Rev.int.med.cienc.act.fís.deporte - vol. 20 - número 79 - ISSN: 1577-0354

Aurell-Badenas, V.; Murias-Lozano, R.; Rodríguez-López, E.S. y García-Giménez, A. (2020). Efficacy of Plyometrics in the Neuromuscular Fatigue During Triathlon: A Pilot Study. Revista Internacional de Medicina y Ciencias de la Actividad Física y el Deporte vol. 20 (79) pp. 551-566 Http://cdeporte.rediris.es/revista/revista79/arteficacia1182.htm
DOI: http://doi.org/10.15366/rimcafd2020.79.011

ORIGINAL

EFFICACY OF PLYOMETRICS IN THE NEUROMUSCULAR FATIGUE DURING TRIATHLON: A PILOT STUDY

EFICACIA DE LA PLIOMETRÍA EN LA FATIGA NEUROMUSCULAR EN TRIATLÓN: ESTUDIO PILOTO

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ACKNOWLEDGEMENTS

We thank the Botorrita (Zaragoza) town hall for providing access to the premises in which the measurements took place. Further, we thank the University of Camilo José Cela for providing the material used to carry out the measurements and the Triathlon Stadium Casablanca Club for their collaboration in the process of sample selection. The present study did not receive any financial support.

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Código UNESCO / UNESCO code: 5899 Otras especialidades pedagógicas (Educación Física y Deporte) / Other pedagogical specialties (physical education and sport)
Clasificación Consejo de Europa / Council of Europe classification: 17: otras (entrenamiento deportivo) / other (sport training)

Recibido 1 de octubre de 2018 **Received** October 1, 2018
Aceptado 4 de enero de 2019 **Accepted** january 4, 2019

ABSTRACT

The transition stage in triathlon effect performance and injury risk. The objective was to determine neuromuscular fatigue induced over 40 km of cycling and the efficacy of plyometric training to combat fatigue and improve performance in the foot race. Twelve triathletes participated, with 5 completing the plyometric training and 7 continuing their normal training. Jump tests were conducted both before and after 40 km of cycling to establish fatigue and pace during the 5 km race was measured. Significant differences were observed in jump height ($p<0,05$) indicated that 40 km of cycling induces fatigue in the lower extremities. Following plyometric training significant improvements were observed in the *Squat Jump* test conducted after cycling ($p=0.038$) and in the pace of the first kilometre ($p=0.015$). Plyometric training appears to be more efficacious than regular training for reducing neuromuscular fatigue and improving the pace of the first kilometre.

KEYWORDS: bicycling**,** running**,** plyometric exercise**,** athletic performance

RESUMEN

Las transiciones en triatlón afectan al rendimiento y riesgo de lesión. El objetivo fue determinar la fatiga neuromuscular inducida por 40 km de ciclismo y la eficacia del entrenamiento pliométrico en la fatiga y rendimiento de la carrera a pie. Participaron doce triatletas, 5 realizaron un entrenamiento pliométrico y 7 continuaron su entrenamiento habitual. Se realizaron tests de salto antes y después de 40 km de ciclismo para determinar la fatiga y se registró el ritmo de 5 km de carrera. Se observaron diferencias significativas en la altura de salto ($p<0,05$) indicando que 40 km de ciclismo inducen fatiga en la extremidad inferior. Tras el entrenamiento pliométrico se observaron mejoras significativas en el test *Squat Jump* posterior al ciclismo ($p=0,038$) y en el ritmo del primer kilómetro ($p=0,015$). El entrenamiento pliométrico parece ser más eficaz que el entrenamiento habitual para mejorar la fatiga neuromuscular y el ritmo del primer kilómetro.

PALABRAS CLAVE: ciclismo, carrera, ejercicio pliométrico, rendimiento atlético

INTRODUCTION

The popularity of triathlon has increased during recent years, with the Olympic distance being particularly popular. This consists of 1.5 km of swimming, 40 km of cycling and 10 km of foot race (1). The transitions between the different phases of the triathlon is a unique characteristic of this sport, which can affect performance as much as injury risk (2). Overall performance is determined by the triathlete's ability to bring together and excel in the three disciplines, with the foot race being the most important aspect determining success in the Olympic distance (3–5). However, the race is also the section most likely to result in injury out of the three, to which 73% of injuries suffered by triathletes are attributed (6).

Transition from the bicycle to the foot race induces neuromuscular fatigue in the lower extremities (EEII), which can cause triathletes to have an uncomfortable sensation at the beginning of the foot race (5). Muscular coordination is required to move from a non weight-bearing activity consisting of predominantly concentric contractions to a weight-bearing activity which combines concentric and eccentric actions (5,7). To this end, efficiency in the foot race is affected by the capacity of the sportsperson to enact this transition optimally (5) and by their capacity to run under conditions of fatigue (7). Specifically, at Olympic distance it has been seen that around 70% of triathletes run at slower velocities during the first kilometre when compared to their normal velocity over the 10 km (8). It has been demonstrated that running after the cycling stage produces a series of specific biomechanical and physiological alterations (5).

Biomechanical alterations are tightly related with the experience of the triathlete and affect to a lesser extent, ore ven to no extent, elite athletes (8-10). Notwithstanding, some moderately trained triathletes experience difficulties when they run after the cycling stage (11). The aforementioned alterations affect neuromuscular control, producing changes in the kinematics of the race and in the motor pattern of muscular recruitment (5,12). As a result, many triathletes experience a perceived impairment in their coordination when they run after the cycling stage (9). This can further impair optimal performance of the sportsperson and increases the risk of musculoskeletal injury (2). With regards to the physiological alterations, data obtained in the laboratory demonstrate that the foot race during the triathlon is more challenging than an isolated foot race at the same velocity. It has been shown that oxygen consumption, respiratory frequency, ventilation rate and cardiac frequency are all increased, with these changes being even more evident in less experienced triathletes (12–14).

The performance of moderately trained triathletes can be more affected by the transition from cycling to the foot race and as a result they may suffer a greater injury risk which limits their physical activity, general health and sport progression (11). Specific training may enable the muscles to efficiently adapt to the transition and in this way improve performance of the overall task (9). It has been suggested that such triathletes should orient their training towards the practice of the foot race after the cycling stage and should include plyometric exercises under conditions of fatigue (10). However, no study has been found that analyses the efficacy of plyometrics in fatigue conditions.

It must be held in mind that the development of resistance is not limited only by the aerobic system but also by characteristics of the neuromuscular system (15–17). Plyometric training has been shown to generate specific neural adaptations such as an increase in motor unit activation (17–19). In this way, it is possible to minimise the negative effects of the cycling stage in certain triathletes (20), above all in those who are less trained relative to elite triathletes (16). Only one study has been found that considers plyometric training in an isolated way, for the improvement of neuromuscular conditions in athletes whose biomechanical pattern during racing changes during the second transition (20). The results reported were positive in that the biomechanical pattern during the race after the cycling phase improved. However, data was not reported regarding the influence of the plyometric training on neuromuscular fatigue caused by the cycling stage.

Plyometrics carried out in conditions of fatigue and in an isolated way may be a good option for improving the neuromuscular conditions with which triathletes enact the second transition and consequently improve efficacy during the foot race. Further, this improvement could bring with it greater sport improvement and a lower injury risk. Thus, the main objective of the present study is to evaluate the efficacy of the aforementioned training for the improvement of neuromuscular conditions in triathletes during the second transition. To this end, the objectives of the present study are as follows: (a) to analyse neuromuscular fatigue following the cycling stage through various jump tests conducting using a contact platform, (b) to determine the differences in outcomes to these tests after eight weeks, between a control group and a specific plyometric training group and, (c) to determine the differences in performance of the foot race following the cycling stage.

MATERIAL AND METHODS

A clinical experimental trial was carried out, a prospective longitudinal pilot study of an eight-week plyometric training program.

Participants

Non professional triathletes with at least two years of experience training and competing in triathlon were included (20). All triathletes came from the Casablanca Stadium Club (Zaragoza). In accordance with previous literature (20), participants with a previous history of engagement in plyometric training, musculoskeletal or neurological injuries affecting the spine or the EEII were excluded. Those who had participated or competed in other sport son two or more occasions a week during the prior three months were also excluded. All participants were informed of the study procedure and the potential associated risks and signed informed consent and Official Law of Data Protection forms. All procedures were carried out in concordance with the Declaration of Helsinki and approval was obtained from the Committee of Research Ethics of the Community of Aragon (CEICA). The 14 participants were divided between 2 groups, a control group which did not receive any intervention and an intervention group which received plyometric training. Randomisation was not performed given that the intervention program required agreement on the part of the triathletes, thus, participants willing to carry out the specific training were included in the intervention group. Data was collected regarding the training of each participant in order to ensure homogeneity of the groups.

Intervention

Both groups continued with their regular training as they had done so during the months prior to study commencement. Further, triathletes from the intervention group participated in an eight-week plyometric training program (Table 1). The training was planned to fit within the competitive calendar of the club, being dividing into 2 blocks of 4 weeks. Sessions were designed based on previous studies (20,22). They included a combination of 3 series of 3 strength exercises (squats, unipodal press and unipodal gastrocnemius) followed by plyometric exercises, with 45 seconds of rest between each series (Figure 1). No more than 200 jumps were performed in every session to avoid the risk of injury (17) and the progressive load principle was followed, with the load and technical difficulty increasing incrementally between the two training blocks.

Each week was composed of 3 weekly plyometric sessions, with the requirement that one of these sessions was performed under conditions of fatigue. This is to say, it was performed immediately after cycling training (10). Sessions were performed on alternate days, with the first 2 sessions during the week combining strength exercises and the third session being at the weekend, during which plyometric exercises were performed following cycling training. Sessions were carried out in a gymnasium and were supervised to ensure that the correct technique was used. Participants were required to complete at least 95% of the specific training sessions in order to be included in the study (22).

Table 1. Plyometric exercises included in the training program.

Exercise	**Series and repetitions (reps)**	
	Weeks 1-4	**Weeks 5-8**
Squat jumps (CMJ)	3x6 reps	3x6 reps
Box jump with horizontal displacement	3x5 reps	3x5 reps (increased box height)
Stride jumps	2x8 reps	3x8 reps
Horizontal jumps	3x5 reps (bipodal)	3x5 reps with each EEII
Skipping with rope	30 reps	1x15 reps with each EEII
Step-ups	2X5 reps with each EEII	2x5 reps (increased box height)
Total number of jumps	**114**	**137**

Material

In order to evaluate neuromuscular fatigue induced by the cycling phase in the EEII, participants completed three jump tests both before and after this phase. A contact platform was used (*Optojump Next; Microgate, Bolzano, Italy*) to measure jump height (cm), as has been done in previous studies (23, 24). All participants were familiarised with the test. Participants carried out the tests wearing trainers in a balanced position with the feet in line with the hips. Each test was performed with a one minute recovery period in between. Tests were conducted in the following order:

1) *Squat jump* (SJ) (23). Participants positioned their hands on their hips to nullify the influence of the arms on the jump. From a squat position with the knee flexed at approximately 90º, participants were asked to perform a maximum effort vertical jump.

2) *Countermovement jump* (CMJ) (23). Following a signal given by the researcher, the participant was instructed to flex their knees and jump as high as possible whilst maintaining their hands on their hips.

3) *Repeated jumps* (15CMJ) (25). Participants were instructed to perform as many CMJ's as possible during 15 seconds. They are asked to strive for the greatest height possible in each jump. For data analysis, the heights of all the jumps performed were summed together.

CMJ. Step-up. Zancadas con salto.

Saltos horizontales. Saltos en comba. Salto desde cajón con desplazamiento horizontal.

Figure 1. Plyometric exercises used in the training program.

Protocol

Measurements were carried out on two days at the beginning and end of the eight-week intervention in order to evaluate the efficiency of said intervention. Measurements were performed in a building that was easily accessed from the road and was loaned by Botorrita Town Hall (Zaragoza). Following a standardised warm-up of 10 minutes duration based on a light jog and jumps, initial evaluation was conducted using the contact platform. Next, each triathlete had to complete a 40 km cycling trial at high intensity. Triathletes used the bicycle with which they normally competed and were allowed to drink up to 500 ml of water.

Following the cycling stage the transition was standardised (20), allowing triathletes a controlled period of 60 seconds to dismount the bicycle and change their footwear. The test on the contact platform was repeated immediately afterwards. To evaluate the neuromuscular fatigue induced in the EEII by the cycling stage, changes in measured jump height were analysed. Next, triathletes were instructed to complete a foot race of 5 km using a 1 km circuit. The time required for each triathlete to complete the first kilometre and the 5 km was measured, as it has been seen that the transition affects performance to a greater extent during the first kilometre (8). The footwear used was that normally worn by the triathlete during competition and was the same during the entire process and during the measurement days.

Triathletes were urged to give their maximum effort in order to simulate a real competition situation (24). To this end, each triathlete had to monitor their cardia frequency using the devices they normally used in training. Other incentives for maximum effort were that the trainer would be aware of the results and that trials were to be completed in a staged manner, with each triathlete starting 10 minutes after the other, creating competition between them. Before each measurement day, participants were not allowed to carry out any activity of high intensity during the previous 72 hours and could not eat at least 2 hours before. Climatic conditions were similar on both measurement days.

Statistical analysis

Statistical analysis was conducted using the program “SPSS” version 22. Descriptive analysis of all of the variables given in the tables was conducted and is presented as mean±SD (standard deviation). Before conducting the statistical analysis the conditions for applying them were considered; the *ShapiroWilks* test was used to check that the sample fulfilled normality criteria and the *Student t-test* was used to examine the homogeneity of distribution between the groups and between the sexes. Least squares estimates were used to quantify the difference intervals between groups. The same measures were used to observe coefficients. Analysis of repeated variance (*ANOVA*) of repeated measures using a lineal model with *Bonferroni* adjustment was used to examine the profile of change in pre-intervention and post-intervention results. This was conducted to examine differences between the study groups, as well as a pairwise comparison according to time and group. For the inferential comparison of neuromuscular fatigue and race pace the *Student t-test* was used. Bivariate correlations between the quantitative variables were analysed using the *Pearson coefficient*. The confidence level was established at 95% and the significance level was set at $p<0.05$, with values conforming to these assumptions being universally considered as adequate in biomedical studies.

RESULTS

Fourteen moderately trained triathletes agreed to participate voluntarily in the study. Two of these had to be excluded, leaving a final sample consisting of 12 participants: 10 male, 2 females; 26.42 ± 6.63 years of age; 1.73 ± 7.64 m in height and with a weight of 69.14 ± 9.56 kg. Both the control group and the training group were formed of 5 males and one female. The triathletes had 3.67 ± 1.37 years of triathlon experience, with the majority of these participating in both regional and national races and only 16.7% of participants participating only at regional level. 41.7% of the sample competed over short distance triathlons and 58.3% did so at middle distance (Table 2). Baseline data followed a normal distribution and distribution was homogenous between groups. No differences according to sex were found at baseline.

With regards to the first objective, neuromuscular fatigue was found to be induced following 40 km of cycling (n=12), with significant impairments being observed in all jump tests (Table 3): SJ [M=3.50, CI95%=1.93-5.06, t(11)=4.91, p>0.001], CMJ [M=2.88, CI95%=0.40-5.35, t(11)=2.56, p=0.026] y 15CMJ [M=39.87, IC95%=19.81-59.94, t(11)=4.37, p=0.001].

In the data reported from the repeated measures ANOVA (Table 4), a significant interaction was found between the factors of group and time in the jump test for SJ, *F* (3.30)= 7.20, p=0.003, n^2= 0.419, with a main time-effect (p=0.001). Specifically, post-hoc analysis showed a significant increase in the post-cycling SJ test result in the group receiving plyometric training, following eight weights of training relevant to initial baseline measures (p=0.038). On the other hand, the group that continued with regular training demonstrated a significant reduction in the height of registered jumps for SJ between the initial measurements taken prior to the cycling test and those taken 8 weeks later (p<0.001).

Table 2. Training history of the triathletes during the three months prior to the study.

		Control Group (n=7)	**Plyometric Group (n=5)**
Swimming	Days of the week; Mean (DS)	3 (1.15)	3.4 (0.89)
	Weekly Km; Mean (DS)	8.29 (4.54)	12 (2.83)
Cycling	Days of the week; Mean (DS)	2.14 (0.38)	2.2 (0.38)
	Weekly Km; Mean (DS)	154.29 (37.8)	154 (28.8)
Running	Days of the week; Mean (DS)	2.86 (0.38)	3
	Weekly Km; Mean (DS)	25 (8.16)	24.4 (5.55)
	Mean pace [a]; Mean (DS)	3.74 (0.44)	3.62 (0.31)

[a] Mean pace measured in min/km, estimated over 10 km.

Table 3. Analysis of neuromuscular fatigue induced during the cycling stage.

	Pre-cycling (n=12)	**Post-cycling** (n=12)	***p value***
SJ; Mean (DS)	31.17 (5.1)	27.67 (5.75)	<0.001
CMJ; Mean (DS)	33.89 (7.16)	31.01 (5.89)	0.026
15CMJ; Mean (DS)	355.87 (61.23)	315.97 (56.91)	0.001

SJ, Squat jump; CMJ, Countermovement jump; 15CMJ, Repeated jumps; DS, standard deviation.

A significant interaction was also found between the factors group and time in the jump test for 15 CMJ, *F* (3.30)= 5.40, p=0.003, n^2= 0.371, with a main time effect (p=0.004). Similar results to that of SJ, were obtained in the post-hoc analysis. This showed a significant reduction in the jumps registered for the initial measurement of 15 CMJ prior to the cycling trial and eight weeks after the cycling in the group that continued its regular training (p=0.015). On the other hand, the plyometric training group maintained very similar values (p<0.05) before and after. No significant interaction was obtained between the factors of group and time in the jump test for CMJ, *F* (3.30)= 8.08, p=0.090, n^2= 0.447, although there was a main effect of time (p<0.001). In the post-hoc analysis, a significant reduction was shown in the jumps registered in the initial measurements for CMJ prior to the cycling trial relative to the eight weeks after cycling, in the group that continued with its regular training (p=0.006), while the plyometric training group maintained similar values in the different measurements (p<0.05) (Table 4).

Table 4. Analysis of covariance of the efficacy of plyometrics on the jump test

		SJ		**CMJ**		**Repeated jumps**	
		CG (n=7)	PG (n=5)	CG (n=7)	*PG (n=5)*	CG (n=7)	*PG (n=5)*
Initial measurement	Pre-cycling 1; *Mean (SD)*	31.11 (4.85)	31.24 (6.03)	34.17 (7.64)	33.50 (7.27)	363.09 (72.61)	345.78 (47.75)
	Post-cycling 1; *Mean (SD)*	26.76 (4.12)	28.94 (7.87)	29.96 (4.69)	32.48 (7.58)	304.59 (61.65)	331.97 (51.56)
At 8 weeks	Pre-cycling 2; *Mean (SD)*	29.09 (5.08)	32.20 (6.89)	32.86 (6.12)	35.16 (7.61)	333.50 (78.79)	366.83 (66.99)
	Post-cycling 2; *Mean (SD)*	26.06 (4.33)	32.58 (5.78)	28.91 (5.15)	32.58 (6.12)	289.66 (60.75)	362.75 (52.55)
Pairwise comparison (Time*Group)	PRE1-POST1; *p value*	0.004	0.314	0.078	1.000	<0.001	1.000
	PRE1-PRE2; *p value*	0.398	1.000	0.913	0.774	0.231	1.000
	PRE1-POST2; *p value*	<0.001	0.678	0.006	1.000	0.005	1.000
	POST1-PRE2; *p value*	0.822	0.509	0.274	0.631	0.173	0.159
	POST1-POST2; *p value*	1.000	0.038	1.000	1.000	1.000	0.543
	PRE2-POST2; *p value*	0.095	1.000	0.003	0.121	0.273	1.000
Test of intra-participant effects	Time	0.001		<0.001		0.004	
	Time*group	0.003		0.090		0.003	

CG, control group; PG, plyometric group, SD, *standard deviation*; PRE1, initial measurement taken before completing the cycling test; POS1, initial measurement following 40 km of cycling.; PRE2, 8-week measurement taken before completing the cycling test; POS2, 8-week measurement following 40 km of cycling.

After eight weeks, no significant differences were observed between the different groups for the pace of the first kilometre of the foot race [M=0.23, CI95%=-0.13-0.60, t(10)=1.43, p=0.182], nor for the pace over 5 km [M=0.15, CI95%=-0.25-0.55, t(10)=0.845, p=0.418]. A significant reduction in time of the first kilometre was found (p=0.015) following 8 weeks of plyometric training, but not in time of the 5 km (p=0.083). In contrast, those athletes who continued with their regular training did not experience such changes for either overall pace over the first kilometre (p=0.103), nor over the 5 km (p=0.155) (Table 5).

Table 5. Analysis of variance of the pace of the foot race

		Initial measurement	**Following 8 weeks**	***p value***	***p value***
Pace 1st km	Control group	4.28 (0.52)	4.06 (0.40)	0.103	0.182
	Plyometric group	4.07 (0.07)	3.62 (0.26)	0.015	
Pace 5km	Control group	4.30 (0.49)	4.12 (0.32)	0.155	0.418
	Plyometric group	3.92 (0.32)	3.58 (0.39)	0.083	

Those triathletes who managed to run the first kilometre of the foot race at a higher speed, required less time to cover the 5 km (r=0.898, p<0.001). Further, the greater the neuromuscular fatigue induced during the cycling phase in the second transition for the SJ test, the slower the pace of the foot race, as much during the first kilometre (r=-0.605, p=0.037) as during the 5 km (r=-0.761, p=0.004). Similarly, the greater the fatigue resulting from the CMJ test, the lower the pace set over the first kilometre (r=-0.614, p=0.034).

DISCUSSION

The results of the study indicate that 40 km of high intensity cycling induces neuromuscular fatigue in the. It should be highlighted that no other studies have been found which analysed the fatigue induced over this distance (Olympic distance in triathlon). In the study reported by García-Pinillos F et al. (24), fatigue induced by sprint distance (20 km of cycling) triathlon was analysed via SJ and CMJ testing, without finding any significant changes in these tests following the cycling phase. However, in this study the triathletes completed the cycling test using their bicycles connected to a roller, which could be much less similar to the real conditions experienced during competition. On the other hand, studies conducted of “half ironman” and “ironman” competitions have shown via CMJ testing, notably impaired neuromuscular capacity in the muscles of EEII, which are used to produce force. In this case neuromuscular fatigue is a limiting factor for performance (23, 26).

Muscular damage has been demonstrated to be one of the main factors leading to neuromuscular fatigue (23). This has been largely related to resistance during the foot race (27), possibly due to the greater demand for concentric and eccentric activity in comparison to cycling (24). This could indicate that it is necessary to exceed a certain intensity threshold before the cycling phase induces fatigue in the EEII. One of the limitations was that in contrast to other studies, biochemical values were not collected in the present study. Thus, the relationship between fatigue in physiological terms and in neuromuscular terms could not be described. Previous studies have analysed, amongst others, the myoglobin concentration of the blood, creatinkinase and lactate dehydrogenase as markers in the blood of muscular damage. These studies have established that triathletes demonstrating a lower reduction in their jump height were those who also showed a trend towards a higher quantity of myoglobin and creatinkinase after a “half ironman” triathlon, though significant variations were not observed in these markers (23). In a similar fashion, other studies have analysed the cycling phase at a physiological level (28), taking into consideration the lactate thresholds, generated potential and perceived effort. The present study also omitted the characteristics as training was more focused on the second transition and the foot race.

This pilot study is novel with regards to the evaluations it presents of the effect of plyometric training on neuromuscular fatigue produced by the second transition. The results suggest that adding plyometric exercises into the normal training regime significantly improves jump height performance in the SJ test following the cycling phase (p=0.038). This could be due to the fact that the SJ test was the first to be executed immediately after the transition and therefore reflected to a greater extent the neuromuscular fatigue provoked by this phase. Further, a trend towards deteriorated performance in the jump test in the regular training group can be seen, while the plyometric group tended to improve. It should be highlighted that the first measurement was carried out before the competitive season started, however, at the time of the second measurements the triathletes had been competing in competitions for approximately one month. This could indicate that as the season progresses, triathletes engaging in plyometric training will adapt better whilst those who carry out normal training will be likely to suffer more from fatigue. It has been previously suggested that monitoring the neuromuscular and physiological response may be a good practice for trainers to be able to track the adaptation of triathletes throughout the season and to develop an individualised training prescription (24).

The plyometric training program employed was similar to that used in other studies (16,20,22). In the study conducted by Saunders PU et al. (16), with highly trained medium and long distance runners, no significant changes were reported in power test performance between a plyometric group and a control group. In their study, Giovanelli N et al. (22) also failed to find significant changes in variables of muscular power amongst endurance runners following a plyometric training program lasting 12 weeks. Both authors associated their findings with an insufficient training volume or intensity. Despite combining plyometrics with exercises with external weights in two of the three proposed sessions, this may have not been sufficient to produce more substantial changes. This is further supported by previously reported findings of significant differences in measures of muscular power when higher workloads were used (29,30). That being said, in both of these studies as with the present study, muscular power values tended to improve in the plyometric training group to a greater extent than the control group (16,22). This indicates that a longer followup should be conducted in order to observe the change over time for these variables.

A significant reduction was reported in the plyometric training group for the time taken to complete the first kilometre, which represented a significant improvement relative to the group who continued their regular training over the eight weeks of the study (p=0.083). This change was not seen over the 5 km. This contrasts with the results reported by Paavolainen L et al. (29), which found significant changes in 5 km performance after a plyometric training program. This intervention program was, however, more intense in that a higher number of jumps were performed and was carried out with highly trained long distance runners during a post-competition period (29). A possible explanation for these findings is that more specific training at this moment of the season and with high level athletes generates more significant changes.

It should be highlighted that in the present study a weekly plyometric session was conducted in fatigue conditions, this is to say, straight after cycling training. No studies have been found that use the same methodology. In their study, Hue et al. (21) conducted a study with triathletes to evaluate the efficacy of combined training incorporating cycling and running. This training consisted of a weekly session of short blocks of cycling-foot race compared to normal training of the two disciplines separately. Similarly to the present study, they reported significant changes with regards to an improved transition between the two disciplines. This translated to an improvement in running pace over the first 333 m of the foot race following the cycling phase (21). This could suggest that certain training strategies oriented specifically towards an improvement in the second transition bring about a greater positive effect over the first minutes of the foot race. These strategies could include plyometrics in fatigue conditions or the combination of the two disciplines in the same session.

Another relevant finding was that the greater the neuromuscular fatigue shown during the SJ test, the lower the running pace of the foot race. This was as much the case for the first kilometre as for 5 km. Similarly, the greater the fatigue shown in the CMJ test, the lower the running pace over the first kilometre. This could indicate a relationship between the neuromuscular fatigue conditions in which triathletes perform the second transition and running performance in the following foot race, highlighting the importance of planning specific training for the improvement of this transition. More studies are required to determine this relationship and analyse strategies directed towards the improvement of fatigue conditions induced during the cycling phase. On the other hand, it was observed that triathletes who managed a greater speed over the first kilometre of the foot race needed less time to complete 5 km. This could indicate a relationship between improved performance over the first kilometre and improved performance of the overall foot race. Although, comparisons with previously collected data shows that around 70% of triathletes run at slower speeds during the first kilometre relative to their normal speed when running a 10 km race (8).

The characteristics of the study made it difficult to access a greater sample size. Future studies employing a larger number of participants are needed.

Nevertheless, previous studies conducted by Saunders PU et al. (16) and Hue et al. (22), using an intervention methodology and population group similar to the present study, also managed a sample size of between 12 and 15 participants. On the other hand, the present study was carried out with moderately trained athletes who are more susceptible to suffering mechanical alterations in their race pattern following the cycling phase, relative to elite triathletes (2,10). As a result, more studies are needed to determine whether the cycling phase is capable of inducing neuromuscular fatigue in the EEII of elite triathletes. In the present study both groups included a female. It should be highlighted that within the studies analysed by Bonacci J et al. (20) females were also found to be present within the sample. Similarly, given the homogeneity of the baseline pre-intervention data reported by the groups, distinctions between sexes could not be determined (20). It is necessary that future studies strive for a greater inclusions of females.

Currently, it is not known whether greater neuromuscular fatigue can predict or result in neuromuscular injury. A relationship between biomechanical alteration of the race pattern following the cycling phase and greater injury risk has been suggested (2), with plyometric training being efficacious for the improvement of this alteration in those triathletes whose pattern was altered after the second transition (20). Studies that establish a relationship between the examined biomechanical transition and fatigue induced by the second transition are also limited. In their study, Chapman AR et al. (9) state that the biomechanical alteration during the foot race after the second transition is not linked with neuromuscular fatigue. Nevertheless, it must be held in mind that these studies conducted their analysis after 20 minutes of cycling with the bicycles connected to a roller (9). As has been previously discussed, this may have not been enough to induce neuromuscular fatigue.

CONCLUSIONS

The present study seems to indicate that 40 km of high intensity cycling induces neuromuscular fatigue in the lower extremities. Knowledge of neuromuscular fatigue caused by the cycling phase in Olympic distance triathlon, is an important requirement when designing training plans with the aim of reducing this fatigue and maximising sport performance. It also shows that plyometric training seems to be more effective than regular training for the improvement of neuromuscular fatigue induced by the second transition. Further, running pace during the first kilometre of the foot race after the transition is improved, from which it could also be assumed that a faster pace over the whole of the race will be achieved and therefore a greater performance. Considering all of this, plyometric training is suggested as one of many possible options to be used in the improvement of performance and prevention or recovery of triathlon injuries. Nevertheless, it is accepted that the present study reports only preliminary findings. It is not suggested here that the correction of neuromuscular fatigue in an isolated way can prevent overuse injuries in triathlon, given that its etiology is multifactorial. More studies are needed that analyse the plyometric training effects in triathlon.

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