Thermographic Assessment of Eccentric Overload Training Within Three Days of a Running Session

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Abstract

Sanz-López, F, Martínez-Amat, A, Hita-Contreras, F, Valero-Campo, C, and Berzosa, C. Thermographic assessment of eccentric overload training within three days of a running session. *J Strength Cond Res* 30(2): 504–511, 2016—The aim of this study was to analyze the changes in patellar and Achilles tendons between a group trained using eccentric overload and an untrained group within 3 days of a running session. To this end, infrared thermography (IRT) will be used. Twenty healthy male subjects were divided into 2 groups. One group performed a 6-week squat training in the flywheel before the running session. During the running intervention, both groups ran in 3 different days, for 1 hour each, at 80% maximal heart rate. Before, just after, and after 10 minutes of the running intervention, participants were assessed using IRT. Eccentrically trained groups showed a statistically significant difference (analysis of variance, $p = 0.0049$) expressed as a smaller bilateral increase in temperature in the patellar tendon just before the first running day (right side, 0.11° C; left side, 0.29° C). On the other days of running and in the Achilles tendon groups, similar changes were observed: an increase in the temperature after running and no significant difference between contralateral limbs. Our results point at eccentric overload training providing a better adaptation for the first day of running. IRT is an easy-to-apply noninvasive tool to analyze and compare the effects of performance on tendon tissues.

Key Words infrared thermography, patellar tendon, Achilles tendon, flywheel device

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Introduction

Understanding which changes in the tissues are caused by training is the best way to improve performance and prevent injuries, especially in sports (28) because injuries stop sports practitioners to reach their maximum level of performance (4). Detection and reduction of changes in tissues before the development of clinical symptoms is an exceedingly useful tool to avoid pathologies (6,19). This is especially relevant in the case of overuse injuries. Runners are particularly vulnerable to overuse injuries that develop, which approximately 59.4% develop (27), and among them, the knee is the most commonly affected joint, with over 20% of the cases, according to authors (32). One of the most common knee injuries affects the patellar tendon (33). The second higher prevalence injuries in runners are Achilles tendon pathologies.

Eccentric contractions have been widely used in fields, such as training, prevention, and treatment. Several studies have looked into this kind of contraction (18,24), with good results in all fields. Eccentric exercise has been chosen by some authors, especially for treatment and prevention purposes, for its ability to improve the state of tendons. For the patellar tendon, squat movement combined with eccentric is the "gold standard" exercise commonly used to cause beneficial changes in the tissues. The protocol of Stanish et al. (31) is the most widely used, with clear results in 12–15 weeks of treatment for patellar tendinosis injuries (25,34,35). For the Achilles tendon, squat kinematics has not proven to have a direct effect. Instead, the protocol developed by Alfredson et al. (2) is widely used to improve the state of the Achilles tendon. A number of studies have used eccentric overload to achieve adaptations in tendon and muscle in reduced time (1,26). Eccentric overload means that the eccentric phase of the movement is performed with higher loads and velocity than the concentric. Isoinertial devices are used to increase the eccentric phase (23). There exists some evidence that eccentric overload improves strength and jumping performance (9,23), although it is not totally clear which tissue adaptations are responsible

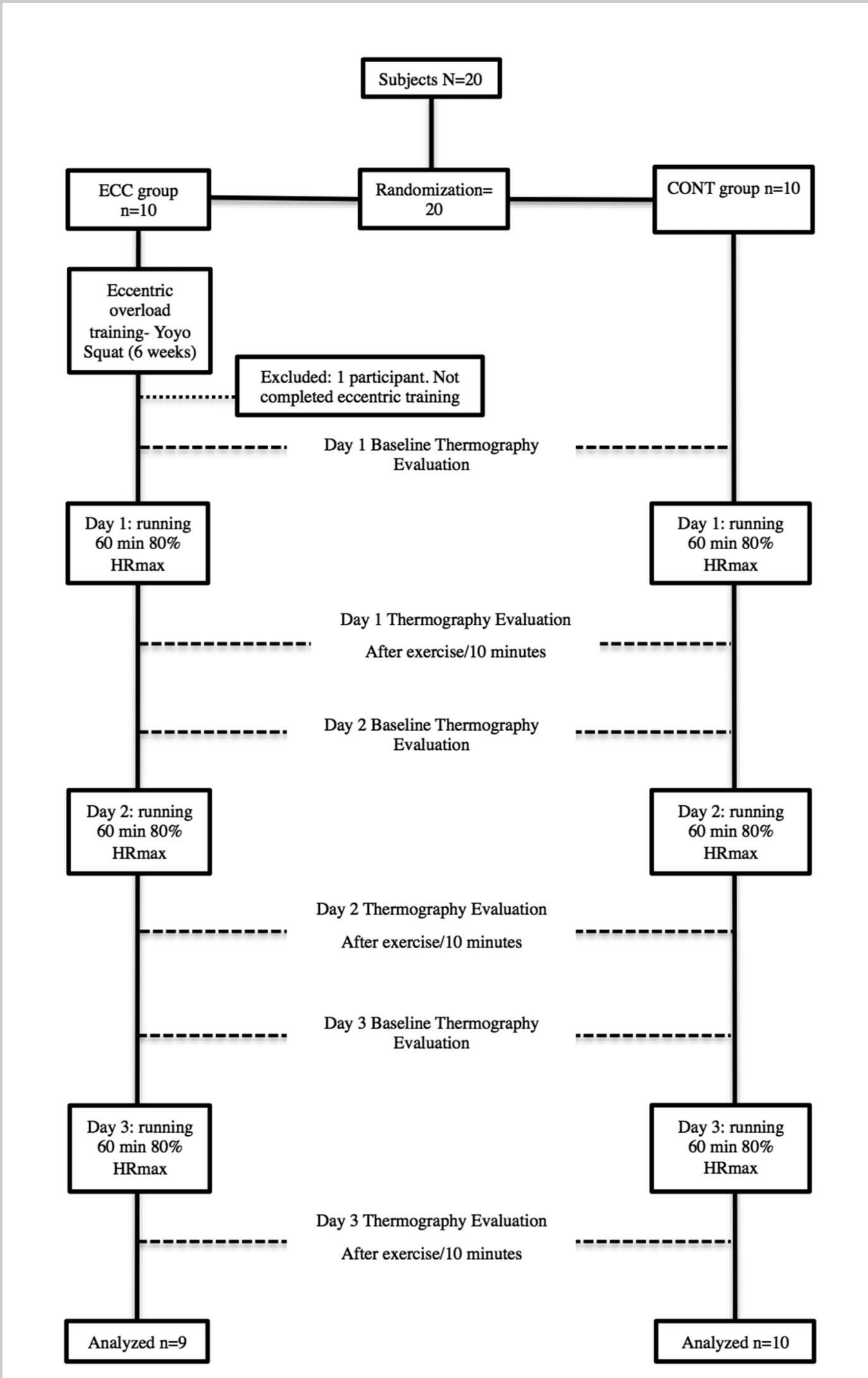

Figure 1. Flow chart of trial design. Eccentric overload group (ECC). Control group (CONT). Maximal heart rate (HRmax).

for the improvements (18). There remains to be seen whether the beneficial effects of eccentric overload training may be applied to other sports, like running.

Infrared thermography (IRT) is a noninvasive and easy-to-perform evaluation technique used in the detection of subclinical changes (21). It has proven to have good interexaminer reliability (36). It has been used in several sports and body areas (37) to detect changes in temperature. The behavior of body temperature is considered pathological when differences larger than 0.6° C appear between contralateral areas (21). Another benefit derived from this technique is that it allows to focus measurement on a concrete area of the body, conventionally called "region of interest" (ROI) (30). In addition, it is a useful tool to determine the degree of adaptation to the intensity of exercise: temperature decreases in anaerobic exercise but increases in aerobic exercise (10). After exercise, untrained subjects experience a larger increase in temperature than well-trained athletes (5).

To our knowledge, no study to date has used IRT to assess the adaptations experienced by the tissues of the patellar and Achilles tendons before and after 3 days of consecutive running. In our study, we also aim to compare the different changes that eccentric overload training may cause before and after the same running effort. Based on previous studies, we hypothesized that adaptations in tendon tissues caused by eccentric exercise will generate distinct behavior patterns when compared with the tissues of untrained participants.

Methods

Experimental Approach to the Problem

A controlled trial was conducted from April to June 2014 to assess the effects of eccentric training on tendon tissues (patellar and Achilles) when running. One group of participants voluntarily performed a 6-week training program with a flywheel (YoYo Squat). The eccentric overload training was finished 1 week before the beginning of the

Figure 2. YoYo Squat. Eccentric phase of the movement finished when the thighs were in parallel to the floor. Concentric phase was executed at a higher velocity than eccentric phase.

running intervention, to provide time enough to reach the tissue adaptation of the training. All participants performed a 1-hour running session for 3 consecutive days. The running intervention was performed at 80% maximal heart rate, which was controlled using a heart rate monitor. IRT imaging was used to assess changes in the tendons. Thermographic data were acquired just before, just after, and 10 minutes after the running intervention. Participants were not allowed to perform any other exercise during the length of the study.

Subjects

In our study, 40 patellar tendons and 40 Achilles tendons from 20 male volunteers, with an age range between 18 and 25 years, from Universidad San Jorge (Spain) were analyzed (age 22.79 ± 4.21 years, weight 72.57 ± 6.73 kg, height 179.77 ± 7.88 cm, body mass index 22.7 ± 2.1, mean ± *SD*). All participants reported habitually performing sports activities more than 3 $d \cdot wk^{-1}$. None of the participants had performed eccentric training before. Participants with a 2-year history of lower limb pathologies were excluded. Not being able to complete the eccentric training or the running intervention was considered an exclusion criterion. The study was conducted in adherence to the standards of the Declaration of Helsinki (2008 version) and after the European Community's guidelines for Good Clinical Practice (111/3976/88 of July 1990) and also the Spanish legal framework for clinical research on humans (Real Decreto 561/1993 on clinical trials). The protocol was approved by CEICA (Ethics Committee of Clinical Research of Aragón, Spain) CP08/2014, and all participants provided written informed consent before participating in the study.

Participants were divided into 2 groups: one control group (CONT, $n = 40$ tendons, 10 subjects) and the other eccentric overload group (ECC, $n = 40$ tendons, 10 subjects). Participants in the ECC were those who voluntarily accepted to perform the eccentric overload training before the running intervention (Figure 1). This eccentric overload training was performed with squat movements, to focus the load and adaptations on the patellar tendon. The Achilles tendon of the ECC was also measured, which would allow us to compare the differences in the patellar tendon between the ECC and CONT and to compare the differences with the Achilles tendon in the CONT.

Procedures

Eccentric Overload Training. Participants in the ECC were trained 2 $d \cdot wk^{-1}$ during 6 weeks, using a YoYo Squat (YoYo Technology AB, Stockholm, Sweden) and after the protocol proposed by Norrbrand et al. (22). One previous session took place to allow the participants to familiarize themselves with the flywheel device and to record a maximum number of repetitions for each participant. Each training session consisted of 4 sets of 7 repetitions interspersed by 2-minute between-set rest periods. Every session was preceded by a standardized warm-up, which included 5 minutes of jogging and dynamic stretches. After warming up, subjects rested for 5 minutes before starting the training session. One 2.7-kg flywheel (0.07 $kg \cdot m^2$ moment inertia) was used in the Yoyo Squat device (Figure 2). Similarly, the concentric phase was performed as fast as possible, whereas the eccentric phase was executed at a lower velocity (2

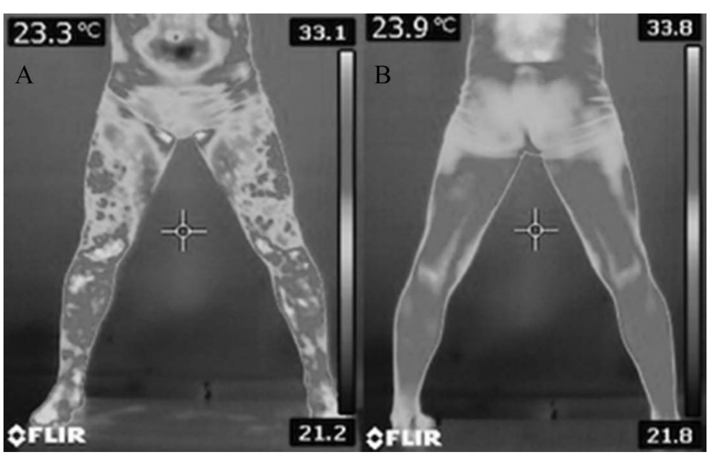

Figure 3. Examples of infrared thermography. A, Anterior view. B, Posterior view.

Table 1. Patellar tendon ROI. Mean (*SD*) in CONT and ECC for each outcome, over the 3 days of running.*

		CONT ($n = 20$), median (*SD*)		ECC ($n = 18$), median (*SD*)	
Running day	Outcomes	Right	Left	Right	Left
1	Baseline-1	29.87 (0.75)	29.86 (0.71)	30.92 (0.82)	30.83 (0.85)
	Just after running	30.98 (1.76)	30.78 (1.57)	31.03 (1.68)	31.12 (1.68)
	10 min after running	31.54 (1.46)	31.17 (1.29)	31.73 (1.27)†‡§	31.65 (1.44)†‡§
2	Baseline-2	30.2 (1.04)	30.13 (0.97)	30.85 (0.66)	30.76 (0.59)
	Just after running	31.06 (1.97)	31.09 (1.87)	31.77 (1.02)	31.93 (1.01)
	10 min after running	31.19 (1.6)	31.15 (1.47)	31.91 (0.79)	32.00 (0.99)
3	Baseline-3	30.01 (1.03)	30.04 (0.93)	30.8 (0.79)	30.74 (0.59)
	Just after running	31.42 (1.65)	31.42 (1.56)	32.16 (1.27)	32.14 (1.35)
	10 min after running	31.73 (1.82)	31.65 (1.68)	32.71 (0.91)†‡§	32.64 (0.82)†‡§

*ROI = region of interest; CONT = control group; ECC = eccentric overload group.
†Significant differences relative to Baseline-1.
‡Significant differences relative to Baseline-2.
§Significant differences relative to Baseline-3.

seconds). Because of the squatting depth influencing the acute and chronic responses (9), the range of motion (ROM) was matched in each exercise (i.e., until the thighs were in parallel to the floor). We ensured that all participants faced the same percentage of load using a linear encoder (SmartCoach Europe AB, Stockholm, Sweden). The whole training was overseen by an experienced investigator.

Running Intervention. The CONT and ECC performed 3 running sessions on consecutive days. The procedure consisted of 1 hour of running. Participants ran at 80% of their maximal heart rate, calculated using the methods described by Karvonen and Vuorimaa (12). Maximal heart rate was measured using a Polar Heart Rate Monitor RS300X (Polar Electro Ibérica, Barcelona, Spain). An investigator controlled the intensity of the whole training. The running surface was the same for all participants: the perimeter of a grass soccer field. After 30 minutes of running, runners were instructed to reverse the direction. Distance running for each participant was measured. Participants did not perform any other physical activity on the day before and during the study.

Thermography Outcomes. IRT has shown to have good interexaminer reliability, with an intraclass correlation coefficient of 0.96 in knee and 0.99 in heel (36). Thermographic evaluation was performed in the same room for all the groups. Room temperature was checked to be always at 21° C, with 60% humidity. The average outside temperature was 19° C for the CONT and 20.5° C for the ECC. During all the thermographic measurements, participants remained in their underwear and were not allowed to sit down.

The device used was a thermal infrared camera (FLIR Thermacam E60; FLIR Systems, Boston, MA, USA). Images in the frontal plane were taken from the anterior and posterior sides. Baseline-1 images were obtained just before the first running session. Baseline-2 images were obtained immediately before the second running session, and Baseline-3 images were obtained just before the third running session. Just after finishing the running protocol, 3 images were taken and 3 more images were taken 10 minutes later. This was repeated on each of the 3 days. During the measurement process, participants remained in their underwear and were not allowed to sit down. All thermographic images were taken with participants standing on a step to avoid contact with the floor. The distance from the camera to the subjects was 2.5 m. All limbs had to be visible on the screen before the image could be taken (Figure 3). Temperature means for patellar and Achilles tendon ROIs were selected and analyzed with the software package provided with the system (FLIRTools-Software; FLIR Systems). It was assumed that the emissivity of the skin was 0.98 for all subjects (15). The study was conducted according to the guidelines of the American Academy of Thermography (29). Images were obtained by one single investigator, trained in the use of thermographic devices.

Statistical Analyses

Mean and *SD* were calculated for all thermographic images on each day of the study. A Shapiro-Wilk test was performed to assess the normality of the distribution. Differences in Baseline-1 between ECC and CONT were compared using Student's *t*-test. Normally distributed data were analyzed using analysis of variance. Post hoc paired analysis was performed using Bonferroni's adjustment. Nonnormalized data (ECC right and left patellar tendons measured just after the first day of running and ECC left Achilles tendon measured 10 minutes after the third day of running) were analyzed using the Kruskal-Wallis test. Post hoc paired adjustment was made using Dunn's multiple comparison test. Significance was set at $p \leq 0.05$. All analyses were conducted using

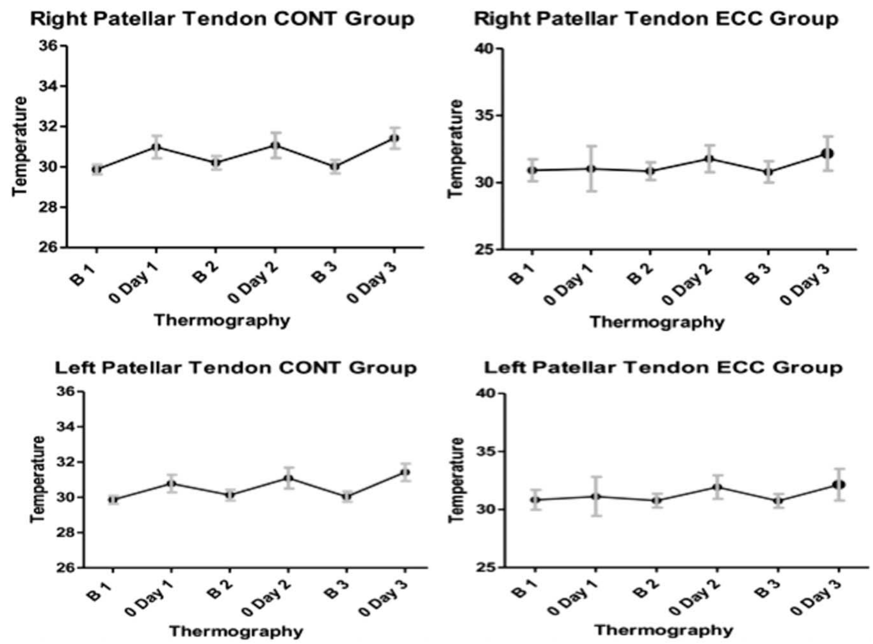

Figure 4. Mean and *SD*. Right and left patellar tendon thermography. B = Baseline. Day 0 = Data obtained just after the running intervention.

the GraphPad Prism V 5.0 statistical package (GraphPad Software, Inc., La Jolla, CA, USA).

Results

Only one of the participants failed to complete the eccentric training. None of the remaining 19 participants was found to have a history of lower limb injuries in the last 2 years. All participants were currently asymptomatic and were not taking any medication or interventions that may have had a systemic effect. Average running distance along the 3 days for the CONT was 10,664.33 (±475.64) and 9,885.33 (±465.97) m for the ECC, with no significant difference ($p = 0.094$). Pairwise adjustment showed statistically significant differences in Baseline-1 between ECC and CONT in the patellar tendon. Also, in Baseline-1, statistically significant differences were analyzed between ECC and CONT for the Achilles tendon. No differences larger than 0.6° C were found in comparison with the contralateral leg in each assessment.

Patellar Tendon Thermography

The ECC measurements taken right after the running intervention showed significantly different values ($p = 0.0049$). Pairwise adjustment did not show statistically significant changes. The ECC measurements taken 10 minutes after the running intervention showed statistically significant values ($p < 0.001$). Pairwise adjustment showed statistically significant changes for all baselines after the first and third day of running ($p \leq 0.05$; Table 1).

The CONT did not show significant differences ($p = 0.0927$) in the measurements taken right after the running intervention. Pairwise adjustment did not show statistically significant changes. Significantly different values were found in the CONT ($p = 0.0032$) in the measurements taken 10 minutes after the running intervention. Pairwise adjustment did not show any statistically significant changes (Table 1). Images from both sides in the ECC, measured just after the running intervention on day 1, showed the smaller values of change of all the groups (Figure 4).

Achilles Tendon Thermography

The ECC measurements taken right after the running intervention showed statistically significant values ($p < 0.001$). Pairwise adjustment showed statistically significant changes ($p \leq 0.05$) from Baseline-1 on the left side on days 2 and 3 of running. Pairwise adjustment also showed statistically significant changes ($p \leq 0.05$) from Baseline-2 and Baseline-3 on both sides in all running sessions. The ECC measurements taken 10 minutes after the running intervention showed statistically significant changes ($p < 0.001$). Pairwise adjustment showed statistically significant changes comparing all baselines on the left side after the first day of running ($p \leq 0.05$). Adjustment by pairs also showed statistically significant changes ($p \leq 0.05$) from Baseline-2 and Baseline-3 on both sides after the first day of running. The same significant change was detected for the right side on day 3 (Table 2).

Table 2. Achilles tendon ROI. Mean (*SD*) in CONT and ECC for each outcome, over the 3 days of running.*

		CONT (n = 20), median (*SD*)		ECC (n = 18), median (*SD*)	
Running day	Outcomes	Right	Left	Right	Left
1	Baseline-1	29.50 (1.13)	29.45 (1.03)	31.50 (0.58)	31.23 (0.52)
	Just after running	31.37 (0.85)†‡§	31.10 (1.05)†‡§	32.26 (0.85)‡§	32.21 (0.48)‡§
	10 min after running	31.10 (1.05)	31.02 (0.94)	32.60 (0.58)‡§	32.63 (0.57)†‡§
2	Baseline-2	29.71 (0.79)	29.58 (0.78)	30.86 (0.61)	30.80 (0.61)
	Just after running	31.30 (0.90)†‡	31.25 (0.78)†‡	32.34 (0.83)‡§	32.46 (0.85)†‡§
	10 min after running	30.60 (0.99)	30.50 (0.98)	32.06 (0.60)	32.13 (0.53)
3	Baseline-3	29.49 (1.71)	29.66 (1.05)	30.76 (0.62)	30.86 (0.74)
	Just after running	32.11 (1.15)†‡	31.97 (1.18)†‡	32.56 (0.82)‡§	32.54 (0.67)†‡§
	10 min after running	31.09 (1.48)	31.15 (1.48)†	32.18 (0.58)‡§	32.19 (0.40)

*ROI = region of interest; CONT = control group; ECC = eccentric overload group.
†Significant differences relative to Baseline-1.
‡Significant differences relative to Baseline-2.
§Significant differences relative to Baseline-3.

Statistically significant variations ($p < 0.001$) were found in the measurements of CONT taken right after the running intervention. Pairwise adjustment showed statistically significant changes ($p \leq 0.05$) from Baseline-1 on both sides on the first day of running. Statistically significant changes ($p \leq 0.05$) from Baseline-1 and Baseline-2 were also found on both sides on days 2 and 3 of running. Significant changes ($p < 0.001$) were found in the measurements of CONT taken 10 minutes after the running intervention. Pairwise adjustment only showed statistically significant changes on the left side on day 3 of running when compared with Baseline-1 (Table 2).

Discussion

As far as we know, this research is the first to analyze the effect of eccentric overload training on 3 consecutive days of running. Its results show that the patellar tendon behaves differently in participants trained with overload eccentric exercise than in untrained participants after 3 consecutive days of performing a 1-hour running session. The main differences are found in the thermographic adaptation experienced on the first day of running. Furthermore, our study provides IRT data based on samples, whereas most studies consulted presented isolated clinical cases. Our study provides an innovative approach to the research of structural changes because it aims at finding the effects of long-term eccentric training on the short term and also after a 3-day sports intervention.

IRT has proven to be an effective tool, and its use has already been justified by several authors (10,30). In our study, thermographic images of the patellar tendon did not show any statistically different behavior between groups. Significant changes between ECC and CONT baselines were observed, with similar values of difference in all the steps, including the Achilles tendon. Any contralateral change of temperature over 0.6° C was recorded because it could be a sign of pathological adaptations. After each day of running, the temperature in both groups increased more than 0.7° C, except for the ECC on the first day of running. Baseline results are similar to those found by Zaproudina et al. (36), who found average values in the knee to be approximately 29.1° C (±0.8), the same as in our study. For the detection of pathologies, several studies have concluded that any difference in temperature larger than 0.5–0.6° C between contralateral limb areas can be considered a predisposing factor for the development of injuries (21,30). Regarding changes in temperature after exercise, Clark et al. (5) found an increase in temperature that could be observed after performing 70 minutes of running. This was corroborated by Hildebrandt et al. (10) for aerobic exercise, in a study in which they recorded a knee temperature increase of 0.7° C immediately after aerobic exercise. These values are similar to our data. However, the ECC did not exhibit comparable values after their first day of running but a very small increase in the temperature of the right and left patellar tendons, instead. This could be associated with a lower level of metabolic activity (10) or with the tendon being better adapted to the load (3). It can be hypothesized that an increased cell number of connective tissue in the tendon could be the response of adaptation to the load (20).

For the Achilles tendon thermography, no significant difference was observed in the contralateral limbs. Significant changes could be perceived between ECC and CONT baselines, with similar values of difference in all the steps, including the patellar tendon. Similar temperature increases without significant changes were observed in all groups. In our study, higher values were observed than those found at baseline, 25.3° C (±2.1), by Zaproudina et al. (36). About the

Achilles tendon, specifically, Alina (3) found variations of 0.9° C in the case of tendinopathy and of more than 2° C if the affected tendon had also suffered alterations to the bursa or adjacent tissues. A similar behavior of the Achilles tendon in the ECC suggests that squat kinematics do not have a clear effect on the Achilles tendon.

Based on the results observed in IRT, the ECC had an improved initial adaptation to the running protocol. In the remaining running days, no significant changes appeared. Eccentric exercise has shown generally good results for the treatment and prevention of patellar tendinosis injuries (25,35). Painful eccentric decline single-leg exercises are the most commonly used type (11). The duration of training averages 12–15 weeks across studies (11,14), although research dealing with eccentric overload shows that adaptations in tendon and muscle happen in a shorter time than that (1,26). Eccentric overload has also been applied to populations such as the elderly (17) or chronic stroke patients (7), seeking to minimize damage and increase force production with a reduced energy cost. The mechanisms of the beneficial effects of eccentric overload are not clear yet (17). Higher loads and velocity in the eccentric phase of the movement could increase levels of peritendinous type-I collagen synthesis (16) in the tendon. In a number of studies (13,22), muscular response after eccentric overload has shown to improve the strength and performance of muscles. Research carried out by Friedmann et al. (8) explains that elevated intramuscular pressure because of the higher tension experienced during the eccentric phase probably impedes the increase of blood flow. This may lead to enhanced hypoxia, which in turn could induce different adaptations in the gene expression patterns of tendons and muscles. This might explain our results because a smaller metabolic adaptation could be enough for the first day of running, but not for a continued 3-day effort.

It can be concluded that eccentric overload training causes particular adaptations in tendon tissues if these have been the focus of the training movement. The changes generated helped tolerate new effort in healthy participants but did not amount to significant differences during the rest of the intervention.

Practical Applications

From a practical point of view, it must be considered that a 6-week eccentric overload program with flywheel devices enhances the response of the patellar tendon tissues and improves metabolic adaptation on the first day of running. This study shows that, compared with a non-eccentrically trained group of participants, eccentric overload training provides positive changes related to IRT outcomes. This study also indicates that this training may play an important role in providing optimal adaptations of the patellar tendon tissues in less time than other eccentric training programs without an overload phase. Despite the beneficial effects of the eccentric overload program, its effects could not be felt on the second and third days of running, nor did they affect the Achilles tendon. We recommend considering these programs as a way to avoid training injuries and to improve the quality of patellar tendon structures. Likewise, IRT is a tool that should be used to assess, in a fast and easy way, the effects of exercise.

Acknowledgments

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References

1. Agyi, TH, Devita, P, Money, J, and Barrier, J. Effects of standard and eccentric overload strength training in young women. *Med Sci Sports Exerc* 33: 1206–1212, 2001.
2. Alfredson, H, Pietila, T, Jonsson, P, and Lorentzon, R. Heavy-load eccentric calf muscle training for the treatment of chronic Achilles tendinosis. *Am J Sports Med* 26: 360–366, 1998.
3. Alina, M. The use of infrared thermography for investigating abarticular rheumatism. *Sports Med J* 9: 2094–2100, 2013.
4. Bahr, R and Krosshaug, T. Understanding injury mechanisms: A key component of preventing injuries in sport. *Br J Sports Med* 39: 324–329, 2005.
5. Clark, RP, Mullan, BJ, and Pugh, LG. Skin temperature during running: A study using infra-red colour thermography. *J Physiol* 267: 53–62, 1977.
6. Cook, JL, Khan, KM, Harcourt, PR, Kiss, ZS, Fehramann, MW, Griffiths, L, and Wark, JD. Patellar tendon ultrasonography in asymptomatic active athletes reveals hypoechoic regions: A study of 320 tendons. *Clin J Sport Med* 8: 73–77, 1998.
7. Fernandez-Gonzalo, R, Nissemark, C, Åslund, B, Tesch, PA, and Sojka, P. Chronic stroke patients show early and robust improvements in muscle and functional performance in response to eccentric-overload flywheel resistance training: A pilot study. *J Neuroeng Rehabil* 11: 150, 2014.
8. Friedmann, B, Kinscherf, R, Vorwald, S, Müller, H, Kucera, K, Borisch, S, Richter, G, Bärtsch, P, and Billeter, R. Muscular adaptations to computer-guided strength training with eccentric overload. *Acta Physiol Scand* 182: 77–88, 2004.
9. Hartmann, H, Wirth, K, Klusemann, M, Dalic, J, Matuschek, C, and Schmidtbleicher, D. Influence of squatting depth on jumping performance. *J Strength Cond Res* 26: 3243–3261, 2012.
10. Hildebrandt, C, Zeilberger, K, Ring, EFJ, and Raschner, C. The application of medical infrared thermography in sports medicine. *Ultrasound* 10: 257–274, 2012.
11. Jonsson, P and Alfredson, H. Superior results with eccentric compared to concentric quadriceps training in patients with jumper's knee: A prospective randomised study. *Br J Sports Med* 39: 847–850, 2005.
12. Karvonen, J and Vuorimaa, T. Heart rate and exercise intensity during sports activities. *Sports Med* 5: 303–311, 1988.
13. Kjær, M, Langberg, H, Heinemeier, K, Bayer, ML, Hansen, M, Holm, L, Doessing, S, Kongsgaard, M, Krogsgaard, MR, and Magnusson, SP. From mechanical loading to collagen synthesis, structural changes and function in human tendon. *Scand J Med Sci Sports* 19: 500–510, 2009.

14. Kongsgaard, M, Aagaard, P, Doessing, S, Hansen, P, Kjaer, M, and Magnusson, SP. Peritendinous corticosteroid injections, eccentric decline squat training and heavy slow resistance training in patellar tendinopathy. *Med Sci Sports Exerc* 40: 790–802, 2008.

15. Lahiri, BB, Bagavathiappan, S, Jayakumar, T, and Philip, J. Medical applications of infrared thermography: A review. *Infrared Phys Tech* 55: 221–235, 2012.

16. Langberg, H, Ellingsgaard, H, Madsen, T, Jansson, J, Magnusson, SP, Aagaard, P, and Kjaer, M. Eccentric rehabilitation exercise increases peritendinous type I collagen synthesis in humans with Achilles tendinosis. *Scand J Med Sci Sports* 17: 61–66, 2007.

17. LaStayo, P, Marcus, RL, Dibble, L, Frajacomo, F, and Lindstedt, SL. Eccentric exercise in rehabilitation: Safety, feasibility and application. *J Appl Physiol (1985)* 116: 1426–1434, 2014.

18. LaStayo, PC, Woolf, JM, Lewek, MD, Snyder-Mackler, L, Reich, T, and Lindstedt, SL. Eccentric muscle contractions: Their contribution to injury, prevention, rehabilitation, and sport. *J Orthop Sports Phys Ther* 33: 557–571, 2003.

19. Malliaras, P and Cook, J. Patellar tendons with normal imaging and pain: Change in imaging and pain status over a volleyball season. *Clin J Sport Med* 16: 388–391, 2006.

20. Malliaras, P, Kamal, B, Nowell, A, Farley, T, Dhamu, H, Simpson, V, Morrissey, D, Langberg, H, Maffulli, N, and Reeves, ND. Patellar tendon adaptation in relation to load-intensity and contraction type. *J Biomech* 46: 1893–1899, 2013.

21. Mangine, RE, Siqueland, KA, and Noyes, FR. The use of thermography for the diagnosis and management of patellar tendinitis. *J Orthop Sports Phys Ther* 9: 132–140, 1987.

22. Norrbrand, L, Fluckey, JD, Pozzo, M, and Tesch, PA. Resistance training using eccentric overload induces early adaptations in skeletal muscle size. *Eur J Appl Physiol* 102: 271–281, 2008.

23. Norrbrand, L, Pozzo, M, and Tesch, PA. Flywheel resistance training calls for greater eccentric muscle activation than weight training. *Eur J Appl Physiol* 110: 997–1005, 2010.

24. Potier, TG, Alexander, CM, and Seynnes, OR. Effects of eccentric strength training on biceps femoris muscle architecture and knee joint range of movement. *Eur J Appl Physiol* 105: 939–944, 2009.

25. Purdam, CR, Johnsson, P, Alfredson, H, Lorentzon, R, Cook, JL, and Khan, KM. A pilot study of the eccentric decline squat in the management of painful chronic patellar tendinopathy. *Br J Sports Med* 38: 395–397, 2004.

26. Rabin, A. Is there evidence to support the use of eccentric strengthening exercises to decrease pain and increase function in patients with patellar tendinopathy? *Phys Ther* 86: 450–456, 2006.

27. Ristolainen, L, Heinonen, A, Turunen, H, Mannström, H, Waller, B, Kettunen, JA, and Kujala, UM. Type of sport is related to injury profile: A study on cross country skiers, swimmers, long-distance runners and soccer players. A retrospective 12-month study. *Scand J Med Sci Sports* 20: 384–393, 2010.

28. Rosengarten, SD, Cook, JL, Bryant, AL, Cordy, JT, Daffy, J, and Docking, SI. Australian football players' Achilles tendons respond to game loads within 2 days: an ultrasound tissue characterisation (UTC) study. *Br J Sports Med* 49: 183–187, 2014.

29. Available at: http://aathermology.org/organization/guidelines/guidelines-for-neuro-musculoskeletal-thermography/. Accessed March 15, 2014.

30. Selfe, J, Hardaker, N, Thewlis, D, and Karki, A. An accurate and reliable method of thermal data analysis in thermal imaging of the anterior knee for use in cryotherapy research. *Arch Phys Med Rehabil* 87: 1630–1635, 2006.

31. Stanish, WD, Rubinovich, RM, and Curwin, S. Eccentric exercise in chronic tendinitis. *Clin Orthop Relat Res* 208: 65–68, 1986.

32. van Gent, RN, Siem, D, van Middelkoop, M, van Os, AG, Bierma-Zeinstra, SM, and Koes, BW. Incidence and determinants of lower extremity running injuries in long distance runners: A systematic review. *Br J Sports Med* 41: 469–480, 2007; discussion 480.

33. van Poppel, D, Scholten-Peeters, GGM, van Middelkoop, M, and Verhagen, AP. Prevalence, incidence and course of lower extremity injuries in runners during a 12-month follow-up period. *Scand J Med Sci Sports* 24: 943–949, 2014.

34. Visnes, H and Bahr, R. The evolution of eccentric training as treatment for patellar tendinopathy (jumper's knee): A critical review of exercise programmes. *Br J Sports Med* 41: 217–223, 2007.

35. Young, MA, Cook, JL, and Purdam, CR. Eccentric decline squat protocol offers superior results at 12 months compared with traditional eccentric protocol for patellar tendinopathy in volleyball players. *Br J Sports Med* 39: 102–105, 2005.

36. Zaproudina, N, Varmavuo, V, Airaksinen, O, and Narhi, M. Reproducibility of infrared thermography measurements in healthy individuals. *Physiol Meas* 29: 515–524, 2008.

37. Zerba, E, Komorowski, TE, and Faulkner, JA. Free radical injury to skeletal muscles of young, adult, and old mice. *Am J Physiol* 258: C429–C435, 1990.