.193333	26.4	24.1	23.7	24.73333
0.236	0.191	0.234	0.220333	24.9	25.1	25.7	25.23333
0.261	0.293	0.198	0.250667	22.1	26.1	23.2	23.8
0.188	0.17	0.181	0.179667	26.9	24.6	25.2	25.56667
0.234	0.232	0.236	0.234	27.4	26.5	24.9	26.26667
0.247	0.185	0.256	0.229333	23.3	25.1	26.6	25
0.252	0.167	0.242	0.220333	22.5	24.3	21.6	22.8
0.234	0.249	0.248	0.243667	24.5	23.6	26.5	24.86667
0.235	0.255	0.224	0.238	24.8	27.9	26.3	26.33333
0.207	0.261	0.177	0.215	26.4	29.1	27.4	27.63333
0.211	0.216	0.19	0.205667	29	27.1	28.5	28.2
0.217	0.213	0.174	0.201333	32.5	35.2	33	33.56667
0.249	0.216	0.188	0.217667	29.1	31.3	33	31.13333
0.238	0.235	0.226	0.233	33.5	28.5	32.3	31.43333
0.23	0.213	0.226	0.223	32.8	34.3	33.8	33.63333

srF1	srF2	srF3	mean srF
37	36	38	37
33.5	36.5	37	35.66667
35	36	37	36
36.25	36.75	38	37
41	47	47	45
41.5	43	44	42.83333
43	45	46	44.66667
43.25	44.5	47	44.91667
50	50	51	50.33333
48	51	52	50.33333
51	51	51	51
50.5	51	52	51.16667
42	42.5	43	42.5
42	43	43	42.66667
41	41.5	43	41.83333
40	42	42.5	41.5
20.5	24	28	24.16667
19.5	23	28.5	23.66667
21.5	25.5	26.5	24.5
24	29	33	28.66667
44.5	45	47	45.5
42	44.5	45	43.83333
45	46	47	46
47	48.5	49	48.16667
33	37	40	36.66667
37	40	41.5	39.5

33	38	38.5	36.5
39	41	42	40.66667
58	59	60	59
53	56	56	55
58	60	61	59.66667
59	60	61	60
39	43	46	42.66667
39	42.5	46	42.5
43	45.5	48	45.5
42.5	44.5	46.5	44.5
47	48	49	48
49.5	49	49	49.16667
51	51	51	51
47	48.5	49	48.16667

Male scores during all trials and testing conditions.

Subject males	Sprint1	sprint2	sprint3	sprint4	sprint5	sprint6	mean sprint
M1gds	2.921	2.901	2.909	2.936	2.937	2.92	2.920666667
M1gsds	2.899	2.912	2.922	2.898	2.901	2.907	2.9065
M1gss	2.951	2.873	2.94	2.971	3.055	2.877	2.9445
M1gsss	2.924	2.839	2.875	2.884	2.906	2.924	2.892
M2gds	3.232	3.266	3.259	3.265	3.207	3.269	3.249666667
M2gsds	3.247	3.133	3.179	3.199	3.239	3.212	3.2015
M2gss	3.282	3.255	3.355	3.313	3.475	3.404	3.347333333
M2gsss	3.386	3.293	3.28	3.279	3.319	3.356	3.318833333
M3gds	3.308	3.18	3.16	3.29	3.14	3.24	3.219666667
M3gsds	3.31	3.26	3.14	3.26	3.24	3.29	3.25
M3gss	3.38	3.25	3.26	3.26	3.25	3.08	3.246666667
M3gsss	3.25	3.25	3.23	3.21	3.24	3.21	3.231666667
M4gds	2.878	2.868	2.864	2.867	2.777	2.881	2.855833333
M4gsds	2.821	2.796	2.782	2.799	2.801	2.808	2.801166667
M4gss	2.836	2.839	2.824	2.749	2.838	2.839	2.820833333
M4gsss	2.867	2.798	2.807	2.798	2.794	2.805	2.8115
M5gds	3.159	3.174	3.212	3.173	3.225	3.149	3.182
M5gsds	3.094	3.073	3.111	3.095	3.097	3.092	3.093666667
M5gss	3.249	3.196	3.16	3.222	3.209	3.197	3.2055
M5gsss	3.07	3.179	3.242	3.398	3.288	3.284	3.2435
M6gds	3.201	3.17	3.255	3.226	3.24	3.294	3.231
M6gsds	3.287	3.244	3.258	3.258	3.264	3.262	3.262166667
M6gss	3.276	3.238	3.246	3.233	3.392	3.235	3.27
M6gsss	3.206	3.123	3.263	3.198	3.266	3.2	3.209333333
M7gds	3.113	3.04	3.043	3.046	3.07	3.077	3.064833333
M7gsds	3.041	3.098	3.009	3.073	3.087	3.154	3.077
M7gss	3.029	3.097	3.069	3.079	3.019	3.009	3.050333333

M7gsss	3.018	3.026	3.049	3.032	3.028	2.998	3.025166667
M8gds	2.883	2.886	2.924	2.917	3.042	3.071	2.953833333
M8gsds	3.113	2.896	2.926	2.975	2.947	2.898	2.959166667
M8gss	2.938	2.927	2.896	2.917	2.936	2.92	2.922333333
M8gsss	2.922	2.999	2.992	3.054	3.079	3.064	3.018333333
M9gds	3.17	3.155	3.285	3.368	3.44	3.384	3.300333333
M9gsds	3.151	3.166	3.161	3.178	3.173	3.193	3.170333333
M9gss	3.285	3.141	3.128	3.157	3.193	3.203	3.1845
M9gsss	3.151	3.08	3.076	3.129	3.177	3.195	3.134666667

MT1	MT2	MT3	meanMT	CM1	CM2	CM3	meanCM
0.149	0.199	0.227	0.191667	46.4	49.1	51.5	49
0.247	0.219	0.221	0.229	44.1	49	51.2	48.1
0.188	0.213	0.185	0.195333	52.3	52.3	54.7	53.1
0.217	0.223	0.18	0.206667	52.8	55	54.7	54.16667
0.184	0.177	0.194	0.185	36.8	33.2	36.6	35.53333
0.212	0.191	0.18	0.194333	31.6	29.9	38.6	33.36667
0.177	0.192	0.185	0.184667	37.6	36	35.6	36.4
0.23	0.184	0.181	0.198333	32.8	32	31	31.93333
0.179	0.18	0.176	0.178333	33.3	35	35	34.43333
0.19	0.179	0.181	0.183333	34.3	34.7	35.4	34.8
0.172	0.176	0.172	0.173333	32.9	32.9	34.2	33.33333
0.178	0.169	0.185	0.177333	36.2	36.4	36.7	36.43333
0.181	0.178	0.165	0.174667	45.9	47.7	51.8	48.46667
0.154	0.143	0.155	0.150667	45	48.5	53.1	48.86667
0.213	0.179	0.175	0.189	44.7	46.7	47.9	46.43333
0.176	0.167	0.147	0.163333	47.1	52.8	55.2	51.7
0.239	0.226	0.206	0.223667	34.8	35.1	37	35.63333
0.214	0.201	0.199	0.204667	39.7	43.7	40.3	41.23333
0.182	0.19	0.176	0.182667	37.5	38.9	39.8	38.73333
0.228	0.143	0.198	0.189667	36.4	37.4	37.8	37.2
0.208	0.182	0.191	0.193667	37.8	43.3	43.3	41.46667
0.198	0.225	0.236	0.219667	35.6	35.4	38.9	36.63333
0.258	0.289	0.286	0.277667	36.2	37.9	40.5	38.2
0.26	0.246	0.235	0.247	38.9	44.9	42	41.93333
0.235	0.213	0.199	0.215667	33	37	38.1	36.03333
0.203	0.25	0.233	0.228667	37	43.4	44.4	41.6
0.18	0.135	0.177	0.164	39.4	42.8	37.5	39.9
0.241	0.21	0.2	0.217	39.4	41	41.7	40.7
0.16	0.167	0.167	0.164667	46.8	47.6	49.3	47.9
0.161	0.149	0.153	0.154333	46.2	46.2	47.4	46.6
0.164	0.156	0.169	0.163	46.2	45.8	44	45.33333
0.154	0.172	0.17	0.165333	49	46.2	48.2	47.8
0.183	0.177	0.184	0.181333	32	32.1	31.9	32
0.178	0.181	0.172	0.177	39.6	37.4	37.2	38.06667

0.156	0.174	0.156	0.162	32.4	32.5	31.5	32.13333
0.163	0.18	0.172	0.171667	30.8	31.5	31.3	31.2

srF1	srF2	srF3	mean srF
34	35	36	35
27	31.5	28	28.83333
37.5	40	40	39.16667
37	38.5	40.5	38.66667
33	37.5	40	36.83333
28	33	35.5	32.16667
38	43	45.5	42.16667
40.5	41.5	44.5	42.16667
26	30	32	29.33333
29	33	34.5	32.16667
33	34	37	34.66667
30	34	36	33.33333
47	50	51	49.33333
43	45	45.5	44.5
40	53.5	45	46.16667
40	43	43.5	42.16667
35	36.5	37	36.16667
34	36	37	35.66667
41	42	43	42
37.5	37.5	37.5	37.5
15.5	17.5	18	17
12	16	16.5	14.83333
14	15	15.5	14.83333
12	14	14.5	13.5
40	38	33	37
32	35	36	34.33333
27	27	32	28.66667
31	32.5	33	32.16667
51	51	50	50.66667
48	51.5	52.5	50.66667
52	53.5	54	53.16667
51	50.5	53	51.5
34	38.5	39	37.16667
30.5	34.5	34	33
32	37	39	36
34	36	36	35.33333

Appendix 4: Pictures of Stretches

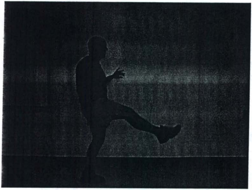
Partner assisted Quadriceps Stretch.

Partner assisted low back stretch

Static Calve stretch against

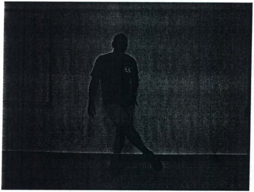
Partner assisted static hamstring stretch

Dynamic hip flexor / extensor stretch

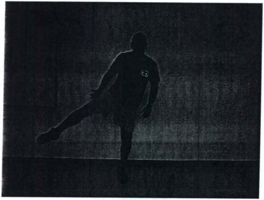


Dynamic hip adductors / abductors stretch

a.



b.



Dynamic trunk rotation stretch

a.