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The Effects of Warm-Up Protocol and Muscle Temperature on Performance

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WARRANTY STATEMENT

Abstract

Purpose: The purpose of this study was to examine the effects of different warmup protocols on performance and muscle temperature. **Methods:** Five healthy (men ± SD age = 21.6 ± 2.19; stature = 179 ± 3.65) cm; mass = 81.94 ± 10.32 kg) volunteered for this study**. Results:** that isokinetic leg flexion PT at angular velocities of $60 \cdot s^{-1}$ and $180 \cdot s^{-1}$ was significantly higher after DS compared to SS and NS, with PT being lowest after SS ($p<0.05$). The same was found to be true for leg extension PT at both velocities; however the differences were not statistically significant ($p>0.05$). Similarly, vertical jump height was significantly higher after DS compared to SS and NS ($p<0.05$), once again performance was lowest after SS. The results of the sit-and-reach test show that flexibility was highest after SS and that there was no significant difference between DS and NS. The results of this study also show a significant effect of time on muscle temperature for all conditions with muscle temperature being higher post warm-up for the quadriceps, hamstrings and calves ($p<0.05$). **Conclusions:** The main overall findings of this study have shown that muscle temperature and performance (excluding flexibility) are highest after DS, followed by NS and then SS, indicating a positive correlation between muscle temperature and performance. This may be one of the reasons why the vast majority of previous studies have reported improved performance after DS.

Contents

Introduction

Warm-up protocols are commonly implemented prior to exercise and sporting events as they are generally believed to promote better performance and reduce the risk of injury (ACSM, 2013). Musculoskeletal injuries represent over 30% of all injuries treated in sports medicine clinics (Woods *et al.,* 2007). Identifying the most effective methods to reduce the risk of injury is of extreme importance to both recreational and professional athletes. Most warm-ups will often consist of low-medium intensity aerobic exercise combined with a stretching protocol. Stretching is performed to ensure athletes have sufficient range of motion (ROM) in their joints in order to optimise performance, and also to decrease muscle stiffness and/or increase muscle compliance so that injury risk is as low as possible (Mchugh & Cosgrave, 2009).

Types of stretching

Although there a number of different types of stretching, static stretching (SS) and dynamic stretching (DS) are the two methods that are most commonly utilised by athletes as part of their warm-up routine (Woods *et al.,* 2007). A SS is applied slowly and progressively at a constant force and is usually held for 15-30 seconds at the muscles greatest possible length (Ghaffarineiad *et al.,* 2007). In contrast, DS consists of functional multi-joint movement patterns that are usually performed during sport. DS involves progressive increases in ROM and intensity as the limb moves from its neutral position to its end range and then back again (O'Sullivan *et al.,* 2009). DS also provides a metabolic warm-up due to its aerobic aspect.

Mechanisms involved during warm-up

Although there is still a degree of uncertainty regarding some of the mechanisms involved during warm-up protocols, changes in performance have been attributed mainly to temperature related mechanisms such as a decrease in muscle-tendon complex stiffness, optimised aerobic function and an increase in nerve conduction velocity (Bishop, 2003). Pearson *et al., (*2011) found that increased muscle temperature following a warm-up protocol, can improve aerobic function due to increases in vasodilation and muscle blood flow, which in turn lead to higher oxygen consumption during subsequent tasks. Although elevating oxygen consumption before a competition may appear to be counterproductive, without warming up, an athlete such as a marathon runner will have to accelerate to race pace at the start of a competition very quickly resulting in profound energetic consequences. This rapid increase in energy turnover means that the muscles adenosine triphosphate (ATP) stores are quickly depleted and because the energy supplied through oxidative metabolism increases slowly, the energy equivalent to the O2 deficit needs to be produced through anaerobic processes (Poole & Jones, 2012). However, these non-oxidative processes lead to higher concentrations of metabolic by-products that are all associated with muscle fatigue such as adenosine diphosphate (ADP), hydrogen ions and lactate (Sahlin, 2014). Warming up before competition has been shown to enhance the VO2 response and increase the time to exhaustion by 30-60% during near maximal exercise (Jones *et al.,* 2003). Poole & Jones (2012) suggest that this change in VO2 response is caused by a combination of factors such as oxygen availability, enzyme function, muscle fibre recruitment and substrate availability. However, in order for this VO2 response to occur, a relatively high-intensity warm-up that elevates blood lactate to a minimum of 2-4mM is required (Jones *et al.,* 2003).

The effects of warm-up on muscle stiffness are of great importance as stiffness has been identified as potential risk factor for soft tissue injuries due to its influence on the forces transmitted from the muscles to the skeleton, specifically the rate of force development (Morales-Artacho *et al.,* 2017). This effect has been observed following both SS and DS warm-up protocols, However SS has been shown to have a more significant effect (Ryan *et* *al.,* 2008). Stiffness is largely responsible for the effectiveness of the muscle-tendon unit in regards to shock absorption and it has been suggested that high muscle-tendon complex stiffness reduces the ability to lessen applied forces, resulting in soft tissues becoming more susceptible to injuries and delayed onset muscle soreness (Watsford *et al.,* 2010).

Effects of warm-up on flexibility

Bradley & Portas (2007) examined 36 elite male football players and found that players that sustained a muscle strain injury in the lower extremities had a significantly lower ROM compared with uninjured players. Similar findings were also reported by Witvrouw *et al.,* 2003 in a study involving 146 professional football players. The results of the study indicate that pre-season flexibility was significantly lower in athletes who experienced a hamstring or quadriceps injury, when compared to the uninjured group. However, a limitation of these studies is that they both only examined muscle flexibility. It is likely that other factors are just, if not more important in the development of injuries. Thus, although the findings of these studies identify muscle flexibility as an intrinsic risk factor, other factors should not go unnoticed and similar research with the inclusion of more variables is necessary. The findings of these studies suggest that decreased muscle stiffness and the associated increase in ROM will aid performance and reduce injury risk, particularly in sports that involve large movement in which resistive forces contribute to muscle performance.

Chan *et al.,* (2000) showed that an eight-week SS protocol where participants performed five sets of five 30s repetitions, three times a week led to a significant increase in hamstring flexibility when compared with the control group. Upon completion of the eight-week SS protocol, an 11.2° increase in ROM was observed when compared to the pre-test range. Furthermore, passive resistance of the hamstrings increased significantly by 4.7 N·m at the corresponding maximal joint angle after four-weeks of SS. Similar findings were reported by Sullivan *et al.,* (2009) in a randomised cross-over trial that used passive knee extension (PKE) ROM to compare the effects of SS and DS on hamstring flexibility in previously injured participants. The results showed that PKE ROM increased by 6.3% following the SS protocol, whereas no significant effect was observed following DS. However, the findings of this study cannot be extrapolated to all athletes due to limitations caused by the sampling strategy (i.e. participants were all previously injured, mostly men of a young age) thus limiting the conclusions that can be made. Furthermore, no objective measure was used to confirm the history of the participant's injuries and several important factors such as time since injury, time away from sport and rehabilitation methods utilised since injury, were not considered. Despite this, the stretching protocols did reflect common clinical practice in terms of the optimal number of repetitions and duration of stretches (ACSM, 2013).

Recent evidence suggests that the effects of warm-up protocols (especially SS) on ROM, may actually not be a result of decreased muscle stiffness, but rather an increase in the participant's tolerance (ability to withstand more force) to stretching (Page, 2012). Muscle length or 'extensibility' is measured by placing a standardised load on the limb and then measuring the joint motion. Whereas increased tolerance to stretch is calculated by measuring the joint ROM using a non-standardised load (Page, 2012). Interestingly, of the four previously mentioned studies that investigated the effects of SS, only one of them (Chan *et al.,* 2000) reported an increase in muscle extensibility following SS. Although the other three studies reported an increase in ROM after stretching, more force was needed to move the muscles to the increased range. Thus there was no shit in the torque/angle curve that was measured. Future studies should ensure the methodology includes a measure of muscle extensibility in order to draw more valid conclusions on the mechanisms involved during warm-up protocols. Studies that did measure muscle extensibility have produced results that support the role of tolerance to stretch. Ben & Harvey (2000) examined passive hip flexion in sixty healthy participants, using a standardised and non-standardised stretch torque. The results of the study indicate that six weeks of SS performed daily for 30 minutes does not increase hamstring extensibility. However, improvements in stretch tolerance leading to increased ROM were observed. Moreover, no changes in reported pain intensity were observed following the six-week trial, indicating that SS enabled participants to endure greater intensities of stretch torque with the same amount of perceived pain. In addition to this, no improvements in ROM were observed in the untreated leg. Similar findings have also been replicated in a number of related studies (Law *et al.,* 2009; Ylinen *et al.,* 2009; Halbertsma & Goeken, 1994).

The primary mechanisms involved in stretch tolerance remain unknown, however it has been suggested that stretching may influence certain characteristics in the neural sensory pathways (Laessoe & Voigt, 2003). It is also possible that stretch tolerance may be affected due to the use of non-blinded participants that have pre-conceived notions regarding the effects of stretching. However, it is not possible for participants to be blinded in these kinds of studies. Regardless of the mechanisms involved, stretching has been consistently proven to increase flexibility and ROM (Ryan *et al.*, 2008; Fowles *et al.*, 2000).

Detrimental effects of warm-up

While most of the existing literature has concluded that certain warm-up protocols may positively influence short-term performance and injury risk, (Costa *et al*., 2014; Manoel *et al*, 2008; Herman & Smith, 2008) several studies found warm-up protocols to have no significant effect or to actually have a detrimental effect on performance and injury risk (Sekir *et al*., 2009; Costa *et al*., 2013). SS has repeatedly been reported to decrease maximal concentric isokinetic strength, peak twitch force, maximal power output, sprint performance and a number of other sport-specific measures (Costa *et al*., 2014). In a recent study, Costa *et al*. (2013) examined the acute effects of SS on hamstring strength in female participants and found that on average hamstring peak torque, decreased approximately 5% following the stretching protocol. Likewise, a study on 11 elite female athletes also found that SS of the leg extensors and flexors actually decreased concentric and eccentric isokinetic strength in the quadriceps and hamstrings (Sekir *et al*., 2009). This effect is often referred to as the stretch-induced strength loss (Weerapong *et al.,* 2004).

Mechanisms involved during stretch-induced force deficit

The negative effects of SS on performance or the 'stretch-induced force deficit' have been attributed primarily to changes in neuromuscular transmission (Avela *et al.,* 2004). Several studies have reported significantly lower EMG activity during maximal voluntary contractions after stretching, indicating that the stretch-induced strength loss is a neural effect (Cramer *et al.,* 2007; Herda *et al.,* 2009). In addition, stretch-induced strength loss has been shown in the contralateral non-stretched limb ((Mchugh & Cosgrave, 2009). Regardless, SS remains an exceptionally effective method for increasing ROM and is still important in scenarios where the main goal is to increase flexibility or for health-related benefits. However due to the overwhelming evidence available, SS should not be included as part of a warm-up when the subsequent activities involve strength, high speed and explosive movements.

A stretch-induced force deficit or decrease in performance following a warm-up may also occur if the intensity of the protocol is too high or if the recovery period is insufficient (Bishop, 2003). The ability to breakdown high-energy phosphate stores is related to short-term performance, decreases in their availability resulting from excessively intense warm-ups may hinder performance (Baker & Buchan, 2016).

Benefits of warming up

A study on eighteen professional football players examined the effects of SS and DS during a pre-exercise warm-up on high-speed motor capacities such as vertical jump, flying 20-m sprint and agility tests. The study found that with the exception of vertical jump, both

SS and DS protocols significantly improved performance in all motor capacitates when compared with the no stretch (NS) protocol (Williams & Little, 2006). However, as this study looked at the effects of stretching on high speed motor capacities alone, it is not possible to generalise the findings to all areas of performance. For example, athletes participating in lower intensity endurance based sports are much less likely to use high speed motor capacities such as those examined in this study. Furthermore this study only tested well-trained elite athletes, which again, reduces the generalisability of the findings and limits the extent to which the data can be applied to athletes or those participating in sport/exercise. Similar findings were reported by Herman & Smith (2008) during a four-week DS warm-up intervention in division 1 male wrestlers. Upon completion of the intervention, several performance improvements were recorded when compared to the NS control group, including increases in quadriceps peak torque (PT), broad jump, underhand medicine ball throw and a decrease in the time taken to complete a 300-yd shuttle run. These findings suggest that the use of DS as a warm-up may result in increased power, strength, muscular endurance and anaerobic capacity. However, once again the results cannot be generalised to the wider population as only elite male athletes were examined.

Dynamic stretching v static stretching

Although many studies support the use of SS as part of a warm-up protocol, an increasing number of studies are suggesting that DS is superior in regards to enhancing performance when utilised prior to exercise. For example, Manoel *et al*. (2008) examined the acute effects of different stretching protocols on peak power output in women and found that DS increased acute muscular power to a greater degree than any other form of stretching. Likewise, Yamaguchi & Ishii (2005) found that leg extension power after DS was significantly higher when compared to the NS protocol, whereas no significant difference was found between SS and NS.

In contrast, following a bout of DS, concentric and eccentric strength increased in both the quadriceps and hamstrings. This study also determined the test-retest reliability by repeating the tests twice at 3-5 day intervals in 11 recreational female athletes and found no significant differences between either testing sessions, suggesting the findings of this study are highly reliable.

Limitations of the existing literature

It is important to consider that flaws in the study design may be a contributing factor to the varied results between SS and DS. When investigating the effects of SS, many studies have simulated an intense stretch that far exceeds what an athlete is likely to attempt before engaging in sport/exercise. Furthermore, the exact intensity and stretching duration required to cause lasting changes in muscle stiffness is still unknown (Fowles *et al*., 2000). If duration and intensity are too high it is possible that the fine balance of neural, architectural, and electrophysiological factors that exists in muscle to generate force may be altered and consequently lead to a decrease in performance (Magnusson *et al.*, 1996). Therefore future testing should ensure stretching protocols are similar to what an athlete is likely to perform in a real life context.

In addition, many of the existing studies suffer from methodological issues. A meta-analysis of 104 studies indicated that numerous studies are lacking internal validity as they are prone to subject and/or researcher bias (Simic *et al*., 2013). However, it is important to take into consideration that blinding of therapists and participants is extremely difficult in exercise interventions. Even so, future studies should improve their quality by randomising subjects into groups, blinding the assessors, and ensuring that treatment allocation is concealed. Finally, despite evidence that the mechanisms involved during warm-ups are mostly temperature related, no studies have examined the effects different warm-up protocols may have on muscle temperature

The purpose of this study was to examine the effects of different warmup protocols on performance. Many studies have already shown that improvements in performance following a warm-up are partly due to an increase in muscle temperature, consequently it has been suggested that the benefits of DS are largely a result of this effect. Therefore this study included a NS protocol that had similar characteristics of DS (i.e. increased heart rate/blood flow, increased muscle/core temp) but without actually stretching the muscle itself, to further investigate the effects of warm-up protocols and muscle temperature on performance.

Theoretical Framework

Research question

This study addressed the following question: Should stretching be included in a pre-exercise warm-up?

Aims and objectives

The primary aim of this study was to determine which warm-up protocol if any, led to the most significant increase in performance.

The objectives of this study were to determine whether or not there were differences in performance between warm-up protocols and to investigate the effects of different warm-up protocols on muscle temperature.

Research (H_1) and null hypothesis (H_0)

H_0 – Pre-exercise warmup protocols have no effect on performance.

H_1 – There is a difference in performance when comparing warmup protocols.

Operational definitions

Static stretching: “a stretch that is applied slowly and progressively at a constant force and is held for 15-30 seconds at the muscles greatest possible length” (Ghaffarineiad *et al.,* 2007).

Dynamic stretching: “functional multi-joint movement patterns in which the limb moves from its neutral position to its end range and then back again” (O’Sullivan *et al.,* 2009).

Assumptions

Throughout the duration of the study, it was assumed that participants would continue engaging in exercise/sport with no change in the type or intensity of activity they would normally engage in. It was also assumed that there would be no learning effect across the study and that participants would complete all performance tests with maximal effort. Finally, it was assumed that participants would not consume any nutritional supplements or ergogenic aids prior to or during the study.

Limitations

The findings of this study only provide information on the acute effects of different warm-up protocols on performance; conclusions on the long-term effects are not possible. Also although participants of a similar physical activity level were recruited, sport-specific differences were not taken into account, which may have resulted in differences in recovery time due to the use of different muscle groups in different sports.

Delimitations

Physical activity levels were self-reported therefore response bias may be present. Also, all participants were aged males aged between 19-25 years reducing the generalisability of the findings.

METHODOLOGY

Participants

Five healthy (men ± SD age = 21.6 ± 2.19; stature = 179 ± 3.65) cm; mass = 81.94 ± 10.32 kg) volunteered for this study. All participants were free from injury at the time of the study and in the 6 months prior. This study was approved by Kingston University, and all participants completed a written informed consent form and a Pre-Exercise Testing Health & Exercise Status Questionnaire (see appendix I). Participants were recruited by handing out informational flyers around Kingston university campuses. Trained individuals were selected to reduce training/learning effects. The flyers/e-mails contained information on the study, its purpose, and inclusion and exclusion criteria.

Inclusion criteria:

Participants had to be aged between 18-40, and were required to perform at least 150 minutes of moderate aerobic activity per week and strength training for all major muscle groups at least twice a week.

Exclusion criteria

Participants were required to be free from any current injuries, injuries incurred in the past 6 months and conditions or physical deficits that may have affected performance. Furthermore, participants were not allowed to use nutritional supplements and ergogenic aids as these may have affected performance.

Experimental design

This study was conducted using a randomised cross-over trial and each participant was examined under all 3 conditions. Often when comparing study groups to control groups, confounding variables such as age and sex may reduce internal validity. A lack of internal validity makes it difficult to establish whether or not a relationship truly exists between the independent variable (IV) and dependant variable (DV) (Wellek & Blettner, 2012). However, in a crossover design each participant will serve as his/her own control group, thus reducing the effects of potential confounding variables. Furthermore, crossover trials require smaller sample sizes than other designs to meet the same criteria in terms of type I and type II error risks (Wellek & Blettner, 2012). History effects were controlled for by ensuring that test days were not immediately after a sporting event or day, in which the participant had engaged in sport or exercise and also by allowing a sufficient washout period to prevent carryover effects (Mill *et al.*, 2009). Also, because participants were recruited from various sports teams, the generalisability of the findings are not be limited to one specific sport. The IV in this study was the warm-up protocol (i.e., SS, DS or no stretch) and the DV's were leg extension/flexion PT (N·m), vertical jump height (cm), flexibility (cm) and muscle temperature (°C).

Equipment and procedures

Participants tested tested on three separate days, with a minimum of 48 hours between testing days to allow full recovery (Bishop *et al.*, 2008). Testing was planned around the participants regular physical activity/exercise program to reduce any threats to internal validity (i.e., history effects). On each day of testing participants were randomly assigned to the static stretching, dynamic stretching or no stretching warm-up protocol. The order of conditions for the remaining days of testing was varied for all participants to reduce potential order effects. Stature and mass were recorded using electronic scales (Seca, Vogel & Halke, Germany) and a floor stadiometer (Holtain Ltd., Dyfed, Wales) at the start of the study. At the start of every visit the researcher demonstrated the correct stretch technique that the participant would be performing; the participant's movement was constantly monitored and adjusted if necessary to ensure that the warm-ups were performed correctly. Before the warm-up, excessive hair was shaven off the sites that would be used to measure skin temperature and then cleaned with an alcohol wipe. Temperature was measured in the rectus femoris, biceps femoris and gastrocnemius medialis using the Squirrel SQ2020 data logger (Grant instruments Ltd, Cambridge). For skin thermistors placement sites see Figure 1.

In all conditions participants began by completed a 5-minute aerobic warm up on the Monark bikes (Monark Exercise AB, S-432 82 Varberg, Sweden) with a braking force of 100watts; whilst maintaining a speed between 70-90 rpm throughout the warm-up Skin temperature (T_S) was measured pre and post warm-up. T_S was then be used to predict muscle temperature (T_M) using the equation: T_M (˚C) = 1.02T_S (˚C) + 0.89 (Whitlock *et al.*, 2013).

Condition 1 – No stretching (NS)

In the NS condition, participants cycled for a total of 10-minutes with a braking force of 100watts, whilst maintaining a speed of 70rpm throughout the warm-up.

Condition 2 – Static stretching (SS)

In the SS condition, participants watched as the researcher demensotrated that correct technique and were then instructed tohold each stretch for a duration of 15s with a 10s rest in-between, performing a total of 3 repetitions for each stretch. Participants were instructed to stretch until they experienced tightness and discomfort, but not pain (Mohr, 2008). The first targeted the hamstrings; participants sat on the ground with their legs straight in front of them. They then leant forward from the hips (trying to keep their backs fairly straight) until a stretch was felt on the back of the thighs. The 2nd stretch targeted the calf muscles. Participants were instructed to step forward with one leg, shifting their weight toward the front leg while keeping the back heel on the ground. The last stretch targeted the quadriceps from a standing position. The participants were told to flex the right knee such that the heel would move toward the buttocks; they then held this position for the specified duration for each leg.

Condition 3 – Dynamic Stretching

In the DS condition, participants performed 3 sets of 10 repetitions for each exercise with 30s rest in between exercises. To begin, participants performed walking lunges which will target the quadriceps, glutes, hamstrings and calves. This exercise was performed by taking a large step forward with one leg whilst maintaining an upright position as the back knee is lowered as close as possible to the floor without making contact with the ground. The lead foot was then driven forward, bringing the bent leg forward to land alongside the lead foot, returning to the standing position. The 2nd exercise was squats; these were performed by standing with the feet positioned slightly wider than the shoulders. Hands were then placed on the head with the elbows flared out. The participants then had to lower down into a squat slowly and then return to the starting position. The final exercise was leg swings. Participants were instructed to stand sideways on a wall placing their right hand on the wall for balance whilst placing their weight on their left leg and swinging the right leg forwards and backwards. Once they completed 10 repetitions they alternated legs.

Performance tests

Vertical jump height, leg extension/flexion peak torque (PT) and sit and reach flexibility was measured immediately after all conditions.

Vertical jump height

Jump height was measured using the Vertex (Sports Imports, USA). During this test participants were instructed to jump as high as they could, using their preferred technique.

Participants had 3 attempts to jump as high as possible and the highest score will be used for analysis.

Sit and Reach Flexibility

Using a sit and reach device, participants were instructed to sit with their legs extended and feet placed flat against the device. They then stretched forward as far as possible whilst exhaling and with one hand over the other, holding the end point for 2 seconds. After 3 attempts the highest score was recorded. The protocol used for this test was designed based on similar studies (Samson *et al.,* 2012).

Isokinetic Testing

An isokinetic dynamometer (Biodex System 4, Biodex Corporation, NY, USA) was used to measure concentric flexion and extension peak torque (N·m/kg) for the hamstrings and quadriceps at the angular velocities of 60°·s and 180°·s. These velocities have been associated with lower body injuries and have been used in many other studies (Costa *et al.,* 2014; Houweling *et al.,* 2009). Once participants were in a seated position with the pads securing the right knee, the input axis of the dynamometer was aligned with the axis of rotation of the right knee. The participant's range of motion was also determined when prompted by the software. Leg extension and flexion were measured during each repetition. 1 set of 5 submaximal warm-up repetitions at 60°·s were performed followed by a 1 minute rest. The participant then performed 3 maximal repitions at 60°·s followed by a 1-min rest and then another 3 maximal repetitions at 180°·s. The order of testing began with isokinetic PT, followed by vertical jump height, and concluded with the sit and reach flexibility test. These tests were not conducted in a randomised order as leg extension strength could be affected by possible potentiating effects of the vertical jump test and sit and reach test.

Statistical Analysis

The effects of warm-up protocol on leg extension/flexion peak torque, jump height and extensibility were evaluated by a one-way analysis of variance (ANOVA) with repeated measures. When a significant interaction was detected, data were subsequently analysed using Fischer's Least Significant Differences (LSD) post hoc test. Although it has been suggested that LSD correction may be too liberal at rejected the null hypothesis, other methods are too conservative considering the small sample size of this study. Furthermore, in this study there were only three comparisons and in this case the LSD test is capable of keeping a tight control over familywise type I error rates at a 0.05 alpha level (Laerd Statistics, 2013) Changes in muscle temperature between conditions and time points were evaluated by a two-way ANOVA with repeated measurements. Significant interactions were analysed using the Sidak correction. The significance level was set to $P<0.05$. Values are presented as means ± SDs.

Results

Leg extension/flexion peak torque

Measurements of peak torque for all conditions are represented in Table 1.

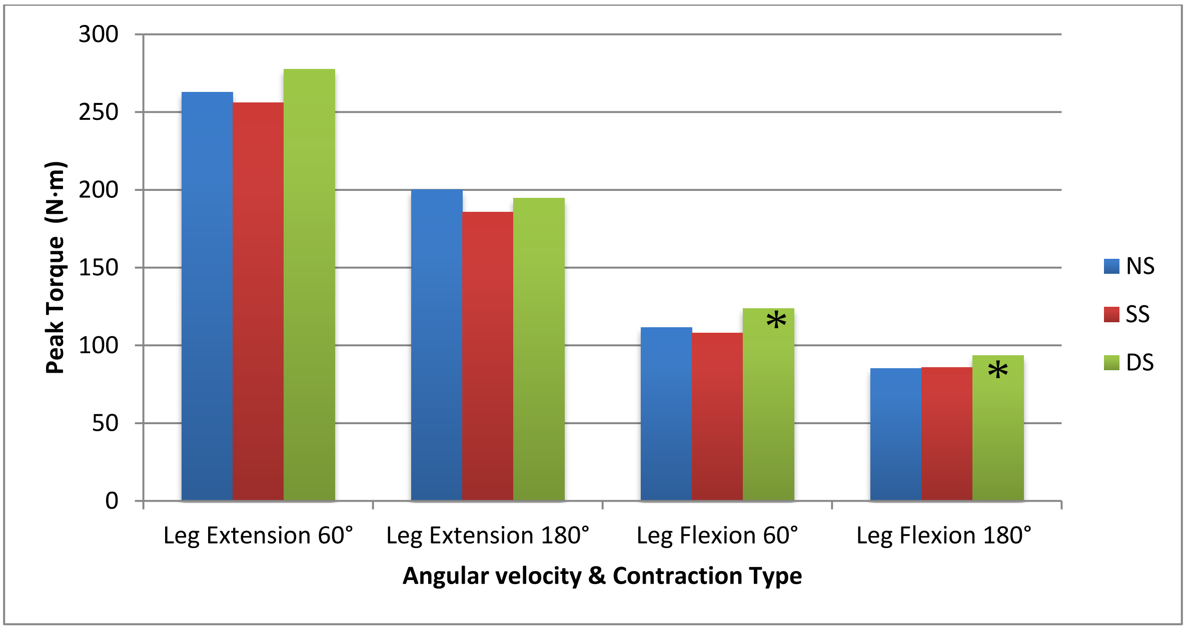
Table 1. Mean (±SD) values for leg extension peak torque and leg flexion peak torque at 60 and 180·s^{-1} post warm-up

	NS	SS	DS
Leg extension PT 60·s^{-1}	262.70 ± 52.86	256.22 ± 60.17	277.72 ± 62.46
Leg extension PT 180·s^{-1}	200.06 ± 17.39	185.66 ± 40.55	194.66 ± 40.93
Leg flexion PT 60·s^{-1}	111.52 ± 19.11	108.12 ± 21.77	123.84 ±18.92*
Leg flexion PT 180·s^{-1}	85.24 ± 8.66	85.98 ± 11.64	93.46 ±10.83*

PT = peak torque, PT values are in N·m. SS = static stretching, DS = dynamic stretching, NS = no stretching. *Indicates significant difference between protocols

There was no significant main effect of warm-up protocol on leg extension at 60° *($F(2,8)=2.510$, $p>0.05$)* or at 180° *($F(2,8)=0.896$, $p>0.05$)*. However there was a significant main effect of warm-up protocol on leg flexion at 60° *($F(2,8)=16.147$, $p<0.05$).* Peak torque was statistically significantly different between DS (123.84 ± 18.92N·m) and both SS (108.12 ± 21.77N·m) and NS (111.52 ± 19.10N·m), a mean difference of 15.72 (95% CI, 7.56 to 23.88) N·m and 12.32 (95% CI, 5.50 to 19.13) N·m, respectively (see Figure 1). There was no statistically significant difference between NS and SS *($p>0.05$).* There was also a significant main effect of warm-up protocol on leg flexion at 180° *($F(2,8)=9.141$, $p<0.05$).* Peak torque was statistically significantly different between DS (93.46 ± 10.82N·m) and both SS (85.98 ± 11.63N·m) and NS (85.24 ± 8.66N·m), a mean difference of 7.48 (95% CI, 4.25 to 10.70) N·m and 8.22 (95% CI, 0.96 to 15.47) N·m, respectively. There was no statistically significant difference between NS and SS *($p>0.05$).*

Figure 2. Effects of Warm-up Protocol on Isokinetic Leg Extension/Flexion Peak Power at Angular Velocities of 60° and 180°



NS = no stretching, SS = static stretching, DS = dynamic stretching. *Indicates significant difference between protocols

Jump height

Measurements of jump height for all conditions are represented in Table 2.

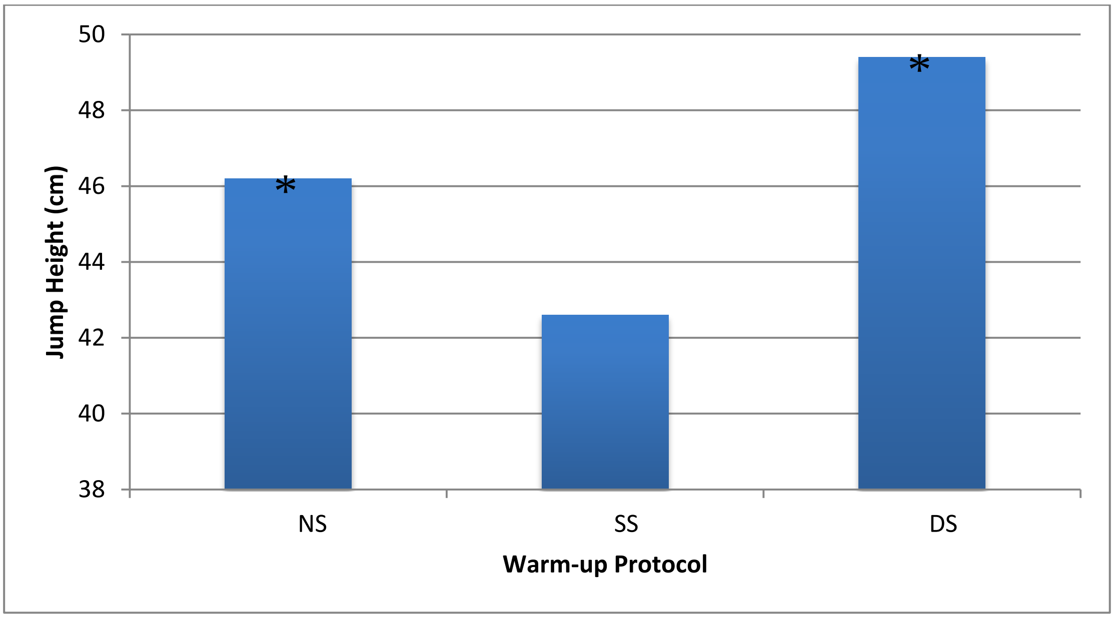
Table 2. Mean (±SD) values for jump height post warm-up

	NS	SS	DS
Jump height (cm)	46.2 ± 7.01*	42.6 ± 7.37	49.4 ± 6.8*

SS = static stretching, DS = dynamic stretching, NS = no stretching. *Indicates significant difference between protocols

A repeated measures one-way ANOVA assuming sphericity *($\chi2(2)=3.042$, $p=0.219$)* showed a significant main effect of warm-up protocol on jump height, *$F(2,8)=28.459$, $p<0.001$*. Jump height was statistically significantly different in DS (49.40 ± 3.04cm) compared with NS (46.20 ± 3.13cm) and SS (42.60 ± 3.29cm) protocols, a mean difference of 3.20 (95% CI, 1.35 to 5.04) cm and 6.80 (95% CI, 4.76 to 8.84) cm, respectively. Jump height was also statistically significantly different between NS (46.20 ± 3.13cm) and SS (42.60 ± 3.29cm), a mean difference of 3.60 (95% CI, 0.24 to 6.95) cm (see Figure 2).

Figure 3. Effects of Warm-up Protocol on Jump Height



NS = no stretching, SS = static stretching, DS = dynamic stretching. *Indicates significant difference between protocols

Flexibility

Measurements of flexibility for all conditions are represented in Table 3.

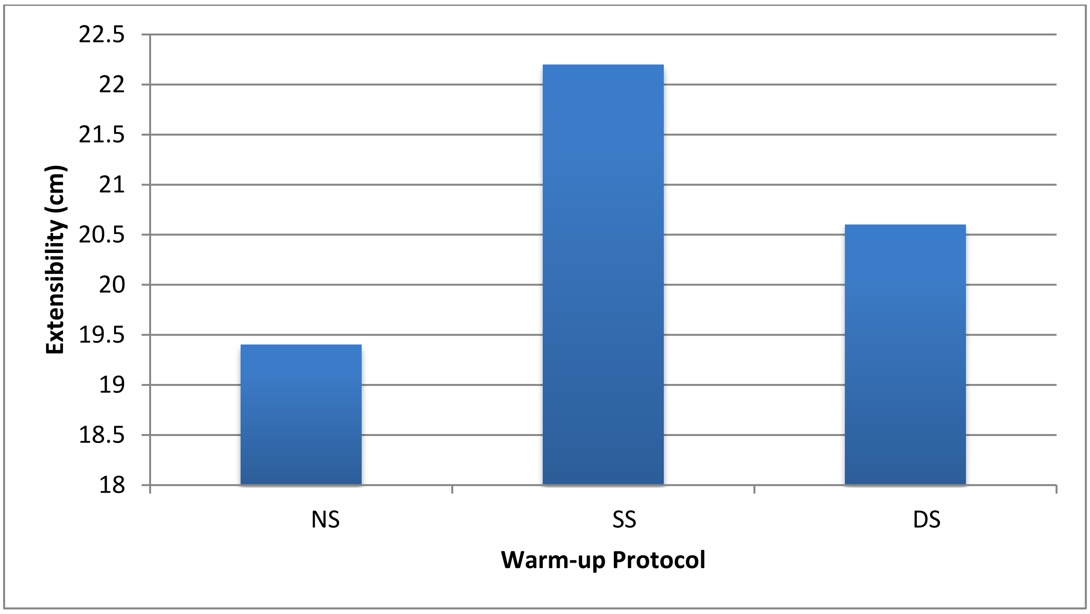
Table 3. Mean (±SD) values for flexibility

	NS	SS	DS
flexibility (cm)	19.4 ± 5.59	22.2 ± 5.81	20.6 ± 5.27

SS = static stretching, DS = dynamic stretching, NS = no stretching. *Indicates significant difference between protocols

There was a significant main effect of warm-up protocol on extensibility *(F(2,8)=12.596, p<0.001*. Extensibility was statistically significantly different between SS (22.20 ± 2.59cm) and both DS (20.60 ± 2.35cm) and NS (19.40 ± 2.50cm) protocols, a mean difference of 1.60 (95% CI, 0.18 to 3.01) cm and 2.80 (95% CI, 1.18 to 4.41) cm, respectively (see Figure 3). There was no statistically significant difference between DS and NS (*p>0.05*).

Figure 4. Effects of Warm-up Protocol on Extensibility



NS = no stretching, SS = static stretching, DS = dynamic stretching. *Indicates significant difference between protocols

Muscle Temperature (T_m)

Sphericity was assumed both for warm-up protocol effects (*(χ2(2)=3,191, p=0.203)* and for the condition and time interaction (*(χ2=1.766,p=0.414).* Measurements for muscle temperature for all conditions are represented in Table 4.

Table 4. Mean (±SD) values for muscle temperature pre/post warm-up

	NS		SS		DS	
	Pre	Post	Pre	Post	Pre	Post
Quadriceps	32.7 ± 1.55	33.72 ± 1.01	32.1 ± 0.87	32.35 ± 0.9	32.71 ± 0.75	33.65 ± 0.8
Hamstrings	32.57 ± 1.42	32.96 ± 1.07	32.31 ± 1.05	32.82 ± 1.13	32.69 ± 0.79	33.2 ± 0.72
Calves	32.18 ± 1.11	32.9 ± 1.7	32.8 ± 0.98	32.65 ± 0.51	33.12 ± 0.43	33.24 ± 0.82

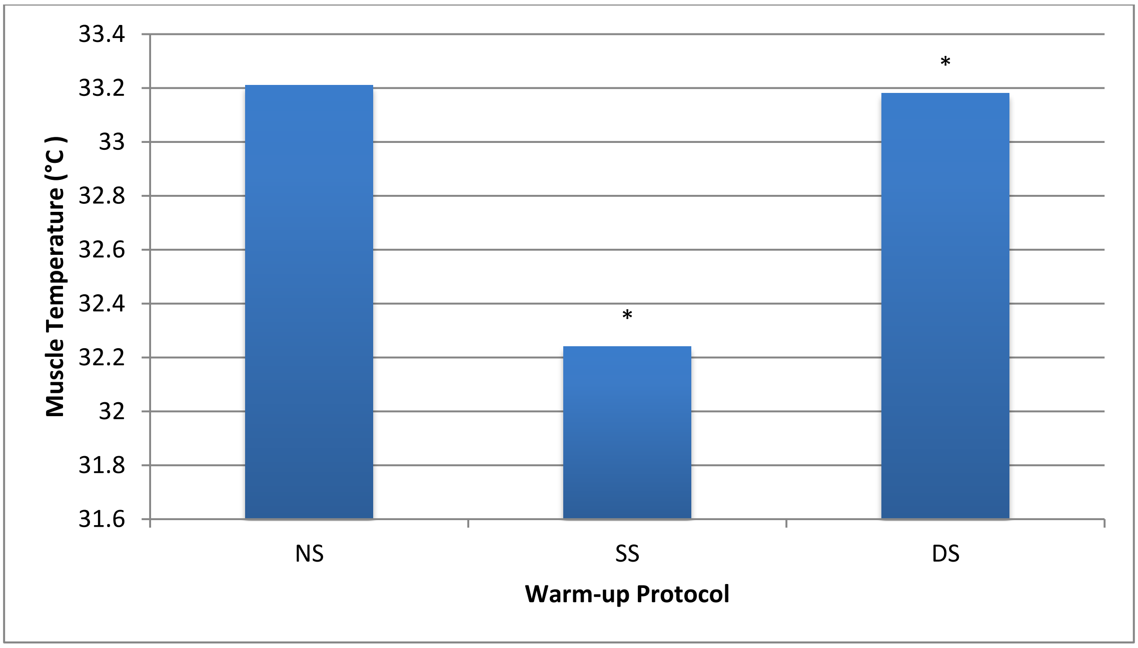
SS = static stretching, DS = dynamic stretching, NS = no stretching. Values displayed are °C

Quadriceps:

Warm-up protocol had a significant main effect on T_m *(F(2,8)=6.842, p<0.05).* T_m was statistically significantly different between DS (33.18 ± 0.33°C) compared to SS (32.22

± 0.39°C), a mean difference of 0.95 (95% CI, 0.55 to 1.36)°C (see Figure 4). There was also a main effect of time on T_m *(F(1,4)=19.334, p<0.05)*. Post warm-up T_m across all conditions (33.24 ± 0.37°C) was statistically significantly different compared to pre warm-up T_m (32.50 ± 0.45°C), a mean difference of 0.73 (95% CI, 0.27 to 1.97) °C.

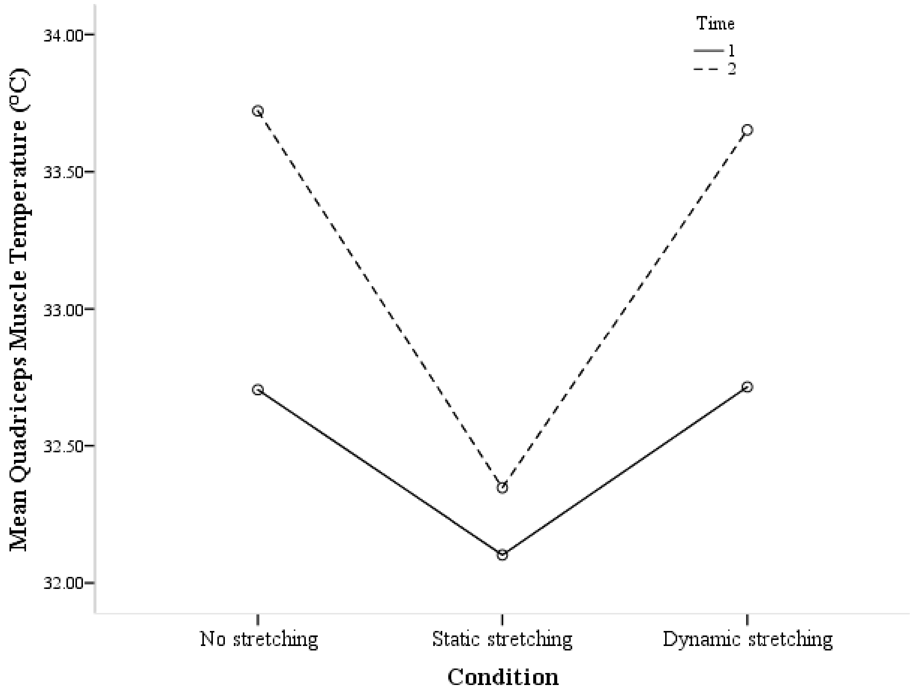
Figure 5. Effects of Warm-up Protocol on Quadriceps Muscle Temperature



NS = no stretching, SS = static stretching, DS = dynamic stretching. *Indicates significant difference between protocols

A significant interaction effect of time and warm-up protocol was also found, *(F(2,8)=6.185, p<0.05)* (see Figure 5). T_m was statistically significantly different between post DS (33.65 ± 0.80°C) compared to both post SS (32.35 ± 0.90°C) and pre DS (32.71 ± 0.75°C), a mean difference of 1.30 (95% CI, 0.57 to 2.04)°C and 0.93 (95% CI, 0.35 to 1.5)°C, respectively. T_m was also statistically significantly different in DS (32.71 ± 0.75°C) compared to SS (32.10 ± 0.87°C) pre warm-up, a mean difference of 0.61 (95% CI, 0.05 to 1.16) °C. Finally, T_m was statistically significantly different post NS (33.72 ± 1.01°C) compared to pre NS (32.70 ± 1.55°C), a mean difference of 1.01 (95% CI, 0.21 to 1.81) °C.

Figure 6. Interaction Effect of time and Warm-up Protocol on Quadriceps Muscle Temperature



Dotted line represents average starting muscle temperature; filled line represents average post warm-up muscle temperature

Hamstrings:

The results indicate no significant main effect of warm-up protocol on hamstring T_m *(F(2,8)=0.306, p>0.05)* and no interaction effect of time and warm-up protocol *(F(2,8)=0.087, p>0.05).*

Calves:

The results indicate no significant main effect of warm-up protocol on calves T_m *(F(2,8)=0.667, p>0.05)* and no interaction effect of time and warm-up protocol *(F(2,8)=1.457, p>0.05).*

Discussion and Conclusions

The purpose of this study was to investigate the effect of various warm-up protocols on concentric isokinetic PT in the quadriceps and hamstring muscles, vertical jump height, flexibility and muscle temperature. The results revealed that isokinetic PT and vertical jump were both highest after DS, whilst flexibility was highest after SS. T_m was higher post warm-up for all protocols, however significant differences between protocols were only found in the quadriceps with DS resulting in the highest temperatures. These findings were unique in that, to our knowledge, no other studies have examined the effects of warm-up protocol on performance in relation to the changes in T_m that different types of warm-up may exhibit.

The findings of this study show that isokinetic leg flexion PT at angular velocities of $60 \cdot s^{-1}$ and $180 \cdot s^{-1}$ was significantly higher after DS compared to SS and NS, with PT being lowest after SS ($p<0.05$). The same was found to be true for leg extension PT at both velocities; however the differences were not statistically significant ($p>0.05$). Similarly, vertical jump height was significantly higher after DS compared to SS and NS ($p<0.05$), once again performance was lowest after SS. The results of the sit-and-reach test show that flexibility was highest after SS and that there was no significant difference between DS and NS. The results of this study also show a significant effect of time on muscle temperature for all conditions with muscle temperature being higher post warm-up for the quadriceps, hamstrings and calves ($p<0.05$). These findings are consistent with previous studies that have suggested that the main effects of warm-up on performance and injury risk are related to increased muscle temperature (Bishop, 2003; Pearson *etl al.,* 2011). Quadriceps muscle temperature was highest after DS and lowest after SS, the same was also true for the hamstrings and calves however these results were not statistically significant. The main overall findings of this study have shown that muscle temperature and performance (excluding flexibility) are highest after DS, followed by NS and then SS, indicating a positive correlation between muscle temperature and performance. This may be one of the reasons why the vast majority of previous studies have reported improved performance after DS (Herman & Smith, 2008’ Manoel *et al.*, 2008; Yamaguchi & Ishii 2005).

The improved performance following DS and decreased force production or stretch-induced strength deficit after SS, are findings that are consistent with previous studies (Herda *et al.,* 2008; Costa *et al.,* 2014; Manoel *et al.,* 2008; Herman & Smith, 2008). However, several studies that have reported no significant difference in performance following a bout of SS, suggest that this is because studies that do report an adverse effect, use protocols that are too long or to intense and therefore elicit neural and mechanical force inhibitory mechanisms (Kay & Blazevich, 2012; Egan *et al.,* 2006). For example, Behm & Kibele (2007) found that SS performed at 100%, 75% and 50% point of discomfort resulted in jump height impairments of 4.2cm, 3.9cm and 2.8cm respectively, suggesting that higher intensities of SS lead to more profound impairments in performance. According to the ACSM (2013) each stretch should be preceded by an active warm-up and should be held for 15-30 seconds with 2-4 repetitions. Interestingly, our study was conducted following the recommended protocols, and yet performance was significantly lower after SS. Based on our findings we suggest that although higher intensities/durations of SS may have a more significant adverse effect on performance, the stretch-induced strength deficit associated with SS is not just a result of excessive stretch duration/intensity and occurs even when following the recommended protocols.

Considering that the only statistically significant differences in isokinetic strength were observed during leg flexion, there is evidence to suggest that decreased muscle stiffness in the hamstrings was a potential mechanism involved with the stretch-induced force deficit that we found in our study. Our findings are also consistent with other studies that suggest reduced muscle stiffness is a potential mechanism involved with the stretch-induced force deficit caused by SS (Costa *et al*., 2014; Costa *et al*., 2013). Although the exact reason as to why this occurs is unclear, SS has been shown to cause changes in viscoelastic characteristics of series elastic components by decreasing actin – myosin overlapping and cross bridge formation (Pagaduan *et al.,* 2012). These alterations can lead to an inadequate transfer of force to the insertion of the tendon and to changes in the length-tension relationship, which can result in reduced force generating capacity (Esposito *et al.,* 2011). Interestingly, many studies have demonstrated that warm-up protocols which increase muscle temperature will also result in decreased muscle stiffness (Weerapong *et al.,* 2004; Pearson *etl al.,* 2011). One study even examined skeletal muscle in vivo and found that warm muscle (40°C) displayed less stiffness and more load-to-failure than cold (35°C) muscle (Noonan & Best, 1993). Based on these findings, our results should have shown that DS and NS had the most significant effect on muscle stiffness due to the temperature increase that was exhibited following these protocols. Consequently it can be argued that the adverse effects of decreased muscle stiffness on force production should have been most prominent in these protocols. However, research on the specific mechanisms involved during warm-up is still lacking and it is unclear as to why this theory is not supported by the findings of our study or by the majority of previous studies. It is possible that increased muscle temperature does not have as much of a significant effect compared to other mechanisms that occur during SS. Further research is needed to investigate the causes of decreased muscle stiffness and the mechanisms that are involved during the process.

In conclusion, in the inclusion of SS during a warm-up may lead to mechanical and/or neural responses that are likely to affect performance. In this study, performing DS led to significantly higher isokinetic PT during concentric leg flexion at 60 and 180 when compared to NS and SS. Likewise, CMJ scores were highest after DS, whilst flexibility increased the most after SS.

The main overall findings of this study have shown that muscle temperature and performance (excluding flexibility) are highest after DS, followed by NS and then SS, indicating a positive correlation between muscle temperature and performance. This may be one of the reasons why the vast majority of previous studies have reported improved performance after DS. SS was also found to cause a stretch-induced force deficit even though the duration of the protocol used in this study was much shorter when compared to the majority of existing research. This finding conflicts with previous studies that claim stretch-induced force deficit as a result of SS does not occur if warm-up protocols are not too excessive in terms of duration and intensity.

Recommendations

Based on the findings of this study, DS during warm-ups, as opposed to SS or NS, is more likely to improve performance in subsequent activities, specifically those that involve high speed motor capacities such as football or sprinting. SS may still be useful for increasing flexibility and may be benefical for sports where this is important (e.g. gymnastics, dance, etc.), however it would be better to perform SS on separate days alone and not as part of a warm-up routine.

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Appendix I – SPSS Output

General Linear Model

Notes

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Within-Subjects Factors

Measure: jump_height

Condition	Dependent Variable
1	Jump_no_stretch
2	Jump_static
3	Jump_dynamic

Descriptive Statistics

	Mean	Std. Deviation	N
Jump height in no stretch condition	46.2000	7.01427	5
Jump_static	42.6000	7.36885	5
Jump_dynamic	49.4000	6.80441	5

Multivariate Tests

Effect		Value	F	Hypothesis df	Error df	Sig.
Condition	Pillai's Trace	0.981	75.667	2.000	3.000	0.003
	Wilks' Lambda	0.019	75.667	2.000	3.000	0.003
	Hotelling's Trace	50.444	75.667	2.000	3.000	0.003

	Roy's Largest Root	50.444	75.667	2.000	3.000	0.003

Mauchly's Test of Sphericity

Measure: jump_height

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Condition	0.363	3.042	2	0.219	0.611	0.739	0.500

Tests of Within-Subjects Effects

Measure: jump_height

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Condition	Sphericity Assumed	115.733	2	57.867	28.459	0.000
	Greenhouse-Geisser	115.733	1.222	94.739	28.459	0.003
	Huynh-Feldt	115.733	1.479	78.275	28.459	0.001
	Lower-bound	115.733	1.000	115.733	28.459	0.006
Error(Condition)	Sphericity Assumed	16.267	8	2.033		
	Greenhouse-Geisser	16.267	4.886	3.329		
	Huynh-Feldt	16.267	5.914	2.750		
	Lower-bound	16.267	4.000	4.067		

Tests of Within-Subjects Contrasts

Measure: jump_height

Source		Type III Sum of Squares	df	Mean Squ	F	Sig.

				are		
Condition	Linear	25.600	1	25.600	23.273	0.008
	Quadratic	90.133	1	90.133	30.382	0.005
Error(Condition)	Linear	4.400	4	1.100		
	Quadratic	11.867	4	2.967		

Tests of Between-Subjects Effects

Measure: jump_height

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	31832.067	1	31832.067	218.427	0.000
Error	582.933	4	145.733		

Estimated Marginal Means

Condition

Estimates

Measure: jump_height

Condition	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	46.200	3.137	37.491	54.909
2	42.600	3.295	33.450	51.750
3	49.400	3.043	40.951	57.849

Pairwise Comparisons

Measure: jump_height

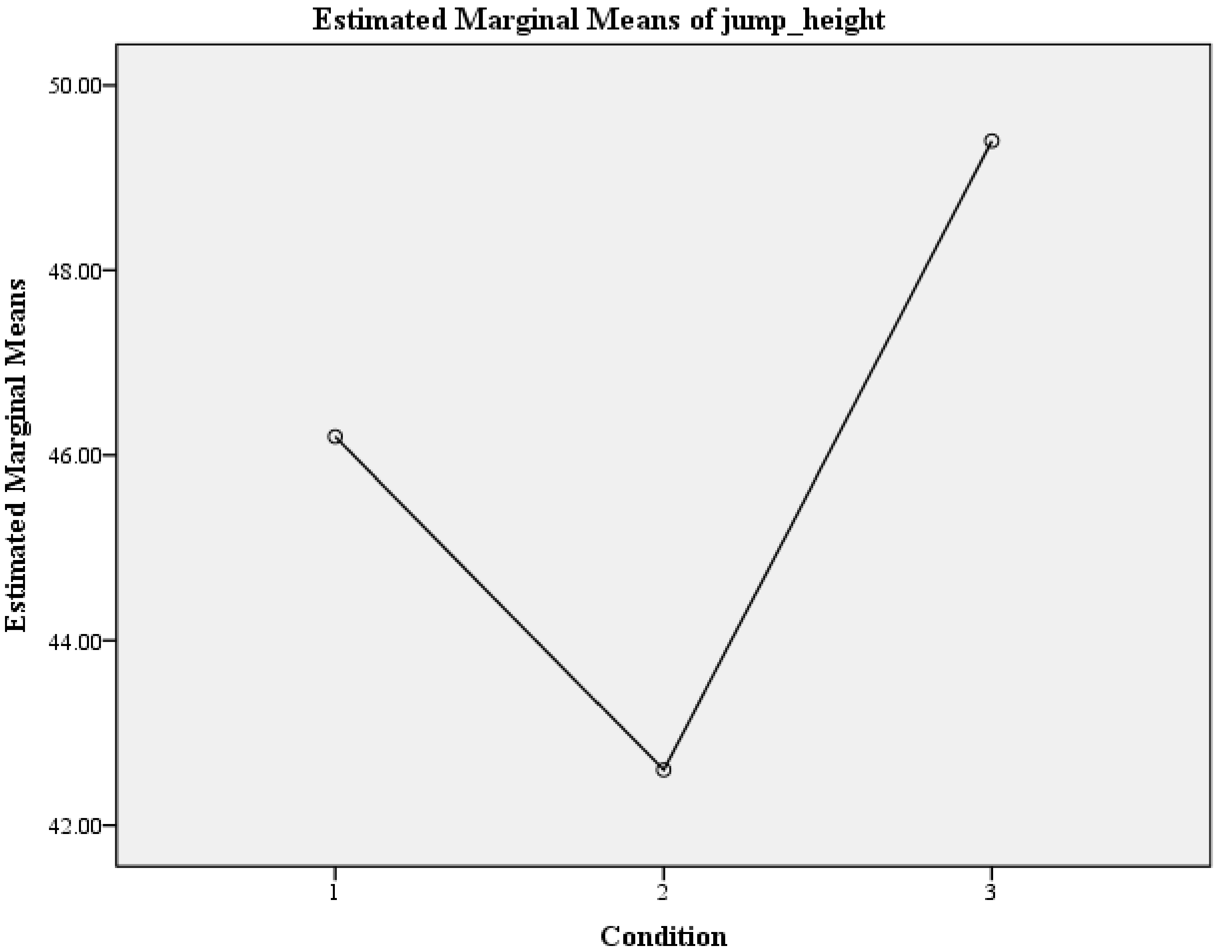
(I) Condition	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval for Difference	
				Lower Bound	Upper Bo

						un d
1	2	3.600	1.208	0.041	0.245	6.955
	3	-3.200	0.663	0.008	-5.042	-1.358
2	1	-3.600	1.208	0.041	-6.955	-0.245
	3	-6.800	0.735	0.001	-8.840	-4.760
3	1	3.200	0.663	0.008	1.358	5.042
	2	6.800	0.735	0.001	4.760	8.840

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.
Pillai's trace	0.981	75.667	2.000	3.000	0.003
Wilks' lambda	0.019	75.667	2.000	3.000	0.003
Hotelling's trace	50.444	75.667	2.000	3.000	0.003
Roy's largest root	50.444	75.667	2.000	3.000	0.003

Profile Plots

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General Linear Model

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Within-Subjects Factors

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Condition	Dependent Variable
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2	Sit_reach_static
3	Sit_reach_dynamic

Descriptive Statistics

	Mean	Std. Deviation	N
Sit_reach_no_condition	19.4000	5.59464	5
Sit_reach_static	22.2000	5.80517	5
Sit_reach_dynamic	20.6000	5.27257	5

Multivariate Tests

Effect		Value	F	Hypothesis df	Error df	Sig.
Condition	Pillai's Trace	0.859	9.147	2.000	3.000	0.053
	Wilks' Lambda	0.141	9.147	2.000	3.000	0.053
	Hotelling's Trace	6.098	9.147	2.000	3.000	0.053
	Roy's Largest Root	6.098	9.147	2.000	3.000	0.053

Mauchly's Test of Sphericity

Measure: sit_and

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Condition	0.971	0.088	2	0.957	0.972	1.000	0.500

Tests of Within-Subjects Effects

Measure: sit_and

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Condition	Sphericity Assumed	19.733	2	9.867	12.596	0.003
	Greenhouse-Geisser	19.733	1.944	10.153	12.596	0.004
	Huynh-Feldt	19.733	2.000	9.867	12.596	0.003
	Lower-bound	19.733	1.000	19.733	12.596	0.024
Error(Condition)	Sphericity Assumed	6.267	8	0.783		
	Greenhouse-Geisser	6.267	7.775	0.806		
	Huynh-Feldt	6.267	8.000	0.783		
	Lower-bound	6.267	4.000	1.567		

Tests of Within-Subjects Contrasts

Measure: sit_and

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Condition	Linear	3.600	1	3.600	4.235	0.109
	Quadratic	16.133	1	16.133	22.512	0.009
Error(Condition)	Linear	3.400	4	0.850		
	Quadratic	2.867	4	0.717		

Tests of Between-Subjects Effects

Measure: sit_and

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	6448.067	1	6448.067	70.677	0.001
Error	364.933	4	91.233		

Estimated Marginal Means

Condition

Estimates

Measure: sit_and

Condition	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
1	19.400	2.502	12.453	26.347
2	22.200	2.596	14.992	29.408
3	20.600	2.358	14.053	27.147

Pairwise Comparisons

Measure: sit_and

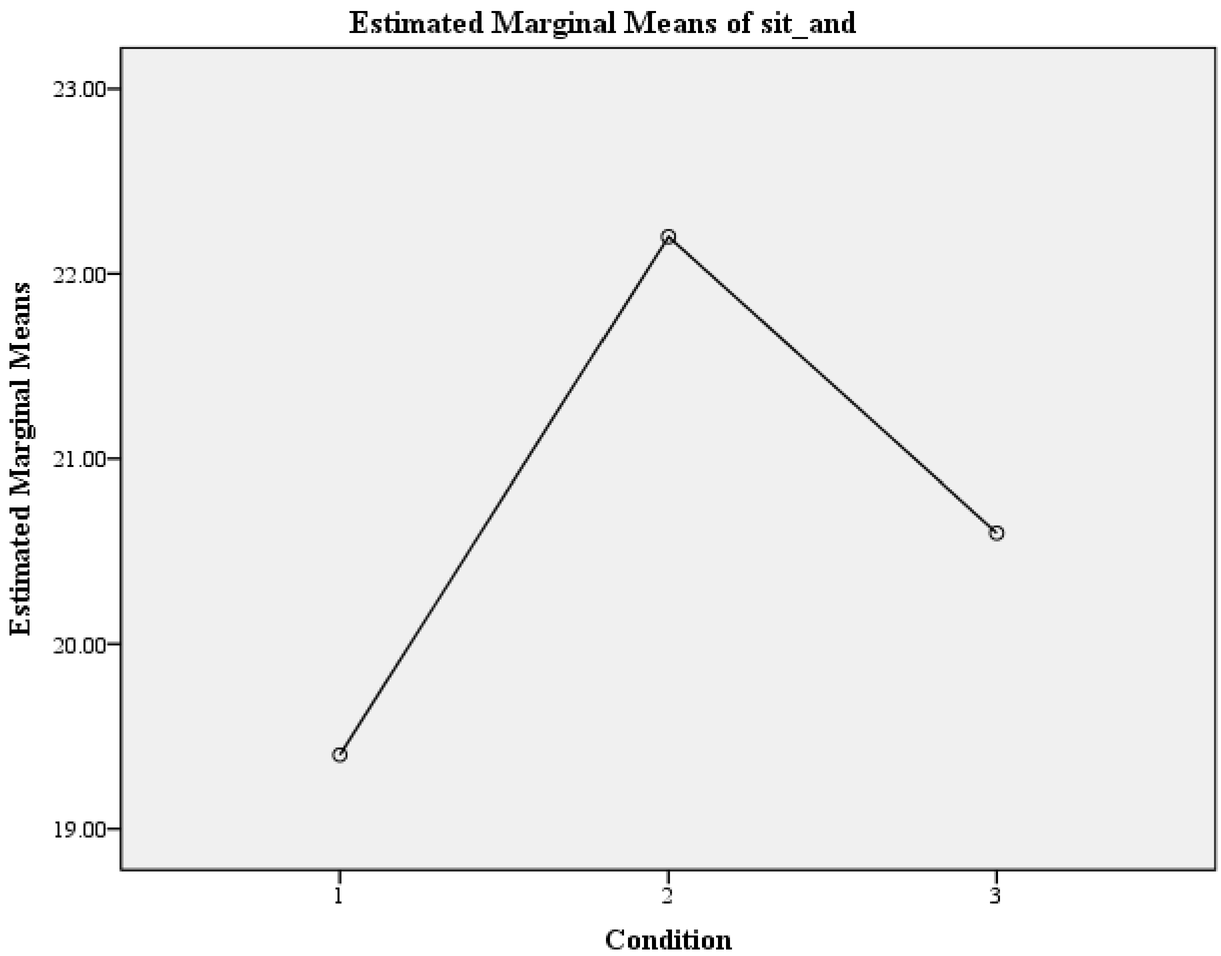
(I) Condition		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval for Difference Lower Bound	95% Confidence Interval for Difference Upper Bound
1	2	-2.800	0.583	0.009	-4.419	-1.181
	3	-1.200	0.583	0.109	-2.819	0.419
2	1	2.800	0.583	0.009	1.181	4.419
	3	1.600	0.510	0.035	0.184	3.016
3	1	1.200	0.583	0.109	-0.419	2.819
	2	-1.600	0.510	0.035	-3.016	-0.184

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.
Pillai's trace	0.859	9.147	2.000	3.000	0.053
Wilks' lambda	0.141	9.147	2.000	3.00	0.053

				0	
Hotelling's trace	6.098	9.147	2.000	3.000	0.053
Roy's largest root	6.098	9.147	2.000	3.000	0.053

Profile Plots

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General Linear Model

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Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Statistics are based on all cases with valid data for all variables in the model.
Syntax		GLM extension_60_no_stretch extension_60_static extension_60_dynamic /WSFACTOR=Condition 3 Polynomial /METHOD=SSTYPE(3) /PLOT=PROFILE(Condition) /EMMEANS=TABLES(Condition) COMPARE ADJ(LSD) /PRINT=DESCRIPTIVE

		/CRITERIA=ALPHA(.05) /WSDESIGN=Condition.
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Within-Subjects Factors

Measure: MEASURE_1

Condition	Dependent Variable
1	extension_60_no_stretch
2	extension_60_static
3	extension_60_dynamic

Descriptive Statistics

	Mean	Std. Deviation	N
extension_60_no_stretch	262.7000	52.86365	5
extension_60_static	256.2200	60.16870	5
extension_60_dynamic	277.7200	62.45876	5

Multivariate Tests

Effect		Value	F	Hypothesis df	Error df	Sig.
Condition	Pillai's Trace	0.459	1.272	2.000	3.000	0.398
	Wilks' Lambda	0.541	1.272	2.000	3.000	0.398
	Hotelling's Trace	0.848	1.272	2.000	3.000	0.398

	Roy's Largest Root	0.848	1.272	2.000	3.000	0.398

Mauchly's Test of Sphericity

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Condition	0.368	2.995	2	0.224	0.613	0.744	0.500

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Condition	Sphericity Assumed	1216.401	2	608.201	2.510	0.143
	Greenhouse-Geisser	1216.401	1.226	992.296	2.510	0.177
	Huynh-Feldt	1216.401	1.488	817.220	2.510	0.165
	Lower-bound	1216.401	1.000	1216.401	2.510	0.188
Error(Condition)	Sphericity Assumed	1938.592	8	242.324		
	Greenhouse-Geisser	1938.592	4.903	395.358		
	Huynh-Feldt	1938.592	5.954	325.603		
	Lower-bound	1938.592	4.000	484.648		

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Condition	Linear	564.001	1	564.001	3.392	0.139
	Quadratic	652.400	1	652.400	2.049	0.226
Error(Condition)	Linear	665.024	4	166.256		
	Quadratic	1273.568	4	318.392		

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	1057725.483	1	1057725.483	107.588	0.000
Error	39325.144	4	9831.286		

Estimated Marginal Means

Condition

Estimates

Measure: MEASURE_1

Condition	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	262.700	23.641	197.061	328.339
2	256.220	26.908	181.511	330.929
3	277.720	27.932	200.167	355.273

Pairwise Comparisons

Measure: MEASURE_1

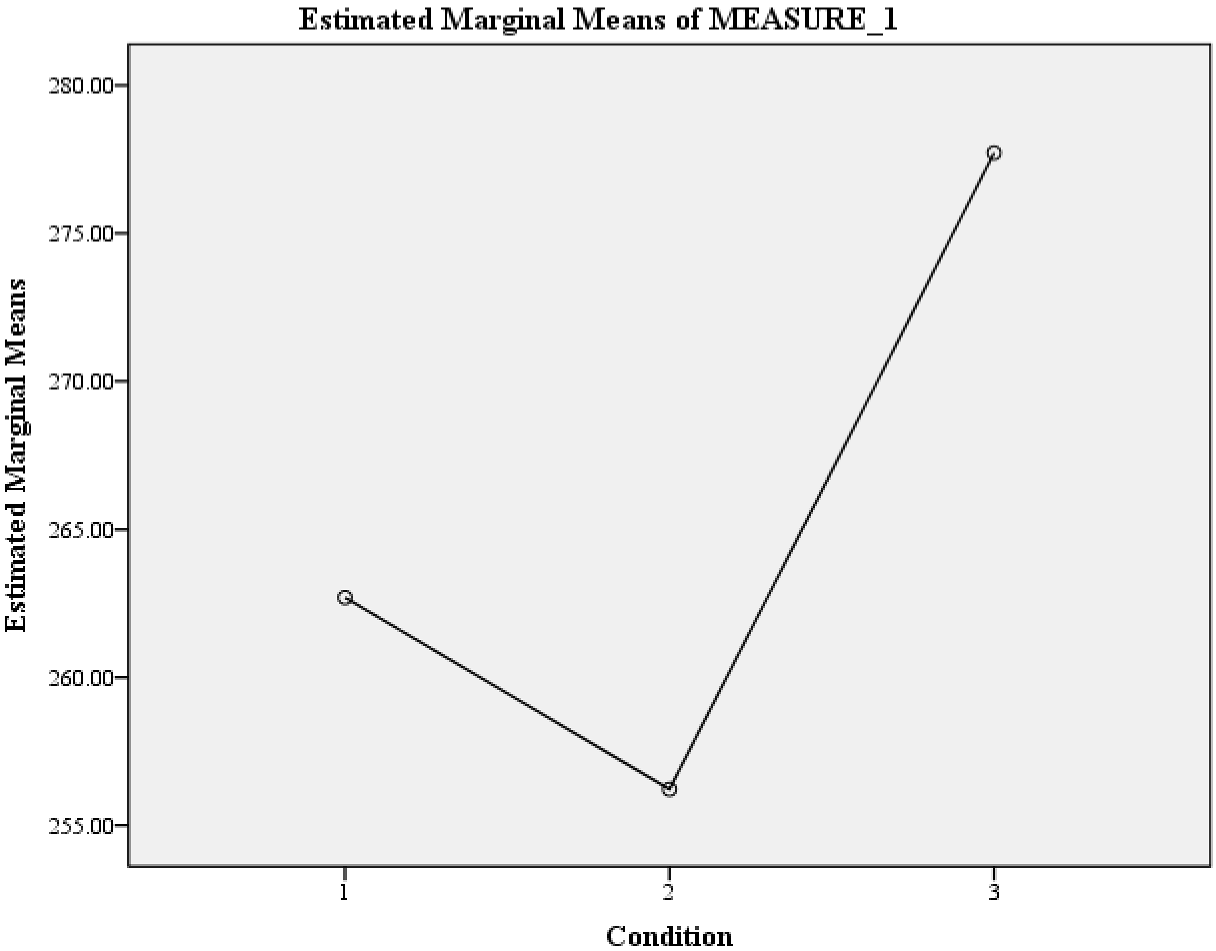
(I) Condition	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval for Difference

					Lower Bound	Upper Bound
1	2	6.480	7.132	0.415	-13.320	26.280
	3	-15.020	8.155	0.139	-37.662	7.622
2	1	-6.480	7.132	0.415	-26.280	13.320
	3	-21.500	13.169	0.178	-58.063	15.063
3	1	15.020	8.155	0.139	-7.622	37.662
	2	21.500	13.169	0.178	-15.063	58.063

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.
Pillai's trace	0.459	1.272	2.000	3.000	0.398
Wilks' lambda	0.541	1.272	2.000	3.000	0.398
Hotelling's trace	0.848	1.272	2.000	3.000	0.398
Roy's largest root	0.848	1.272	2.000	3.000	0.398

Profile Plots

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GLM extension_180_no_stretch
extension_180_static
extension_180_dynamic
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Polynomial
  /METHOD=SSTYPE(3)
  /PLOT=PROFILE(Condition)
  /EMMEANS=TABLES(Condition)
COMPARE ADJ(LSD)
  /PRINT=DESCRIPTIVE
  /CRITERIA=ALPHA(.05)
  /WSDESIGN=Condition.
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General Linear Model

Notes

Output Created	17-MAR-2017 17:02:09
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Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Statistics are based on all cases with valid data for all variables in the model.
Syntax		GLM extension_180_no_stretch extension_180_static extension_180_dynamic /WSFACTOR=Condition 3 Polynomial /METHOD=SSTYPE(3) /PLOT=PROFILE(Condition) /EMMEANS=TABLES(Condition) COMPARE ADJ(LSD) /PRINT=DESCRIPTIVE /CRITERIA=ALPHA(.05) /WSDESIGN=Condition.
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Within-Subjects Factors

Measure:	MEASURE

_1

Condition	Dependent Variable
1	extension_180_no_stretch
2	extension_180_static
3	extension_180_dynamic

Descriptive Statistics

	Mean	Std. Deviation	N
extension_180_no_stretch	200.0600	17.39477	5
extension_180_static	185.6600	40.54705	5
extension_180_dynamic	194.6600	40.93181	5

Multivariate Tests

Effect		Value	F	Hypothesis df	Error df	Sig.
Condition	Pillai's Trace	0.299	0.641	2.000	3.000	0.586
	Wilks' Lambda	0.701	0.641	2.000	3.000	0.586
	Hotelling's Trace	0.427	0.641	2.000	3.000	0.586
	Roy's Largest Root	0.427	0.641	2.000	3.000	0.586

Mauchly's Test of Sphericity

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Condition	0.762	0.815	2	0.665	0.808	1.000	0.500

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Condition	Sphericity Assumed	529.200	2	264.600	0.896	0.446
	Greenhouse-Geisser	529.200	1.616	327.517	0.896	0.431
	Huynh-Feldt	529.200	2.000	264.600	0.896	0.446
	Lower-bound	529.200	1.000	529.200	0.896	0.398
Error(Condition)	Sphericity Assumed	2363.267	8	295.408		
	Greenhouse-Geisser	2363.267	6.463	365.651		
	Huynh-Feldt	2363.267	8.000	295.408		
	Lower-bound	2363.267	4.000	590.817		

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Condition	Linear	72.900	1	72.900	0.228	0.658
	Quadratic	456.300	1	456.300	1.681	0.265
Error(Condition)	Linear	1277.650	4	319.413		
	Quadratic	1085.617	4	271.404		

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	561401.574	1	561401.574	185.205	0.000
Error	12124.949	4	3031.237		

Estimated Marginal Means

Condition

Estimates

Measure: MEASURE_1

Condition	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
1	200.060	7.779	178.462	221.658
2	185.660	18.133	135.314	236.006
3	194.660	18.305	143.836	245.484

Pairwise Comparisons

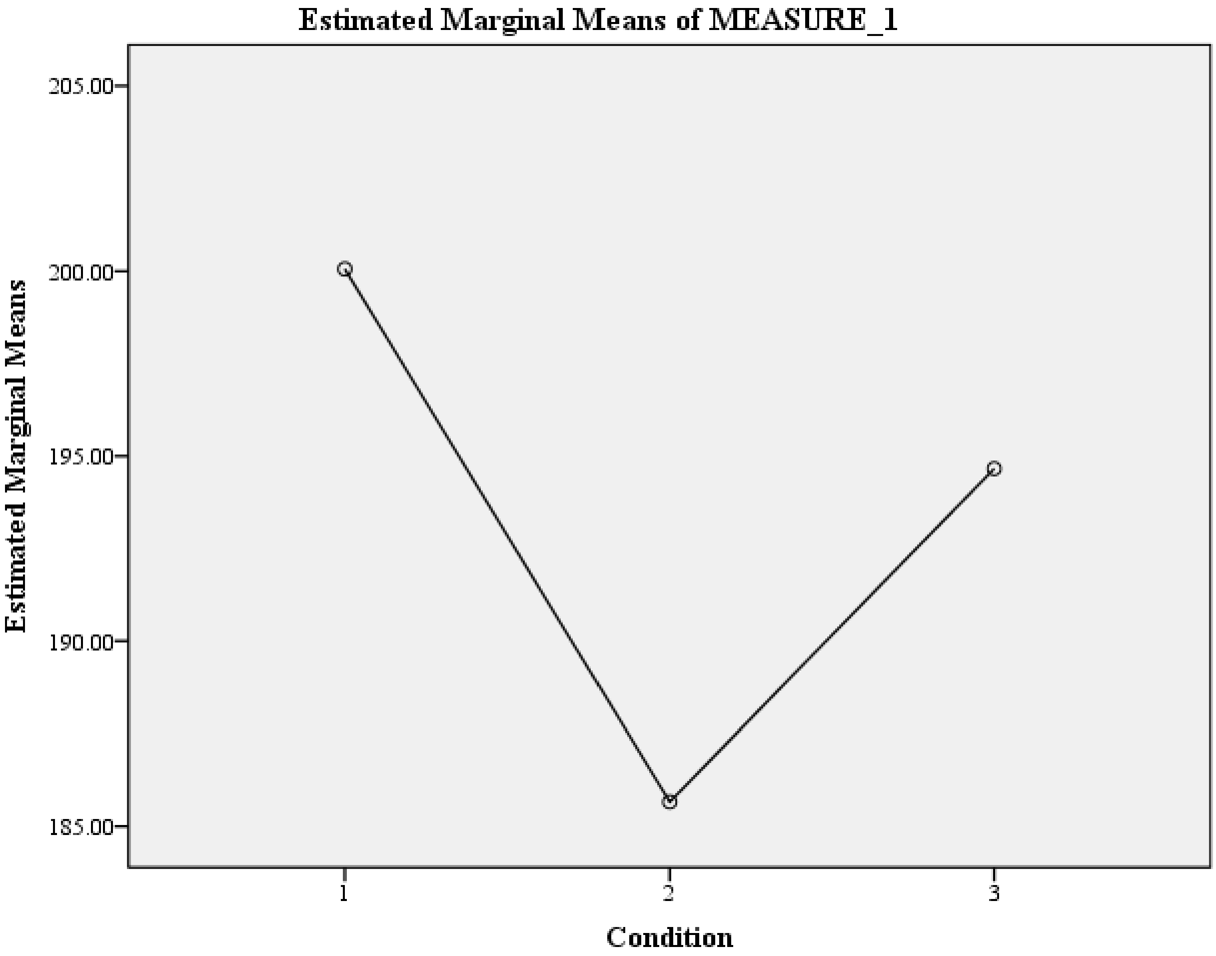
Measure: MEASURE_1

(I) Condition		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval for Difference Lower Bound	95% Confidence Interval for Difference Upper Bound
1	2	14.400	12.750	0.322	-21.000	49.800
	3	5.400	11.303	0.658	-25.983	36.783
2	1	-14.400	12.750	0.322	-49.800	21.000
	3	-9.000	8.010	0.324	-31.239	13.239
3	1	-5.400	11.303	0.658	-36.783	25.983
	2	9.000	8.010	0.324	-13.239	31.239

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.
Pillai's trace	0.299	0.641	2.000	3.000	0.586
Wilks' lambda	0.701	0.641	2.000	3.000	0.586
Hotelling's trace	0.427	0.641	2.000	3.000	0.586
Roy's largest root	0.427	0.641	2.000	3.000	0.586

Profile Plots

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GLM flexion_60_no_stretch
flexion_60_static
flexion_60_dynamic
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Polynomial
  /METHOD=SSTYPE(3)
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  /PLOT=PROFILE(Condition)
  /EMMEANS=TABLES(Condition)
COMPARE ADJ(LSD)
  /PRINT=DESCRIPTIVE
  /CRITERIA=ALPHA(.05)
  /WSDESIGN=Condition.
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General Linear Model

Notes

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Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Statistics are based on all cases with valid data for all variables in the model.
Syntax		GLM flexion_60_no_stretch flexion_60_static flexion_60_dynamic /WSFACTOR=Condition 3 Polynomial /METHOD=SSTYPE(3) /PLOT=PROFILE(Condition) /EMMEANS=TABLES(Condition)

		COMPARE ADJ(LSD) /PRINT=DESCRIPTIVE /CRITERIA=ALPHA(.05) /WSDESIGN=Condition.
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Within-Subjects Factors

Measure: MEASURE_1

Condition	Dependent Variable
1	flexion_60_no_stretch
2	flexion_60_static
3	flexion_60_dynamic

Descriptive Statistics

	Mean	Std. Deviation	N
flexion_60_no_stretch	111.5200	19.10803	5
flexion_60_static	108.1200	21.77055	5
flexion_60_dynamic	123.8400	18.92493	5

Multivariate Tests

Effect		Value	F	Hypothesis df	Error df	Sig.
Condition	Pillai's Trace	0.914	15.887	2.000	3.000	0.025
	Wilks' Lambda	0.086	15.887	2.000	3.000	0.025
	Hotelling's Trace	10.592	15.887	2.000	3.000	0.025

	Roy's Largest Root	10.592	15.887	2.000	3.000	0.025

Mauchly's Test of Sphericity

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Condition	0.896	0.330	2	0.848	0.906	1.000	0.500

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Condition	Sphericity Assumed	684.101	2	342.051	16.147	0.002
	Greenhouse-Geisser	684.101	1.811	377.731	16.147	0.002
	Huynh-Feldt	684.101	2.000	342.051	16.147	0.002
	Lower-bound	684.101	1.000	684.101	16.147	0.016
Error(Condition)	Sphericity Assumed	169.472	8	21.184		
	Greenhouse-Geisser	169.472	7.244	23.394		
	Huynh-Feldt	169.472	8.000	21.184		
	Lower-bound	169.472	4.000	42.368		

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Squ	F	Sig.

				are		
Condition	Linear	379.456	1	379.456	25.190	0.007
	Quadratic	304.645	1	304.645	11.157	0.029
Error(Condition)	Linear	60.254	4	15.064		
	Quadratic	109.218	4	27.305		

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	196630.851	1	196630.851	170.264	0.000
Error	4619.436	4	1154.859		

Estimated Marginal Means

Condition

Estimates

Measure: MEASURE_1

Condition	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	111.520	8.545	87.794	135.246
2	108.120	9.736	81.088	135.152
3	123.840	8.463	100.342	147.338

Pairwise Comparisons

Measure: MEASURE_1

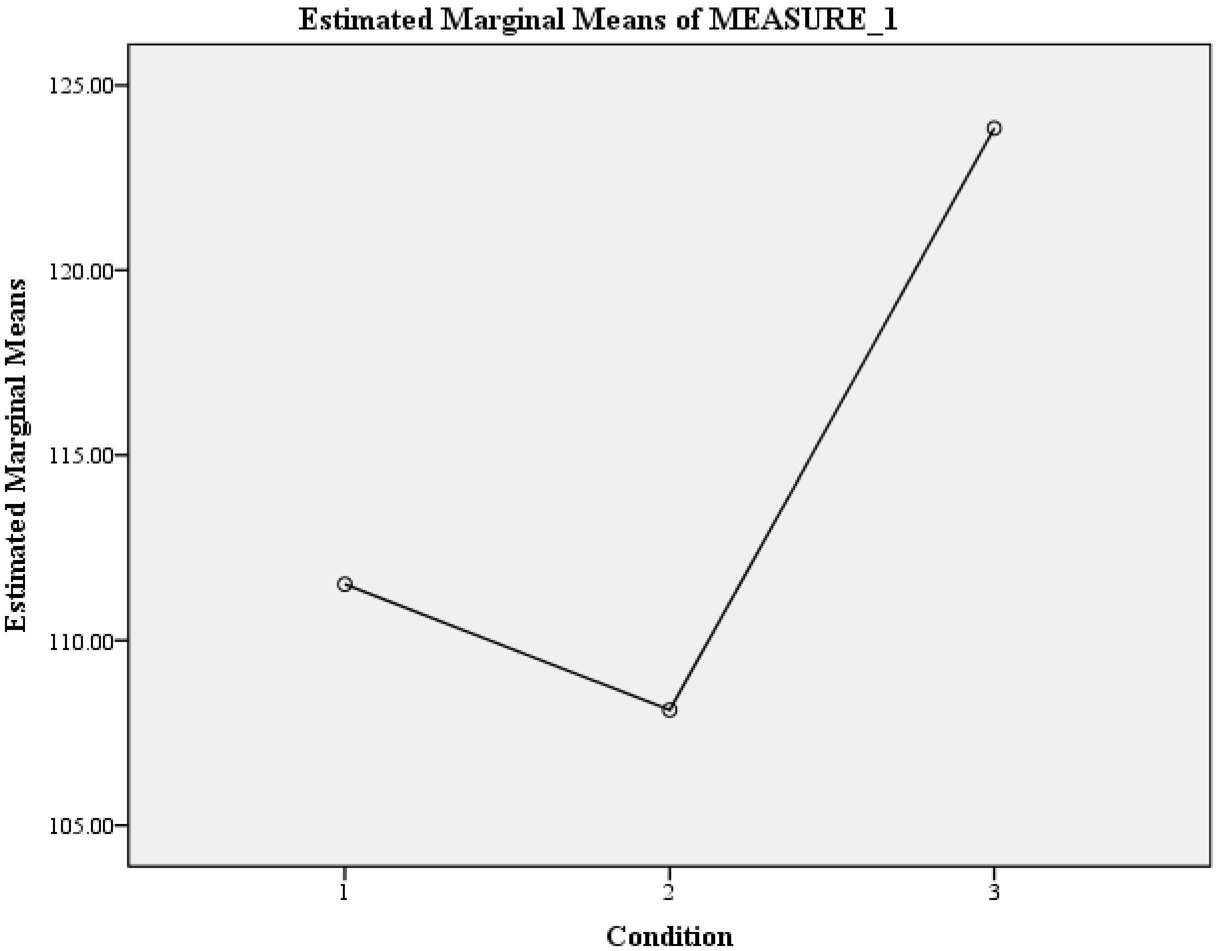
(I) Condition	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval for Difference	
				Lower Boun	Upper

					d	Bound
1	2	3.400	3.280	0.358	-5.706	12.506
	3	-12.320	2.455	0.007	-19.135	-5.505
2	1	-3.400	3.280	0.358	-12.506	5.706
	3	-15.720	2.939	0.006	-23.880	-7.560
3	1	12.320	2.455	0.007	5.505	19.135
	2	15.720	2.939	0.006	7.560	23.880

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.
Pillai's trace	0.914	15.887	2.000	3.000	0.025
Wilks' lambda	0.086	15.887	2.000	3.000	0.025
Hotelling's trace	10.592	15.887	2.000	3.000	0.025
Roy's largest root	10.592	15.887	2.000	3.000	0.025

Profile Plots




```
GLM flexion_180_no_stretch
flexion_180_static
flexion_180_dynamic
  /WSFACTOR=Condition 3
Polynomial
  /METHOD=SSTYPE(3)
  /PLOT=PROFILE(Condition)
  /EMMEANS=TABLES(Condition)
COMPARE ADJ(LSD)
  /PRINT=DESCRIPTIVE
  /CRITERIA=ALPHA(.05)
  /WSDESIGN=Condition.
```

General Linear Model

Notes

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Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Statistics are based on all cases with valid data for all variables in the model.
Syntax		GLM flexion_180_no_stretch flexion_180_static flexion_180_dynamic /WSFACTOR=Condition 3 Polynomial /METHOD=SSTYPE(3) /PLOT=PROFILE(Condition) /EMMEANS=TABLES(Condition) COMPARE ADJ(LSD) /PRINT=DESCRIPTIVE /CRITERIA=ALPHA(.05) /WSDESIGN=Condition.
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Within-Subjects Factors

Measure: MEASURE

_1

Condition	Dependent Variable
1	flexion_180_no_stretch
2	flexion_180_static
3	flexion_180_dynamic

Descriptive Statistics

	Mean	Std. Deviation	N
flexion_180_no_stretch	85.2400	8.66129	5
flexion_180_static	85.9800	11.63559	5
flexion_180_dynamic	93.4600	10.82534	5

Multivariate Tests

Effect		Value	F	Hypothesis df	Error df	Sig.
Condition	Pillai's Trace	0.912	15.566	2.000	3.000	0.026
	Wilks' Lambda	0.088	15.566	2.000	3.000	0.026
	Hotelling's Trace	10.377	15.566	2.000	3.000	0.026
	Roy's Largest Root	10.377	15.566	2.000	3.000	0.026

Mauchly's Test of Sphericity

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Condition	0.474	2.240	2	0.326	0.655	0.846	0.500

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Condition	Sphericity Assumed	206.777	2	103.389	9.141	0.009
	Greenhouse-Geisser	206.777	1.311	157.771	9.141	0.024
	Huynh-Feldt	206.777	1.693	122.138	9.141	0.014
	Lower-bound	206.777	1.000	206.777	9.141	0.039
Error(Condition)	Sphericity Assumed	90.483	8	11.310		
	Greenhouse-Geisser	90.483	5.242	17.260		
	Huynh-Feldt	90.483	6.772	13.361		
	Lower-bound	90.483	4.000	22.621		

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Condition	Linear	168.921	1	168.921	9.894	0.035
	Quadratic	37.856	1	37.856	6.824	0.059
Error(Condition)	Linear	68.294	4	17.074		
	Quadratic	22.189	4	5.547		

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	116759.171	1	116759.171	382.852	0.000
Error	1219.889	4	304.972		

Estimated Marginal Means

Condition

Estimates

Measure: MEASURE_1

Condition	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
1	85.240	3.873	74.486	95.994
2	85.980	5.204	71.533	100.427
3	93.460	4.841	80.019	106.901

Pairwise Comparisons

Measure: MEASURE_1

(I) Condition	(J) Condition	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval for Difference Lower Bound	95% Confidence Interval for Difference Upper Bound
1	2	-0.740	2.322	0.766	-7.188	5.708
	3	-8.220	2.613	0.035	-15.476	-0.964
2	1	0.740	2.322	0.766	-5.708	7.188
	3	-7.480	1.162	0.003	-10.705	-4.255
3	1	8.220	2.613	0.035	0.964	15.476
	2	7.480	1.162	0.003	4.255	10.705

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.
Pillai's trace	0.912	15.566	2.000	3.000	0.026
Wilks' lambda	0.088	15.566	2.000	3.000	0.026
Hotelling's trace	10.377	15.566	2.000	3.000	0.026
Roy's largest root	10.377	15.566	2.000	3.000	0.026

Profile Plots