How are Spanish athletes using technological advanced running shoes (TARS)? Do they influence injuries?

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Summary

Objectives: To determinate how technological advanced running shoes (TARS) are being used by high-level athletes and to detect changes in the distribution of musculoskeletal injuries among athletes who use TARS.
Material and method: A descriptive, cross-sectional study was designed. All Spanish athletes who participated in international championships (n = 221) during summer 2023 were invited to complete a questionnaire with demographic, training load, using of TARS and status health questions.
Results: The questionnaire was completed by 221 (100%) athletes; 184 (83.3%) athletes claimed to use TARS, for 1.93 years on average, of whom 157 (71%) used TARS in both competition and training. In relation to muscle fatigue and muscle recovery using TARS, 28 (75,6%) of long distance and 16 (66,6%) of middle distance runners perceived less muscle fatigue, whereas 36 (52,8%) of sprinters perceived more muscle fatigue. 105 (47.5%) reported a time-loss injury. Athletes who use more time TARS and run more kilometres with them perceived more muscle fatigue (P <0.001) and reported more time-loss injuries (P <0.01).
Conclusions: More than 85% of sprint, middle and long distance, hurdles, multiple events and race-walking athletes use TARS. More than two thirds of middle and long distance athletes accumulate less muscle fatigue with its use, while more than half of the sprint, hurdles and multiple events athletes accumulate greater muscle fatigue. Time of use, both in years and percentage of use, could be associated with a greater accumulated muscle fatigue and a greater presence of time-loss injuries.

Key words:
Athlete. Injury. Musculoskeletal. Technological. Advanced. Shoe.

Zapatillas tecnológicamente avanzadas. ¿Cómo las utilizan los atletas de la Selección Española?¿Influye en la aparición de lesiones?

Resumen

Objetivos: Determinar el uso de zapatillas avanzadas tecnológicamente (TARS) por parte de atletas de profesionales y detectar cambios en la distribución de lesiones musculoesqueléticas entre aquellos que las utilizan.
Material y método: Se diseñó un estudio descriptivo y transversal. Se invitó a todos los deportistas españoles que participaron en campeonatos internacionales (n = 221) durante el verano de 2023 a completar un cuestionario con preguntas demográficas, de carga de entrenamiento, uso de TARS y estado de salud.
Resultados: El cuestionario fue completado por 221 (100%) deportistas; 184 (83,3%) deportistas afirmaron utilizar TARS, durante 1,93 años de media, de los cuales 157 (71%) utilizaron TARS tanto en competición como en entrenamiento. En relación a la fatiga muscular utilizando TARS, 28 (75,6%) de los corredores de larga distancia y 16 (66,6%) de los de media distancia percibieron menos fatiga muscular, mientras que 36 (52,8%) de los velocistas percibieron más fatiga muscular. 105 (47,5%) refirieron una lesión con pérdida de tiempo. Los atletas que utilizan más TARS y corren más kilómetros con ellos perciben más fatiga muscular (p <0,001) y refieren más lesiones con pérdida de tiempo (p <0,01).
Conclusiones: Más del 85% de los atletas de velocidad, medio fondo, vallas, multieventos y marcha utilizan TARS. Más de dos tercios de los atletas de medio fondo y multieventos acumulan menos fatiga muscular con su uso, mientras que más de la mitad de los atletas de velocidad, vallas y multieventos acumulan mayor fatiga muscular. El tiempo de uso, tanto en años como en porcentaje de uso, podría estar asociado a una mayor fatiga muscular acumulada y a una mayor presencia de lesiones con pérdida de tiempo de entrenamiento o competición.

Palabras clave:
Atleta. Lesión. Musculoesquelético. Tecnológico. Avanzado. Zapatilla.

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Introduction

Background

Technological development of running shoes plays a determinant role in the race to improve athletes' performance, allowing them to break ever-increasing demanding records[1].

So much that, in recent years, the sport of running has been revolutionised by technologically advanced running shoes (TARS) that combine cushioning with a resilient midsole and a carbon fiber plate (CFP)[2,3].

The main differences between TARS and conventional ones are mainly:

- Embedded carbon fiber plate[4,5].
- Curvature of the carbon plate[6].
- Innovative midsole material[7].
- Appreciable midsole thickness[1].

Since the launching of the first TARS by Nike® in 2016, men and women's world records in long-distance road running (i.e., from 5 km to the marathon) have all been broken by TARS wearers[8].

The scope of race performance improvements by athletes running with TARS was so significant that World Athletics had to react, publishing the statement "Athletics Shoe Regulations". The new regulation, which came into force on January 1st 2022, allows the combination of a single CFP and responsive foam midsoles if not exceeding 20 mm of sole thickness for field (except triple jump) and track events, 25 mm for track events from 800 metres and above, and 40 mm for road events[9].

Biomechanics of TARS

The use of TARS has prompted the irruption of relevant biomechanical changes in lower extremities[10].

Hoogkamer, *et al*.[4] investigated the biomechanical differences in marathon runners using three models of shoes, one TARS and two conventional. Athletes usings TARS were observed to have decreased cadence, with longer steps and longer flight time. Furthermore, peak vertical ground reaction forces and the vertical impulse per step were higher in TARS group.

Concerning the ankle joint, peak ankle dorsiflexion during stance and peak ankle moments were revealed to be reduced and lower negative and positive ankle work were observed in TARS compared to standard competitive footwear during running[4].

At the metatarsophalangeal (MTP) joint, peak extension (i.e., dorsiflexion) was lesser, peak dorsiflexion velocity was slower and peak moment was smaller. Besides, negative work at the MTP joint was least in TARS in comparison with standard shoes[4].

Regarding the knee and hip, it is not clear whether TARS determine any biomechanical changes. Hoogkamer did not observe any difference[4]. However Cigoja observed a redistribution of positive lower limb joints work from the knee to MTF with decreased positive work at the knee and increased positive work at MTF[11].

The possible redistribution of lower limb work could determinate changes in muscle function during running. A recent biomechanical investigation revealed how midsole bending stiffness of shoes alters gastrocnemius medialis muscle function during running. The study concluded that running in stiff shoes resulted in less muscle shortening, slower average shortening velocity and greater estimated Achilles tendon energy return, which allows ankle plantarflexor muscle-tendon unit to operate on a more favourable position of the muscle's force-length-velocity relationship[12].

As far as running economy concerns, there seems to be a broad consensus about the benefit of TARS advantage use over conventional shoes, effecting a variation of 2-4%, depending on the series[4,7,13-16].

Data research has primarily focused on performance enhancements by TARS, namely regarding biomechanical advantages and improvements in running economy. Nevertheless, there is paucity of studies investigating changes in injuries distribution using TARS or possible associations between TARS and running-related injuries. So much so, a very recent editorial (July 2023) from one of the sports medicine journals with the highest impact factor draws attention to this lack of studies and encourages more research to be carried out on this topic[2].

To date, only one study that aims to establish an association between bone stress fractures of navicular and the use of TARS has been published. However, it is just an observational research in the form of a case series of 5 patients. Consequently, the evidence provided is limited[10].

Not only that, but the exact way that athletes use TARS is unknown. It is not clear since when they are using them, nor if they combine them with conventional shoes or not; and in this case, what percentage of the total kilometres or hours of weekly training they do with TARS. In addition, the differences that may arise in this sense between the different athletics events are also unknown.

The aim of this study is twofold. Firstly, to describe how TARS are being used in different areas (i.e., training, competition, kilometres run, hours of training or years of use) and clarify whether there are variations between event groups. Secondly, to detect possible changes in the distribution of injuries among athletes who use TARS that would allow the establishment of hypotheses in future researches.

Material and method

Study design and population

A descriptive, cross-sectional study was designed. The target population was Spanish international level athletes that were selected by Spanish Athletics Federation to participate in one of the international track and field championships held during summer 2023 (i.e., European Athletics Team Championships Silesia 2023, European Athletics Under-23 Championships Espoo 2023, European Athletics Under-20 Championships Jerusalem 2023 and World Athletics Championships Budapest 2023).

Patient and public involvement

Athletes were involved in the design and conduct of this research. During the design stage, they were informed through structured interviews of the research questions, choice of outcome measures and methods of recruitment.

Once the research is published, participants will be sent details of the results in a study newsletter suitable for a non-specialist audience.

Data collection

All the athletes were invited to complete a questionnaire. No one refused to participate.

The questionnaire was designed by the researchers. The overall goal was to know how athletes nowadays use TARS and to identify possible risks factors between de use of TARS and injuries. The questionnaire was developed to collect information directly from the athletes regarding their personal characteristics (gender, age, height, weight, event group) and training load in the last four weeks (i.e., kilometres of training accumulated on average in middle distance, long distance and race walking athletes and training hours accumulated in the rest of events).

Four questions were asked concerning the use of TARS: whether athletes use them or not and if so, when they started to use it (year), whether they use TARS only in competition, only in training or both; and how many kilometres or hours of training they performed with TARS per week during the last four weeks.

Two final questions were raised about health status. First, a subjective question about whether the athletes experienced changes in terms of muscle fatigue and muscle recovery since they started using TARS; and a second question asking about time-loss injuries in the last two years regardless of the use of TARS.

The questionnaire was available in a paper format and was distributed by the medical team three days before the competition. Athletes were asked to individually complete the questionnaire or with the help of the team physician, if needed.

Data analysis

First, questionnaire data, response rate and completeness of the questionnaire were assessed, and athletes' characteristics, muscle fatigue and time-loss injuries were analysed using descriptive statistics. For quantitative variables, the mean, standard deviation (SD), minimum and maximum were used, whereas absolute and percentage frequencies were used for categorical variables. All selected athletes completed the questionnaire, so it was not necessary to perform analysis of the non-responders.

Second, in order to describe the association between the different qualitative variables (event, time-loss injuries and muscle fatigue), Chi-square tests were performed on those contingency tables in which 80% of the cells were greater than 5, and Man-Whitney tests were performed between the quantitative (years of using TARS and percentage of using TARS) and qualitative variables (event, time-loss injuries and muscle fatigue) that did not present normality. All the data obtained were transferred to a Microsoft Excel® database, while IBM SPSS Statistics® (version 28.0.1.1) was used for the statistical analysis.

Finally, this study accepted a confidence level of 95%, considering statistically significant results with an associated probability value of $P < 0.05$.

Ethical aspects

The project was approved by the Ethics and Research Committee of the Pontifical Comillas University in June 2023.

Data confidentiality

All the questionnaires were completed on an anonymous and voluntary basis and all data obtained were anonymized in order to keep the information confidential.

All the information was recorded in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki).

The researchers undertook to comply with the Organic Law 3/2018 of December 5 on the Protection of Personal Data and Regulation 2016/679 of the European Parliament and of the Council of April 27, 2016, on the protection of natural persons about the processing of personal data and on the free movement of such data.

Equity, diversity, and inclusion statement

The author group consisted of two men and one woman from different disciplines (sports orthopaedics, sports medicine and physiotherapy) who are junior (first autor), mid-career (third autor) and senior (second autor) researchers; however, all members of the author group are from one country (Spain).

Our study population included both male and female athletes from different socioeconomic backgrounds of a developed country participating in international athletics championships; thus, findings may not be generalizable to settings with fewer resources. The influence of gendered environments on injury is considered in the discussion.

Results

Descriptive results

The study was carried out between June and August 2023. The questionnaire was completed by 221 Spanish athletes, out of which 105 (47.5%) were female, with an average age of 22.66 ± 4.9 years and a body mass index (BMI) of 19.70 ± 4.53; and 116 (52.5%) were male, with an average age of 21.88± 4.45 and a BMI of 20.8 ± 5.12.

The distribution by age categories was: 76 (34.4%) athletes competed in the U20 category, 73 (33%) in the U23 and 72 (32.6%) in the absolute category.

The distribution by event was: 70 (31.7%) sprint and relays, 37 (16.7%) long distance and marathon, 24 (10.9%) middle distance, 21 (9.5%) race walking, 21 (9.5%) long and triple jump, 15 (6.8%) throwing, 13 (5.9%) high jump and pole vault, 13 (5.9%) hurdles and 7 (3.2%) multiple events.

Regarding the use of TARS, 184 (83.3%) athletes claimed to use them. 157 (71%) used TARS in both competition and training, 14 (6.3%) used them only for competition, and 10 (4.5%) only for training. The data on the use of TARS, years of use and percentage of use (kilometres or hours of training performed with TARS over the total kilometres or hours trained) by event are shown in Table 1.

As regards subjective sensations perceived by athletes in relation to muscle fatigue and muscle recovery using TARS (n = 184); 49 (26.6%) athletes stated that they did not feel any change; 67 (36.4%) perceived less muscle fatigue; while 68 (37%) claimed to feel greater fatigue and poor muscle recovery after using TARS. The distribution by event and muscular group are in Figure 1.

Table 1. Number of athletes use TARS by event groups (n = 221).

	Use of TARS n (%)	Years of use	Percentage of use (%)
Sprints	69 (98.57)	1.66 ± 0.70	28.8
Middle Distance	23 (95.83)	2.58 ± 1.01	29.04
Long Distance	37 (100)	2.46 ± 0.97	25.57
Long/Triple Jump	15 (71.42)	1.17 ± 0.85	21.38
High/Pole Jump	5 (38.46)	0.46 ± 0.66	12.38
Hurdle	12 (92.3)	1.46 ± 0.66	23.08
Throwing	0 (0)	0	0
Walking	16 (76.19)	1.19 ± 1.23	39.19
Multiple Events	7 (100)	1.57 ± 0.53	25.43
Total	184 (83.3)	1.93 ± 0.88	30.27

Use of TARS n (%): numer of athletes by event that stated use TARS; Years of use (y SD): mean of years using TARS by event; Percentage of use (%): kilometres or hours of training performed with TARS over the total kilometres or hours trained by event group.

To the question of time-loss injuries (n = 221) (Figure 2), 116 (52.5%) athletes confirmed not to have suffered injuries during the last two years, while 105 (47.5%) had. Of them, 45 (20.3%) suffered injuries that affected the hamstrings, most of them muscle tears and tendinopathy, although 2 (0.9%) athletes had a complete rupture of the proximal hamstring tendon. 20 (9.2%) suffered time-loss injuries affecting the knee extensor compartment (patellar tendinopathy, patellofemoral syndrome and rectus femoris muscle tear), 15 (6.8%) affecting the calf (Achilles tendinopathies or soleus tears) and 14 (6.4%) affecting the foot, mostly plantar fasciitis, although 3 (1.36%) athletes had a stress bone fracture in the metatarsal bones. Finally, 10 (4.5%) had time-loss injuries related to back, 6 (2.7%) suffered pelvic pain (dynamic osteopathy of the pubis and adductor muscle tear) and 5 (2.3%) other time-loss injuries.

Associations between use of TARS and reported muscle fatigue and injuries

Regarding the association between the percentage of use of TARS and years of use, it has been observed that muscle fatigue in athletes is greater the more use and the more years of use (U = 1684, *P* <0.001 and U = 1137, *P* <0.01 respectively) (Figure 3 and 4). Likewise, in the association with the appearance of injuries, these are more frequent the higher the percentage of use and the more years of use (U = 4834.50, *P* < 0.01 and U = 4874.50, *P* <0.01 respectively), not being found differences between diagnoses (Figure 4 and 5).

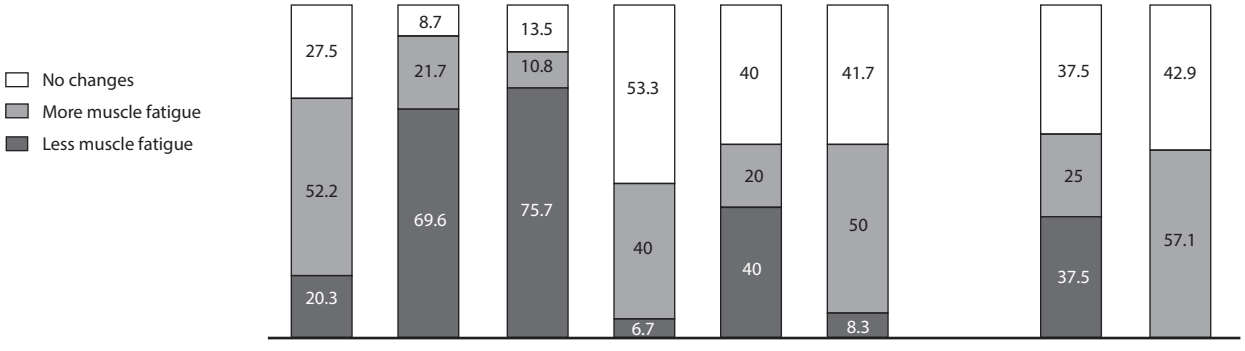
No differences were found by gender or age. However, the ANOVA test revealed that the U20 athletes presented fewer injuries (*P* <0.05).

Discussion

The main findings of this study are:

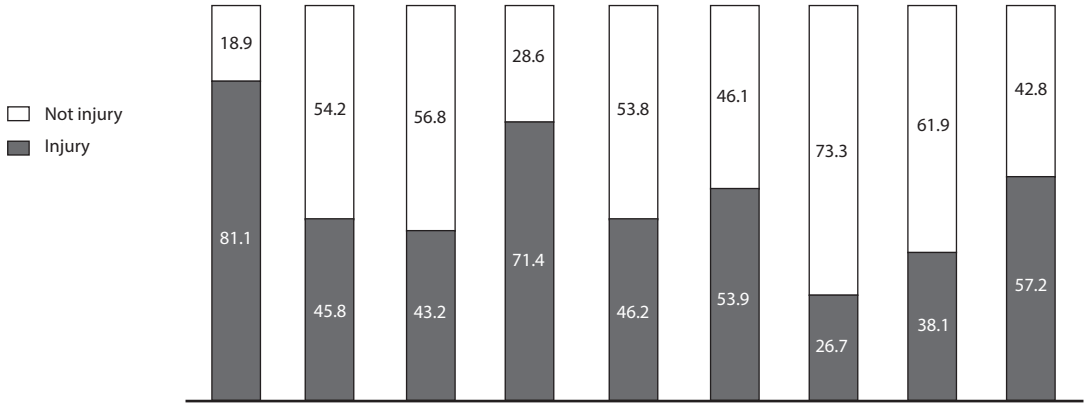
– More than 85% of sprint, middle and long distance, hurdles, multiple events and race-walking athletes of the sample use TARS. About two thirds of long and triple jump athletes use TARS and about one third of high jump and pole vault athletes use them. No throwers use TARS.

Figure 1. Distribution by event group of variations in muscle fatigue and muscle recovery perceived by athletes that use TARS (n=184).



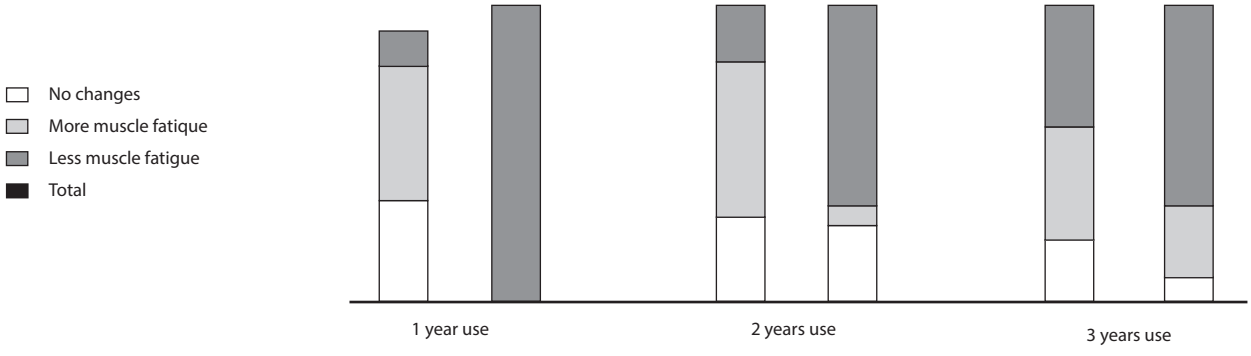
	Sprints	Midle distance	Long distance	Long/ Triple jump	High/ Pole jump	Hurdles	Throwing	Walking	Multiple Events	Total
No changes	19 (27.5)	2 (8.7)	5 (13.5)	8 (53.3)	2 (40)	5 (41.7)	0 (0)	6 (37.5)	3 (42.9)	50 (27.2)
More muscle fatigue	14 (21.3)	1 (4.3)		0	0	3 (24.9)	0	1 (6.3)	0	19 (10.3)
More gastrocnemius fatigue	8 (11.6)	1 (4.3)	1 (2.7)	6 (40)	1 (20)	1 (8.3)	0	1 (6.3)	3 (42.9)	22 (12)
More hamstring fatigue	15 (21.7)	3 (13)	3 (8.2)	0	0	2 (16.7)	0	2 (12.5)	1 (14.2)	26 (14.1)
Less muscle fatigue	9 (13)	11 (47.8)	21 (56.7)	1 (6.7)	1 (20)	0	0	6 (37.6)	0	49 (26.6)
Less gastrocnemius fatigue	4 (5.8)	5 (21.7)	7 (18.9)	0	1 (20)	1 (8.3)	0	0	0	18 (9.8)
Total	69 (100)	23 (100)	37 (100)	15 (100)	5 (100)	12 (100)	0 (0)	16 (100)	7 (100)	184 (100)

Figure 2. Distribution by event group of time-loss injuries (n=221).



	Sprints	Midle distance	Long distance	Long/ Triple jump	High/ Pole jump	Hurdles	Throwing	Walking	Multiple Events	Total
Not injury	26 (18.9)	23 (54.2)	21 (56.8)	6 (28.6)	7 (53.8)	6 (46.1)	11 (73.3)	13 (61.9)	3 (42.8)	116 (52.48)
Calf injury	6 (11.5)	3 (12.6)	2 (5.4)	5 (23.8)	0	2 (15.4)	0	2 (9.5)	0	20 (9.05)
Lumbar and pelvic injury	5 (8.7)	1 (4.2)	3 (8.1)	0	2 (15.4)	1 (7.7)	3 (20)	1 (4.8)	0	16 (7.24)
Foot injury	7 (11.5)	0 (0)	4 (10.8)	1 (4.8)	1 (7.7)	0	0	0	1 (14.3)	14 (6.33)
Extensor patellar injury	3 (5.8)	1 (4.2)	3 (8.1)	5 (23.8)	2 (15.4)	2 (15.4)	1 (6.7)	2 (9.5)	1 (14.3)	20 (9.05)
Hamstring injury	23 (43.6)	6 (24.8)	4 (10.8)	4 (19)	1 (7.7)	2 (15.4)	0	3 (14.3)	2 (28.6)	45 (20.36)
Total	70 (100)	24 (100)	37 (100)	21 (100)	13 (100)	13 (100)	15 (100)	21 (100)	7 (100)	221 (100)

Figure 3. Distribution of muscle fatigue perceived by event groups (sprint and hurdles on the one side and middle and long distance on the other side) at first, second and third year of using TARS.



	Sprints and Hurdles	Middle and long distance
Total	31 (100)	5 (100)
Less muscle fatigue	3 (9.7)	5 (100)
More muscle fatigue	17 (45.8)	0
No changes	11 (35.5)	0

Sprints and Hurdles	Middle and long distance
41 (100)	20 (100)
8 (19.5)	14 (70)
22 (53.7)	1 (5)
11 (26.8)	5 (25)

Sprints and Hurdles	Middle and long distance
5 (100)	24 (100)
2 (40)	16 (66.7)
2 (40)	6 (25)
1 (20)	2 (8.3)

Figure 4. Distribution of muscle fatigue and time-loss injuries regard percentage of use (%) by event groups (sprint and hurdles on the one side and middle and long distance on the other side).

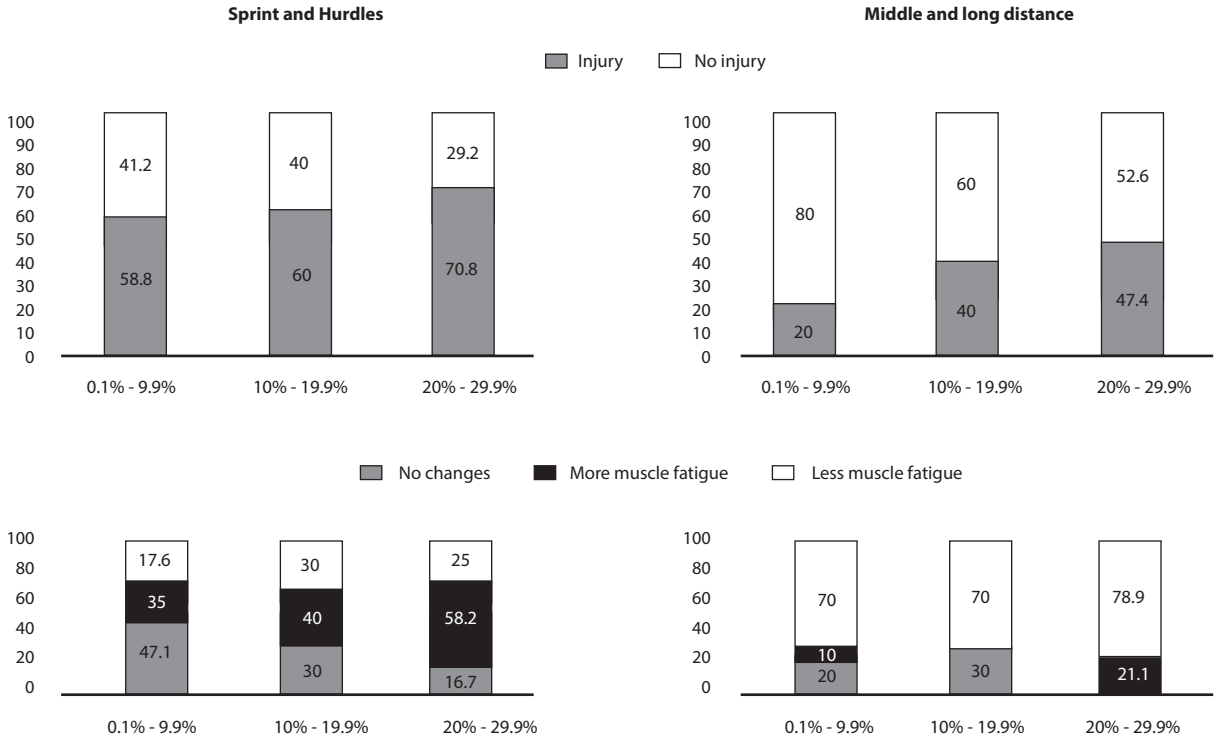
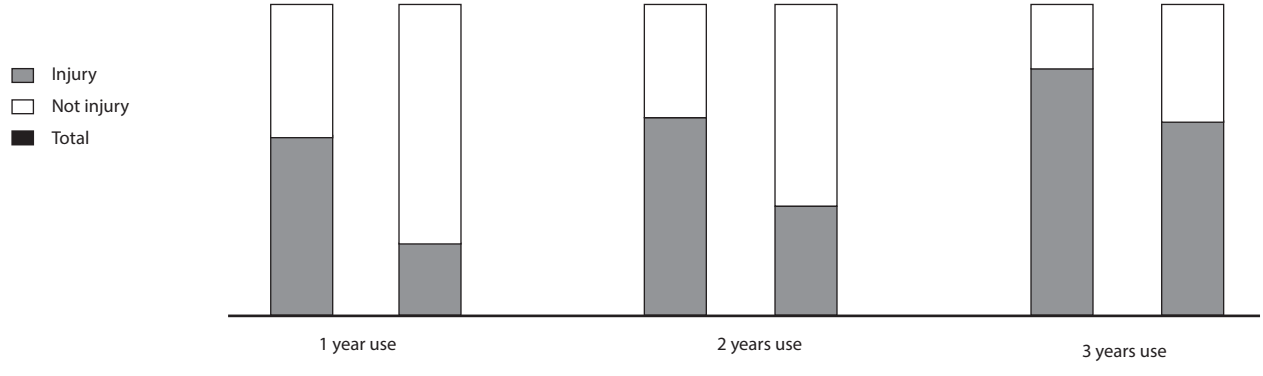


Figure 5. Distribution of time-loss injuries by event groups (sprint and hurdles on the one side and middle and long distance on the other side) at first, second and third year of using TARS.



	Sprints and Hurdles	Middle and long distance
Total	31 (100)	5 (100)
Not injury	13 (41.9)	4 (80)
Injury	18 (58.1)	1 (20)

Sprints and Hurdles	Middle and long distance
41 (100)	20 (100)
15 (36.6)	13 (65)
26 (63.4)	7 (35)

Sprints and Hurdles	Middle and long distance
5 (100)	24 (100)
1 (20)	9 (37.5)
4 (80)	15 (62.5)

- Most athletes use TARS for both training and competition and use them between 20-40% of their total weekly accumulated kilometres or weekly accumulated training hours.
- Middle and long distance athletes are the ones who have been using them for the longest time (more than two and a half years).
- More than two thirds of middle and long distance athletes accumulate less muscle fatigue with its use (specifically in gastrocnemius), while more than half of the sprint and multiple events athletes accumulate greater muscle fatigue (sprints at hamstrings and multiple events at gastrocnemius).
- Time of use, both in years and percentage of use, is associated with greater accumulated muscle fatigue and a greater presence of time-loss injuries.

As far as researchers of this study know, this paper is the first epidemiological study on the use of TARS in high-level athletes. Since the launch of the first TARS in 2016, its use has expanded both in middle and long distance runners, and in sprinters and jumpers; as well as in high level and popular athletes, but we did not know exactly how and since when[8,13].

Most articles published on TARS are biomechanical studies in long-distance runners[11]. There is a certain consensus about them regarding the biomechanical advantages they provide in the ankle and metatarsophalangeal joint, the reduction in running economy and the more favourable function of medial gastrocnemius[17]. This supports the results of our study that middle and long distance athletes feel less muscle fatigue (many of them pointing to gastrocnemius) with a better muscle recovery. However, the rest of the athletes do not agree with these results, on the contrary, they report greater muscle fatigue with its use (specifically in the hamstrings). The explanation provided by this research is that TARS have been designed for long-distance athletes; however, they do not provide the same advantages to sprinters, jumpers and walkers due to the biomechanical differences in the way this latter group runs[18].

In relation to the possible association with the use of TARS and the appearance of injuries, only Tenderfore et al. published a series of cases that related its use to navicular stress bone fracture[10]. This study does not report any. Three cases of stress bone fracture in the foot have been reported (one fracture of third metatarsal in a male sprinter who used TARS and two stress bone fractures of the second metatarsal in a female high jumper and female long distance runner who used TARS), which represents 1.6% of athletes using TARS. In this way, we do not consider that a relationship can be established with the navicular stress bone fracture nor with metatarsals, since the frequency of appearance in our sample is similar to others previously published[19,20].

According to this study, greater use of TARS, both in years and percentage of kilometres and hours of training accumulated with TARS, is related to a greater accumulated muscle fatigue and a greater presence of time-loss injuries. This is in relation to the hypothesis stated by Hoenig et al for injury prevention consisting of limiting its use for selected competitions and training[2]. The distribution of injuries per event is similar to comparable studies prior to the launch of TARS[21,22] although the increase in injuries recorded in sprints and hurdles stands out.

Limitations

Several potential limitations should be acknowledged when interpretating the results of this study. First, there is a selection bias since only athletes able to compete in the international championships, that is, healthy and in good physical condition, filled out the questionnaire. We believe that such circumstance may understate injury data.

Second, self-reported data might provide a limited description of time-loss injuries, so some diagnoses and locations may not be accurate.

Third, the study is retrospective, so it could represent a recall bias. Future prospective studies would be necessary to establish more solid conclusions in the association of TARS and injuries.

Fourth, TARS is a concept that encompasses a wide variety of athletics shoes from different brands with differences in terms of the shape of the FCP, cushioning material and height of the sole, fundamentally. This can lead to differences in the distribution of muscle fatigue and injuries depending on the brand of shoes. This paper has not registered the different brands of TARS used.

Conclusions

More than 85% of sprint, middle and long distance, hurdles, multiple events and race-walking athletes use TARS.

More than two thirds of middle and long distance athletes accumulate less muscle fatigue with its use, while more than half of the sprint, hurdles and multiple events athletes accumulate greater muscle fatigue.

Time of use, both in years and percentage of use, could be associated with a greater accumulated muscle fatigue and a greater presence of time-loss injuries.

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Conflict of interest

Authors report no conflict of interest.

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