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Using complex systems to understand running-related injuries

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ABSTRACT

This study aims to investigate anthropometric and training characteristics associated with injuries in runners using a complex approach. We conducted a cross-sectional study with 97 Brazilian runners of both sexes (age: 39.1 ± 11.5 years; body mass index: 24.2 ± 4.2 kg/m²). A web survey was used for data collection, including age, sex, body weight, body height, training volume/frequency, session duration, running pace and injury information (yes or no; the number of injuries). The partial correlation parameter was used for network estimation, considering both sexes. For women, injury occurrence was positively and strongly associated with training frequency ($r=0.57$) and the number of competitions ($r=0.64$), while for men, a negative and strong association was found with age ($r=-0.69$), and positive associations were observed with BMI ($r=0.89$) and training volume ($r=0.82$). Network centrality showed that training session duration and the number of competitions/year presented a higher expected influence value for women (-1.47) and men (-1.31). Using a non-linear approach with Brazilian non-professional runners, training characteristics had a stronger influence on running-related injuries.

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Injuries; exercise; training; endurance

Introduction

Running is one of the main trends of physical activity and physical exercise around the world (Hulteen et al., 2017; Thompson, 2021). Despite the health-related benefits (Junior et al., 2015), running-related injuries per 1000 h of running range from 2.5 (i.e., long-distance track and field runners) to 33.0 (e.g., novice runners) (Videbæk et al., 2015). For non-professional runners, despite the negative effect on their daily work

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tasks, injuries can also affect their quality of life, temporarily or permanently (Araujo et al., 2015). Moreover, injuries may reduce the pleasure of exercise and result in increased medical expenses (J. L. Ryan et al., 2019), especially in countries without public health networks. Ultimately, injuries can lead to an interruption of running training (Kakouris et al., 2021).

Running-related injuries are multifactorial (Winter et al., 2020), influenced by individual characteristics (e.g., age, sex, anthropometry), training experience (e.g., running frequency and volume, training intensity, equipment), previous injuries and lifestyle behaviours (van Gent et al., 2007). Despite the multifactorial characteristic, running injuries have been studied through a unidirectional approach, in which fatigue (Riazati et al., 2020), biomechanical variables (Willwacher et al., 2022), training characteristics (Junior et al., 2013) and morphological variables (M. Ryan et al., 2006) have been considered exposures for injuries outcomes. Despite the relevance of these findings to preventive medicine advances, few studies were developed considering the multifactorial characteristics of running-related injuries (Winter et al., 2020).

To understand the multifactorial nature of running injuries, a synergy between theoretical and statistical concepts needs to be considered. The complex systems approach has been contextualized and applied in the context of sports injuries (Bittencourt et al., 2016). Complex systems are characterized as nonlinear, which means that predicting outputs is a challenging task since they are sensitive to initial conditions (Rickles et al., 2007). As an open system, the interactions with the environment also need to be considered (Rickles et al., 2007). In statistical terms, network analysis is used to estimate complex behaviours, and outcomes, considering the interplay between different variables (Hevey, 2018). Network analysis is a graphical representation of networks in which the variables are represented as nodes and the relationship between variables as edges (Hevey, 2018). Through the use of different indicators, it is possible to understand the relative importance of each variable within the system (Hevey, 2018).

Considering the importance of running as a factor to increase physical activity at the population level, as well as the higher rate of injuries associated with this practice, this study aimed to investigate anthropometric (body mass index) and training characteristics (training volume and frequency, session duration, running pace and the number of competitions) associated with injuries in runners, using the complex systems as framework. Based on previous studies, we hypothesized that training variables are the most important variables contributing to running-related injuries.

Methods

Study design and sample

This was a cross-sectional study, which is part of the InTrack project (intrackproject.com), sampling Brazilian non-professional runners. Eligibility criteria included providing informed consent for participation in the study, self-classification as a runner, and answering all mandatory questions (i.e., country of residence; running pace). This study did not consider runners younger than 18 years and non-Brazilian runners. The sample was composed of 97 recreational runners (age: 39.1 ± 11.5 years; body mass index: 24.2 ± 4.2 kg/m²) of both sexes (45.4% women). Prior to participating of this study, participants were informed about the

purpose, benefits and risks, and provided informed consent to participation. The project was approved by the ethics committee at the Federal University of Sergipe (Protocol number 5.286.914).

Sampling procedures and data collection

We used a non-randomized sampling strategy from April to August 2022. The questionnaire used was transcribed to the Google Forms platform and distributed via an online link (<https://forms.gle/SKRyGe6cmXUjTPy3A>) across social media used by runners (i.e., Facebook, WhatsApp and Instagram). This strategy is similar to previous studies (Deelen et al., 2019; Janssen et al., 2020) and was used to cover a large number of runners. For the present study, we used information on:

Individual characteristics

Runner's identification: Age (years), sex (male; female).

Anthropometric variables: Body weight (kg) and body height (m) were self-reported. Body mass index (BMI) was calculated based on the standardized equation [body mass (kg)/height (m)²].

Training characteristics

Running training volume (km/week): Participants recalled average training volume through the item: *"on average, how many kilometers do you run per week?"*

Frequency/week: Participants recalled the weekly average training frequency through the item: *"What is your weekly training frequency?"* Responses were categorized into "1 training/week" to "7 training/week)

Running training session duration: Participants recalled the average session duration through the item: *"On average, how long (in minutes) does your training session last?"*

Running pace (min/km): The time (in minutes) to cover one kilometre was recalled through the item: *"What is your average running pace (pace-min/km)?"*

Competitions/year: Participants recalled the average of competitions/year answering the question: *"On average, how many running competitions do you participate per year?"*

Injuries information

Injuries were considered as any physical complaint or observable damage, associated with running practice (Timpka et al., 2014). Information regarding the occurrence of injuries was obtained from the item: *"Did you have any injuries associated with running practice?"*. Answers were dichotomized into "Yes" or "No". In case of a positive answer, runners were invited to answer the question: *"How many injuries did you experience?"* .

Statistical analysis

Descriptive information was presented as mean \pm standard deviation (SD) and frequency (%). Data normality was tested using the Kolmogorov–Smirnov test. The t-test (continuous variables) and chi-square test (categorical data) were used to compare runners who reported injuries against those who did not report injuries. Network analysis was performed to evaluate the association between variables and injury occurrence, considering

both sexes. The weight matrix was graphically presented, showing relationships between variables. The partial correlation parameter was used for network estimation. Centrality indicators (closeness, strength and expected influence) were estimated. The closeness values show the average distance between nodes, whereas those with higher closeness scores are more dependent on the network (Hevey, 2018). High values indicate that these nodes are important connections between other nodes in the network. For the expected values, variables with the highest values are more sensitive to change and can act as a hub by connecting other pairs of variables on the network (Hevey, 2018). The blue and orange colours presented positive and negative relationships, respectively. Statistical analyses were performed in JASP software, considering 95% of the confidence interval.

Results

The sample was composed of 97 runners, in which 60 reported injuries from running practice (women: 48.3%; men: 51.7%). Athletes reporting injuries were older (40.5 ± 11.4 vs. 36.8 ± 11.6 years), presented a higher training volume/week (33.4 ± 18.6 vs. 30.8 ± 20.4 km/week) and a higher training session duration (63.7 ± 27.3 vs. 62.5 ± 48.0 min/session). Participation in competitions was higher for injured runners (mean 8 races/year) when compared to non-injured (mean 6 races/year). **Figure 1** shows a box plot for morphological and training variables for both groups. Non-significant differences were shown between groups for morphological, demographic and training variables.

Figure 2 presents a correlation matrix between variables. The runners' age, BMI and training duration were negatively related to injury occurrence for women, while for men, a negative relationship was shown for age, duration and training frequency. A positive correlation was shown for BMI, slow running pace and the number of competitions/year in both sexes.

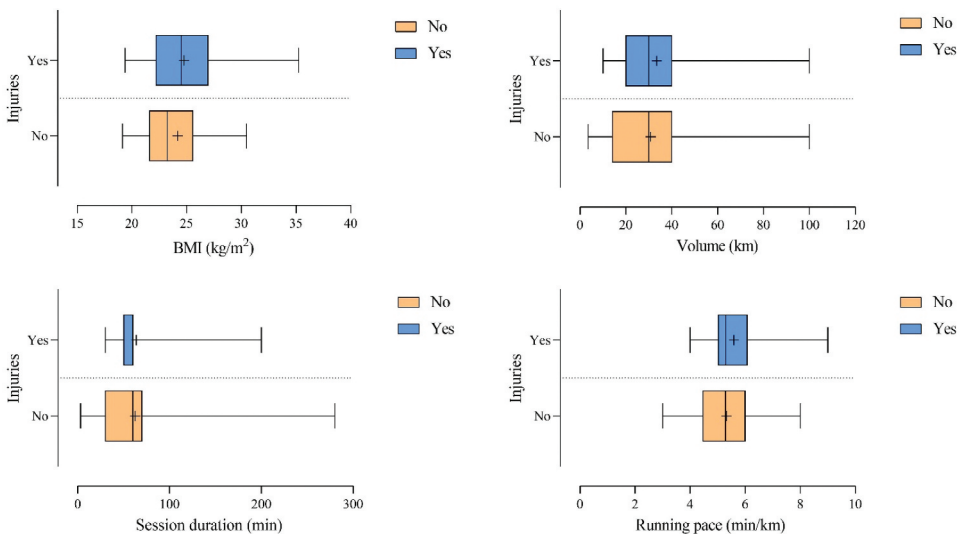


Figure 1. Comparison of morphological and training characteristics between injured and non-injured runners (mean values indicated by +).

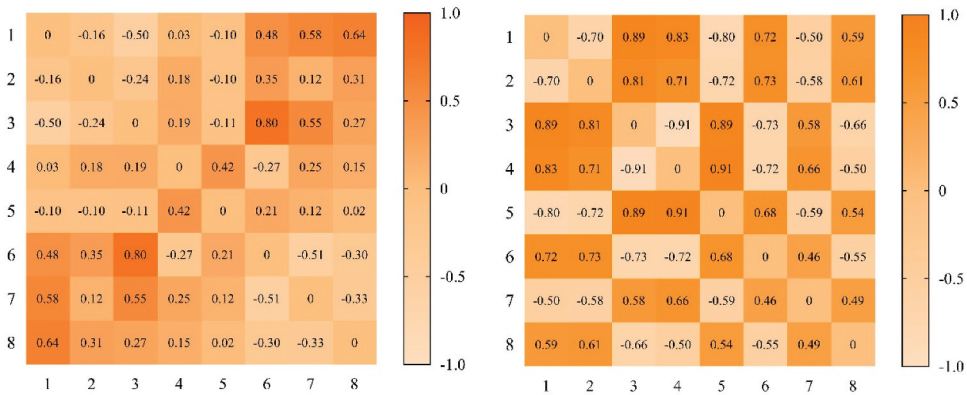


Figure 2. Weight matrix between variables (left panel: Women; right panel: men). Legend: 1: injuries occurrence; 2: age; 3: BMI; 4: training volume; 5: session duration; 6: running pace; 7: training frequency; 8: number of competitions/year.

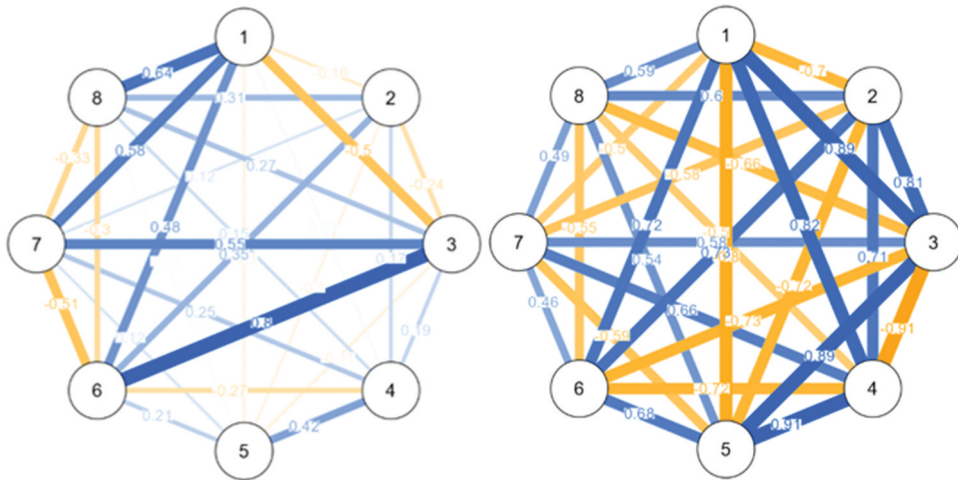


Figure 3. Network topology for women (left panel) and men (right panel). Blue and orange colours presented positive and negative relationships, respectively. Legend: 1: injuries occurrence (yes); 2: age; 3: BMI; 4: training volume; 5: session duration; 6: running pace; 7: training frequency; 8: number of competitions.

Figure 3 presents the network topology for both sexes. For women (left panel), injury occurrence was positively and strongly associated with the training frequency and number of competitions. At the same time, a negative and strong association was shown for age, and a positive relationship was shown between BMI and training volume for men. For women and men, the higher centrality values were running pace and training frequency, respectively. The duration of the training sessions presented the highest expected influence values (-1.47) for women, while for men, the number of competitions presented the highest value (-1.31) (Table 1).

Table 1. Centrality indicators' results for network analysis in both sexes.

Variable	Women			Men		
	Closeness	Strength	Expected influence	Closeness	Strength	Expected influence
Injury occurrence	0.479	0.628	0.99	0.368	0.436	1.138
Age	-0.724	-0.921	-1.456	0.295	0.16	0.344
BMI	0.612	0.897	0.959	1.263	1.195	0.454
Training volume	-0.733	-0.879	0.894	0.696	0.772	0.929
Session duration	-1.544	-1.499	-1.473	0.602	0.639	0.61
Running pace	1.589	1.26	-0.035	-0.317	-0.281	-0.876
Training frequency	0.592	0.584	0.092	-1.533	-1.52	-1.286
Number of competition	-0.272	-0.07	0.028	-1.374	-1.401	-1.314

Legend: Injuries occurrence (no, yes); Age (years); BMI (Body Mass Index (kg/m^2)); Training volume (km/week); Session duration (min); Running pace (min/km); Training frequency (session/week); Number of competition (year).

Discussion

The role of training, morphology, and behavioural variables in injury prevalence has been extensively studied (Mousavi et al., 2021; Sanfilippo et al., 2021). However, most studies used linear models for this complex, multifactorial and dynamic outcome (Costa et al., 2020; Linton & Valentin, 2018; Mousavi et al., 2021; Toresdahl et al., 2022). To better understand and also to prevent runners' injuries, etymologically, injuries must be considered as a multifactorial phenotype (Duffey et al., 2000), which means that the use of statistical models that consider the complexity of this system needs to be considered. For the present study, we used complex systems as a theoretical framework and network analysis as a procedure to investigate anthropometric and training characteristics associated with injuries in runners. The results support our hypothesis about the role of training variables to explain runners' injuries.

Differences in demographic and training characteristics were not observed between injured and non-injured runners. These results can be related to the complex interactions between variables and injury occurrence (Bittencourt et al., 2016). In addition to the importance of BMI as a predictor of running performance (Sedeaud et al., 2014), BMI was also identified as an injury-related factor in overweight novice runners (Buist & Bredeweg, 2011), and obese novice runners (R. O. Nielsen et al., 2014). For the present study, non-significant differences in BMI were observed between injured and uninjured runners. These results follow previous findings (Gajardo-Burgos et al., 2021; Junior et al., 2013), in which no differences were shown for age and anthropometry (body mass, body height, BMI) between injured and uninjured runners. Methodological differences, including sample size and runners' profiles, may contribute to these inconsistent findings.

The network analysis results showed that competition participation and training session duration showed the highest value for the expected influence for men and women. To the best of our knowledge, few studies have investigated participation in competition as a factor associated with running-related injuries (Middelkoop et al., 2008). For the present study, injured runners reported a mean of eight competitions per year, while non-injured runners reported six. Similar to what was found by Middelkoop et al. (2008), running injuries background and involvement in more than six races in the prior year were risk factors for the incidence of injuries. The association between events participation and injury occurrence can be mediated by training load (i.e., volume, frequency, intensity) during the preparation for competition, especially for men (Tanous et al., 2022).

Considering that most of the participants in long-distance events (>10 km) were male (Hollander et al., 2021), the results of the present study can be related to the higher mechanical stress for training and competition, given that training volume/week is similar to previous studies with non-professional runners (Junior et al., 2013).

Available evidence about the role of training characteristics on running-related injuries (Fredette et al., 2022; van der Worp et al., 2015) is conflicting. For recreational and competitive runners, training frequency was related to a higher risk of injury (Walter et al., 1989). The systematic review conducted by van Gent et al. (2007) pointed out that between training frequency and injuries, there are many other factors involved, such as the increase in the number of training sessions, participation in long-distance running, level of competitiveness, type of surface and shoes used in practice. These factors, when combined with training factors, can increase the risk of injury (van Gent et al., 2007). Therefore, training planning and load are important factors to consider in assisting with injury prevention (Fokkema et al., 2020).

The average running pace and duration of running training sessions were important variables for connecting other nodes within the network. The role developed for the running pace as exposure to running-related injuries has been previously investigated (Hulin et al., 2014; R. O. Nielsen et al., 2013; R. Ø. Nielsen et al., 2014). Sudden changes in running pace (Hulin et al., 2014; R. O. Nielsen et al., 2013; R. Ø. Nielsen et al., 2014) and slower runners are associated with an increased risk of developing injuries (Wen et al., 1997). However, in the present study, the percentual of change for running pace or intensity during training sessions were not considered. The role of the running pace acting as a hub presents important practical implications regarding the synergy between training load and risks of injuries.

This study has limitations to consider. Even though we used a complex systems approach, training surface, biomechanical variables, footwear, body composition, training background and other morphological variables (van Gent et al., 2007; van Iperen et al., 2022) associated with injuries were not considered. Despite self-reported information being largely used in scientific literature, the misunderstanding and recall bias (Althubaiti, 2016) must not be disregarded. Runners reported injuries sustained throughout their training years, while information about training characteristics was based on the current state of training. Considering the dynamic characteristics of training load and performance, the generalization of these findings should be considered carefully. Strengths of the present study include the use of complex systems as a theoretical framework. Future studies should consider some covariates (health status, dietetics and smoking habits) and the use of devices to measure training and periodization information (Janssen et al., 2020) to deeply understand these relationships. Generalization of these findings should be considered carefully for differences in sample characteristics, including runners from different countries, and performance levels. For the present study, we only presented information for Brazilian runners, and even in the Brazilian context, the data is not representativeness of the population.

Conclusion

The session duration and the number of competitions per year were the most important variables for injuries in both women and men. Running pace and training frequency were

the key variables for connecting other variables in the network. Investing in running schedules could be an important strategy for manage injury risk.

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