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Nonlinear approach to study the acute effects of static and dynamic stretching on local dynamic stability in lower extremity joint kinematics and muscular activity during pedalling

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ABSTRACT

Researchers have reported contradictory results on the effect of static and dynamic stretching on subsequent performance. Due to the importance of performance through static and dynamic stretching, the aim of this study is to investigate the acute effects of static and dynamic stretching protocols on local dynamic stability in lower extremity joint kinematics and muscular activities during pedalling using a nonlinear dynamics approach. Using a randomised crossover trial design, fifteen active males participated voluntarily in this research (mass: 69.02 ± 10.52 kg, height: 174.00 ± 6.74 cm, and age: 21.20 ± 1.47 years) and completed a pedalling trial in situations of without stretching (WS), after static (SS), and dynamic stretching (DS) of lower extremity. The lower extremity joint angles in the sagittal plane and the electrical activity of soleus, gastrocnemius medialis, tibialis anterior, vastus medialis, biceps femoris, and rectus femoris muscles were collected during 30 pedalling cycles at 70 rates per minute. The results of the repeated measure ANOVA indicated that the knee and ankle angle largest LyE was significantly lower in DS compared to WS and SS. The largest LyE in muscle activity is also significantly lower for all the muscles after DS compared to WS and SS ($P \leq 0.05$). Regarding the positive effects of DS on the joints and the muscle activity local dynamic stability, it is suggested to use DS than SS in the warm-up program before repetitive activities like pedalling.

1. Introduction

Using different warm-up strategies has been shown to improve performance and reduce the risk of injuries. Static stretching (SS) is generally considered an integral part of sport conditioning programs and warm-up routines. It was thought that SS could reduce muscle soreness, improve athletic performance, and decrease the risk of injury (High, Howley, & Franks, 1989; Smith, 1994; Young & Behm, 2002; Young, 2007). Nevertheless, some recent studies have concluded that SS has no effect on injury prevention (Gleim & McHugh, 1997; Herbert, 2002), or it may temporarily decrease the muscle's ability to generate force (Avela, Finni, Liikavainio, Niemelä, & Komi, 2004; Avela, Kyröläinen, & Komi, 1999; Behm, Button, & Butt, 2001; Costa et al., 2009). Recent studies encourage athletes to avoid using SS before athletic events (Nelson, Driscoll, Landin, Young, & Schexnayder, 2005; Walsh, 2017) and utilising other forms of stretching (i.e. dynamic stretching (DS)) (Chatzopoulos, Galazoulas, Patikas, & Kotzamanidis, 2014; Galazoulas, 2017;

Yamaguchi & Ishii, 2005). These studies have suggested that using DS in warm-up not only does not reduce muscle force production but also can enhance performance (Herda, Cramer, Ryan, McHugh, & Stout, 2008; Hough, Ross, & Howatson, 2009). Sports scientists have completed several studies to obtain the differences between SS and DS effects on subsequent performance, and they have reported different and nonsteady results (Behm & Chaouachi, 2011; Herbert, 2002; McHugh & Cosgrave, 2010; Rubini, Costa, & Gomes, 2007; Smith, 1994; Su, Chang, Wu, Guo, & Chu, 2017; Zakaria, Kiningham, & Sen, 2015). On the other hand, these studies have focused primarily on muscle strength, power output, isokinetic, and EMG parameters, and the effects of stretching on biomechanical parameters during real situations of repetitive activities such as pedalling have not been examined.

Pedalling, as a rehabilitation exercise in a stationary situation (e.g. ergometer cycling) or as athletic cycling, is used as a well-known rehabilitation, athletic, and recreational activity with several health benefits. For instance, Hancock, Shepstone, Rowe, Myint, and Pomeroy (2017) have suggested that people with substantial paresis early after stroke and who cannot walk, can produce smooth movement during upright pedalling using a variety of muscle activation strategies (Hancock et al., 2017). Although pedalling is generally regarded as a closed-kinetic chain exercise, the joints' positions and loadings in this kinetic chain may not always be predicted at a particular sequence. The effects of pedalling rate, body direction, saddle height, and muscular fatigue on pedalling mechanics have been examined in previous studies (Asplund & St Pierre, 2004). However, as athletes use stretching in their warm-up routines, understanding the effect of static and dynamic stretching on subsequent pedalling biomechanics can help physiotherapist, coaches and athletes to decide use the proper kind of stretching in their warm-up routines. Moreover, investigation the effect of intervention (here stretching) on joint kinematics, and muscle activity variability and stability from the nonlinear dynamic analysis perspective can be helpful in developing more effective warm-up and exercise protocols and decreasing the risk of overuse injuries during pedalling.

Variability is a typical feature of human movement. Human movement variability can be described as the normal variations that occur in motor performance across several repetitions of a task (Stergiou, Harbourne, & Cavanaugh, 2006). Hence, if a person attempts to repeat the same effort twice, the two actions will never be identical. Bernstein (1966) utilised the expression 'repetition without repetition', where each repetition of an act involved unique, nonrepetitive neural and motor patterns (Bernstein, 1966). It is generally proposed that increased variability in a movement pattern is equal to a loss of stability, while reduced variability generally indicates a highly stable behaviour. Variability and stability in human movements have been examined by linear (traditionally) and nonlinear (new perspective) methods. Linear methods (such as standard deviation and range), are measures of central tendency, and thus provide a description of the amount or magnitude of the variability around a central point. However, this is only feasible for linear systems. In contrast, variations in motor behaviour are captured better by tools that have been developed for the study of nonlinear systems.

In recent studies, variability in motor performance has been considered from a variety of theoretical perspectives such as the generalised motor program theory (Summers & Anson, 2009), uncontrolled manifold hypothesis (Latash, Scholz, & Schöner, 2002), and dynamical systems theory (DST) (Hamill, van Emmerik, Heiderscheit, & Li, 1999). Researchers have introduced different methods to analyse variability and stability from the DST perspective. The primarily used methods are approximate entropy, sample entropy, correlation dimension, largest Lyapunov exponent (LyE), and detrended fluctuation analysis (Stergiou, 2004). Our aim in this research is to ascertain whether acute static and dynamic stretching as a perturbation (used as a warm-up protocol) can affect the local dynamic stability in joint kinematics and muscle activity. Based on the results of previous studies (Chatzopoulos et al., 2014; Galazoulas, 2017; Yamaguchi & Ishii, 2005), our hypothesis is that static and dynamic stretching separately exhibit different effects on the local dynamic stability in joint kinematics and muscle activity during pedalling, i.e. DS increases and SS reduces this parameter. The aim of this study is to examine the acute effects of both static and dynamic stretching on the local dynamic stability in lower extremity joint kinematics and muscular activity during pedalling from the nonlinear dynamic perspective.

2. Methods

Fifteen physically active male students participated voluntarily in this study (mass: 69.02 ± 10.52 kg, height: 174.00 ± 6.74 cm, and age: 21.20 ± 1.47 years). The experimental protocol was approved by the Human Subjects Institutional Review Board at the university. The participants had no history of injuries to the head, knee, and ankle, or balance disorders during the last 6 month, and all of them had a right dominant leg. They also completed the medical health questionnaire and signed an informed consent form before participating in the research. They were familiarised to the static and dynamic stretching protocols, measurements of lower limb kinematics, EMG, and pedalling on the bicycle ergometer (Biodex system 3 cycling ergometer). The participants were asked to complete the testing sessions (performing 30 pedalling cycles on bicycle ergometer at 70 RPM) within three visit, and their kinematics parameters and EMG of the dominant lower limb muscles were recorded during the testing sessions. All participants performed a general warm-up for 5 min on the bicycle ergometer. They completed pedalling (in situations of WS, after SS, and after DS) in a randomised crossover trial design during three different days. The testing occurred at the same time each day, and all testing sessions were separated by at least 48 h to provide the participants with sufficient time to recover (Serefoglu, Sekir, Gür, & Akova, 2017) (Chart 1).

2.1. Reflective markers and electrode placement

Reflective markers were utilised for the hip, knee, and ankle joints to record the kinematic data. These markers were placed on the tuberosity of the fifth metatarsal, lateral malleolus, lateral femoral condyle, greater trochanter of the femur, and anterior superior iliac spine. One marker was also placed at the centre of the pedal spindle to determine the pedalling cycle. One camera with the
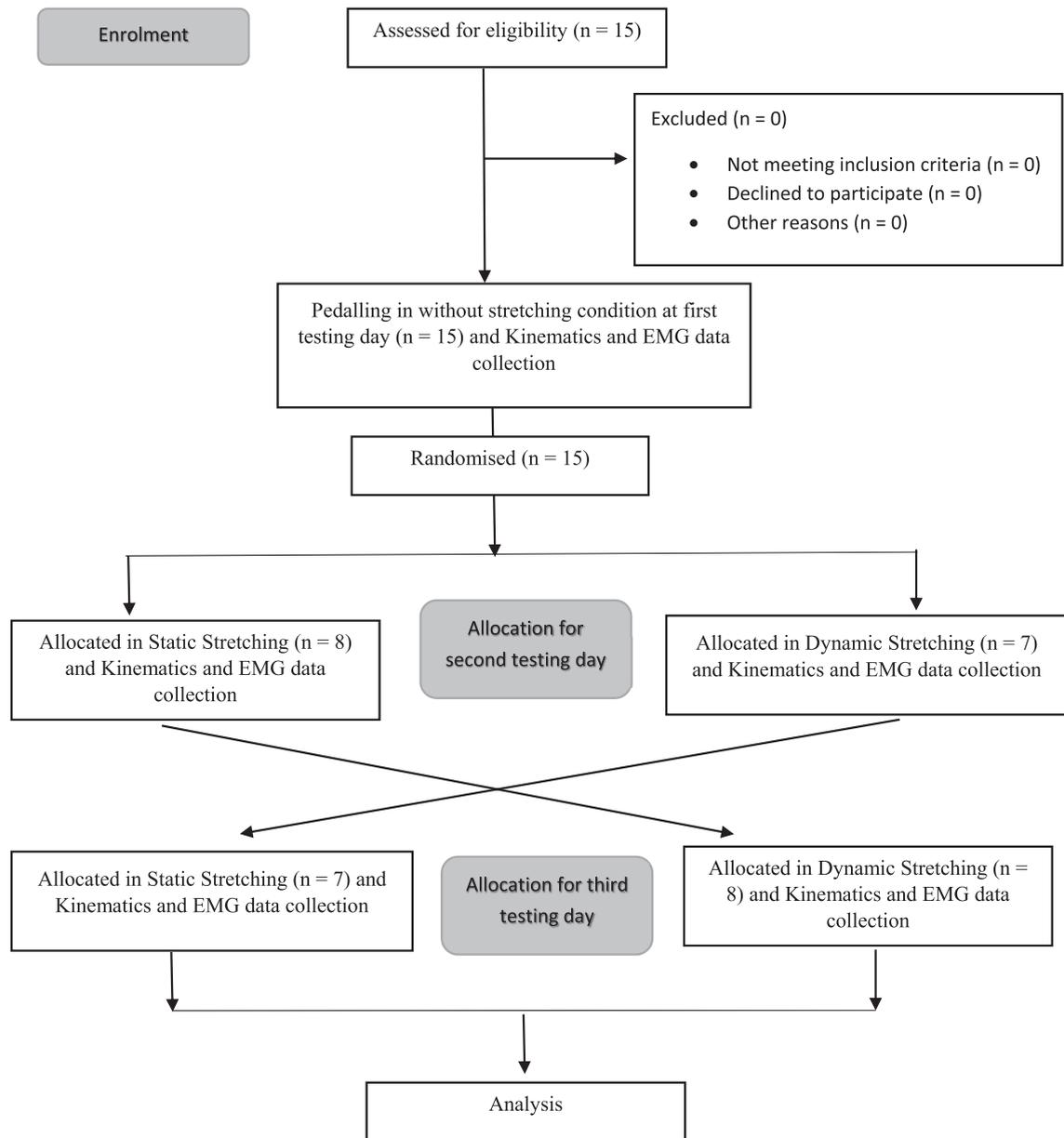
Chart 1. CONSORT Flow Diagram.

sampling frequency of 100 Hz was installed 5 m from the calibration centre perpendicular to the sagittal plane of the pedalling movement (MIE motion analysis system).

A pair of Ag/AgCl electrodes with a diameter of 10 mm was applied on the soleus (SL), gastrocnemius medialis (GM), tibialis anterior (TA), vastus medialis (VM), biceps femoris (BF), and rectus femoris (RF) muscles that had been reported to be involved in pedalling (Hug, Turpin, Couturier, & Dorel, 2011). Surface EMG for non-invasive assessment of muscles (SENIAM) recommendations were followed for the electrode placement. To minimise the skin impedance, the skin surface was shaven and subsequently cleaned with alcohol. In accordance with the SENIAM guidelines, the subjects were asked to lie on a bed while the proper sites for the electrode placement were determined and marked, and electrodes were placed along the direction of the muscle fibres. EMG signals were recorded at 1000 samples/s (MIE motion analysis system).

After positioning the electrodes and the reflective markers, the participants prepared to perform the pedalling protocol. The participants sat on the bicycle ergometer, and the height of the saddle was adjusted such that when the pedal spindle was at the lowest position the participant's lower limb was fully extended. The participants were asked to pedal with an intensity of 70 revolutions per minute (RPM). The EMG and kinematics data were recorded from the lower limbs for 30 s once the intensity reached 70 RPM.

2.2. Static and dynamic stretching protocols

Based on the protocols of previous studies (Hough et al., 2009; Yamaguchi, Ishii, Yamanaka, & Yasuda, 2006), the SS in each limb followed the proximal-to-distal pattern: hip flexors, knee extensors, knee flexors, hip extensors, ankle dorsiflexors, and ankle plantarflexors. Each static stretch was performed by lengthening the muscle to the limit of its range of motion at the pain threshold, and the position was held for 30 s. Intervals of 2–5 s occurred between stretches to allow for the change in the body position. For the DS condition, each participant assumed a standing upright position and began to perform the DS exercises under the verbal guidance of the experimenter. The exercises were performed in the following order: plantar flexors, hip extensors, hamstrings, hip flexors, and quadriceps femoris. Each DS was performed by repetitively bouncing the stretched muscle to its limit of motion range with 15 repetitions, each lasting 2 s (Hough et al., 2009; Yamaguchi et al., 2006). The procedure was performed on the right leg and subsequently the left leg. The same 10–15 s rest period was taken between exercises similar to the SS protocol, and the total DS time was 7 ± 1 min.

2.3. Kinematics and EMG data processing

The raw positional data were filtered with a fourth-order, zero-lag, and low-pass Butterworth digital filter with a cut-off frequency of 6 Hz. The data related to the angular displacement and angular velocity of the hip, knee, and ankle joints were calculated by custom-written MATLAB code. The kinematic data were synchronised with EMG to locate the start and end points of each cycle within the EMG data. The pedalling cycles were determined by the vertical position of the marker that was placed on the pedal spindle. The raw EMG data were imported into MATLAB and bandpass filtered between 10 and 450 Hz and full-wave rectified. All signals were time normalised to 101 data points, representing a cycle from 0 to 100%.

2.4. Largest Lyapunov exponent calculation

The EMG and kinematics data time-series for 30 cycles were selected to calculate the largest LyE. The largest LyE was utilised to calculate the nonlinear local dynamic stability in the EMG and joint angles time series. The largest LyE is a measure of the rate at which nearby trajectories in the state space diverge (Stergiou, 2004). In other words, the largest LyE quantifies the exponential separation of trajectories with time in the state space. As the nearby points separate, they diverge rapidly and produce instability. The largest LyE estimates that this instability is affected primarily by the initial conditions of the system. Specifically, the largest LyE is calculated as the slope of the average logarithmic divergence of the neighbouring trajectories in the state space, and thus provides a direct measure of the sensitivity of a system to local perturbations. The largest LyE (λ_1) for a dynamical system can be defined using Eq. (1) as follows:

$$d(t) = Ce^{\lambda_1 t} \tag{1}$$

where $d(t)$ represents the mean displacement between neighboring trajectories in the state space at time t, and C is the initial separation between neighboring points. λ_1 is defined in the dual limit as $C \to 0$ and $t \to \infty$ in Eq. (1).

The largest LyE calculation, similar to other nonlinear dynamic methods, requires the reconstruction of the state space where the behaviour of the system is embedded. To calculate the state space, the time delay and embedding dimension must be obtained. The time delay was calculated with an autocorrelation function. The autocorrelation function of the sampled data set $S_i = S(t_0 + iT_s)_t$, where T_s is the sampling time and $i = 1, 2, \cdots, N$ is given as follows:

$$C(T) = \frac{\sum_{k=1}^{N} [S(t_0 + kT_s + T) - S_{av}][S(t_0 + kT_s) - S_{av}]}{\sum_{k=1}^{N} [S(t_0 + kT_s) - S_{av}]^2} \tag{2}$$

$$S_{av} = \frac{1}{N} \sum_{k=1}^{N} S(t_0 + kT_s) \tag{3}$$

If the autocorrelation function $C(T)$ has a zero crossing at T, the corresponding value of the time delay is chosen to be T. Otherwise, the first local minimum of the autocorrelation function is utilised to specify T (Nayfeh & Balachandran, 2008). The embedding dimension was calculated using the false nearest neighbours' methods. The time delay and embedding dimension for the joint angle time series were calculated as 10, and 4 respectively. The time delay and embedding dimension for the muscular EMG time series were calculated as 4 and 5, respectively. The time delay and embedding dimension for the hip joint angle are illustrated in Figs. 1 and 2, respectively.

After calculating the time delay and embedding dimension, the state space was reconstructed. The reconstructed state space for the hip joint angle and RF EMG are shown in Figs. 3 and 4, respectively.

After reconstructing the state space, the largest LyE was calculated by a written MATLAB code. In order to examine the validation of written MATLAB code, Lorenz and Rossler equations have calculated in MATLAB and their raw data used to calculate largest LyE by written MATLAB code. The results of this calculations showed there are not significant differences between calculated largest LyE and the ones that reported in the textbooks (Nayfeh & Balachandran, 2008).
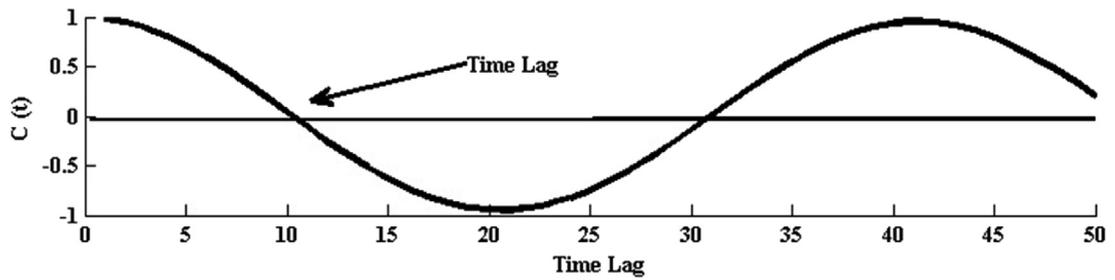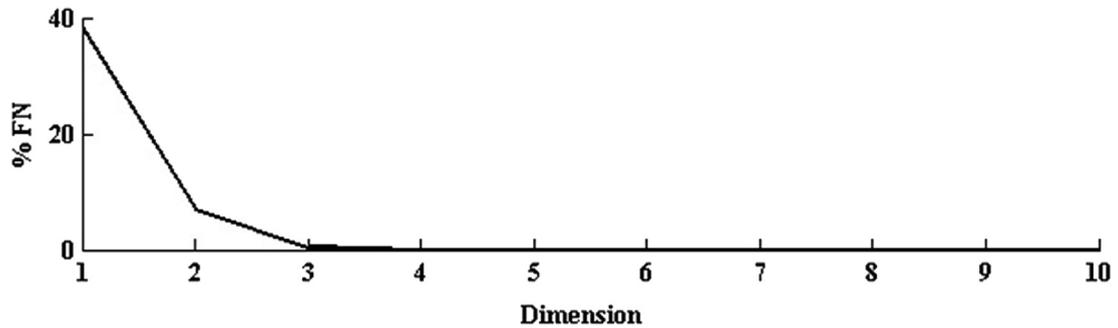
Fig. 1. Time delay curve for hip joint angle.

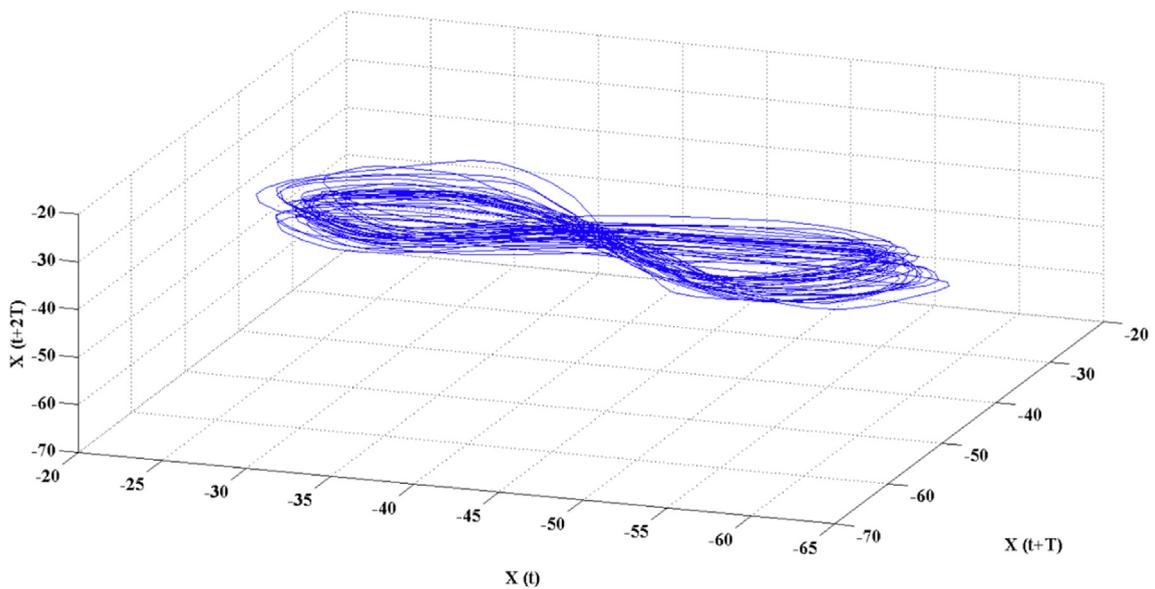**Fig. 2.** Embedding dimension for hip joint angle.

Fig. 3. State space for hip joint angle during 30 pedalling cycles in WS.

2.5. Statistical processing

The one-way repeated measurement ANOVA was utilised for all dependent variables. The assumption of sphericity was tested using Mauchly's test. When appropriate, Bonferroni post-hoc tests were performed to determine the differences between the conditions. The SPSS statistical package version 16 (SPSS Inc., Chicago, IL) was used for data analysis, and the significance level was set at $p = 0.05$. To measure the effect size, the eta squared index was used. The interpretations of this value were: 0.01 = small effect, 0.06 = medium effect, and 0.14 = more or large effect (Cohen, 1988).
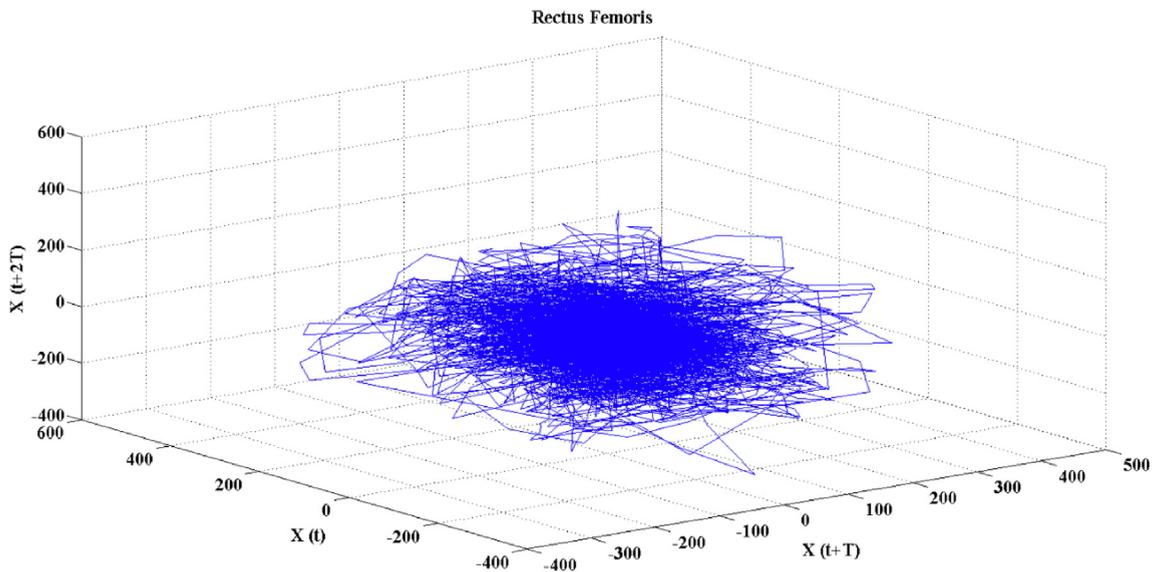
Rectus Femoris

Fig. 4. State space for RF EMG during 30 pedalling cycles in WS.

3. Results

The results of the repeated measurement ANOVA showed significant differences in the knee and ankle joint angle LyE ($p \leq 0.05$) with a large effect size, but no significant differences in the hip joint angle LyE between static and dynamic stretching. The electromyography LyE of SL, GM, TA, VM, BF, and RF muscles between stretching conditions were significantly different ($p \leq 0.05$) with a large effect size. The results of the repeated measure ANOVA and Bonferroni tests for joint angle LyE and EMG LyE are shown in Tables 1 and 2, respectively.

4. Discussion

The aim of this study is to examine the acute effect of static and dynamic stretching on the local dynamic stability of lower extremity joint angles and muscle activity during pedalling using nonlinear dynamics methods. The results revealed that the knee and ankle joints' local dynamic stabilities were significantly higher after DS compared to SS and WS with a large effect size. A significant increase was shown with the large effect size in all muscular EMG local dynamic stabilities after DS compared to WS. Previous studies on the effects of SS and DS on the performance have primarily focused on neurophysiological aspects such as strength and power performance. For example, Hough et al. (2009) reported a higher vertical jump performance and lower EMG activity of the vastus medialis two minutes after static and dynamic stretching (Hough et al., 2009). The positive effect of DS on gait parameters in the elderly has also been reported (Rodacki, Souza, Ugrinowitsch, Cristopoliski, & Fowler, 2009), and it has been demonstrated that DS is a more appropriate exercise for the improvement in the kinematics of instep soccer kicking (Amiri-Khorasani, MohammadKazemi,

Table 1

Mean and standard deviation for joint angles LyE during WS, SS, and DS conditions and the results of repeated measurement ANOVA and Bonferroni tests.

Joint Angles	Condition	LyE (Mean ± S.D.)	95% Confidence Interval		F	P value	Effect Size	Observed Power
			Lower Bound	Upper Bound				
Hip	WS	1.00 ± 0.20	0.896	1.121	1.936	0.163	0.121	0.367
	SS	0.97 ± 0.21	0.857	1.095				
	DS	0.96 ± 0.23	0.837	1.092				
Knee	WS	0.86 ± 0.29	0.702	1.030	13.468	0.000	0.490	0.995
	SS	0.84 ± 0.18	0.739	0.940				
	DS	0.53 ± 0.25[*†]	0.397	0.679				
Ankle	WS	1.25 ± 0.30	1.087	1.425	9.360	0.001	0.401	0.964
	SS	1.19 ± 0.31	1.023	1.368				
	DS	0.97 ± 0.27[*†]	0.828	1.129				

[*] Significant differences with WS condition.

[†] Significant differences with SS condition

Table 2

Mean and standard deviation for RF, VM, BF, TA, GM, and SL EMG LyE during WS, SS, and DS conditions and the results of repeated measurement ANOVA and Bonferroni tests.

Muscle EMG	Condition	LyE (Mean ± S.D.)	95% Confidence Interval		F	P value	Effect Size	Observed Power
			Lower Bound	Upper Bound				
RF	WS	1.09 ± 0.13	1.016	1.174	9.582	0.001	0.424	0.967
	SS	0.91 ± 0.30	0.745	1.093				
	DS	0.73 ± 0.28*	0.567	0.899				
VM	WS	1.09 ± 0.32	0.903	1.277	8.660	0.001	0.400	0.949
	SS	0.86 ± 0.27	0.706	1.028				
	DS	0.63 ± 0.28*	0.473	0.802				
BF	WS	1.10 ± 0.36	0.899	1.315	16.378	0.000	0.557	0.999
	SS	0.93 ± 0.33	0.745	1.133				
	DS	0.62 ± 0.30*†	0.447	0.795				
TA	WS	0.99 ± 0.34	0.802	1.196	8.385	0.002	0.392	0.942
	SS	0.81 ± 0.31	0.631	0.987				
	DS	0.54 ± 0.42*	0.300	0.786				
GM	WS	1.18 ± 0.19	1.072	1.296	7.267	0.003	0.359	0.906
	SS	1.06 ± 0.22	0.939	1.197				
	DS	0.90 ± 0.27*	0.746	1.060				
SL	WS	0.89 ± 0.29	0.726	1.064	10.655	0.000	0.450	0.980
	SS	0.80 ± 0.19	0.688	0.917				
	DS	0.68 ± 0.19*†	0.568	0.794				

* Significant differences with WS condition.
† Significant differences with SS condition.

Sarafrazi, Riyahi-Malayeri, & Sotoodeh, 2012). Nevertheless, the study on the effect of static and dynamic stretching on the strength, explosive power, performance, and risk of injury has been equivocal, as studies have reported the improvement, decrease, or no change in these variables after static and dynamic stretching (Behm & Chaouachi, 2011; Herbert, 2002; McHugh & Cosgrave, 2010; Rubini et al., 2007; Smith, 1994). However, different stretching protocols and durations that have been utilised in these studies rendered any conclusion about the effect of static and dynamic stretching on subsequent performance more difficult.

Stability can be quantified using the response examination of system behaviour to perturbations regarding the changes in its first state (Full, Kubow, Schmitt, Holmes, & Koditschek, 2002). Local stability refers to the behaviour of a system in response to small perturbations, i.e., whether it returns to its stable state. From the mathematical perspective, local dynamic stability is quantified by comparison with the current trajectory of a system to a nearby trajectory in response to a small perturbation. The largest LyE quantifies the average exponential rate of divergence of neighbouring trajectories in the state space, and thus provides a direct measure of the sensitivity of a system to local perturbations (Rosenstein, Collins, & De Luca, 1993). A larger LyE indicates less local dynamic stability and conversely a lower LyE indicates greater local dynamic stability. As pedalling is a repetitive dynamic task, it might be better to use nonlinear dynamic analysis methods, such as largest LyE, for its biomechanical evaluations and the effects of perturbation (here stretching types) on the stability of joints and muscle activity during this dynamic task. To the best of the authors' knowledge, this is the first research that has examined the effect of DS and SS on the kinematics and EMG factors during functional tasks such as pedalling from the nonlinear dynamical analysis perspective.

As shown in Table 1, the knee and ankle joint angle LyEs were reduced significantly after DS, while the hip angle LyE did not change. This indicates that the knee and ankle joints angles reached greater local dynamic stability after DS compare to SS and WS. Previous studies have attributed the effects of stretching to the neurological and viscoelastic effects of muscles. Therefore, the increase in the local dynamic stability in joint kinematics after DS can be attributed to these effects. DS can cause increased irritability of muscular proprioceptive receptors such as the muscle spindle and Golgi tendon organ, and also increases the muscular compliance (Behm, Blazevich, Kay, & McHugh, 2016). This increase can affect the muscular contraction properties and increase the local dynamic stability in joint kinematics. Regarding neurological effects, it has been demonstrated that performing a series of static stretches on a resting muscle leads to an immediate reduction in strength (stretching-induced force deficit). The reduced range of surface EMG signals during maximal voluntary contractions after stretching suggests that a stretch-induced force deficit is a neurological effect (Avela et al., 1999, 2004). Studies have also shown that stretching-induced force deficit is found in the unstretched opposite limb (Cramer et al., 2005). During repetitive DS, muscles and their muscle spindles stretch repetitively; hence, their irritability increases as a result of an increase in their Gama neuron irritability. Consequently, the muscle spindles' increased irritability control muscle activations during the forthcoming movements.

As shown in Table 2, the muscular EMG LyE decreased significantly after DS compared to SS and WS. Variations in muscular activations and their timing could lead to variations in the joint kinematics. Hence, it is reasonable that stability in muscular activations lead to stability in joint kinematics, as is shown in the more local dynamic stability in knee and ankle joint angles after DS. However, as a hip complex contains massive muscles, the stretching protocols might not be sufficiently strong to exhibit significant effects on LyE variations. Meanwhile, as hip joints are near bicycle saddles and linked to them, their variations might be less than

those of knee and ankle joints; therefore, the hip joint LyE did not change after the stretching protocols. Nevertheless, future research can focus on stretching protocols with different durations and frequencies, with both active and inactive male and female participants to provide more insights into the effects of static and dynamic stretching on human movements.

Regarding the viscoelasticity effect, changes in the range of motion and stretching resistance following a bout of acute stretching can be explained by the viscoelastic properties of hysteresis, creep, and stress relaxation. Studies regarding the viscoelastic effects of stretching have revealed that an increased range of motion of joints is associated with a decrease in passive stretching resistance (Magnusson et al., 1995; Magnusson, Simonsen, Aagaard, & Kjaer, 1996; Mchugh & Nesse, 2008; Ryan et al., 2008). This reduced stretching resistance can be attributed to reduced muscle stiffness or increased muscle compliance.

During repetitive movements such as pedalling, exploring how the nervous system responds to disturbances during the execution of a repetitive skill is important. The skeletal-muscle system receives these perturbations and activates the movement paths, and ultimately muscles active in such a way to execute the skill correctly. If any of these functions fail owing to a deficit in the sensory, cognitive, and motor system, or a deficit in muscular function, the person cannot correct the effect of the perturbation on the skills and performance deterioration. The person should have a stable and correct movement pattern and also a suitable response in correcting the perturbations to execute a stable performance (Dingwell, Cusumano, Cavanagh, & Sternad, 2001; Stergiou, 2004). In this study, we attempted to examine the response of a system to static and dynamic stretching using the dynamical system theory and state space reconstruction, and considerable results were obtained.

In the present research, active male participants performed the pedalling tasks at a constant RPM, and the results revealed that SS had no effect on the muscle activity and joint kinematics local dynamic stability. The duration of the stretching protocols used in this study was approximately 10 min. SS was held until the pain threshold, and DS was performed with the maximum effort. Because the participants were active, it is possible that the intensity and duration of the SS protocol were insufficient to induce significant changes in the EMG and joint kinematics. However, we attempted to examine the effect of static and dynamic stretching as they have been used in warm-up when longer duration stretches could not be used. Thus, long-duration static stretches may induce significant changes in the joint kinematics during pedalling.

5. Conclusions

The results of the present research demonstrated that local dynamic stability in joint kinematics increased significantly after DS compared to SS and the baseline condition. Therefore, according to previous studies that have suggested using DS during warm-ups, it was suggested that physically active males participating in repetitive activities like pedalling could use DS in their warm-up programs.

Declaration of Competing Interest

There is no conflict of interest associated with this manuscript.

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