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Research article

Acute Hemodynamic Responses to Three Types of Hamstrings Stretching in Senior Athletes

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Abstract

Although stretching is recommended for fitness and health, there is little research on the effects of different stretching routines on hemodynamic responses of senior adults. It is not clear whether stretching can be considered an aerobic exercise stimulus or may be contraindicated for the elderly. The purpose of this study was to compare the effect of three stretching techniques; contract/relax proprioceptive neuromuscular facilitation (PNF), passive straight-leg raise (SLR), and static sit-and-reach (SR) on heart rate (HR) and blood pressure (BP) in senior athletes (119 participants: 65.6 ± 7.6 yrs.). Systolic blood pressure (SBP), diastolic blood pressure (DBP), mean arterial pressure (MAP) and HR measurements were taken at baseline (after 5-minutes in a supine position), 45 and 90-seconds, during the stretch, and 2-minutes after stretching. Within each stretching group, (SLR, PNF, and SR) DBP, MAP and HR at pre-test and 2-min post-stretch were lower than at 45-s and 90-s during the stretch. SLR induced smaller increases in DBP and MAP than PNF and SR, whereas PNF elicited lower HR responses than SR. In conclusion, trained senior adult athletes experienced small to moderate magnitude increases of hemodynamic responses with SLR, SR and PNF stretching, which recovered to baseline values within 2-min after stretching. Furthermore, the passive SLR induced smaller increases in BP than PNF and SR, while PNF elicited lower HR responses than SR. These increases in hemodynamic responses (HR and BP) were not of a magnitude to be clinically significant, provide an aerobic exercise stimulus or warrant concerns for most senior athletes.

Key words: Systolic blood pressure; diastolic blood pressure; heart rate; flexibility; age.

Introduction

Stretch training programs have been shown to increase range of motion (ROM) (Bandy et al., 1997; 1998; Behm, 2018), which can reduce passive stiffness and is reported to improve postural balance (Nelson et al., 2012; Palmer et al., 2018). Although, stretching will not decrease the incidence of all-cause injuries (Behm et al., 2016; McHugh and Cosgrave, 2010; Pope et al., 1998; Shrier, 1999), it has been reported to decrease the prevalence of musculotendinous injuries (Behm et al., 2016; Smith, 1994). Furthermore, chronic stretching has been shown to improve (Lima et al., 22019a; 2019b; Mizuno, 2019; Nelson et al., 2012; Wilson et al., 1992; Yahata et al., 2021), impair (Barbosa et al., 2020) and have no significant effect on strength measures (Sato et al., 2020). Similarly, stretch training research also demonstrates either improvement (Handrakis et al., 2010; Lima et al., 2019a; 2019b) or no significant change (Bazett-Jones et al., 2008; Donti et al., 2021; Gunaydin et al., 2020) in jump performance. Whereas there is some conflict in the literature regarding the strength and power adaptations with acute and chronic stretch training (Behm et al., 2016; 2021; Behm and Chaouachi, 2011; Kay and Blazevich, 2012), it is generally perceived as a beneficial fitness training component for improving ROM and attenuating the incidence of musculotendinous injuries (Behm, 2018).

While the literature on the effects of stretch training on ROM is extensive (Behm, 2018; Behm et al., 2021; Lima et al., 2019a; 2019b), there is far less information on hemodynamic responses such as heart rate (HR), and blood pressure (BP). Thomas et al. (Thomas et al., 2021) published a meta-analysis analyzing 13 measures and reported static stretch-induced small to medium magnitude reductions (mean effect size = 0.38) in HR contrasting with no significant changes in systolic (SBP) or diastolic (DBP) blood pressure. While Thomas et al. (Thomas et al., 2021) reported overall reductions in HR with stretching, two studies in this meta-analysis disclosed no changes (Hotta et al., 2018; Inami et al., 2015), while another study reported increased HR (Kato et al., 2017). Three other studies not included in the Thomas meta-analysis further illustrate some of the conflict in the literature. Whereas da Silva Araujo et al. (da Silva Araujo et al., 2018) reported large magnitude HR decreases with stretching, Costa et al. (2019) found increased HR whether stretching was performed with a large to small muscle order or vice versa. While performing 10 sets of 30-s stretching, Lima et al. (2015) also reported stretch-induced HR increases with all 10 sets. These discrepancies may be related to whether the HR was measured during or after the stretch protocol, stretching duration (volume), rest intervals between stretching repetitions, stretch intensity (e.g., point of discomfort or below), the volume of muscle used, trained state of the participants among a myriad of other factors.

Similarly, there is also conflicting stretch-induced modifications to BP. With static stretching, lower BP reported during the stretch intervention (Costa et al., 2019; da Silva Araujo et al., 2018) contrasts with increased BP during all 10 sets of static stretching (Lima et al., 2015). With proprioceptive neuromuscular facilitation (PNF) stretching, Cornelius and Craft-Hamm (1988) reported insignificant changes in BP utilizing PNF techniques such as "hold-relax," "contract-relax," and "slow-reversal-hold-relax" (average increase in systolic blood pressure: SBP =

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6 mmHg and diastolic blood pressure: DBP = 3 mmHg). Cornelius et al. (1995) reported that while 1-2 trials of contract-relax PNF stretching of the hamstrings, utilizing a straight-leg-raise technique, did little to increase BP, the completion of three or more trials did increase acute BP (SBP: +10 mmHg and DBP: +3.6 mmHg). However, these increases, while statistically significant, were reported to be clinically insignificant at less than 15 mmHg above baseline values for both SBP and DBP. Holt et al. (Holt et al., 1995), reported a 27 mmHg SBP increase by the fourth repetition of a contract (12-s)-relax PNF stretching protocol of the hamstrings (supine) and erector spinae (seated). Notwithstanding the aforementioned result conflicts, all these studies involved young adults and hence there is no information regarding the effects of an acute bout of stretching on the hemodynamic responses of senior adults.

While heart disease and stroke are ranked first and fourth respectively as the leading causes of death in the USA (Johnson et al., 2014), physical inactivity is a primary cause of most chronic diseases (Booth et al., 2012). However, there is some evidence for positive hemodynamic outcomes for older individuals with chronic training studies. An 8-week longitudinal training study of 40 older men and women (mean: 61 years) that compared static stretching to walking (5 sessions per week for 30-min each) found that stretching was more effective for decreasing BP (Ko et al., 2020). Kato et al. (2020) in a meta-analysis of eight trials (213 middle-aged and older adults) reported significantly reduced resting HR (-0.95 beats/min) and DBP (-1.43 mmHg) as well as reduced arterial stiffness and improved vascular endothelial function.

As an individual reaches middle age, cardiovascular performance begins to decline progressively (American College of Sports Medicine, 2014). This may result from a decrease in cardiac output, which may be due in part to an increased "stiffness" of the arterial walls and ventricular walls, leading to a decline in early diastolic ventricular filling and an increase in afterload (Wei, 1992). Resting systolic pressures tend to rise approximately 20 mmHg between the ages of 20 to 60 years, and by another 20 mmHg between 60 and 80 years of age (Wei, 1992). The presence of these age-related physiologic changes may alter elderly responses to stretching.

Therefore, the purpose of this study was to investigate the acute hemodynamic (HR and BP) effects of three different stretching techniques on senior athletes (> 50 years of age as per the definition and regulations of the World Senior Games: https://seniorgames.net/information/rules-and-information): contract-relax proprioceptive neuromuscular facilitation (CRPNF) and two different forms of static stretch; passive-straight-leg-raise (P-SLR) and a unilateral sit-and-reach (SIT).

Methods

Participants

A total of 119 participants (age 65.8 ± 7.3 yrs.; 50-94 yrs., height: 1.71 ± 0.10 m, mass: 74.7 ± 12.4 kg) were recruited from a health fair offered to participants of the World Senior Games in St. George, Utah. In order to qualify for this stretching study, subjects had to demonstrate some "tightness" of the hamstrings. For this study, participants had to achieve greater than 80º of hip flexion in a straight-leg raise. While this may be considered within normal limits, it assured that the subject would be able to be put into this position without needing to go into excessive ROM. Any recent history (past three months) of hip or knee pathology or any history of hip or knee replacement surgery disqualified prospective subjects. Subjects taking blood pressure medication or with a baseline blood pressure of greater than 160/95 were not allowed to participate in the study. Even though 140/95 is considered hypertensive, the value of 160/95 was chosen as the cut-off point to allow for the typical age-related increase in systolic values (as previously mentioned). There were four subjects who were disqualified due to medication, and three participants who were disqualified due to a baseline blood pressure greater than 160/95.

Subjects were informed of any possible risks in the study and signed an institutionally approved informed consent form. The study was approved by the university research board and adhered to the Declaration of Helsinki. Subjects were randomly assigned to one of three groups: a passive-straight-leg-raise (SLR) group (n = 41; 29 male, 12 female; mean age = 66 ± 8.4), a contract-relax PNF group (n = 39; 24 males:15 females; mean age = 64.5 ±8.2), or a sit and reach static stretch (SR) group (n = 39; 25 males:14 females; mean age = 66.4±6.1.

Hemodynamic measurements

All blood pressure measurements were taken using the Dinamap™ Pro 400 (GE Medical Systems) vital signs monitor and BP cuff. This system provided HR and BP (SBP, DBP, and mean arterial pressure (MAP)). The MAP (MAP = (1/3)(SBP - DBP) + DBP) is a measurement of the average pressure during the cardiac cycle, and is frequently used in the clinical setting to calculate vascular resistance, and is important in relation to critical closing pressures for organ perfusion. Dinamap™ accuracy compared to central aortic mean values in adults is reported as being within -1.11 mmHg for DBP, -3.53 mmHg for SBP, and -2.12 mmHg for MAP (https://www.dremed.com/catalog/documents/dinamap_pro100_400.pdf). The Dinamap pro series monitors have been validated and shown to exceed the standards suggested by the Association for the Advancement of Medical Instrumentation (AAMI) (Brothwell et al. 2013). All subjects had their BP and HR measurements taken at four different times from their right arm. The first measurement (baseline or pre-test) was taken after 5-minutes of resting in a supine position. The subject was then positioned appropriately to start the assigned stretch. After approximately 1-minute, the 2nd and 3rd measurements were taken and recorded by the 45-second and 90-second period of the stretch. The 4th measurement was taken two minutes after stretching was completed. The Dinamap™ was used in 'stat' mode to allow for manual starting of blood pressure measurements at different time intervals. This setting is commonly used in critical care, and the Dinamap™ has a reported mean difference of -2.83 mmHg for early systolic "stat" mode when compared to central aortic mean values in adults (as reported by GE Medical Systems).

In order to check the validity of the Dinamap™ monitors, 22 subjects had their BP taken by manual sphygmomanometry in a seated position from the same tester. Seated BP measurements were then taken 3-5 minutes later with the Dinamap™ Pro 400 monitor. The mean difference in the Dinamap™ measurements were 3.6 mmHg for SBP and -2.8 mmHg for DBP. These values were acceptable based on guidelines from the National High Blood Pressure Education Program Working Group Report on Ambulatory Blood Pressure Monitoring (1990), which considered ambulatory pressure monitors to be valid if SBP and DBP are within ±5mmHg.

Stretching methods

All the stretching methods had the following controls:

1. The time of stretch was monitored by a stopwatch from a research assistant. Two research assistants were used, one for each primary researcher performing the stretching techniques. These "time-keepers" were also responsible to start the BP monitor at the appropriate time intervals.
2. All contract-relax PNF stretches were performed by the same researcher (#1), and all passive SLR and SR stretches were performed by the same researcher (#2). These responsibilities were divided to assure consistent instruction and performance of each stretching technique.
3. The contralateral leg in the contract relax PNF and passive SLR methods was held down to the table using a strap.

Supine Passive-Straight-Leg-Raise Stretch (SLR): While lying in a supine position, the right leg of the subject was elevated passively to the point where the subject stated that the stretch had reached a point of "mild discomfort," and held for 90 seconds. Tension was retained during the stretch in order to maintain the point of "mild discomfort".

Contract-Relax Proprioceptive Neuromuscular Facilitation (PNF) stretch: For this intervention we chose to utilize the contract-relax method of PNF stretching, due to its ease of administration. While lying supine on the examining table, the subject's right leg was held by the researcher in a position of neutral internal/external rotation, and the foot was held in neutral plantar flexion/dorsiflexion. The leg was then lifted by the researcher in a SLR to the point where the subject began to feel "mild discomfort." The contralateral leg remained in contact with the table, held by a strap. The subject was then asked to perform a maximum voluntary isometric contraction (MVIC) of the hamstrings for 6-seconds while the researcher held the leg motionless. This contraction was immediately followed by 15-seconds of rest, during which the leg was adjusted to the new point of "mild discomfort." Then a BP measurement was taken while the leg remained in the SLR position. Two more contract-relax cycles (6-second contractions followed by 15-second relaxation in a "mild discomfort" position) were performed, followed once again by a final BP measurement. The limb was in a stretched position (duration of stretching and BP measures) for approximately 90-seconds.

Seated Sit and Reach Static Stretch (SR): While seated on the examining table the subject was instructed to keep the back straight and reach toward the toes of the right leg (with the knee fully extended) to the point of "mild discomfort". The left leg was allowed to hang off the table and touch the ground for support. The stretch was then held for 90-seconds.

Statistical analysis

Statistical analyses were completed using the SPSS software (Version 27.0, SPSS, Inc. Chicago, IL). The assumption of sphericity and normality were tested for all dependent variables and if a violation was noted, the corrected values for non-sphericity with Greenhouse-Geisser were reported. A 3 x 4 (stretch technique x time with stretch technique as a between factor and time as a within factor) repeated measures ANOVA was performed on all BP (SBP, DBP, and MAP) and HR data to determine if HR and BP responses were different over time between the three different stretching protocols. Scheffe's post hoc analyses were run to determine where differences existed. Significance was set at $p \leq 0.05$. Standardized (Cohen's) effect sizes (d) were qualitatively interpreted as: trivial: <0.2, small: $0.2 \leq d < 0.5$; medium: $0.5 \leq d < 0.8$; large: $d \geq 0.8$) (Cohen, 1988). Eta^2 values of 0.01, 0.06, and 0.14 correspond to small, moderate, and large main effects and interactions, respectively.

Results

Systolic Blood Pressure (SBP)

A main effect for testing time ($F_{3,456} = 102.7$; $p < 0.0001$; eta^2: 0.403) demonstrated that pre-test SBP was 7.4% (d = 1.3) and 9.7% (d = 1.6) lower than at 45-s and 90-s during the stretch respectively. Secondly, the 45-s SBP measure was 2.5% (d = 0.4) lower than the 90-s stretch test. Furthermore, the 45-s and 90-s tests during the stretch were 6.4% (d = 0.99) and 9.2% (d = 1.4) greater than the 2-min post-stretch measure respectively. There were no significant interactions or main effects for stretch groups.

Diastolic Blood Pressure (DBP)

A group x time interaction ($F_{9,462} = 3.7$; $p < 0.0001$; eta^2: 0.067) revealed that SLR DBP was 11.1% (d = 0.5, p = 0.03) and 5.02% (d = 0.4, p = 0.08) lower than PNF and SR at 45-s during the stretch. At 90-s and 2-min, SLR DBP was also lower than PNF by 4.9% (d = 0.4, p = 0.08) and 5.2% (d = 0.3, p = 0.05) respectively. Within each group, (SLR, PNF, and SR) DBP at pre-test and 2-min post-stretch were lower than at 45-s and 90-s during the stretch (Table1 and Figure 1).

A main effect for testing time ($F_{3,462} = 85.3$; $p < 0.0001$; eta^2: 0.356) showed that the pre-test DBP was 7.9% (d = 1.3) and 7.7% (d = 1.2) lower than at 45-s and 90-s of stretch. Similarly, the 2-min post-test DBP was 7.3% (d = 1.1) and 7.1% (d = 1.1) lower than 45-s and 90-s stretch tests. There were no significant main effects for groups.

Mean Arterial Pressure (MAP)

A group x time interaction ($F_{9,462} = 8.6$; $p < 0.0001$; eta^2: 0.143) exhibited that the 45-s stretch test SLR MAP was 5.8% (d = 0.5, p = 0.03) and 5.4% (d = 0.46, p = 0.04) lower than PNF and SR respectively. At 90-s and 2-min, SLR

MAP was 5.2% (d = 0.4, p = 0.06) and 6.5% (d = 0.6, p = 0.01) lower than PNF. SLR MAP was near significantly lower than SR at 90-s and 2-min by 5.3% (d = 0.4, p = 0.07) and 4.6% (d=0.4, p=0.08) respectively. Within each group, (SLR, PNF, and SR) MAP at pre-test and 2-min post-test were lower than at 45-s and 90-s during the stretch (Table 1 and Figure 2).

Table 1. Systolic and diastolic blood pressur, mean arterial pressure and heart rate mean ± standard deviation values for each stretch group over the testing periods.

	Pre-test	45-s	90-s	2-min
	Systolic Blood Pressure (SBP: mmHg)			
Single Leg Raise	125.5 ± 12.3	135.3 ± 16.3	136.5 ± 16.7	127.1 ± 15.0
PNF	131.0 ± 15.7	137.6 ± 16.7	142.3 ± 18.2	132.2 ± 14.7
Sit and Reach	125.1 ± 13.7	136.6 ± 16.7	141.3 ± 18.9	127.5 ± 15.9
	Diastolic Blood Pressure (DBP: mmHg)			
Single Leg Raise	72.02 ± 8.2	76.1 ± 10.4 *#	76.4 ± 10.7 *†	71.6 ± 9.4 †
PNF	75.6 ± 8.6	81.0 ± 9.04 *	80.4 ± 9.5 *†	75.5 ± 8.1 †
Sit and Reach	69.5 ± 8.6	80.2 ± 10.2 *	79.9 ± 11.1 *	73.6 ± 9.8
	Mean Arterial Pressure (MAP)			
Single Leg Raise	89.9 ± 10.4	96.9 ± 11.5 *#	98.5 ± 12.4 *†	89.9 ± 11.04 †
PNF	96.1 ± 12.1	102.9 ± 12.5 *	103.9 ± 13.1 *†	96.2 ± 11.2 †
Sit and Reach	88.0 ± 9.9	102.4 ± 12.5 *	104.0 ± 14.0 *	94.2 ± 10.9
	Heart Rate (HR: beats/min)			
Single Leg Raise	64 ± 10	67 ± 13 *	67 ± 12 *	65 ± 12
PNF	62 ± 11	68 ± 10 *†	69 ± 11 *†	61 ± 10 †
Sit and Reach	63 ± 11	74 ± 13 *†	74 ± 14 *†	67 ± 13 †

For each stretch group and testing time, the 45-s and 90-s values significantly (*) exceeded the pre-test and 2-min post-tests with the exception of systolic blood pressure (no significant interaction). Hashtags (#) indicate significant differences between SLR and the other two groups at that time point. The asperand (†) symbol shows significant differences between the two stretches at those time points (MAP: PNF>SLR, HR: SR>PNF).

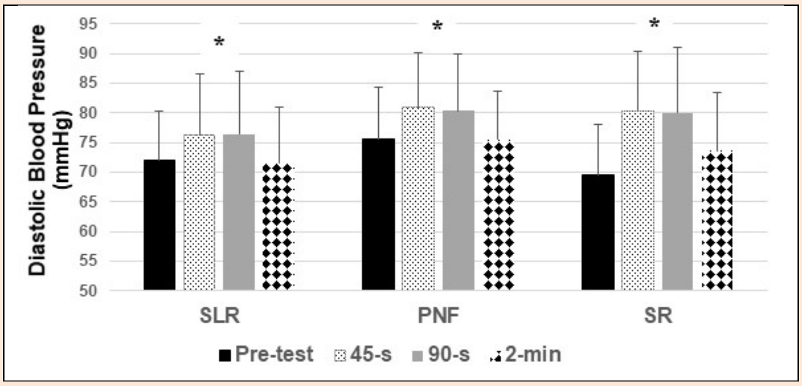

Figure 1. Diastolic blood pressure changes with each stretch group (SLR: single leg raise, PNF: proprioceptive neuromuscular facilitation, SR: sit and reach) over the four testing times. * represents a significant difference at 45-s and 90-s versus pre-test and 2-min post-test.

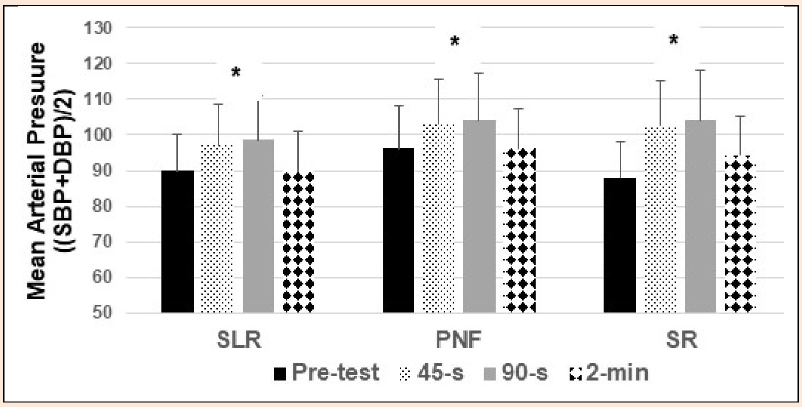

Figure 2. Mean arterial pressure changes with each stretch group (SLR: single leg raise, PNF: proprioceptive neuromuscular facilitation, SR: sit and reach) over the four testing times. * represents a significant difference at 45-s and 90-s versus pre-test and 2-min post-test.

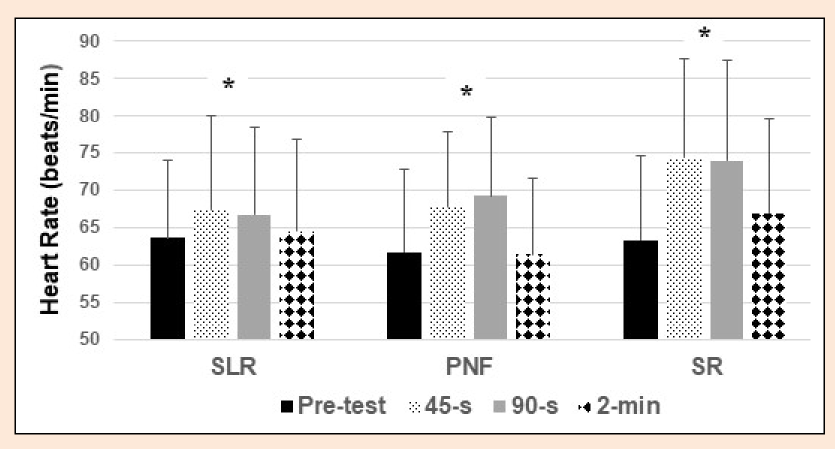

Figure 3. Heart rate changes with each stretch group (SLR: single leg raise, PNF: proprioceptive neuromuscular facilitation, SR: sit and reach) over the four testing times. * represents a significant difference at 45-s and 90-s versus pre-test and 2-min post-test.

A main effect for testing time ($F_{3,462} = 103.4$; $p < 0.0001$; eta^2: 0.402) revealed that pre-test MAP was 8.7% (d = 1.4) and 9.9% (d = 1.6) lower than at 45-s and 90-s during the stretch. Additionally, 45-s and 90-s MAP scores were 8.0% (d = 1.25) and 9.6% (d = 1.4) higher than 2-min post-test respectively. A near significant main effect for group ($F_{3,154} = 2.44$; p = 0.06; eta^2: 0.045) suggested that SLR group exhibited small to moderate magnitude 5.9% (d = 0.55), and 3.4% (d = 0.3) lower MAP values than the PNF and SR groups.

Heart Rate (HR)

A significant group x time interaction ($F_{9,462} = 8.6$; $p < 0.0001$; eta^2: 0.143) exhibited that PNF HR were lower than SR at 45-s, 90-s and 2 min by 8.8% (d = 0.5, p = 0.01), 6.5% (d = 0.4, p = 0.09) and 8.2% (d = 0.4, p = 0.04) respectively. Within each group, (SLR, PNF, and SR) HR at pre-test and 2-min post-test were lower than at 45-s and 90-s during the stretch (Table 1 and Figure 3).

A main effect for testing time ($F_{3,462} = 167.6$; $p < 0.0001$; eta^2: 0.521) revealed that pre-test HR was 9.8% (d = 1.1) and 1.6% (d = 0.16) lower than 45-s, 90-s and 2-min post-stretch respectively. The 45-s and 90-s post-tests were 9.2% (d = 0.95) and 9.3% (d = 0.96) higher than the 2-min post-test respectively.

Discussion

The major findings of this stretching study involving trained senior adult athletes were that stretching significantly elevated hemodynamic responses by small to moderate magnitudes, which recovered to baseline values within 2-min after stretching. Secondly SLR induced smaller increases in DBP and MAP than PNF and SR, whereas PNF elicited lower HR responses than SR.

Although all stretches increased hemodynamic responses, the magnitude of increased stress would not provide sufficient stress to be considered a training stimulus (American College of Sports Medicine, 2014; Association, 2021) nor would the stretching constitute a health risk to an older trained population (Association, 2021). The elite level senior athletes in this study demonstrated an average resting blood pressure of 127/74 mmHg, (SBP/DBP), HR of 64 bpm, and MAP of 94 mmHg. These values would be considered "normal healthy" in a young adult population (Association, 2021). It has been documented that physically conditioned elderly have lower resting BP and HR (Larson and Bruce, 1987) than inactive seniors, with training helping to maintain positive health characteristics and slow a number of age-related cardiovascular changes (Wei, 1992). As such, the significant, small to moderate magnitude increases in hemodynamic measures may be less pronounced and the recovery may be accelerated with this trained group of seniors compared to less active senior adults.

The average SBP, DBP and MAP increases of 13, 5, and 16 mmHg respectively may be considered clinically insignificant as the average blood pressure increased to 140/79 during the 90 second stretch. Although a chronic SBP of 140 has been classified as stage I hypertension (Lionakis et al., 2012), less than 2 minutes at this value would not be risky. The Eighth Joint National Committee (James et al., 2014) recommend that individuals over 60 years achieve chronic readings below 150/90 mmHg. It is not uncommon for younger individuals to exercise for prolonged periods (e.g., 20 minutes of running or cycling) with SBP approaching 200 mmHg (Wen et al., 2019) without undue health risks. However, the stretch-induced BP increase to 140/79 is only a mathematical average, and individuals may have greater than average changes, which may be unhealthy. In this study, 31 subjects had SBP increases of >20 mmHg and two participants had increases of >40 mmHg. Furthermore, 15 subjects had MAP elevations of 18 mmHg or lower (down to -17 mmHg), however, 23 of the 39 subjects in the SR group had elevations of 20 mmHg or greater, and two subjects had MAP elevations of 43 and 44 mmHg. Such elevations in MAP could put a senior at cardiovascular risk (e.g., stroke), and may indicate that the SR stretching should be closely monitored in these individuals. These results support the importance of individual monitoring or screening of hemodynamic responses with these stretching methods.

Overall, each method of stretching does not appear to elevate HR significantly enough (combined average increase of 5 BPM) to be of concern to the average senior athlete. The HR changes observed in this study were clinically insignificant when compared to baseline as an increase to 69 BPM is still below the resting HR average range of 70-75 bpm across the lifespan. Furthermore, this stretch-induced elevation in HR would not constitute an exercise training session since according to the American Heart Association (Association, 2021), recommended exercise HR target zones for various senior age groups are 60 years: 80-136 bpm, 65 years: 78-132 bpm, and 70 years: 75-128 bpm. Thus, an average HR of 69 bpm during stretching should pose minimal or no risk to those individuals involved in a stretching routine as part of an ongoing physical fitness regimen.

A second major finding in this study was that passive SLR (DBP: 76 mmHg, MAP: 94 mmHg) induced smaller increases in DBP and MAP than PNF (DBP: 80-81 mmHg, MAP: 100 mmHg) and SR (DBP: 80 mmHg, MAP: 97 mmHg). Since PNF and SR involved active large lower limb and trunk muscle contraction-induced constriction of vasculature, there would be a pressor response (Cornelius et al., 1995) with the extent of the pressor response related to muscle mass volume (Buck et al., 1980; Fleck, 1988). The lack of active contractions with the researcher assisted passive SLR would have involved less constriction of the calibre of the vessels inducing less hemodynamic stress. In addition, activation of muscle mechanoreceptors with muscle contractions and passive stretch can augment HR and BP (Baum et al., 1995; Gladwell and Coote, 2002; Murata and Matsukawa, 2001). In contrast, active stretching of smaller muscle groups would elicit lower hemodynamic responses (Smolander et al., 1998). There are also reported age effects as significantly lower rise in HR and a greater rise in BP was found in subjects above 50 (54-59) years of age when compared to younger subjects (23-29 years) when performing isometric hand grip and knee extension exercises (Smolander et al., 1998).

These findings are in accord with prior studies that demonstrate PNF-induced higher SBP and DBP measures when either greater contraction intensities were used (50% vs. MVIC) (Holt et al., 1995) or both the agonist (hamstrings) and antagonist (quadriceps) muscles were contracted (contract relax antagonist contract: CRAC vs. contract relax: CR PNF methods) (Cornelius and Craft-Hamm, 1988; Cornelius et al., 1995). The contract relax PNF SBP responses in the present study were slightly lower than Cornelius et al. (1995) (SBP: 143-148 mmHg)) but relatively did present similar DBP responses (DBP: 77-89 mmHg). Holt et al. (1995) reported similar results as the present study when using 50% MVIC during PNF (SBP: 133-150 mmHg, DBP: 72-80 mmHg), but substantially higher values when using MVICs (SBP: 150-163 mmHg, DBP: 85-91 mmHg). Finally, the second Cornelius and Craft-Hamm (1988) study demonstrated lower SBP (127-130 mmHg) contrasting with higher DBP responses (83-88 mmHg) than the present study. Hence, hemodynamic responses to PNF stretching differences between studies may be attributed to the variation in contraction intensities, use of CRAC versus CR PNF methods as well as participants' age (seniors vs. younger adults) and trained state (elite senior athletes versus active young adults). Since CRPNF stretching using submaximal contractions has been reported to be just as beneficial at improving hamstrings flexibility as maximal contractions, lower intensity contractions should be advocated when considering flexibility (Behm et al. 2016, Behm 2018) and hemodynamic responses (Feland and Marin, 2004).

The lower HR responses with PNF versus SR may be related to the intermittent occlusion of vasculature with PNF versus the continuous 90 second active stretch with SR. The PNF sequence involved 3 sets of 6 second contractions followed by 15 seconds of passive stretch. The PNF transitions from contraction to a passive stretch versus a continuous active stretch with SR would allow a better transit of blood through the vessels oscillating BP from higher (contraction) to lower (passive stretch) values, and therefore, improved oxygenation of the tissues. Occlusion-induced reductions in BP have been reported with isometric resistance training (after more than 4 weeks) (Lawrence et al., 2015). They suggested that mechanisms such as occlusion-induced changes in skeletal muscle afferents, baroreflexes, nitrous oxide, and substance P could impact post-exercise hypotension. Similar responses might contribute to stretch-induced decrements in HR and BP. Future research should observe if longer contraction times for CRPNF training could lead to augmented reductions in BP over time. The safety of such a stretching investigation could be improved based on the finding that submaximal contraction intensity (20-50% of maximum) has also been found to elicit similar BP reducing effects over time (Millar et al., 2014).

Limitations

Anticipating a difference in sitting versus supine resting heart rates, both 5-minute supine and sitting baseline measurements of BP and HR were obtained for all subjects in the SR group. The supine baseline measurement was used for analysis in this study since it was similar to the baselines obtained for the other two treatment methods. The SR baseline HR was elevated as suspected when comparing the means of each baseline (lying baseline avg. HR = 63 vs. sitting baseline avg. = 67). This difference in HR was partially attributed to the positional effect of sitting.

Another limitation of this study was the decision to take BP measurements just 2 minutes after stretching. Since BP measurements were not taken before this time period, we were unable to determine if values returned to baseline values prior to 2 minutes.

Conclusion

In conclusion, trained senior adult athletes experienced small to moderate magnitude increases of hemodynamic responses with SLR, SR and PNF stretching, which recovered to baseline values within 2-min after stretching. Furthermore, the passive SLR induced smaller increases in BP than PNF and SR, while PNF elicited lower HR responses than SR. Although prior research has reported that daily muscle stretching may enhance blood flow, endothelial function, capillarity, vascular volume and connectivity in aged skeletal muscle (Hotta et al. 2018), the hemodynamic elevations in the present study were not of a magnitude to be clinically significant, provide an aerobic exercise stimulus or warrant concerns for senior athletes. However, it was observed that some individuals did present more substantial responses and thus monitoring or screening of seniors when initiating or performing an active stretching program would still be recommended. Caution must be taken when applying the results of this study, conducted on an athletic senior population to a sedentary, senior population, who may have other medical or physical limitations. Further studies should be conducted to investigate stretching effects on non-athletic populations or those with pre-existing hypertension or other cardiovascular diseases.

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Key points

- Trained senior adult athletes experienced small to moderate magnitude increases of hemodynamic responses with SLR, SR and PNF stretching, recovering to baseline values within 2-min after stretching.
- Passive SLR induced smaller increases in BP than PNF and SR, while PNF elicited lower HR responses than SR.
- The elevated hemodynamic responses were not of a magnitude to be clinically significant, provide an aerobic exercise stimulus or warrant health concerns for senior athletes.

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