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Cluster analysis of selected biomechanical variables related to backwards running in soccer

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Abstract
Introduction. Running, of which backwards running (BR) is one type, is a basic skill that has to be maintained at a high level by athletes. Aim of Study. Use cluster analysis to evaluate some kinematic variables for BR. This analysis is applied to classify players and identify differences in their classification to determine relevant dynamic solutions to raise players' performance levels. Material and Methods. Twelve volunteer university soccer players (age: 20.8 ± 0.83 years old; experience: 4.7 ± 0.78 years; height: 175.6 ± 6.01 cm; body mass: 68.63 ± ± 5.06 kg) participated in the present study. The participants tried two 10-m BR, in which the best attempt based on the shortest time was analysed. Results. The study showed that cluster analysis may be used to classify and divide participants into two groups via evaluations of selected biomechanical variables. The first group, which consisted of 7 participants, represents the indistinctive performance level, while the second group, which consisted of 5 participants, represents the distinctive performance level. Statistically significant differences were found between the classifications of the participants. The second group excelled regarding certain biomechanical variables, including average stride length, average speed, angular velocity of the arms, peripheral velocity of the arms, angular velocity of the legs, peripheral velocity of the legs, instantaneous force and time of achievement. Conclusions. This classification ensures the correct selection and full consideration of practical training to achieve the ideal biomechanical characteristics for BR in soccer.

KEYWORDS: biomechanics, motion analysis, football, performance, backwards running.

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Introduction

Soccer is considered an intense multi-directional and intermittent field sport [22]. The play efficiency depends on the player's ability to perform certain movements of varying intensity in different directions and in different sections of the field [11]. Players should exhibit well-developed basic and specific motor abilities [15]. One of the basic skills that has to be performed at a high level is running. A specific type of running is backwards running (BR), which Uthoff et al. (2018) defined as "any form of locomotion in a reverse direction where movement is accomplished through a single leg of support throughout foot-ground contact and both feet simultaneously in the air between contralateral foot strikes" [35].

There is a likely interplay of factors that influence running performance during soccer matches. Some of the most important factors include the player's characteristics, match location, field position, phase of the season, recovery period, competition strength and the match results [8, 32].

Match analyses revealed that elite soccer players usually cover 9-12 km during a 90-minute game [14, 17, 21]. About 58% of a game is spent standing (15%) and walking (43%), whereas about 30% of a game is spent running at 7-14 km/h. Meanwhile, about 8% of a match is spent running at a moderate speed (15-19 km/h), 3% is spent running at a high speed (20-25 km/h), and only about 1% is spent sprinting at maximum speed [1].

Reports have also revealed that BR accounts for approximately 5% of the total competition performance [31]. Recently, BR has been proposed as a means to enhance athletic performance due to its unique acute and longitudinal adaptations [35]. Including BR when preparing players for the demands of competition reduces injury rates [29, 34] and enhances performance [16, 36].

In American football a defensive back who employs BR, for instance, can keep both the receiver and the quarterback in their field of vision. Once the player turns to run forward, he loses sight of one or both of these players, placing him at a disadvantage since both the quarterback and the receiver know where the ball is going. Athletes in sports such as soccer and basketball often run forward while on offence and backwards while on defence. Thus, superior BR speed is advantageous for players in these sports, as it allows players to better defend against attacks [3].

Recently, there has been an increasing interest in examining and analysing many soccer skills (e.g. kicking, throwing, and goalkeeper's skills). Unfortunately, BR has not been sufficiently investigated. Even when studies investigated BR, it was considered merely as a training tool or for rehabilitation. As far as the researchers know, no study has applied cluster analysis of the kinematic variables that are investigated in the present work. Thus, our study aims to use cluster analysis to evaluate selected kinematic variables for BR to evaluate applicability of this analysis to classify players and identify differences in players' classifications to propose relevant dynamic solutions to raise players' skill levels.

Methods

Participants

A total of 12 voluntary university soccer players (age: 20.8 ± 0.83 years old; experience: 4.7 ± 0.78 years; height: 175.6 ± 6.01 cm; body mass: 68.63 ± 5.06 kg) participated in the present study. The players belonged to the same team, which at the time of the study was training three times a week (for a total of 6 hours of training per week) and was playing one official match every week. All participants were informed of the study design and protocol; accordingly, each participant signed a free informed consent before the testing procedure. The study protocol was approved by the university ethics committee, while all the procedures followed the ethical standards of the Declaration of Helsinki for the study on humans.

Experimental approach to the problem

This study followed a cross-sectional design. The data collection occurred over four weeks after the beginning of the 2018/2019 academic year. The participants performed two BR trials, with the best attempt selected based on the shortest time taken to cover 10 metres. None of the participants reported any previous injuries. The tests were performed on the same day at the same time on the same field with natural grass. Each participant was asked to avoid any strenuous activity for 12 hours before the test. They were also instructed to follow their regular diet as closely as possible before the test. It was ensured that each participant reached the recovery stage before performing their second attempt.

Testing procedure

Before starting the basic test, the players warmed up for 10 minutes by running on a treadmill at 5 km/h and then stretching. The participants wore soccer boots with all the equipment required for soccer players as determined by FIFA. During the main session, each participant performed a BR test for 10 metres. One of the most important tests was to run backwards as fast as possible. After all participants performed one trial, a second trial was carried out. The best attempt (i.e. the shortest time) of each participant was chosen for analysis.

The data were collected using a mobile phone (Huawei Y9 prime 2019, China) with a frequency of 120 FPS. The mobile was placed 14 metres away from the middle of the test area and from the player's movement field, with a height of 125 cm between the centre of the lens and the surface of the ground to correspond to approximately the centre of the mass of the participants. Then the video clips were transferred to the Kinovea software program (2D motion analysis software under the GPLv2 license, version 0.8.27) to perform motion analysis and extract biomechanical variables.

Biomechanics variables

1. Time of achievement (TA): The BR time during the test distance of 10 meters.
2. Stride number (SN): Number of the participant's BR strides to finish the 10-meter test.
3. Average stride frequency (ASF): The rhythm for the stride's movement at a specific period of time (stride number per second).
4. Average stride length (ASL): The distance between

the point of initial contact of one foot and the point of initial contact of the opposite foot during the 10-m test distance.

5. Average speed (AS): The test distance of 10 meters divided over the time of achievement.
6. Angular velocity of the arms (AVA): The angular velocity of the arms is extracted by counting the number of degrees from the end of the back swing to the forward swing end of the time unit.
7. Peripheral velocity of the arms (PVA): The arms' circular distance during a specified period of time.
8. Angular velocity of the legs (AVL): The angular velocity of the legs is extracted by counting the number of degrees from the end of the back swing to the forward swing end of the time unit.
9. Peripheral velocity of the legs (PVL): The legs' circular distance during a specified period of time.
10. Instantaneous force (IF): The rate of change of linear momentum with respect to time.

Statistical procedures

The statistical package for Social Sciences (SPSS for Windows, version 22.0, IBM Corp., Armonk, NY, USA) was used for the statistical processing to calculate the mean, standard deviation (SD), and to perform the cluster analyses. Significant statistical changes were set at $p < 0.05$. Practical differences were assessed by calculating Cohen's d effect size (ES) [10]. The interpretation of inference's magnitudes was used by following [6]: <0.2 = slight; 0.2-0.6 = small; 0.6-1.2 = = moderate; 1.2-2.0 = large; 2.0-4.0 = very large; and >4.0 = extremely large.

Results

Cluster analysis for the measured biomechanical variables was used to classify the participants into two groups as shown in Table 1.

Table 1 clearly shows the possibility of dividing the participants into two groups using cluster analysis according to the measured biomechanical variables: the first group, which consists of 7 participants, represents the indistinctive performance level, while the second group, which consists of 5 participants, represents the distinctive performance level.

For comparison and to acquire accurate information about these groupings, one-way analysis of variance

Table 1. Classification of participants into two groups using cluster analysis

Player No.	1	2	3	4	5	6	7	8	9	10	11	12
TA (sec)	2.74	2.62	2.81	2.78	2.64	2.71	2.79	2.73	2.66	2.63	2.60	2.68
Cluster No.	1	2	1	1	2	1	1	1	2	2	2	1

Note: TA = time of achievement

Table 2. Biomechanical parameters (mean ± standard deviation, F values, and effect size) during BR

Biomechanical variables	Distinctive performance	Indistinctive performance	F(p)	Effect size	Magnitude
SN (number)	13.40 ± 0.55	15.14 ± 1.22	8.809(0.014)	1.735	Large
ASF (number/sec)	5.07 ± 0.16	5.50 ± 0.37	5.898(0.036)	1.422	Large
ASL (cm)	74.55 ± 3.03	66.25 ± 4.16	14.281(0.004)	2.213	Very large
AS (m/sec)	3.78 ± 0.06	3.63 ± 0.07	15.549(0.003)	2.309	Very large
AVA (degree/sec)	4.69 ± 0.30	4.21 ± 0.25	8.827(0.014)	1.740	Large
PVA (m/sec)	2.39 ± 0.17	1.99 ± 0.17	16.21(0.002)	2.357	Very large
AVL (degree/sec)	3.12 ± 0.16	2.88 ± 0.15	6.808(0.026)	1.528	Large
PVL (m/sec)	3.21 ± 0.20	2.88 ± 0.15	11.161(0.007)	1.956	Large
IF (N)	2627.06 ± 297.12	1943.81 ± 214.73	21.62(0.001)	2.723	Very large
TA (sec)	2.63 ± 0.02	2.75 ± 0.05	27.182(<0.001)	2.539	Very large

Note: SN = step number; ASF = average step frequency; ASL = average step length; AS = average speed; AVA = angular velocity of the arms; PVA = peripheral velocity of the arms; AVL = angular velocity of the legs; PVL = peripheral velocity of the legs; IF = instantaneous force; TA = time of achievement

(ANOVA) was used. It is part of the classification method to determine the statistical differences between the two groups in the biomechanical variables as shown in Table 2. Significant differences were found between the two groups under investigation in all the biomechanical variables ($p < 0.05$). A very large effect size was also observed for the differences between the two the groups in: (i) ASL (d = 2.213); (ii) AS (d = 2.309); (iii) PVA (d = 2.357); (iv) IF (d = 2.723); (v) TA (d = 2.539). Large ES was found for differences in: (i) SN (d = 1.735); (ii) ASF (d = 1.422); (iii) AVA (d = 1.740); (iv) AVL (d = 1.528); (v) PVL (d = 1.956).

Discussion

Cluster analysis was used to reduce the amount of interference between the two groups according to the measured biomechanical variables, not according to just one variable. As such, the treatment and distinction between the two groups were simplified when BR is practised. This is because cluster analysis is a classification method, by which a class of data reduction methods is used to sort cases, observations, or variables of a given data set into homogeneous groups that differ from each other. Using just one standard for classification cannot provide a classification that is free from criticism [2].

A crucial distinctive skillful performance factor is the player's application of proper mechanical principles that are suitable for an accomplished skill based on the situation the player is in by relying on the extensive range of motion that he has acquired for this skill [19]. Appropriate motor coordination, which is considered the most important factor in starting a run, affects the amount of force generated by the legs at the right time and for the optimal duration [7].

The difference in the SN variable is due to the influence of the ASL variable; this is the case because any SL will reduce the SN in the specified distance. Some studies claim that ASF is the most significant variable affecting AS [26, 28], whereas others claim that ASL is the most significant [38]. Some researchers indicated that the interaction between ASL and ASF is important for maximising AS [24]. However, Murphy et al. (2003) examined the difference between faster and slower field sport athletes (including soccer players) and found that the faster group had greater ASF [27].

The AS increase could be explained by the significant increase in SL when compared with ASF and SN, which allowed the participants to better coordinate the actions of their body parts to accomplish the requirements of the technique acceleration. Babić et al. (2011) defined ASL as a very complex kinematic variable that depends on many factors apart from the morphological characteristics (leg length), such as muscle structure, reflex mechanisms, and ground force in the propulsion phase, as they are of particular importance in speed development [4]. Optimal ASL has been recommended for both the sub-maximal and maximal phases of FR [20].

It is believed that the increases in ASF lead to maximal sprint running performance [35]. Therefore, AS is considered as the result of an interaction between SF and SL [13]; greater speeds are achieved through large ground reaction forces that are produced during short ground contact times [37]. The results of many studies have revealed that stride length is a biomechanical variable that is related to running economy [5, 9]. It would be worthwhile to conduct an in-depth study of joint kinematic and kinetic variables to understand the mechanisms that cause such a relationship. Usually, sprint running at maximal velocity is considered the most important part of a race [12]. The most apparent general performance description in the sprint is horizontal velocity (i.e. the athlete who can produce the most horizontal velocity will be the most successful) [25].

The arms actively contribute to balance the rotary momentum of the legs. They are also vital to sprint BR performance and contribute to propulsive forces [23]. The arms act as passive mass dampers that move by the lower part of the body [30]. When a push is made by the right leg, for instance, the body rushes backwards and rotates around its centre of gravity to the left direction. To stop body rotation, the participant has to move the opposite arm of the driving leg with the same speed and force. As for the AVL during the swing, the significant mechanic basis that the participant has to meet is to let the leg's parts approach the rotation axis and any means that could reduce the moment of inertia while increasing the angular velocity amount. This is accomplished by bending the hip and knee joint angles.

One of the mechanical bases in the BR is to control the leg's length (turning radius) during the performance period, by which the knee joint angle plays a significant role in determining the leg's peripheral velocity. This, in turn, affects the force production, and, consequently, the body velocity. Force production during multi-joint leg extension depends on the combined effects of angle and angular velocity [18]. Slawinski et al. (2010) were of an opinion that improved synchronisation between the upper and lower limbs can increase the efficiency of the pushing phase [33]. Thus, faster participants are probably able to achieve higher running speed by striking the ground with greater force and much faster than the slower ones. This might be due to another mechanical element that distinguishes fast participants from the slower ones. Accordingly, one could say that maximum running speed is largely determined by how much force a participant can apply on the ground during each stride [24].

As far as we know, this is a pioneering study in that we classified the players using cluster analysis according to several biomechanical variables. Nevertheless, one should acknowledge that, as with any study, this study faced some limitations. For one, the test that participants completed during BR did not include all aspects of an official match, such as the psychological, physical and physiological pressure. Therefore, a test that mimics match situations should be designed. Undoubtedly, analysing 2D movement would reveal some significant and essential issues concerning soccer players' BR skills. As such, the 2D study has set the basis to evaluate this skill. Nevertheless, we cannot be sure that the 2D analysis can accurately describe the movement of the entire body without losing some significant characteristics. Hence, additional studies need to be conducted using other techniques, such as 3D analysis.

We recommend the extensive use of cluster analysis to include the physical, skillful, planned and psychological aspects of sports, since such an analysis can organise observations and divide them into homogeneous groups that share some characteristics. We also recommend that soccer coaches adopt the mechanical bases and rules that are essential during the soccer players' training while providing an environment that mimics that of a real match.

Conclusions

Cluster analysis can be used to classify and divide the participants into two groups by evaluating some biomechanical variables for the BR skill. Statistically significant differences were found between the classifications of participants regarding the biomechanical variables of BR. A very large effect size was also found for the differences between the two groups in variables: ASL, AS, PVA, IF and TA. Large ES was recorded for differences in such variables as SN, ASF, AVA, AVL and PVL. It has become evident that the second group (i.e. the group with the distinctive skillful performance) excelled in terms of certain biomechanical variables, including ASL, AS, AVA, PVA, AVL, PVL and IF. Hence, we can say that this classification ensures correct selection and fully considers practical training to achieve the ideal biomechanical characteristics for the BR skill in soccer.

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Conflict of Interests

The authors declare no conflict of interest.

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