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The Effect of Static Stretching Exercises at Different Times on Heart Rate Variability Before Anaerobic Capacity Test

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Abstract

This study aimed to examine the acute effect of different durations of static stretching on heart rate variability (HRV) and, the anaerobic capacity of moderately physically active men during the Wingate anaerobic test (WAnT) at two different pre-exercise periods. Sixty-five healthy young male volunteers performed 10 s static stretching (STS) and 30 s static stretching (LTS) consisting of five static stretching exercises before WAnT on two non-consecutive days. HRV was measured pre (60 s), during (30 s) and post (60 s) WAnT after two different periods of static stretching. Anaerobic capacity variables were also measured during WAnT. STS and LTS had similar effects on other HRV parameters except for Mean-RR during the WAnT. There was no significant difference between the protocols applied in any of the anaerobic capacity test values. But there was a negatively significant relationship between the average power output of 30 s static stretching and pNN50. This result has shown that STS and LTS exercises have a similar effect during maximal exercise, so if the practitioners carry out static stretching exercises before maximal or high-intensity exercise, it is recommended to perform the STS exercise in terms of the economy of the exercise.
Keywords: Autonomic Nervous System, Anaerobic Performance, Stretching

Anaerobik Kapasite Testi Öncesi Farklı Sürelerde Statik Germe Egzersizlerinin Kalp Atım Hızı Değişkenliğine Etkisi

Öz

Bu çalışmanın amacı, egzersiz öncesi iki farklı sürelerde uygulanan yapılan aktif statik germenin Wingate anaerobik testi (WAnT) sırasında orta derecede fiziksel olarak aktif erkeklerde kalp hızı değişkenliği (HRV) ve anaerobik kapasite üzerindeki akut etkisini incelemektir. Altmış beş sağlıklı genç erkek gönüllü, art arda olmayan iki farklı günde WAnT öncesi beş statik germe egzersizinden oluşan 10 s statik germe (STS) ve 30 s statik germe (LTS) uyguladı. HRV, iki farklı statik germe süresinden sonra WAnT öncesi (60 s), sırasında (30 s) ve sonrasında (60 s) ölçülmüştür. WAnT sırasında anaerobik kapasite değişkenleri de ölçülmüştür. STS ve LTS, WAnT sırasında Mean-RR dışında diğer HRV parametreleri üzerinde benzer etkilere sahipti. Anaerobik kapasite test değerlerinden hiçbirinde uygulanan protokoller arasında anlamlı bir fark yoktu. Ancak 30 s statik gerdirmenin ortalama güç çıkışı ile pNN50 arasında negatif anlamlı bir ilişki vardı. Bu sonuçlarla STS ve LTS egzersizleri maksimal egzersiz sırasında benzer bir etkiye sahiptir, bu nedenle uygulayıcılar maksimal veya yüksek yoğunluklu egzersizden önce statik germe egzersizi yapıyorsa, egzersizin ekonomisi açısından STS egzersizinin yapılması önerilir.
Anahtar Kelimeler: Otonomik Sinir Sistemi, Anaerobik Performans, Germe Hareketleri

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INTRODUCTION

Stretching is often suitable before or after physical activities to increase range of motion (ROM), prevent injury, and optimize performance and forms an important part of an exercise program (Opplert and Babault, 2018; Santos et al., 2019). It is also claimed to be an influential adjunctive rehabilitation for decreases in cardiovascular (CV) function associated with a sedentary lifestyle and aging (Kruse and Scheuermann, 2017). Before or after exercise, static, dynamic, proprioceptive neuromuscular facilitating stretching, etc. Various types of stretching are performed for warm-up or recovery purposes, for this reason, the effects of stretching technique on physical and physiological performance have been investigated in many studies. (Young and Behm, 2002). Static stretching is generally defined as extending a limb to the end of its ROM and holding it at that endpoint for 15-60 s (Behm and Chaouachi, 2011). Although studies are stating that the sympathetic system (SS) negatively affects anaerobic performance symptoms such as neuromuscular performance, speed, and vertical jump (Behm et al., 2011; Leone et al., 2012), it is seen as an effective method to increase joint ROM and performance by reducing muscle tension (Behm et al., 2016) and is often used before physical activities. In addition, it has also been reported that static stretching can support muscle relaxation (Khattab et al., 2007). These reports indicate those stretch stimuli in the muscles can support positive changes in the autonomic nervous system (ANS) (Inami et al., 2014).

During stretching, static contractions of the antagonist muscle groups increase the mechanoreceptor transmissions, and as a result, the ANS is activated by sympathetic/parasympathetic (S and P) ways, and CV responses to stretching occur (Gladwell and Coote, 2002). Many objective measure methods are used to determine the effectiveness of the stretching process on the cardiovascular system (CVS), one of which is the HRV device. HRV is defined as the oscillation in the interval between successive R-waves (R-R intervals) and is used as a reliable and non-invasive tool for the evaluation of cardiac autonomic activity (Task Force, 1996). As such, it has been used in many studies and clinical applications, including monitoring changes in autonomic nervous system balance during exercise or physical activity (Goldberger et al., 2006; Sundaram et al., 2009). HRV parameters can be used to derive sympathovagal balance (SV-b), which gives information about the magnitude of sympathetic/parasympathetic nerve activity (Lahiri et al., 2008). Thus, HRV makes it possible to identify different cardiac autonomic statuses (Greiser et al., 2009). A developed SV-b due to rising sympathetic activity and decrease in parasympathetic activity leads to suppressed HRV (Task Force, 1996). It is claimed that the increase in SV-b and the decrease in HRV are related to increased CV risk factors and mortality. (Pal et al., 2013). Consequently, any strategy that favors reducing SV-b and increasing HRV can be considered beneficial for the CVS. However, many studies are reporting that the balance of the ANS is dominated by sympathetic nerve activity during SS and parasympathetic nerve activity becomes dominant after SS (Farinatti et al., 2011; Inami et al., 2014).

Stretching exercise can reduce HRV when applied in different volumes (Farinatti et al., 2011; Silva et al., 2016), flexibility levels (Weymann et al., 2004), and with different stretching techniques (Silva et al., 2013). Ogura et al. (2007) reported that 60 seconds of static stretching significantly reduced muscle strength, while 30 seconds of stretching did not affect muscle performance. Similar effects were reported in a systematic review, while shorter stretch durations (<45 s) can be used in pre-exercise routines without the risk of a significant reduction in strength, power, or speed-related tasks, longer stretches (>60 s) will slightly or moderately reduce performance (Kay and Blazevich, 2012). However, as far as we know, there is no study examining the effects of static stretching applied at various periods (short-long) before exercise on HRV during WAnT.

Understanding the physiological responses to static stretching at different periods during the anaerobic performance is important for effective programming. Thus, the present study aimed to investigate the acute effect of two different periods of static stretching on the HRV and anaerobic capacity of moderately physically active men. We hypothesize that LTS exercise will have a more significant effect on HRV parameters and anaerobic performance variables during WAnT.

MATERIAL AND METHOD

Study Design

Data collection for each participant occurred on the weekday during the morning hours (i.e., from 10:00 am to 12:00 am). Moderate water consumption was allowed for each volunteer during the tests. All measurements were performed in a quiet and air-conditioned (temperature 22-24 °C, humidity 33-45 %) room. The participants performed the warm-up protocol of the orientation session and then began WAnT, a 30-second test of maximum anaerobic exercise on a bicycle ergometer against 7.5% of their body mass. The tests were performed randomly in groups of 5 or 6 participants on different days on weekdays for two months. In the study, anaerobic power test (Wingate test 30 s) was applied to the volunteers after STS and LTS. HRV was recorded as 60 s before (T1) 30 s during (T2) and 60 s after (T3) the Wingate test. This protocol was completed on 2 different days with a minimum interval of 2 days for all subjects. Each subject performed the Day 1 STS and Day 2 LTS protocol. Stretching exercises (Hamstring Stretch, Adductor Stretch, Quadriceps Stretch, Ankle Stretch, and Hip Flexor Stretch; figure 1) were performed by subjects for 10 seconds 2 sets (STS) a day before WAnT and 30 seconds 2 sets (LTS) before the 2^{nd}-day WAnT. 10 s rest was given between rest (figure 2).

Figure 1. Stretching exercises

Table 1. Stretching exercises

	STS				LTS			
	Exercise	**Set**	**Duration***	**Rest***	**Exercise**	**Set**	**Duration**	**Rest**
1	Quadriceps Stretch	2	10	10	Quadriceps Stretch	2	30	10
2	Hamstring Stretch	2	10	10	Hamstring Stretch	2	30	10
3	Ankle Flexion	2	10	10	Ankle Flexion	2	30	10
4	Hip Flexor	2	10	10	Hip Flexor	2	30	10
5	Adductor Stretch	2	10	10	Adductor Stretch	2	30	10
	Total	10	100	100		10	300	100

*Second

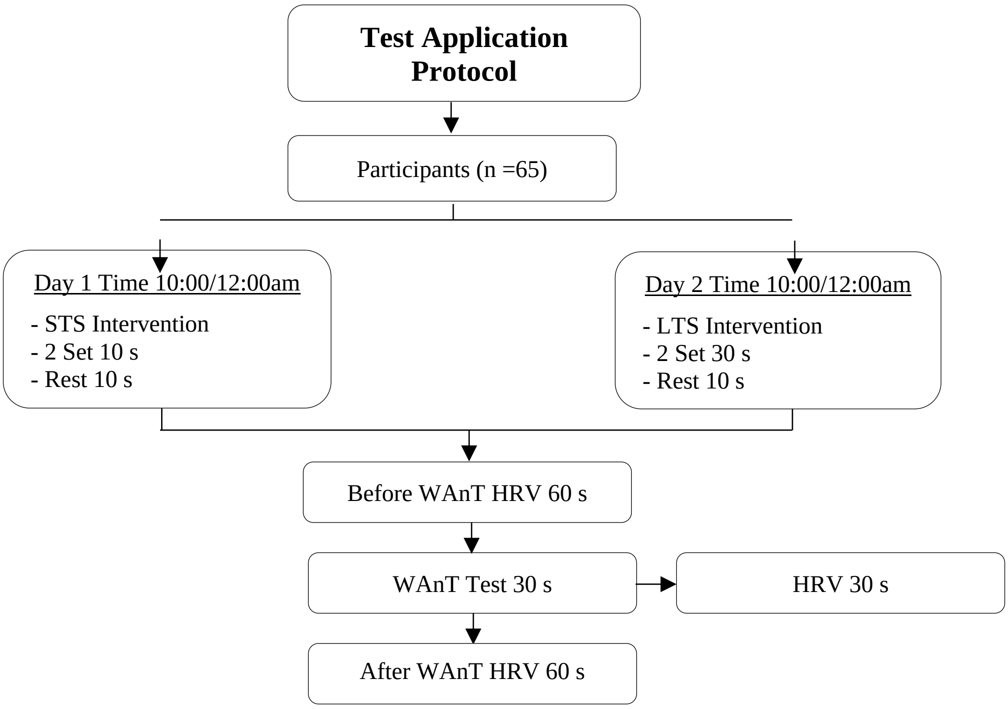

Figure 2. Test application protocol

Participants

The sixty-nine healthy males were recruited on a volunteer basis through advertisement posters. Four participants were excluded from the present study due to their busy schedules. The final sample comprised sixty-five individuals (age = 25.6 ± 2.9 years; height = 175.9 ± 5.4 cm; weight = 77.3 ± 8.0 kg; Body mass index (BMI) =25.0 ± 1.9 kg/m^2; % Body fat = 19.9 ± 4.5 %). All participants were reported being free from illness and injury in the last six months and no medical drugs were used in the past one week before the experiments took place. Informed consent was obtained from all participants. According to the International Physical Activity Questionnaire-Short Form (IPAQ-SF) applied before the tests, the participants were 12.3% high, 50.8% medium, and 36.9% low physically active (Saglam et al., 2010).

Measurements

Body composition: The height of the participants was measured as recommended by the International Society for the Advancement of Kinanthropometry (ISAK) and with a 1/10 cm sensitivity (Holtein Harpenden 601, Holtain Ltd., UK). The body weights of the participants were measured with a scale of 1/10 kg using the scale model of the InBody brand 270 models (Biospace Co., S. Korea) body analyzer. To obtain the BMI values of the participants InBody brand 270 models (Biospace Co., S. Korea) body analyzer was used, and measurements were performed according to the procedure specified in the device manual. The data obtained were recorded in %.

Wingate anaerobic test: WAnT of the volunteers was performed by using a Wattbike brand ergometer using WAnT (Wattbike WPM ModelB, Wattbike Ltd., UK). The reliability study for a 30-sec run-down sprinkle in Wattbike has already been done (Driller et al., 2013). It records a calculation of the average power in each 5-sec interval of a 30-sec test and provides a peak power value based on the highest 5-sec average and, a rate of deterioration. During this test, participants were encouraged verbally to exert maximal effort. The mean power, peak power, and relative power were measured by the WAnT.

Heart rate variability: HRV was measured by Elite HRV 4.7.2 IOS version Heart Rate Monitor and Polar H7 band (Polar Electro, Kempele, Finland). HRV analyses were processed in Kubios HRV standard HRV analysis software for Mac (Biosignal Analysis and Medical Imaging Group, Department of Physics, University of Kuopio, Finland, version 3.1.0.1) with time, frequency, and nonlinear domain analysis. Before the exercise test, each subject was instructed to lie on the exercise mat in a dimly controlled climate-controlled laboratory for 10 minutes following the recommendations adopted (Task Force, 1996). HRV was recorded 60-sec before the test, 30-sec during the test, and 60-sec after the test. Recordings were subsequently imported into Kubios HRV version 3.3.1 software (Tarvainen et al., 2014) for offline analyses. Specifically, we computed heart rate (beats per minute) as well as the mean of R-R intervals in milliseconds (Mean-RR), standard deviation of R-wave to R-wave intervals (SDNN), root mean square of successive R-R intervals (RMSSD), the natural logarithmic transformation of the square root of the mean squared differences between successive R-R intervals in milliseconds (LnRMSSD), percentage of successive RR intervals that differ by more than 50 ms (pNN50), as three time-domain measures of heart rate variability with the absolute power of the low-frequency band ex-pressed in normal units (LFnu), absolute power of the normalized high-frequency band ex-pressed in normal units (HFnu), and the ratio of LF- to- HF power (LF/HF).

Research Ethics

The experiments were approved by the Eskişehir Osmangazi University research ethics committee (Approved date 04.06.2020 and number 2020-09).

Statistical Analysis

Data is presented in means and standard deviations (SD). The differences based on magnitudes (Batterham and Hopkins, 2006) were calculated to check the differences in the pre and post moments. To compare the intra-group HRV parameters, repeated two-way analysis of variance (ANOVA) was used. The assumption of sphericity was tested using Mauchly's test and the Greenhouse-Geisser correction factor to the degrees of freedom was used for all positive tests. The Effect Size Cohen's d was calculated, which was considered small (0.20), medium (0.50), or large (0.80). All calculations were made with SPSS version 22, statistical software (SPSS Inc., Chicago, IL, USA), and the level of significance was set at $p<0.05$.

RESULTS

The data obtained from our study shows respectively the performance values of the participants in Table 2, and the comparisons between the pre-test, test, post-test HRV values of participants in Table 3.

Table 2. WAnT Performance values for stretching exercises performed by participants at different times.

Performance Values	STS Mean ± SD	LTS Mean ± SD	*t*
Power 5-sec max (W)	722.6 ± 114.0	711.7 ± 120.4	1.104
Max 5 sec (W/kg)	9.4 ± 1.3	9.3 ± 1.3	0.882
Power 5-sec min (W)	335.7 ± 58.8	342.0 ± 51.7	-0.500
Fatigue (%)	52.6 ± 10.1	50.6 ± 10.7	0.896
Power Average (W)	518.0 ± 66.4	519.7 ± 66.0	0.069
Power / Mass (W/kg)	6.7 ± 0.7	6.8 ± 0.6	-0.970
Power Peak (W)	825.7 ± 133.8	816.0 ± 138.1	0.428
Energy (kcal)	16.6 ± 1.9	16.7 ± 1.9	-0.217
Speed avg (km/h)	52.1 ± 2.7	52.1 ± 2.4	0.134
Distance (m)	433.7 ± 20.6	434.6 ± 20.0	-0.464

STS=Short time stretching, LTS=Long time stretching

WanT performance values of the participants results have shown in Table 2. There were no significant differences in terms of Power 5-sec max (W) ($p>0.05$; $t=1.104$). In addition, there were no significant differences Power Average (W) ($p>0.05$; $t=0.069$), and Power / Mass (W/kg) ($p>0.05$; $t=-0.970$).

Table 3. The Comparison of HRV values before, during and after the test for stretching exercises performed by participants at different times

Variables	**Time**	**Pre-test (T1) Mean ± SD**	**Test (T2) Mean ± SD**	**Post-test (T3) Mean ± SD**	**F**	**$\eta_{partial}^2$**	**Cohen's d**
Mean-RR (bpm)	STS	523.8 ± 9.1	387.7 ± 4.9	354.4 ± 2.9	3.10*	0.03	0.1
	LTS	557.2 ± 14.0	416.4 ± 8.8	361.2 ± 3.3			
SDNN (ms)	STS	30.2 ± 1.9	14.4 ± 1.5	7.5 ± 1.0	0.65	0.01	0.0
	LTS	33.4 ± 3.1	18.6 ± 2.5	8.2 ± 1.2			
RMSSD (ms)	STS	21.2 ± 2.1	15.1 ± 2.4	9.2 ± 1.4	0.65	0.01	0.0
	LTS	27.3 ± 4.8	23.1 ± 4.4	12.2 ± 2.1			
pNN50 (%)	STS	3.7 ± 0.7	3.8 ± 1.3	1.0 ± 0.3	0.27	0.00	0.0
	LTS	6.1 ± 1.5	6.3 ± 1.6	2.3 ± 0.7			
Lfnu (ms^2)	STS	76.7 ± 1.8	71.4 ± 3.2	68.7 ± 3.3	0.80	0.01	0.0
	LTS	80.4 ± 2.4	72.2 ± 3.4	65.5 ± 4.0			
Hfnu (ms^2)	STS	23.1 ± 1.8	28.4 ± 3.1	31.0 ± 3.2	0.80	0.01	0.0
	LTS	19.5 ± 2.4	27.6 ± 3.4	34.0 ± 3.9			
LF/HF	STS	5.3 ± 0.5	7.7 ± 1.2	6.3 ± 0.9	2.4	0.02	0.0
	LTS	8.2 ± 1.0	14.1 ± 4.0	5.8 ± 1.0			
LnRMSSD	STS	2.7 ± 0.1	2.1 ± 0.1	1.7 ± 0.1	0.52	0.00	0.0
	LTS	2.8 ± 0.1	2.4 ± 0.2	1.9 ± 0.2			

Mean-RR; Mean of R-R intervals in milliseconds, SDNN; Standard deviation of R-wave to R-wave intervals, RMSSD; Root mean square of successive R-R intervals, LnRMSSD; The natural logarithmic transformation of the square root of the mean squared differences between successive R-R intervals in milliseconds, pNN50; Percentage of successive RR intervals that differ by more than 50 ms, LFnu; Normalized low-frequency band ex-pressed in normal units, HFnu; Normalized high-frequency band ex-pressed in normal units, LF/HF; Ratio of LF- to-HF power; *$p<0.05$; STS=Short time stretching, LTS=Long time stretching.

Table 3 shown comparison statistics for pretest, test, and post-test HRV values by stretching time. For Mean-RR there are statistically significant difference ($F = 3.10$; $p<0.05$; $\eta_{partial}^2 = 0.03$) between STS and LTS according T1, T2 and T3. There was no significant difference between STS and LTS in terms of SDNN ($F = 0.65$; $p>0.05$; $\eta_{partial}^2 = 0.01$), RMSSD ($F = 0.65$; $p>0.05$; $\eta_{partial}^2 = 0.01$), pNN50 ($F = 0.27$; $p>0.05$; $\eta_{partial}^2 = 0.00$), Lfnu ($F = 0.80$; $p>0.05$; $\eta_{partial}^2 = 0.01$), Hfnu ($F = 0.80$; $p>0.05$; $\eta_{partial}^2 = 0.01$), LF/HF ($F = 2.04$; $p>0.05$; $\eta_{partial}^2 = 0.02$), LnRMSSD ($F = 0.52$; $p>0.05$; $\eta_{partial}^2 = 0.00$).

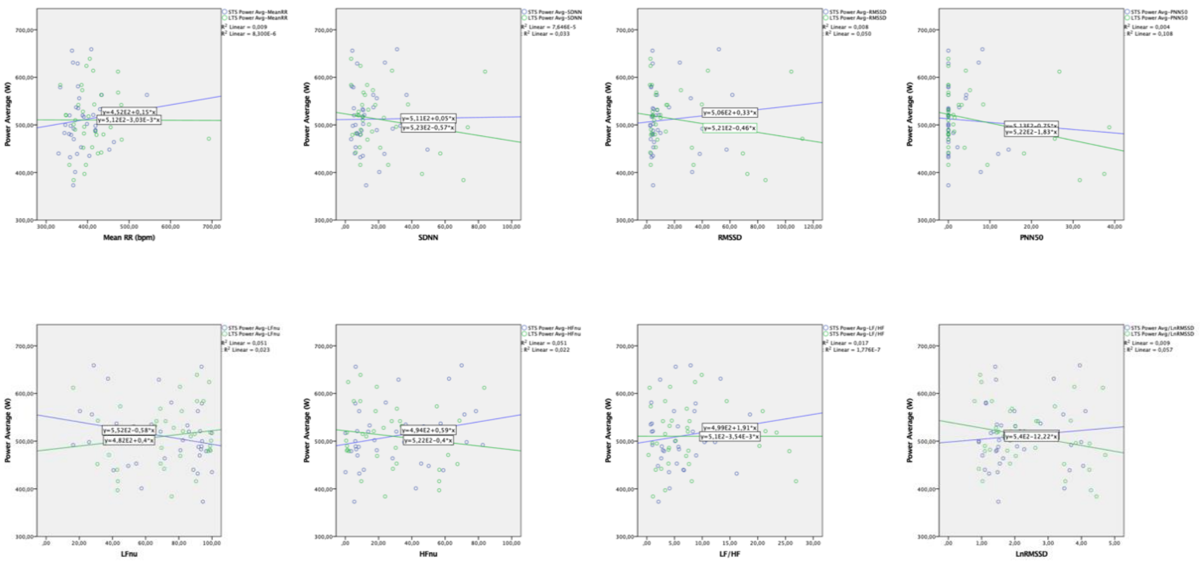

Figure 3. The Relationship between exercise data of HRV and Power Average (W) by Pearson correlation test.

When figures 3 was examined, there was a significant relationship between LTS Average Power and pNN50 (R=-0.34; p<0.05). There were no significant relationship between STS Average Power and SDNN (r= 0,069; p>0,05), LTS Average Power and SDNN (r= -0,205; p>0,05). There were no significant relationship between STS Average Power and RMSSD (r= 0,128; p>0,05), LTS Average Power and RMSSD (r=-0,237; p>0,05).

DISCUSSION

The present study aimed to investigate the acute effect of two different durations (10 s vs 30 s) of static stretching on the HRV and anaerobic capacity of moderately physically active men. The main results have shown that (a) both STS and LTS had similar effects on other HRV parameters except Mean-RR during the WAnT, there was a significant difference in favor of LTS in Mean-RR, but the Cohens d value was trivial. (b) No significant difference was detected between the two protocols in any of the WAnT test parameters. (c) there was a negatively significant relationship between the Average Power of LTS and pNN50.

Mean-RR was significantly lower in the STS than LTS intervention, which consequently reflected higher mean HR compared to LTS group. With parasympathetic withdrawal during exercise, the sympathetic activity becomes predominant, thereby increasing heart rate (Javorka et al., 2003). Cottin et al. (2004) found that the Mean-RR was reduced more during a high-intensity exercise (316±15 ms) compared to a medium-intensity exercise (508±40 ms). Buchheit et al. (2007) suggested that catecholamine release and levels of lactate, hydrogen ions, and inorganic phosphate accumulation may play a role in increasing cardiac sympathetic modulation by decreasing cardiac parasympathetic modulation, with the activation of fast-twitch muscle fibers in high-intensity exercises. It can be argued that LTS exercise keeps the sympathovagal activity more balanced than STS exercise by affecting the accumulation of some ions such as hydrogen ions, levels of lactate, and catecholamine release during the WAnT. But we did not do blood analysis, also the Mean-RR effect size was trivial. Silva et al. (2018) determined that 3 sets of 30 s static stretching exercises before strength training decreased RMSSD and HF (parasympathetic) parameters and increased LF (sympathetic) parameters after strength training. They also found that static stretching exercises performed between strength training sets decreased RMSSD and HF parameters. HRV is a cardiac autonomic marker (Task Force, 1996). Thus, both STS and LTS exercises seem to elicit similar HRV responses during maximal exercise. This shows that our hypothesis was partially unsuccessful.

In the present study, it was determined that both stretching protocols (STS and LTS) elicited similar responses in all anaerobic capacity variables during WAnT. Franco et al. (2012) also reported that 30 s of static passive stretching did not have a significant effect on peak-power output compared with the non-stretching trial. Oshita et al. (2016) found that 30 s static stretching during the WAnT did not affect peak power performance compared to the control group, but the average power performance increased in the WAnT after static stretching. It has been demonstrated in many studies that static stretching of 60 s and above causes reductions in maximum strength and power output (Behm et al., 2016; Caldwell et al., 2019; Palmer et al., 2019; Pulverenti et al., 2019). In a systematic review, while shorter stretch durations (<45 s) can be used in pre-exercise routines without significant reduction in strength, power, or speed-related tasks, longer stretches (>60 s) have been reported to slightly or moderately reduce performance (Kay and Blazevich, 2012). It has been stated that long-term static stretching exercise (>60 s) affects the neural system negatively and reduces motor unit activation (Trajano et al., 2013), as well as reduces musculotendinous unit (MTU) stiffness (Matsuo et al., 2013). The reduction in MTU stiffness partially results in a reduced torque-producing capacity of the muscles (Matsuo et al., 2013). But it is stated that short-term STS does not have a negative effect on motor activation and MTU stiffness during maximal exercise (Matsuo et al., 2013; Palmer et al. 2019). In our study, there was a negatively significant relationship between the average power of LTS and pNN50 during WAnT. It is stated that pNN50 is closely related to parasympathetic nervous system activity (Shaffer et al. 2017). The negative correlation between the average power of LTS and pNN50 shows us that the effect of sympathetic activity increased during WAnt after LTS.

The similar responses in both HRV (except Mean-RR) and anaerobic capacity variables in STS and LTS during the Wingate test suggest that a 10 s static stretching exercise may be sufficient before maximal or high-intensity exercise. This study is important because it is the first study to investigate the effect of static stretching applied in different short periods (10 s vs 30 s) before exercise on HRV parameters during maximal exercise. The limitations of the study are the absence of blood analysis and EMG tests, which will provide information about variables such as fatigue, muscle strength, etc.

CONCLUSION

As a result, it determined that active static stretching applied in different periods did not affect HRV (except Mean-RR) and anaerobic capacity variables during WAnT. This shows that 10 s and 30 s of static stretching exercises have a similar effect during maximal exercise. So if the practitioners carry out static stretching exercise before maximal or high-intensity exercise, it is recommended to perform the STS exercise in terms of the economy of the exercise.

Conflict of interests: The authors state that there is no conflict of interest.

Authors' Contribution: Study design; TA, RA, NK –Data collection; TA, NK, LŞ –Statistical analysis; TA, RA, AKG –Manuscript Preparation; TA, AKG, RA

Information on Ethics Committee Permission
Committee: Eskişehir Osmangazi University, Clinical Research Ethic Committee
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REFERENCES

Batterham, A.M., & Hopkins, W.G. (2006). Making meaningful inferences about magnitudes. *International Journal of Sports Physiology and Performance, 1*(1), 50-57. https://doi.org/10.1123/ijspp.1.1.50

Behm, D. G., & Chaouachi, A. (2011). A review of the acute effects of static and dynamic stretching on performance. *European Journal of Applied Physiology*, *111*(11), 2633. https://doi.org/10.1007/s00421-011-1879-2

Behm, D. G., Blazevich, A. J., Kay, A. D., & McHugh, M. (2016). Acute effects of muscle stretching on physical performance, range of motion, and injury incidence in healthy active individuals: a systematic review. *Applied Physiology, Nutrition, and Metabolism*, *41*(1), 1-11. https://doi.org/10.1139/apnm-2015-0235

Buchheit, M., Laursen, P. B., & Ahmaidi, S. (2007). Parasympathetic reactivation after repeated sprint exercise. *American journal of Physiology-Heart and Circulatory Physiology*, *293*(1), H133-H141. https://doi.org/10.1152/ajpheart.00062.2007

Caldwell, S.L., Bilodeau, R.L., Cox, M.J., Peddle, D., Cavanaugh, T., Young, J.D., & Behm, D.G. (2019). Unilateral hamstrings static stretching can impair the affected and contralateral knee extension force but improve unilateral drop jump height. *European Journal of Applied Physiology*, *119*(9), 1943-1949. https://doi.org/10.1007/s0042101904182-x

Cottin, F., Médigue, C., Leprêtre, P. M., Papelier, Y., Koralsztein, J. P., & Billat, V. (2004). Heart rate variability during exercise performed below and above ventilatory threshold. *Medicine and Science in Sports and Exercise*, *36*(4), 594-600. https://doi.org/10.1249/01.mss.0000121982.14718.2

Driller, M. W., Argus, C. K., & Shing, C. M. (2013). The reliability of a 30-s sprint test on the Wattbike cycle ergometer. *International Journal of Sports Physiology and Performance*, *8*(4), 379-383. https://doi.org/10.1123/ijspp.8.4.379

Gladwell, V. F., & Coote, J. H. (2002). Heart rate at the onset of muscle contraction and during passive muscle stretch in humans: a role for mechanoreceptors. *The Journal of Physiology, 540*(3), 1095-1102. https://doi.org/10.1113/jphysiol.2001.013486

Goldberger, J. J., Le, F. K., Lahiri, M., Kannankeril, P. J., Ng, J., & Kadish, A. H. (2006). Assessment of parasympathetic reactivation after exercise. *American Journal of Physiology-Heart and Circulatory Physiology*, *290*(6), H2446-H2452. https://doi.org/10.1152/ajpheart.01118.2005

Farinatti, P. T., Brandão, C., Soares, P. P., & Duarte, A. F. (2011). Acute effects of stretching exercise on the heart rate variability in subjects with low flexibility levels. *The Journal of Strength & Conditioning Research*, *25*(6), 1579-1585. https://doi.org/10.1519/JSC.0b013e3181e06ce1

Franco, B. L., Signorelli, G. R., Trajano, G. S., Costa, P. B., & de Oliveira, C. G. (2012). Acute effects of three different stretching protocols on the Wingate test performance. *Journal of Sports Science & Medicine*, *11*(1), 1. PMCID: PMC3737835, PMID: 24149116

Greiser, K. H., Kluttig, A., Schumann, B., Swenne, C. A., Kors, J. A., Kuss, O., & Werdan, K. (2009). Cardiovascular diseases, risk factors and short-term heart rate variability in an elderly general population: the CARLA study 2002–2006. *European Journal of Epidemiology*, *24*(3), 123-142. https://doi.org/10.1007/s10654-009-9317-z

Inami, T., Shimizu, T., Baba, R., & Nakagaki, A. (2014). Acute changes in autonomic nerve activity during passive static stretching. *Am J Sports Sci Med*, *2*(4), 166-70. https://doi.org/10.12691/ajssm-2-4-9

Javorka, M., Žila, I., Balhárek, T., & Javorka, K. (2003). On-and off-responses of heart rate to exercise–relations to heart rate variability. *Clinical Physiology and Functional Imaging*, *23*(1), 1-8. https://doi.org/10.1046/j.1475-097X.2003.00460.x

Kay, A. D., & Blazevich, A. J. (2012). Effect of acute static stretch on maximal muscle performance: a systematic review. *Medicine & Science in Sports & Exercise*, *44*(1), 154-164. https://doi.org/10.1249/MSS.0b013e318225cb27

Khattab, K., Khattab, A. A., Ortak, J., Richardt, G., & Bonnemeier, H. (2007). Iyengar yoga increases cardiac parasympathetic nervous modulation among healthy yoga practitioners. *Evidence-Based Complementary and Alternative Medicine*, *4*(4), 511-517. https://doi.org/10.1093/ecam/nem087

Kruse, N. T., & Scheuermann, B. W. (2017). Cardiovascular responses to skeletal muscle stretching: “Stretching” the truth or a new exercise paradigm for cardiovascular medicine. *Sports Medicine*, *47*(12), 2507-2520. https://doi.org/10.1007/s40279-017-0768-1

Lahiri, M.K., Kannankeril, P.J., & Goldberger, J.J. (2008). Assessment of autonomic function in cardiovascular disease. Physiological basis and prognostic implications. *Journal of the American college of Cardiology*, *51*(18), 1725-1733. https://doi.org/10.1016/j.jacc.2008.01.038

Leone, P., Shera, D., McPhee, S.W., Franci, J.S., Kolodny, E.H., & Bilaniuk, L.T. (2012). Long-Term Follow-Up After Gene Therapy for Canavan Disease. *Science Translational Medicine*, *4*(165), 165-163. https://doi.org/10.1126/scitranslmed.3003454

Matsuo, S., Suzuki, S., Iwata, M., Banno, Y., Asai, Y., Tsuchida, W., & Inoue, T. (2013). Acute effects of different stretching durations on passive torque, mobility, and isometric muscle force. *The Journal of Strength & Conditioning Research*, *27*(12), 3367-3376. https://doi.org/10.1519/JSC.0b013e318290c26f

Ng, J., Sundaram, S., Kadish, A.H., & Goldberger, J.J. (2009). Autonomic effects on the spectral analysis of heart rate variability after exercise. *Am J Physiol Heart Circ Physiol*, *297*(4), H1421-H1428, https://doi.org/10.1152/ajpheart.00217.2009

Ogura, Y., Miyahara, Y., Naito, H., Katamoto, S., & Aoki, J. (2009). Duration of static stretching influences muscle force production in hamstring muscles. *Journal of Strength and Conditioning Research*, *21*(3), 788-792. https://doi.org/10.1519/R-18785.1

Opplert, J., & Babault, N. (2018). Acute Effects of Dynamic Stretching on Muscle Flexibility and Performance: An Analysis of the Current Literature. *Sports Medicine*, *48*(2), 299-325. https://doi.org/10.1007/s40279-017-0797-9

Oshita, K., Yamaguchi, K., & Ariyoshi, K. (2016). Effect of 30 s of static active stretching on anaerobic power using the Wingate test. *Malaysian Journal of Movement, Health & Exercise*, *5*(2). https://doi.org/10.15282/MOHE.V5I2.117

Pal, G.K., Adithan, C., Ananthanarayanan, P.H., Pal, P., Nanda, N., & Durgadevi, T. (2019). Sympathovagal Imbalance contributes to prehypertension status and cardiovascular risks attributed by insulin resistance, inflammation, dyslipidemia and oxidative stress in first degree relatives of type 2 diabetics. *PLoS One*, *8*(11), e78072. https://doi.org/10.1371/journal.pone.0078072

Palmer, T.B., Pineda, J.G., Cruz, M.R., & Agu-Udemba, C.C. (2019). Duration-dependent effects of passive static stretching on musculotendinous stiffness and maximal and rapid torque and surface electromyography characteristics of the hamstrings. *The Journal of Strength & Conditioning Research*, *33*(3), 717-726. https://doi.org/10.1519/JSC.0000000000003031

Pulverenti, T.S., Trajano, G.S., Kirk, B.J., & Blazevich, A.J. (2019). The loss of muscle force production after muscle stretching is not accompanied by altered corticospinal excitability. *European Journal of Applied Physiology*, *119*(10), 2287-2299. https://doi.org/10.1007/s00421-019-04212-8

Saglam, M., Arikan, H., Savci, S., Inal-Ince, D., Bosnak-Guclu, M., Karabulut, E., & Tokgozoglu, L. (2010). International physical activity questionnaire: reliability and validity of the Turkish version. *Perceptual and Motor Skills*, *111*(1), 278–284. https://doi.org/10.2466/06.08.PMS.111.4.278-284

Santos, C.X., Beltrão, N.B., Pirauá, A.L., Durigan, J.L., Behm, D., & Araújo, R.C. (2019). Static Stretching Intensity Does Not Influence Acute Range of Motion, *Passive Torque, and Muscle Architecture. Journal of Sport Rehabilitation*, *1*(6). https://doi.org/10.1123/jsr.2018-0178

Shaffer, F., & Ginsberg, J.P. (2017). An overview of heart rate variability metrics and norms. *Frontiers in Public Health*, 258. https://doi.org/10.3389/fpubh.2017.00258

Silva-Batista, C., Urso, R.P., Silva, A.E.L., & Bertuzzi, R. (2013). Associations between fitness tests and the International Physical Activity Questionnaire-Short form in healthy men. *The Journal of Strength & Conditioning Research*, *27*(12), 3481-3487.1. https://doi.org/0.1519/JSC.0b013e31828f1efa

Tarvainen, M.P., Niskanen, J.P., Lipponen, J.A., Ranta-Aho, P.O., & Karjalainen, P.A. (2014). Kubios HRV–heart rate variability analysis software. *Computer Methods and Programs in Biomedicine*, *113*(1), 210-220. https://doi.org/10.1016/j.cmpb.2013.07.024

Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. (1996). Heart rate variability: Standards of measurement, physiological ınterpretation, and clinical use. *Eur Heart J*, (17), 354–381. PMID: 8737210

Trajano, G.S., Seitz, L., Nosaka, K., & Blazevich, A.J. (2013). Contribution of central vs. peripheral factors to the force loss induced by passive stretch of the human plantar flexors. *Journal of Applied Physiology*, *115*(2), 212-218. https://doi.org/10.1152/japplphysiol.00333.2013

Weymann, M.M., Janshoff, G., & Mueck, H. (2014). Stretching increases heart rate variability in healthy athletes complaining about limited muscular flexibility. *Clin Auton Res*, (14), 15-18. https://doi.org/10.1007/s10286-004-0123-0

Young, W., & Behm, D. (2002). Should static stretching be used during a warm-up for strength and power activities? *Strength Cond J*., (24), 33-37. https://doi.org/10.1519/00126548200212000-00006