Poznan University of Physical Education

TRENDS in SPORT SCIENCES

(formerly Studies in Physical Culture and Tourism)

quarterly • number 1 • volume 27 • year 2020

Editorial board address
Poznan University of Physical Education
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ISSN 2299-9590

Publisher
Poznan University of Physical Education
ul. Królowej Jadwigi 27/39
61-871 Poznań, Poland
tel. +48 61 835 51 96
e-mail: gronek@awf.poznan.pl
e-mail: tss@awf.poznan.pl
www.tss.awf.poznan.pl

Printed by
ESUS Tomasz Przybylak
ul. Południowa 54
62-064 Plewiska, Poland

Indexed in
SCOPUS
EBSCO Publishing, Inc.
SPORTDiscus
Ulrich's International Periodical Directory
ICI Journals Master List
AGRO database

Index Copernicus (2017): 88.38 points
KBN/MNiSW (2019): 20 points

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CONTENTS

ORIGINAL ARTICLE

TRENDS in
Sport Sciences
2020; 27(**1**): 5-11
ISSN 2299-9590
DOI: 10.23829/TSS.2020.27.1-1

Increasing role of three-point field goals in National Basketball Association

MACIEJ JAGUSZEWSKI

Abstract
Introduction. Since introduction of three-point field goal NBA teams have used this shot more frequently and nowadays it is inseparable part of teams' game plan in basketball. The increasing role of three-point shot is recently topic of many conversation around basketball. Aim of Study. The purpose of this study was to examine if the growth of the role of three-point shots in the NBA is statistically significant, to find out the reason for that growth and whether three-point field goal attempts have an impact on result of basketball games. Material and Methods. Statistical data concerning three-point field goal attempts over the course of 15 most recent NBA regular seasons were collected and used in analysis. Increasing role of three-point shot was examined by original method, using 3PA/FGA coefficient which measures the frequency of three-point field goal attempts in all field goal attempts. Statistical calculations were carried out using STATISTICA software package. Results. Statistically significant differences in frequency of three-point field goal attempts between seasons taken in consideration were revealed by Friedman's ANOVA. Results also showed that the biggest increase of frequency of three-point shots was between 2015/16 and 2016/17 seasons after the most successful regular season in NBA history by Golden State Warriors. Conclusions. Three-point field goal became one of the most important part of basketball and its role has increased over the years. Nowadays ability to shoot from beyond the arc is crucial as lack of this ability decreases number of options in offensive tactic by any team. Even though three-point field goal is not the most important factor in determining winner of basketball game, it has significant impact on result of basketball games.

KEYWORDS: three-point field goal, basketball, National Basketball Association, trend in sport.

Received: 16 November 2019
Accepted: 12 February 2020

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Introduction

In basketball, like in the other sports, rules change from time to time. Some articles examine the impact of principles adjustments on game-related statistics, mainly in basketball [7, 13, 14], but also in other sports like water polo [16]. The present study shows how much introducing three-point field goal changed the approach to the game of basketball in National Basketball Association (NBA). NBA is a men's professional basketball league in North America, since 2004 composed of 30 teams (29 from United States and 1 from Canada) and is widely considered to be the best and the most popular men's professional basketball league in the world. There are many research around the NBA concerning impact of injuries [3, 18] and examining factors leading to wins [1, 12, 15, 19]. Although there are some articles mentioning increasing impact of three-point shots in the NBA [4, 5, 6, 11, 17, 21], they are popular science. In this particular paper this trend was examined scientifically in order to receive significant results useful in understanding recent tendencies in basketball.

In National Basketball Association before 1979 every basket made from the field was worth two points. Since 1979/80 season in the NBA there has been a three-point line and every shot made from behind that line is worth three points while every other made field goal gives two points [20]. Adding three-point line did not immediately change approach to basketball as three-point shots were not used as often as they are nowadays. At the beginning of three-point era people around NBA were skeptical to new rule and did not think that could change the game of basketball [10] and that was observed as three-pointers were taken occasionally, average less than 3 attempts during whole game by team.

It is worth noting that the number of three-point shot attempts is growing almost every season. This is probably the consequence of coaching staff trying to find the best way to maximize number of points in the same number of possessions which could lead to more wins. It is examined in many analyses what is better for team, for example it is more efficient to attempt a three-point field goal if player makes 35% shots from that area (1.05 points per possession) than a two-point field goal if player shoots 50% from this particular area (1.00 points per possession). Most recently teams use analyses of mapping shots [4] which lead to conclusion three-point field goal attempts are analytically better and make offense more efficient as they give more point per one possession than two point field goals from certain areas.

Even though the result of basketball game consists many factors [8] such as rebounds, free throws and turnovers, in this article only three-point field goal attempts (and their frequency in all field goal attempts) are taken into account to examine increasing role of three-point shots in basketball.

To examine if there is significant growth of role of three-point shots, coefficient 3PA/FGA(%) (three-point field goal attempts/field goal attempts (%)) was used. It is worth mentioning that this is a new idea of examining growth of role of three-point shots by this coefficient and there was no scientific article based on 3PA/FGA(%). This coefficient measures frequency of three-point field goal attempts among all field goals attempts (two-point and three-point shots) and directly did not depend on pace of the game, rebounds, turnovers, free throws and any other descriptive statistics other than field goal attempts. 3PA/FGA(%) coefficient is count as proportion of team's three-point field goal attempts and all field goal attempts per game and then result is presented in percentage (multiplied by 100%). In the text the abbreviation 3PA/FGA will be used. This coefficient is better estimate for examining three-point shots' role than just three-point field goal attempts which could give misleading results. For example if team A plays fast, attempts 100 field goals per game and attempts 30 three-point field goals on average and team B plays much slower (and draws more fouls or has more turnovers), attempts 80 field goals per game with 28 three-point field goal attempts, only three-point shot attempts give advantage to team A (30 to 28), but if 3PA/FGA is taken, team B has higher score (35% to 30%) and that is more reliable result because team B is attempting three-point shots more frequently than team A.

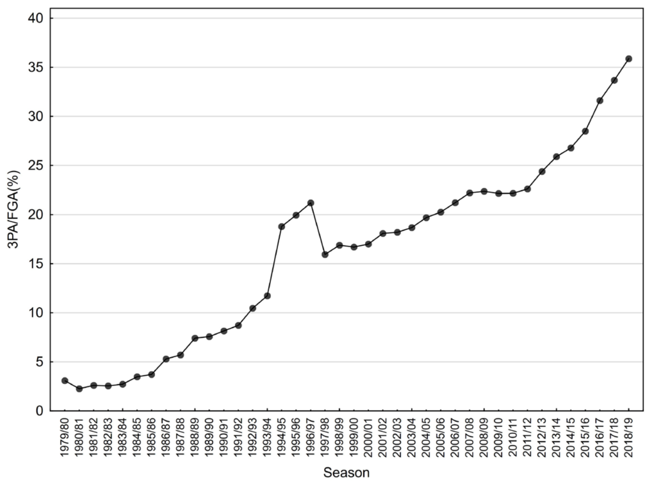


Figure 1. Changes of 3PA/FGA(%) coefficient in the NBA since introduction of three-point field goal

Since the beginning of three-point era (1979/80 NBA season) the growth of three-point shot role is observed. The differences of 3PA/FGA(%) through 40 regular seasons in NBA are presented on Figure 1. It is worth noticing that in first 15 seasons of three-point era on average in every season 3PA/FGA coefficient was 0.62 percentage points (abbreviation p.p. will be used) higher than season before. Then there were three seasons with three-point line shorter, which led to massive increase of 3PA/FGA (by 7 p.p. between 1993/94 and 1994/95 seasons) and then over 5 p.p. decrease after going back to distance of line 7.24 meters away from the rim in 1997/98. Next, there were another 15 seasons in which the average growth of 3PA/FGA in between consecutive seasons was 0.48 p.p., similarly to the start of three-point era. However, since 2011/12 season larger increase of number of shots from distance has been observed as 3PA/FGA coefficient has grown on average by 1.9 p.p. in between consecutive seasons, reaching more than 35% in most recent season. 3PA/FGA coefficient on this level means that over one third of field goal attempts come from behind the three-point line.

In this particular paper, the growth of three-point shot in the NBA in a span of 15 years (between 2004/05 and 2018/19 seasons) is examined and its impact on basketball teams' wins is discussed.

Aim of Study

The purpose of the study is to show the growth of the role of three-point field goals in regular seasons in the NBA last 15 years and check if it is statistically significant. This fact should be useful for coaches to think about how important three-point shot is in their teams' tactics. This should also be important for coaches responsible for development of young players to lay emphasis on three-point shots as a preparation for them to enter professional league with ability to consistently make three-point field goals. This could also encourage coaches to invent new drills in practice to improve the efficiency of shots from behind the three-point line.

Moreover, gaining information on the development of tendencies in basketball can constitute a basis for programming the future evolution of sports results in this particular sport.

Material and Methods

Sample and procedure

Taking into account lack of full statistical data up to 1996, the increasing number of teams in the NBA until 2004 and other rules changes (for example hand checking), it seemed rational to look at latest trends in three-point shots, in most recent 15 years, especially with observation of the biggest improvement last couple of seasons. In this analysis only regular seasons were taken in consideration as there are games between every pair of teams by contrast to playoffs where only some teams participate and they play multiple times against their particular opponent in given round.

Statistical data from the NBA from 2004/05 to 2018/19 season (15 seasons) was collected from https://stats.nba.com, the official page of statistics from NBA games. From every single one of those 15 seasons the average number of each team's three-point shot attempts and field goal attempts per game were taken and the proportion (in percentage) of those factors was counted. This gave aforementioned coefficient 3PA/FGA which shows the frequency of three-pointers for every team each season. So basically database consisted of 15 seasons (terms) and for every season there were 30 sorted out results of every team's 3PA/FGA coefficient.

Statistical analysis

Initially, 3PA/FGA coefficient each season was presented by mean, standard deviation, coefficient of variance, minimum and maximum. Then, the normality of data distribution each season was examined by Shapiro–Wilk's test. It was found out that not every season has normal distribution of coefficient 3PA/FGA. That led to conclusion the Friedman's one-way ANOVA should be used to check if there are statistically significant differences between seasons (dependent variables). Also the Friedman's post-hoc test for multiple comparisons was used to examine in between which seasons statistically significant differences are observed.

All statistical analyses were conducted using Dell Inc. (2016). Dell Statistica (data analysis software system), version 13. software.dell.com. The level of significance for all statistical tests was set at $p \leq 0.05$.

Results

It is observed that mean usually grows between seasons. Although average growth between 2004/05 and 2011/12 was only 3 p.p. (0.43 p.p. on average between any two seasons in a row), 7 years later (in 2018/19 season) 3PA/FGA coefficient was higher over 13 p.p. (growth between two consecutive seasons since then was 1.9 p.p. on average). Standard deviation has been changing between seasons, but it is relatively settled around 4.5. Combining that with the growth of the mean of 3PA/FGA, coefficient of variation is decreasing (by 50% between 2004/05 and 2018/19 seasons). This means that the differences between teams in 3PA/FGA are becoming smaller (Table 1).

Examining changes at the span of 15 most recent seasons, the increase of 3PA/FGA coefficient was 16.3 p.p. for average team and statistically significant differences (χ^2 (N = 30, df =14) = 395.85, $p \leq 0.0001$) were revealed (Table 1).

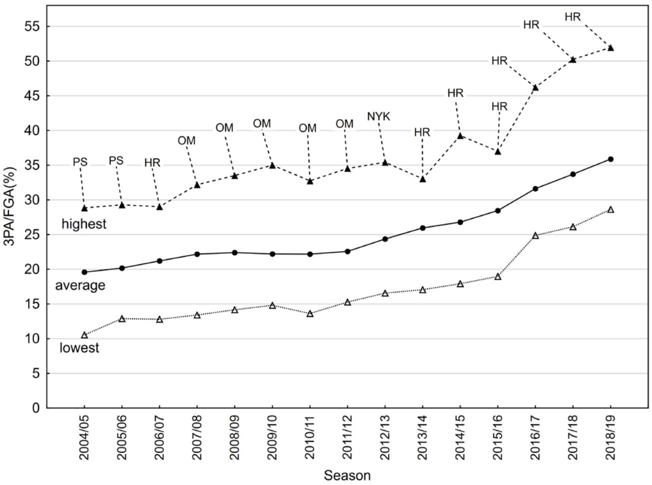
It is worth noting that team with highest 3PA/FGA in 2004/05 season has 23 p.p. smaller coefficient than a team with the highest 3PA/FGA in 2018/19 season, 7 p.p. smaller 3PA/FGA than average team from 2018/19 season and similar 3PA/FGA (just 0.3 p.p. higher) to team with the lowest value of 3PA/FGA from most recent season. Also, there are statistically significant differences ($p \leq 0.001$) between 2004/05 season and seasons in between 2011/12 and 2018/19. Slightly smaller, but also statistically significant differences ($p < 0.05$) are between 2004/05 season and every season in between 2007/08 and 2010/11 (Table 1, Figure 2).

Similarly to 2004/05 season, there are statistically significant differences ($p \leq 0.001$) between each of two following seasons (2005/06 and 2006/07) and every season in between 2012/13 and 2018/19 (Table 1).

Table 1. Post-hoc for Friedman's ANOVA for 3PA/FGA(%) in between all seasons from 2004/05 to 2018/19 and descriptive statistics for every season taken in consideration in analysis

Season	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19
2004/05	---														
2005/06		---													
2006/07			---												
2007/08	**			---											
2008/09	**	*			---										
2009/10	*					---									
2010/11	*						---								
2011/12	***	**						---							
2012/13	***	***	***						---						
2013/14	***	***	***	*		**	*			---					
2014/15	***	***	***	**	**	***	**				---				
2015/16	***	***	***	***	***	***	***	***				---			
2016/17	***	***	***	***	***	***	***	***					---		
2017/18	***	***	***	***	***	***	***	***	**					---	
2018/19	***	***	***	***	***	***	***	***	***	**	*				---
Mean	19.6	20.2	21.2	22.2	22.4	22.2	22.2	22.6	24.4	26.0	26.8	28.5	31.6	33.7	35.9
SD	5.00	4.41	4.08	4.34	4.29	4.35	4.23	4.50	4.24	3.81	4.88	4.94	4.80	4.76	4.83
V (%)	26	22	19	20	19	20	19	20	17	15	18	17	15	14	13

* $p < 0.05$, ** $p < 0.01$, *** $p \leq 0.001$



Note: PS – Phoenix Suns, HR – Houston Rockets, OM – Orlando Magic, NYK – New York Knicks

Figure 2. Changes of 3PA/FGA(%) coefficient in the NBA in between 2004/05 and 2018/19 seasons for teams with the highest, average and the lowest 3PA/FGA(%) every given season

The biggest growth of 3PA/FGA (just over 3 p.p.) was between 2015/16 and 2016/17 seasons. Also between those two seasons results of teams with the highest and the lowest coefficients increased by respectively 9 p.p. and 6 p.p. (25% and 31%) (Figure 2).

Furthermore, there are statistically significant differences ($p < 0.05$) in between every pair of seasons taken into account if they varies from each other by at least 6 seasons. Moreover, there are statistically significant differences ($p \leq 0.001$) in between every season from 2015/16 to 2018/19 and every season in between 2004/05 and 2011/12 (Table 1).

It is worth noticing that there are statistically significant differences ($p \leq 0.001$) between 2018/19 season and all seasons between 2004/05 and 2012/13, then slightly smaller statistically significant differences ($p < 0.01$) between 2018/19 and 2013/14 seasons and the smallest possible statistical significance ($p < 0.05$) in between 2018/19 and 2014/15 seasons. Moreover, the average team from 2018/19 season has higher coefficient than every team with the highest 3PA/FGA until 2013/14 season. That shows how big the growth of role of three-point shot is over the course of recent years (Table 1, Figure 2).

Discussion

One aspect of this study is to show that there are significant differences in 3PA/FGA between seasons and that role of the three-point shot is increasing. That was examined and presented results give clear statement that is fact. The other topic are reasons for growth of frequency of three-point field goals and impact of 3PA/FGA on the result of basketball games.

It is worth mentioning that since 2004/05 season every team with the highest 3PA/FGA coefficient in particular season has won at least as many games as lost, with average winning rate of 66% (almost two third games won by that team). Teams with the highest 3PA/FGA who were at the top of this coefficient's classification for two or more consecutive seasons were examined more precisely to find out impact of 3PA/FGA on results of basketball games.

First of all, there was Phoenix Suns (2004-2006) who won respectively 62 and 54 games (from 82) in those two seasons and was coached by Mike D'Antoni [2]. That Suns' team played with the fastest pace in league in that particular seasons and combining that with many three-point specialists on the team they were pioneers in attempting many more three-point shots than other teams. It is worth noticing that in 2018/19 season 29 of 30 teams had higher 3PA/FGA coefficient than Suns' team from 2004/05 season. Then there was Orlando Magic (2007-2012) who had many specialists in shooting three-point field goals. They won at least 52 games (from 82-game seasons) in every season they led the league in 3PA/FGA(%), but their highest result (35%) is still smaller than value of 3PA/FGA for average team from 2018/19 season. Comparing those two teams who had the highest 3PA/FGA before with result of teams in most recent season shows how massive the growth of role of three-point field goal was in a span of 15 years.

Most recently there is Houston Rockets (2013-2019) with Daryl Morey as general manager. Morey trusts analytical methods and tries to build a team relying on three-point shots because that should give more points to his team [9]. Furthermore, since 2016 Rockets are coached by Mike D'Antoni who was mentioned earlier as Suns' coach from 2004 to 2006. Since then 3PA/FGA coefficient has grown rapidly for Rockets – starting from 9 p.p. jump (from 37% to 46%) when D'Antoni took over the team, to 3PA/FGA equals to a little over 50% and almost 52% respectively in two most recent seasons (Figure 2). Moreover, Rockets had almost 10 p.p. higher 3PA/FGA coefficient than team with the second highest result in that coefficient during 2018/19 season.

What is worth noticing, in 2015/16 season Rockets, who won 41 games that season, were a team with the highest 3PA/FGA, but close behind them there were Golden State Warriors who made the most three-point field goals in the NBA that season, were second in 3PA/FGA and had the best regular season's record 73-9 (73 wins, 9 loses) in NBA history. Warriors were led by Stephen Curry, who had himself the best shooting season in NBA history as he made 402 three-point shots in that particular regular season. It is worth mentioning that the biggest growth of 3PA/FGA coefficient in span of 15 years taken in consideration happened after this spectacular season by Warriors as their result in that season was example of successful application of offense heavily relying on three-point shots and inspired others to build team in similar style of play to their team.

However, it is observed that teams with second highest result of 3PA/FGA won 54% of games, much less than teams with the highest result (66%) and even less than ninth and fifteenth highest result of 3PA/FGA (respectively 60% and 56% winning rate). It is also worth mentioning that there are examples of teams who won many games in regular season despite not being at top of 3PA/FGA. One of that team were San Antonio Spurs in 2015/16 season who had 67 wins and sixth lowest 3PA/FGA in the league this particular season. It shows that teams can win many games despite not relying on three-point shots as much as other teams and 3PA/FGA is not always decisive factor when it comes to result of basketball games.

It is worth noting that when three-point field goal attempts are used more often, their impact on results of game is bigger. Impact on results of game by 3PA/FGA was examined in between 2015/16 and 2017/18 NBA seasons [21] and results showed that teams having a value of 3PA/FGA more than 55% given game won over 78% of those games and teams who had 3PA/FGA in between 50% and 55% attempts coming from three-point shots in particular game, won over 58% of games. It suggests that bigger number of three-point field goal attempts increases a chance to win basketball game.

Although the number of three-point field goal attempts have significant impact on results of basketball games, it is important to point out that they are not the most important factor to determinate winning team in basketball game according to study by Ibañez [8]. It is worth noting that this study only concerns three-point attempts and makes, but not 3PA/FGA coefficient, which could give different results. Moreover, this study based on junior championship in 1999, so it was not examined for professional league and it was before years taken in consideration in analysis which examined this trend in this particular paper. It is interesting how it looks with 3PA/FGA coefficient during different period of times (in between 2004/05 and 2018/19 seasons) and in the NBA (or at least in professional league), but such studies were not found. That type of study would be helpful to confirm three-point field goals' impact on result of basketball games in recent years.

Even though three-point field goals are not yet the most important factor in determining winner of basketball game, players' ability to make three-point shots has an impact on offense not seen in the descriptive statistics. This becomes crucial in creating good offense in basketball as ability to consistently making three-point shots makes two-point shots easier and more efficient because defenders are not willing to help when players they defend are good three-point shooters and help would mean they allow open three-point field goal attempts for them.

This study was made based on NBA regular season games which might not be fully representative for all kind of basketball leagues, especially taking in consideration some differences in rules between NBA and other basketball leagues. Moreover, different results could be observed if playoff games were taken into account. That can be interesting topic to examine in another study.

Conclusions

In conclusion, this study shows that there is statistically significant growth of frequency of attempting three-point field goals in the NBA. It was also presented that many successful teams in recent years used three-point shots as important part of their game plan and three-point shot has an impact on result of basketball games. Observation of how other successful teams are built and using more analytics tools are probably the reason for increasing role of three-point shots in whole NBA league. Basketball fans and experts since more than a decade can see how big is difference between approach to the game back then and now. The question is how role of three-point field goals will look in the future – is increase going to stop and if so, when and why? Also the question is – will rules concerning three-point shots change? There are many suggestions like moving three-point line further or maybe even create four-point field goals. Thinking about changing basketball rules due to increasing number of three-pointers just confirms that three-point shot became very important part of basketball despite the fact that at the beginning it wasn't considered as a thing that could change approach to the basketball.

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ORIGINAL ARTICLE

TRENDS in
Sport Sciences
2020; 27(**1**): 13-18
ISSN 2299-9590
DOI: 10.23829/TSS.2020.27.1-2

Effect of drop height on different parameters of drop jump among soccer players

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Abstract
Introduction. **Drop jump is one of the most researched plyometric exercises. Different drop heights were earlier investigated for ground reaction forces, biomechanical analysis, and other parameters. There has been no research into the influence of drop height on maximum jump height during drop jump among soccer players.** Aim of Study. **This study aimed to find out the optimal drop height for maximum vertical jump height in drop jumps.** Material and Methods. **The researchers selected 17 male soccer players (mean ± SD; age 21 ± 2 years, height 174 ± 8 cm, body mass 63 ± 5 kg, isometric leg strength 122 ± ± 18 kg) for the study. Drop jump from different heights (35 cm, 45 cm, 50 cm, 65 cm, and 72 cm) was investigated for jump height, take-off force, take-off speed, impact force, maximum concentric power, and peak speed.** Results. **Repeated measures ANOVA revealed significant difference in jump height from different drop height ($F_{2.54,40.59}$ = 5.605, p = 0.004, partial η^2 = 0.259). Post-hoc analyses through Bonferroni adjustment showed significant differences between jump height from 35 cm box and 45 cm box (t_{16} = 4.31, p = 0.001, d = 0.47) and 35 cm box to 72 cm box (t_{16} = 3.52, p = 0.003, d = 0.60). However, no significant differences could be observed in take-off force, impact force, maximum concentric power, peak speed, and take-off speed from different drop heights. Isometric leg strength were significantly correlated with jump height from 35 cm (p = 0.014), 45 cm (p = 0.021) and 50 cm (p = 0.022) drop height.** Conclusions. **The study concludes that to improve maximum jump ability of soccer players, box height ranging around 65 cm to 72 cm may be selected for training purposes and thus may help improve the body's ability to convert the momentum generated by a run to maximum vertical height.**

KEYWORDS: drop jump, drop height, jump height, soccer players.

Received: 6 January 2020
Accepted: 24 February 2020

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Introduction

Soccer is among the most popular sports and is being played by many countries across the globe. Now and then, the teams want to perform better than their opponents. Moreover, thus, changes in training methodology to improve the performance of soccer players are very much accepted by teams all around the world [22]. This has led to more researches being conducted in soccer, and one such widely researched area is plyometric training for soccer players [22, 28]. Even if soccer player's aerobic capacity is critical in a soccer game [25], high-intensity player's efforts cannot be overlooked as they play a vital role in a soccer match [1, 8]. These high-intensity bouts include repeated kicking actions, changing directions, explosive sprinting, and jumping, all making significant contributions to the soccer player's performance [25, 26, 29]. Developing a soccer player's ability to generate power quickly would be an advantage to the soccer player during a match [20].
The successful transition of plyometric training to soccer performance is probably because many soccer activities need

movements with rapid stretch-shortening sequence, with players having to bounce against the surface with minimal surface contact phases [2, 17, 20]. Soccer coaches widely use plyometric exercises in their training periodization as it may increase the VO_2 peak percentage in soccer players [9], increase endurance and power generation in muscles [23], and also improve the ball velocity during soccer kick [6]. Drop jump is one of the most commonly used plyometric exercises to develop and evaluate jumping performance [15, 19]. Due to its proper metrics, such as reliability, validity, and sensitivity, the implementation of drop jump as a standard test has also been widely used and well supported in the literature [3, 12, 15, 27]. Thus, drop jump has been a choice of soccer coaches in developing muscle power of lower limbs for a long time [3, 15]. Also, numerous studies on drop jump revealed positive effects on jumping performance after the inclusion of drop jump in training or rehabilitation program [13, 14].

A drop jump is attempted by dropping from an elevated surface and attempting to make a vertical jump for maximum height after landing on the ground. A characteristic pattern is observed while the muscle elastic energy is retained and used during a drop jump. The gravitational force causes the body to move down, and energy is retained in the elastic components of the stretched muscles during the eccentric process. Furthermore, when the body moves up during the concentric process, it uses the muscle's stored energy [5, 10].

Many types of research were carried out to see the impact of the technique, optimum drop height, ground reaction force, body mass on peak power output, and drop jump intensity [11, 15, 19]. Our study was being conducted to find out the best possible drop height (from 35 cm to 72 cm) for maximizing the vertical jump of soccer players.

Aim of Study

The aim of the present study was to (a) to compare drop jump parameters shown by soccer players from different drop height, and (b) investigate the relationship of isometric leg strength with jump height from different drop height. It was hypothesized that soccer players would exhibit significant differences in drop jump parameters from different heights and a significant correlation between isometric leg strength and jump height from different drop heights.

Material and Methods

Subjects

Seventeen male subjects who were a part of the university soccer team which participated in national university games were selected for the study (mean ± SD; age 21 ± ± 2 years, height 174 ± 8 cm, body mass 63 ± 5 kg, isometric leg strength 122 ± 18 kg). The subjects had a minimum playing experience of 6 years during the collection of data. Plyometrics had been included and been a part of the training sessions of soccer players for 3 or more years. The subjects who participated in this study were physically active and training for national competitions. The inclusion criteria in this investigation were the absence of recent lower limb injury, lower back injury, or any musculoskeletal dysfunction within 6 months, which could hinder the execution of a proper drop jump. The execution of the study was in line with the Helsinki declaration's ethical principles for human research. Subjects were asked to fill out forms of informed consent. The research was approved by the institution's Sports Biomechanics department's research committee.

Procedure

All the subjects performed 10-minutes warm-up, which included dynamic stretching, plyometric exercises, and mobility exercises for the joints before the conduct of the test [26]. The subjects had to perform drop jump from varying heights (35 cm, 45 cm, 50 cm, 65 cm, 72 cm) with an instantaneous vertical jump intended for maximum height [11]. Participants were instructed to jump right after landing and cover the maximum vertical height possible. Each subject was allowed three trials in each box height. The order of the box height for drop jump was randomly assigned. The subject performed a total of 15 jumps. A rest interval of 30-seconds was allowed in between each trial [11].

BTS G-Sensor (S.P.A., Italy) which has tri-axial accelerometer with multiple sensitivity (±1.5 g, ±6 g), tri-axial magnetometer and tri-axial gyroscope with multiple sensitivity (±300 gps, ±1200 gps) was used to measure the outcomes of the drop jump. The protocol was set to drop jump in G Studio's (ver. 3.3.22.0) jump protocol section. Jump height, take-off force, impact force, maximum concentric power, peak speed, and take-off speed were the outcome variables of drop jump using the G-sensor and G-studio software. The drop jump with the maximum jump height among three trials was selected for analysis [26].

To measure the isometric leg strength, a leg and back dynamometer (T.K.K. 5402, Takei Scientific Instrument CO., LTD, Japan) was used. The subjects were asked to stand upright on the base of the dynamometer with the feet shoulder-width apart. Arms were hanged straight down to hold the bar at the centre with both hands, and palms facing towards the body. The knee was allowed to flex approximately 110 degrees, and then the chain was adjusted. The subjects were then asked to pull as hard as possible and asked to straighten the legs without bending the back [30].

Statistical analysis

Statistical analysis of the acquired data was performed using IBM SPSS (version 20.0.0). Shapiro–Wilk test was conducted to check the violations of the assumptions of normality. Non-parametric tests equivalent to its parametric counterpart were used for the analysis of non-normal data. Single-factor repeated measures ANOVA with five levels (box heights) were used separately for jump height, peak speed, and take-off speed. Greenhouse-Geisser corrections were used in cases where we found violations of assumptions of sphericity using the Mauchly's sphericity test. Post-hoc paired t-test with a Bonferroni adjustment (p = 0.01) was used to find any significant differences between the levels. Friedman's test (non-parametric) was used to analyze take-off force, impact force, and maximum concentric power, since one or more variables failed the test of normality and violated the assumptions of RMA. The relationship between isometric leg strength and output variables from various drop heights was evaluated with the Pearson product-moment correlation.

The effect sizes were calculated using partial η^2 for repeated measures ANOVA, with 0.01 defining small, 0.06 medium, and 0.14 large effect. While for Friedman's test, Kendall's W was calculated with 0.1 defining small, 0.3 moderate, and 0.5 large effects [7]. For Pearson correlation r = 0.10 specifies a low, r = 0.30 a moderate, and r = 0.50 a high association [7]. Cohen's d was calculated to determine the effect size for the student's t-test for paired sample, with d = 0.20 defining a small, d = 0.50 defining a medium and d = 0.80 defining a large effect size. The level of significance for all tests was set at 0.05.

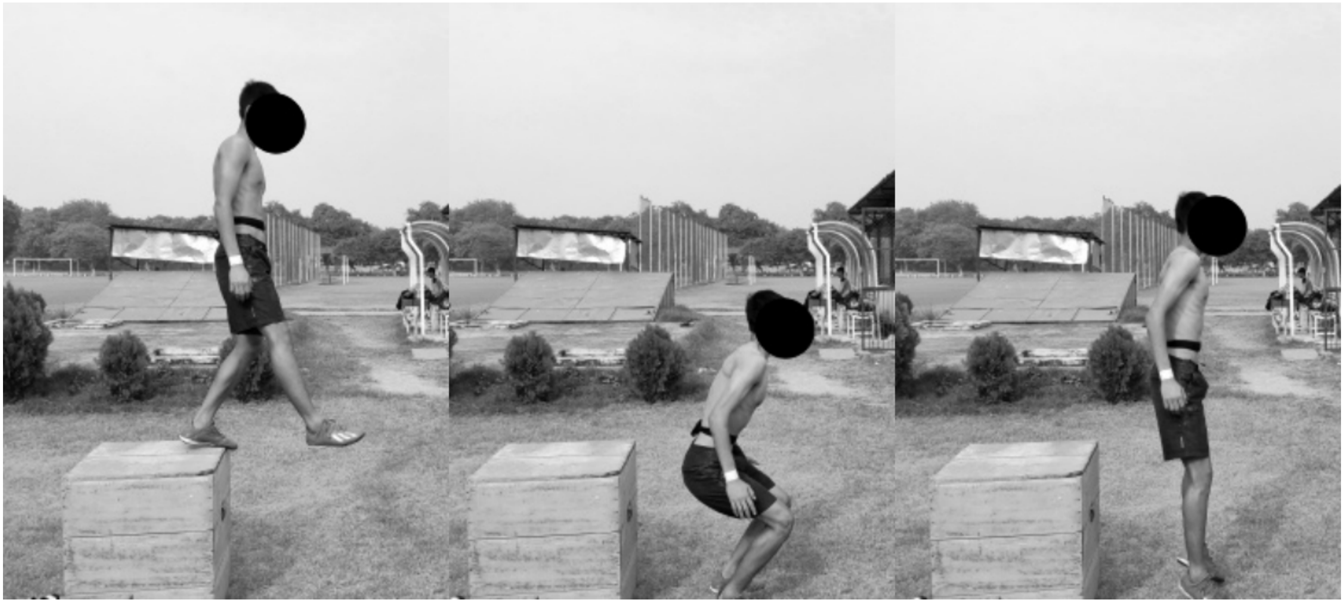

Figure 1. Subject performing drop jump with the BTS G-sensor tied on the waist of the subject

Results

Table 1 shows the values of all the measured variables. The outcome of the repeated measures ANOVA was significant in jump height from different box height, $F_{2.54,40.59}$ = 5.605, p = 0.004, partial η^2 = 0.259. Post-hoc analyses by means of Bonferroni adjustment discovered significant differences between jump height from 35 cm box and 45 cm box (t_{16} = 4.31, p = 0.001, d = 0.47) and 35 cm box to 72 cm box (t_{16} = 3.52, p = 0.003, d = 0.60).

There were no significant differences in take-off force (p = 0.198), impact force (p = 0.455), maximum concentric power (p = 0.858), peak speed (p = 0.828), and take-off speed (p = 0.883) from different drop heights.

There was a statistically significant correlation between the isometric strength of the leg and the height of the jump from 35 cm (p = 0.014), 45 cm (p = 0.021), and 50 cm (p = 0.022) drop heights.

Table 1. Drop jump parameters using G-sensor from the different drop heights

	Box (35 cm) Mean ± SD; *median (IQR)*	Box (45 cm) Mean ± SD; *median (IQR)*	Box (50 cm) Mean ± SD; *median (IQR)*	Box (65 cm) Mean ± SD; *median (IQR)*	Box (72 cm) Mean ± SD; *median (IQR)*	p-value (effect size: partial η^2 or Kendall's W)
Jump height (cm)	34.71 ± 6.06	37.46 ± 5.9	36.96 ± 4.5	36.49 ± 4.32	38.18 ± 5.22	**0.004*** (0.259)
Take off force (kN)	0.73 ± 0.22	*0.69 (0.53-0.84)*	0.71 ± 0.24	0.71 ± 0.17	0.66 ± 0.24	0.198 (0.088)
Impact force (kN)	1.02 ± 0.23	1.02 ± 0.3	0.93 ± 0.23	*0.95 (0.77-1.12)*	0.97 ± 0.32	0.455 (0.054)
Maximum concentric power (kW)	*3.03 (2.72-3.61)*	*3.1 (2.72-3.61)*	3.21 ± 0.76	3.23 ± 0.69	*3.16 (2.64-3.56)*	0.858 (0.019)
Peak speed (m/s)	2.81 ± 0.27	2.83 ± 0.3	2.82 ± 0.31	2.85 ± 0.27	2.85 ± 0.25	0.828 (0.023)
Take off speed (m/s)	2.7 ± 0.27	2.72 ± 0.3	2.71 ± 0.3	2.73 ± 0.29	2.73 ± 0.26	0.883 (0.018)

Note: IQR = interquartile range, SD = standard deviation
* denotes significant differences at 0.05 level of significance

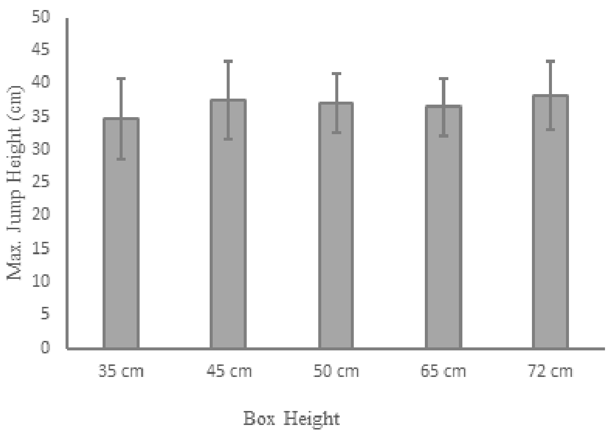

Figure 2. Bar diagram of maximum jump height from different box height

Table 2. Correlation of isometric leg strength with jump height from different drop heights

	Box (35 cm)	Box (45 cm)	Box (50 cm)	Box (65 cm)	Box (72 cm)
Isometric leg strength (r)	0.585*	0.556*	0.550*	0.328	0.478
p-value	0.014	0.021	0.022	0.199	0.052

* denotes significant correlation at 0.05 level

Discussion

In this present study, the assumption was that different drop heights would contribute to different vertical jump height for drop jump amongst soccer players. When the drop height rose from 35 cm to 45 cm, there was a significant increase in the height of the jump with a medium effect size. While the height of the jump did not differ significantly between 45 cm, 50 cm, and 65 cm drop height. A significant difference could also be seen in jump height when drop height increased from 35 cm to 72 cm with a medium effect size. A similar finding was observed in a study conducted by Ramirez-Campillo et al. [22], where the transference effect coefficient (TEC) was found higher for drop jump training from 40 cm than 20 cm height. The results of this study suggest that, with the increase in drop height, the height of the jump increases. A study conducted by Ramirez-Campillo et al. reported an increase in ground reaction force when the height of drop was increased from 20 cm to 40 cm and 60 cm when the toes and heels were in contact with the ground. A similar study by Caster found an increase in the maximum GRF when drop height was increased by 15 cm, 30 cm, 45 cm, and 60 cm. Some other studies were also conducted with different heights, like McKay et al. [16] who investigated 10 cm, 30 cm, and 50 cm, while Seegmiller and McCaw [24] investigated 30 cm, 60 cm, and 90 cm. All these experiments showed that there were higher ground reaction forces with a drop height increase. Also, our finding suggests that a height of 45 cm, 50 cm, and 65 cm used for drop jump yield similar jump height, and thus using any drop height between 45 and 65 cm would have the same effect on the jump height of soccer players.

No significant differences in take-off force, impact force, maximum concentric power, peak speed, and take-off speed between different drop heights were observed.

Soccer is a body contact sports [31], which includes jumps ranging from 1 to 36 during a top-level game [18]. A soccer player, thus, is accustomed to numerous jumps and landing during his entire career, including games and training. This might have led the soccer players capable of maintaining a similar impact force, take-off force, maximum concentric power, peak speed, and take-off speed throughout the jumps from different heights.

Further analysis of the relationship of isometric leg strength with jump height from different drop height revealed that a significant correlation was established among isometric leg strength and 35 cm, 45 cm, and 50 cm drop height while the relationship could not be established with the higher end of drop height. Pedersen et al. [21] conducted a study, where improved maximal strength was found not to be associated with jump height in countermovement jump in high-level female soccer players. This study partially supports our study. The jump height in the lower end of drop height may be contributed more by isometric leg strength. This might mean that the higher the isometric strength of the leg, the higher the jump height will be in drop heights from 50 cm and below. The results also reveal that the isometric strength of the leg does not contribute significantly to drop heights above 50 cm. The reason for this may be more flight time allowed during a drop from heights above 50 cm, which allows the body to generate more momentum, which then is utilized by the body to gain maximum vertical heights [4].

Conclusions

From the results and findings of the study, it can be concluded that soccer coaches may utilize different box height ranging from 35 cm to 72 cm to improve maximum concentric power, take-off speed and force ability, and ability to minimize the impact force while landing since all drop heights had shown a similar contribution to all those parameters. To improve maximum jump ability of soccer players, box height ranging around 65 cm to 72 cm may be selected for training purposes since these two drop heights exhibited maximum jump height, and thus may help improve the body's ability to convert the momentum generated by a run to maximum vertical height. Further, more studies are required in this area to investigate the effects of drop heights on other sports athletes, who require improvement in jump ability.

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SHORT REVIEW

TRENDS in
Sport Sciences
2020; 27(**1**): 19-24
ISSN 2299-9590
DOI: 10.23829/TSS.2020.27.1-3

The influence of temperature on function of mammalian skeletal muscles

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Abstract
The influence of the thermal environment on physiological processes and body temperature have been widely studied. Skeletal muscles are one of the tissues that are very sensitive to different thermal conditions. The temperature of muscle, especially in limbs, is frequently different than core temperature and fluctuates daily. For example, the resting muscle temperature of humans (core temperature 37°C) may vary from 29.4 to 34°C but may be increased to 40°C in the same muscle during activity [3]. The change in temperature between resting and working muscle has the potential to considerably alter the rate of contractile muscle properties and power outcomes. This review presents the current state of knowledge regarding the effect of temperature on properties of mammalian skeletal muscle contractions, specifically the biomechanical, metabolic, and neuromuscular aspects.

KEYWORDS: skeletal muscle, physiology, contraction, hypothermia, hyperthermia, metabolism.

Received: 16 February 2020
Accepted: 15 March 2020

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Introduction

In the mid-1950s, Huxley detailed the sliding filament theory, which described muscle structure and proposed theories of contraction. Active muscle contraction involves the relative sliding between two sets of filaments in a sarcomere (the thin, actin filaments and the thick, myosin filaments). The repetitive mechanical interaction of cross-bridges (myosin heads) on actin filaments are the biomechanical basics underlying muscle force generation. The cross-bridge attaches to the actin, changing the conformation and starting the muscle contraction, before they detach. This mechanical cycle is combined with an enzymatic reaction: hydrolysis of ATP by actomyosin and ATPase, release of phosphate (P_i) and adenosine diphosphate (ADP), and liberation of energy, which is converted into work and heat [14]. This mechanism is responsible for changes in muscle temperature during activity. The potential muscle elements featured in temperature changes are the biomechanical properties of soft tissue, biochemical properties of metabolism, and neuromuscular components. It is hard to divide all these components in independent research; however, some studies shed a light on these processes. Bits of knowledge about biomechanical properties of muscle tissue come from *in vitro* muscle experiments.

Non-contractile muscle fiber structures

For the most part, muscle experiments have been done in three functional and mechanical states: relaxed (or resting), rigor, and active state. The tension of a relaxed muscle is largely insensitive to temperature. In the relaxed state, the cross-bridges remain detached and force develops when stretching beyond the rest length. This tensile-resistance results from the stretch of non-cross-bridge structures in the sarcomere. However, stretched, relaxed muscle can develop a type of "elastic" force due to heat-contracture at higher temperatures

(30-40°C) [25]. In the rigor state, there is no ATP, all cross-bridges are attached to actin (there is no cross-bridge cycle), and the muscle is stiff (after death, the muscle stays in the rigor state). As the temperature rises, force decreases slightly and linearly (exothermic process). In active muscle, cross-bridges attach to actin, develop force, and detach. The development of force, in this case, is very sensitive to temperature and increases with the absorption of heat (endothermic process) [24].

Muscle fibers are composed of two primary components, which are biomechanically distinct but structurally interconnected, called exo- and endosarcomeric lattices. Exosarcomeric lattices are a network of intermediate filaments that surround and interconnect myocyte organelles and sarcomeres with costamere and sarcolemma. The sarcomere, a basic unit of the contractile apparatus of striated muscle, are linked longitudinally to adjacent sarcomeres of the same myofibril by Z and M lines and radially to parallel myofibrils. On the other hand, an endosarcomeric lattice refers to extensible titin filaments, which attach between the M line region and the Z line, and inextensible nebulin, which runs along the thin actin filament [32, 33].

Previous findings have shown that elasticity characteristics of muscle fibers are more dependent on myofibrils than connective tissue [16]. Titin (connectin)-containing cap filaments were identified as a component of muscle fibers and are largely borne to resting tension [11, 13]. Titin is a protein connecting the myosin thick filament to the Z-disc in a sarcomere [19]. Maruyama et al. [18] showed that the isometric tension of isolated titin has a positive temperature coefficient. Furthermore, the resting tension of skinned fibers from a rat's extensor digitorum longus muscle increased with warming, from 20°C to the highest physiological temperature (30--40°C), and decreased with cooling, lowering back to the initial temperature. The reversibility of warming-cooling procedures was repeated until the temperature reached an upper limit of 43-45°C [25]. Summarizing the available evidence shows that the non-contractile endosarcomaric components, which build muscle cells, are temperature sensitive.

Relationship between length and resting tension

In general, mammalian muscles consist of two main types of muscle fibers: slow- and fast-twitch fibers. A rat's soleus muscle is often used as an example of a slow-twitch muscle and the extensor digitorum longus is used as an example of a fast-twitch muscle for studies of muscle properties [7]. In one of the first studies of mammalian muscle, Hill observed, in temperatures below 15°C, that rat muscle showed different characteristics than frog muscle [12]. The resting tension of the rat's slow soleus muscle, at the optimal length, started to rise when temperatures decreased from 15°C to 10-8°C. At the lowest temperature, the resting tension was increased roughly four fold. The "cold tension" effect was very unpredictable and not reproducible below 2°C. The opposite effect was observed in the fast-twitch extensor digitorum longus muscle. Below 15°C, resting tension decreased and near 0°C resting tension was slightly increased. As a function of time (in 5-8 hour experiments), developed resting tension was always higher than at the beginning of experiments (20 g vs 100 g) [12]. These experiments revealed that fast and slow-twitch muscles have different passive effects during temperature changes.

Relationship between length and tetanic tension

One of the classical physiological properties of muscle is the length/tetanic tension relationship, which is another feature sensitive to changes in muscle temperature. This relationship describes the force produced by progressively increasing muscle or sarcomere length and has a characteristic reversed U-shape. In a rat's short head of biceps brachii muscle (fast-twitch muscle), the largest force was developed when sarcomere length reached 2.2-2.5 μm and by 4.0 μm the tetanic tension was predicted to be 0. Interestingly, the U-shape of the length/tetanic tension curve was similar at both examined temperatures (27 and 15°C) [10]. Moreover, Elmubarak and Ranatunga [10] showed that cooling sensitivity (measured as a rate of change in muscle tension rise under change in temperature) for a short head of biceps brachii muscle increased below 23°C. A similar observation was noted in extensor digitorum longus and soleus muscles, where the temperature sensitivity rose below 25°C [26]. In conclusion, the experimental data demonstrated that the relationship between sarcomere length and tetanic tension does not change based on temperature.

Isometric twitch and tetanic contraction

The twitch is a single contraction of muscle in response to a single command (stimulus) from the nervous system. In physiological experiments, twitch contractions could be evoked by electrical stimulation delivered directly to muscle fibers, via a cut axon in the supplying nerve, or by the filament of the ventral roots containing axons of motoneurons. Furthermore, the isometric tetanic contraction (also called tetanus) is a sustained muscle contraction evoked by a train of stimuli delivered at a high rate. Using these two kinds of muscle contractions researchers can describe basic characteristics of twitch (twitch force, contraction time, half relaxation time) and tetanus (plateau tension, maximum tetanic force, rate of tension development), as well as, a possible range of changes in the force, including the minimum and the maximum force, which can be modulated by changes in motoneuronal firing rate.

In female rats, the peak twitch tension and the isometric tetanic tension of intact soleus muscle decreased when the temperature dropped from 35 to 20°C, whereas in the extensor digitorum longus muscle the isometric tetanic tension decreased, but the maximum twitch tension increased 1.7 fold [8, 23]. Surprisingly, in the other fast-twitch muscle, short head of biceps brachii, the peak twitch tension rose 1.65 fold with cooling at the same temperatures [10]. The peak twitch tension for soleus muscle at 12, 8, and 4°C (compared to that at 22°C) was 74, 61, and 47%, respectively. This tension didn't drop when exposure to cooling was prolonged, except when the temperature was decreased to 3°C. For example, cooling the soleus muscle from 21 to 3.8°C reduced tension to 29.5% after 1 minute, and 27.1, 24.8, and 23.2% after 2, 6, and 20 minutes, respectively. At 0.3°C, the peak twitch tension was reduced to 31.0, 17.1, and 6.2% after 1, 3, and 10 minutes, respectively [12]. The twitch time-to-peak, also called the twitch contraction time, was prolonged during cooling in both types of muscles, but consistent results could only be obtained above 3°C. It is worth it to mention that in the soleus muscles, twitches after cooling to 0.5°C could last up to 60 seconds. At physiological temperatures, the contraction time is 0.15 seconds in the soleus muscle and about 0.095 seconds in the short head of biceps brachii muscle [10, 12]. The prolonging of twitch contraction time was not associated with a delay in restoration of the normal membrane potential. In such a case, a second pulse applied during the twitch would produce a multiple mechanical response, which was observed [12].

The course of twitch relaxation is very important from a physiological point of view as it considerably influences summations of individual twitches into tetanic contractions. This process is crucial to produce force in unfused tetanic contractions, which are generated by muscle fibers during voluntary activity. Experimental data indicate that with cooling, retardation of the time-to-half relaxation was even longer than that of the time-to-peak. The Q_{10} (temperature coefficient for the rate of relaxation) was estimated to be 10, at a length of l_0 + 1 mm (l_0 is the length of the muscle during a maximal isometric twitch – 1 mm), for twitches in soleus and extensor digitorum longus muscles at 4-14°C; whereas, at length l_0 + 3 mm, this coefficient was lower, 5.4 and 6.5 for soleus and extensor digitorum longus muscles, respectively [12]. Segal and Faulkner [29] investigated changes in peak twitch tension, time-to-peak twitch tension, twitch half relaxation time, the maximum rate of twitch tension development, and maximum tetanic tension at 20-40°C. In both muscles (soleus and extensor digitorum longus), there was a shorter time-to-peak twitch tension at higher temperatures. In comparison to the soleus muscle, the extensor digitorum longus muscle had a faster time-to-peak twitch tension at each temperature. The peak twitch tension for the soleus muscle did not vary with a range in temperature, but tension in the extensor digitorum longus muscle rose when the temperature increased [29].

Experimental data from skinned muscle fibers and intact muscle models showed with plateau tension (tetanic force), maximum rate of tension development, time to half-rise of tension, and time to half-relaxation of tension in isometric tetanus, that mammalian skeletal muscle's temperature dependence was biphasic in nature between 10 and 36°C. There was an increase in cooling sensitivity for the rate of muscle tension rise at temperatures below the border temperature level (23-25°C) [26, 31]. When the extensor digitorum longus muscle was cooled from 35 to 10°C, a nearly 40% depression of tetanic tension occurred and after rewarming the tetanic tension was 10% less than tension was prior to cooling. Relative to the initial values, tetanic tension after rewarming was higher in the soleus muscle (104.0 ± 2.3%) than in the extensor digitorum longus muscle (91.2 ± 3.9%). This disparity in tension may have resulted from differences in fatigue resistance of muscle fibers. Most of the tetanic tension was recovered between 10 and 25°C in both muscles [22, 26]. The rate of tetanic tension development and time to half-relaxation of tetanic tension was also biphasic with cooling. The temperature sensitivity of the rate of tetanic tension development and half-relaxation of tetanic tension was more pronounced below 22°C in both muscles. However, at higher temperatures (24--36°C), the rate of tetanic tension development was more temperature-sensitive in the soleus than extensor digitorum longus muscle [26].

Force-frequency curve

Two studies examined the dependence of force on the frequency of stimulation at a physiological (35°C) and reduced (25°C) temperature. Ranatunga [23] found that cooling shifted the steep part of the force-frequency curve to the left side in both the soleus and extensor digitorum longus muscles. This means that a higher relative force (relative to tetanic tension) was achieved at a considerably lower frequency of excitations [23]. Similar dependencies were observed by Segal et al. [30] for the soleus muscle at 20 and 40°C and for the extensor digitorum longus at 20, 30, and 40°C.

Fatigue resistance

Elevated muscle temperatures are associated with changes in time parameters associated with a muscle twitch. The contraction and relaxation time were shortened [23, 29], the intramuscular pH declined [27, 34], and the rates of anaerobic [9] and aerobic metabolism increased [5, 29, 35] with an increase in temperature.

An increase in temperature (43°C compared to 37°C) of a mouse's soleus muscle does not change fatigability [21]. However, Segal et al. [30] determined that the soleus muscle requires more stimuli to develop fatigue at 25 and 30°C than at 20 and 40°C. They also showed that the extensor digitorum longus muscle had a higher fatigue resistance at 30°C, than at 20, 25, 35, and 40°C. The similar nature of these changes were observed in *in vivo* studies in humans. The highest resistance to fatigue was found when the quadriceps muscle temperature was 31.6°C (30.3-32.6°C). A significantly lower fatigue resistance was observed at a higher muscle temperature (38.2-39.6°C), but at a lower muscle temperature (19.4-25.8°C), the difference was not significant. On the other hand, the fatigue resistance of the extensor digitorum brevis muscle (fast-twitch) decreased at a lower temperature, which was measured at 10, 20, and 30°C. Similar trends were observed in the mechanical power output calculated based on the shortening contractions. Moreover, an increased fatigue effect was more pronounced in the isotonic contraction (shortening mode) than in the isometric contraction (non-shortening mode) [28]. It is important to note that acidosis impaired the skinned mammalian muscle fibers kinetics at a low temperature (10°C), but only slightly impaired it's kinetics at high temperatures (30°C). This data showed that a decreased pH had less of an effect in the fatigue development process at higher temperatures [20, 34]. Metabolic changes were observed in analyses of human muscle biopsies taken during rest at 22.5, 31.6, and 38.6°C, after a water bath at 12, 26, and 44°C, respectively. The resting level of glucose, glucose 1-P, glucose 6-P, fructose 6-P, glycerol 1-P, pyruvate, and lactate were significantly higher at 38.6°C than at 31.6°C in the quadriceps muscle. When compared to 31.6°C, similar trends were observed at 22.5°C, but it was not as consistent as at 38.6°C [9]. Enhanced levels of a few glycolytic intermediates could be associated with an increased rate of glycolysis at higher temperatures during rest. After a series of sustained isometric contractions, ATP levels decreased to nearly 80%, but after the first contraction at 38.6°C, levels were significantly lower compared to the concentration of ATP at 22.5 and 31.6°C. There were no differences in the concentration of ADP and AMP at each of the studied temperatures. In addition, at high temperatures, phosphocreatine levels dropped to about 23% (compared to resting levels), and this almost depleted those resources. There was no effect of temperature on the levels of glucose, hexose monophosphates, dihydroxyacetone-P, glycerol 1-P, fructose 1,6-diP, and dihydroxyacetone-P [9].

Enzymatic activity

Contraction time is strongly dependent on ATPase activity and it likely plays a significant role in temperature-dependent impairment of skeletal muscle contractions [1]. In the fast-twitch muscles of rabbits (gastrocnemius and extensor digitorum longus), ATPase activity was 2-3 times higher than in the slow-twitch muscles (soleus and crureus). The isolated myosin experiment by Bárány et al. [2] showed that actin-activated ATPase was biphasic in behaviour, with a break at 15°C and greater activity at 35°C than at lower temperatures. Additionally, Zoladz et al. [35] studied the effect of temperature on fatty acid metabolism in a series of experiments on isolated skeletal muscle mitochondria. They observed that the capacity for fatty acid oxidation was more efficient at higher temperatures (25 vs 35 vs 42°C) under phosphorylating conditions (state 3). The upgrade to non-phosphorylating respiration (state 4) was observed with a rise in temperature. Previously, Brooks et al. [5] reported that the elevation of temperature from 25 to 45°C was associated with an increased rate of mitochondrial state 3 (60%) and 4 (200%), with pyruvate and malate as respiratory substrates.

Neuromuscular junction

Electromyographic studies suggest that the mechanism of transmission at the neuromuscular junction may be temporarily impaired in humans by temperatures near 20°C [6]. Only one study has investigated the influence of decreased temperatures on the motor endplate and these effects were compared at 20-23°C and 15-17°C. These data were obtained for the motor endplates of the sciatic nerve in the sartorius muscles of frogs. Kordaš et al. [15] found that the amplitude of the endplate current was depressed and that the time course of the post-synaptic potential was lengthened.

Motoneuronal firing properties

Under reduced muscle temperature by 5°C (from initial at 30°C), the motor neuron discharge rate did not decrease; although there was a reduction in contractile speed of the first dorsal interosseous muscle. Additionally, as fatigue developed, differences in the motor neuron discharge rate were not significant. However, differences did include a lengthened duration and declined amplitude in the M wave. The authors suggested that changes in the M wave under reduced temperature conditions were associated with the increase in the propagation time of the muscle fibers action potentials [4]. Temperature changes considerably influence the electromyogram recorded during muscle activity. Temperate decreases may evoke a loss in synchrony of motor unit recruitment. Using surface EMG and decomposition techniques in the forearm, Mallette et al. [17] observed a prolonged duration in motor unit action potentials (10.5%) and a lower amplitude (10.9%) at 22°C, when compared to 32°C. Moreover, more motor units were recruited (20 ± 7 vs 16 ± 5) at a lower temperature, which suggested that the cold muscle needed to compensate for the attenuated muscle force.

Future challenges

Despite a long history of research, there is still much to explore about the effect of temperature on the properties of mammalian skeletal muscle contraction. Three specific topics are of particular interest: 1) the effect of temperature on individual motor units of the three physiological types; 2) the temperature dependence at motor endplates of fast- and slow-twitch muscle fibers; and 3) the effect of core hypothermia and hyperthermia on the excitability of motoneurons and the temperature sensibility of origin neurons in the pyramidal tract of the motor cortex. Moreover, the development of experimental technology allows simultaneous recording of activity in individual motor units of muscles and their synchronization over time while performing motor tasks. The possibility of such an assessment would allow a more comprehensive understanding of the effect of temperature on neuromuscular performance.

Conclusions

As with almost all biological systems and structures, skeletal muscle is notably temperature sensitive. The change in temperature of mammalian skeletal muscle occurs under the influence of internal processes (endothermic) and the environment (exothermic processes). The final effect observed in the efficiency of muscle contraction and/or performance of motor skills is the result of combining the changes on the properties of non-contractile (connective tissue) and contractile elements (sarcomeres) and metabolic and neuronal processes at lower and higher than physiological temperatures. These changes in single structures are inseparably connected with each other. A deeper understanding of the nature of these changes requires further research.

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SHORT REVIEW

TRENDS in
Sport Sciences
2020; 27(**1**): 25-28
ISSN 2299-9590
DOI: 10.23829/TSS.2020.27.1-4

Resistance training in football

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Abstract
Among the methods that can improve football players' motor skills, resistance training plays an important role, being one of the components of functional training in which players use their own body weight in all planes of movement. Currently in football, refining motor skills takes place on many levels, for instance, through resistance training. Optimal performance of a specific motor pattern and development of specific dominants such as stability, mobility and neuromuscular coordination increases the chance of improving the level of fitness. While discussing the importance of soccer training, attention was paid to the specific nature of work performed as well as the intensity and volume of applied effort during the broadly understood training process in football. In the aspect of developing motor skills, the role of functional loads in resistance training was emphasized which has a beneficial effect on improving speed, strength, coordination and endurance in football.

KEYWORDS: functional training, football, speed.

Received: 16 January 2020
Accepted: 22 February 2020

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Introduction

Football belongs to one of the most popular disciplines in the world [12, 20] in which the development and search for new factors that determine success seems not so much a duty as a necessity. The role of comprehensive fitness preparation in team sports games is indisputable [7]. Excellent technical and tactical, mental and motor preparation are required [12]. It is worth noting that motor preparation has a considerable impact on the use of technical and tactical skills during the match. As the discipline develops, the pace and intensity of the game are constantly increasing [20]. The purpose of the work was to attempt to define the factors influencing the development of footballers' speed and strength abilities.

Motor preparation

The work performed on the pitch is characterized by a large number of leaps, starts, accelerations, braking, jumps, turns, changes of direction and performing movement tasks with the ball [8]. The determinant for assessing endurance training is the distance covered by a player during a match. According to Bompa et al. [3], a high level of aerobic endurance is necessary to increase the efficiency of speed training, develop high activity during the game and to rebuild energy resources after sprints [6].
In the analyzed motor aspect, it is worth paying attention to the efforts made with maximum intensity and speed of traveled distances [21]. In football, speed plays an important role which should be understood as a comprehensive ability to perform the fastest and most effective technical and tactical action during the game

under time pressure and the pressure coming from an opponent [3]. The competitor performs about 100 sprints during one meeting, the running speed for the sprint is from 23 km/h (6.4 m/s) to 30 km/h (8.3 m/s) [3] in time from 3 to 6 seconds which is approximately 2500-3000 meters. Another variable determining the level of speed abilities is the number of sprints performed by players during the match [13]. Relying on data generated with the help of the Amisco-Pro system, it was found that in the English league this value is on average 11.5, while in the Spanish league it is 10.5 (24 km/h is the sprint). Due to the changing intensity of the game, running at maximum speed alternates with activities of medium and low intensity. These types of activities are on average 40-50 minutes during which players cover a distance of 4-8 km, the remaining distance of about 1-2 km is covered for 30-35 minutes. A football player covers a distance of around 9-13 km in one meeting [2, 25, 26]. During the application of effort in march all metabolic transformations are exploited. For example, aerobic, aerobic-anaerobic, anaerobic-phosphagenic and anaerobic-glycolytic [3]. Oxygen processes allow players to move with moderate intensity. Approximately 2% of the energy used is covered by anaerobic processes during which explosive activities such as jumps, slides, sprints or tactical activities such as counterattack occur. The average footballer's heart rate during a game is between 156 and 171 bpm. In the competitors' individual analysis, these values range from 140 to even 195 bpm [4]. Szwarc [23] shows that the efforts shaped in the first and second intensity range on average 27-30% of the total load. Cometti [9] in his work showed that players in the French league defeat 40% of effort with low intensity, 35% rest, 20% effort with medium intensity, and 5% is high intensity work. Therefore, it can be assumed that football players should be prepared for maximum efforts in each part of the match. Bangsbo [2] assumes that one of the basic goals of the training process is to shape and maintain "ability to exercise with varying intensity (running speed) over long periods of time (endurance)" [pp. 87-88]. Hence, it can be assumed that the formation of anaerobic endurance, speed and explosive strength is of fundamental importance in football.

Functional training and its role in football

We can categorize the athlete's physical activity in four types such as locomotion, lowering/lifting, pushing/pulling and rotational movements. These four types can be considered fundamental for all other activities performed on a daily basis [22]. Functional training plays a significant role among methods that can improve the football players' speed and strength which is perceived as performing a specific sequence of isolated exercises using their own body weight in all movement planes [27]. The premise of functional training is shaping motor skills through optimal performance of a specific motor pattern and the development of specific dominants like stability, mobility and neuromuscular coordination. Functional exercises support the stabilization of body segments and play a role in controlling the athletes' fitness [1, 15, 19, 28]. They are also used as exercises that are important for the development of motor skills such as speed, strength, endurance and coordination [24]. The proposed exercises in which the FMS test is used are applied to maintain mobility, stabilization and prepare the player for specific tasks related to the performance of technical and tactical activities during the game. Brake movements, acceleration and dynamic direction changes are very important for football players. They depend on mobility and stability in the ankle joint [10]. To sum up, the introduction of systematic functional training has a positive effect on the correct and comprehensive work of muscles and joints in all planes of movement [14, 17]. Functional training can be a supplement to the training process because it is focused on making a movement that activates and synchronizes the activity of the myofascial chain in an appropriate way without the need to train a specific sports skill. Another task of functional training is to increase developed strength without increasing body weight. Activation of entire muscle groups causes the load to be distributed over a larger number of muscles so that a single muscle that is less strained adapts to it but without much growth [7].

Summary and conclusions

The level of football in the world is constantly increasing. Therefore, the search for new factors conditioning success in football is justified. It should be mentioned that details determine the final results at the highest level. Sports practitioners and theorists still recognize the fundamental importance of speed and strength parameters. This work focuses on searching for training methods and means to shape selected motor skills. In the motor aspect, these are variables related to game time as well as to dynamic change of game conditions in different intensity ranges [12]. In the methodological aspect, it is suggested to look for measures to enrich the training process. Functional training is important for shaping and developing motor skills. The analysis of the impact of functional loads on the ability of motion speed in their works was shown by Haycraft et al. [11] on Australian league players in the U14 and U16 categories and Köklüa et al. [16] on players training in Turkey in the selected U16 team. In the research of Tunisian players conducted by Chaalali et al. [5], the positive impact of functional training on improving the results of speed abilities was demonstrated based on a 5-0-5 trial [18] in a 6-week program aimed at changing direction and acceleration. In addition, taking into account the constantly growing area of resistance training, it is worth looking for more predictors that have a positive impact on the result of competition in football. Based on the study, the following final conclusions were formulated:

Referring to motor preparation in a team play which is football, speed and strength skills among players play an extremely important role.

It can be assumed that functional training supplements the broadly understood training process.

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ORIGINAL ARTICLE

TRENDS in
Sport Sciences
2020; 27(**1**): 29-34
ISSN 2299-9590
DOI: 10.23829/TSS.2020.27.1-5

Changes in the somatic build and physical fitness of physical education students in the years 2004 and 2014

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Abstract
Introduction. In the current situation of the demographic low and strong competition on the educational market, such issues as the level of education as well as competences and predispositions of students are under discussion more and more frequently. Aim of Study. The aim of this study was to analyse differences in body build and physical fitness of physical education (PE) students in the years 2004 and 2014. Material and Methods. In 2004 the authors examined 112 females and 287 males who were second-year students. The tests were repeated in 2014 and included 98 females and 242 males. Anthropometric features were measured according to Martin and Saller guidelines, and these measurements, in turn, were used to calculate body build type according to Heath–Carter method. Physical fitness was assessed with the use of Eurofit test. Results. In the assessed decade only slight changes in basic somatic features and negative changes in body build (especially in men) were noted. Physical fitness of students was similar to the results obtained 10 years earlier. Conclusions. The observed secular trends in body build and physical fitness may be interpreted as the effects of the improvement of living conditions of the male subjects and the improvement of admission process at the university.

KEYWORDS: secular trend, Heath–Carter method, somatotype, Eurofit.

Received: 18 December 2018
Accepted: 14 January 2020

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Introduction

The development of science and technology which serve as the foundation of socio-economic progress has led to a significant improvement of living conditions. Civilization changes are not a linear process; they differ depending on the pace of economic development and geographic location. They influence the pace at which a young generation develops. The improvement of living conditions combined with an increased consumption of food products and a lower level of physical activity leads to an increase in the occurrence of overweight and obesity in the population [3, 4]. It is highly distressing, especially with regard to a younger generation [11, 12, 26]. In the literature devoted to academic youth we can find studies revealing positive changes in physical growth and negative changes in motor abilities at the end of the 20th century, and then the slowdown of this trend at the beginning of the 21st century. Such conclusions were reached, inter alia, by Mleczko and Januszewski [13], Stachoń et al. [23], Avila et al. [1] and Rębacz-Maron [18]. Authors dealing with the issue of the somatic build of academic youth, athletes and particular professional groups indicate close similarities concerning morphological features with regard to groups of people performing the same jobs, practising the same sport or studying the same courses at university [21, 22, 27]. Students from the University of Physical Education should demonstrate a high level of physical fitness and have more active tissue and less fat tissue compared to the academic youth from other fields of study [14].

Aim of Study

Taking into account the aforementioned facts, it was decided that this study should analyse changes in somatic and motor predispositions of female and male PE students in the years 2004 and 2014.

Material and Methods

In 2004 the authors examined 112 female and 287 male second-year PE students from the Faculty of Physical Education and Sport in Biala Podlaska. Anthropometric features were measured according to Martin and Saller guidelines, and these measurements, in turn, were used to calculate body build type according to Heath–Carter method [5]. The level of physical fitness was measured with Eurofit test [2]. The results were collected within the authors' own research No. VII/146. The same research methods were applied in 2014 when examining 98 females and 242 males within statutory activity No. 172. The research was carried out in compliance with the rules included in the Declaration of Helsinki and was accepted by the Senate Ethics Commission.

The collected variables were described with the use of sample size (n), arithmetic mean ($\tilde{x}$) and standard deviation (SD). The data gathered in the physical fitness tests were converted to points on T scale. Calculated from the formula:

$$T = \left(\left(\frac{x_i - \tilde{x}}{SD}\right) * 10 + 50\right)$$

x_i – mean of 2014 results
$\tilde{x}$ – mean of 2004 results
SD – standard deviation of 2004 results

Afterwards, the results obtained in 2014 were normalised to the findings from 2004. In test attempts, when a lower result means a better result (e.g. agility), the order of the means was changed in the formula. In such calculations, the 2004 group results are 50 points. Differences between the selected groups concerning the analysed features were estimated with the use of the Student's t-test for independent trials at the level from $p \leq 0.05$ to $p \leq 0.001$. All statistical analyses were conducted using Statistica Software 10.0 (StatSoft Inc., 2011). The detailed p-values were presented in the tables.

Results

Long-term tendencies of changes in basic somatic features and body build components were defined on the basis of mean differences in absolute values (Table 1). It was concluded that women currently studying were taller by 0.47 cm and heavier by 0.32 kg than female students from ten years before. Moreover, the endomorphy

Table 1. Values of basic somatic features and body build components as well as Student's t-test of female and male students in the years 2004 and 2014

Somatic features and body build components	2004		2014		Student's t-test value	p-value
	$\bar{x}$	SD	$\bar{x}$	SD		
Females						
Calendar age	21.02	2.34	20.84	2.59	0.53	0.597
Body height	165.84	5.71	166.31	5.75	0.59	0.556
Body mass	59.30	7.18	59.62	8.62	0.29	0.072
Endomorphy	4.08	1.15	4.17	1.36	0.52	0.604
Mesomorphy	3.06	0.90	4.00	3.75	2.57*	0.011
Ectomorphy	2.73	0.99	2.60	1.14	0.88	0.380
Males						
Calendar age	21.11	1.87	20.97	1.21	1.00	0.318
Body height	181.21	6.27	180.58	6.52	1.13	0.259
Body mass	76.77	9.25	78.45	10.63	1.94	0.053
Endomorphy	3.36	1.19	3.75	1.28	3.63*	0.001
Mesomorphy	4.51	0.96	4.00	1.65	4.42*	0.001
Ectomorphy	2.73	0.96	2.55	1.14	1.97*	0.049

Note: $\bar{x}$– mean, SD – standard deviation
* statistically significant differences at the level of $p \leq 05$ and $p \leq 0.001$

component increased slightly by 0.09 points (from 4.08 to 4.17), while the ectomorphy component decreased by 0.13 points (from 2.73 to 2.60). Only the decrease in the mesomorphy component by 0.94 points was statistically significant.

However, statistically insignificant differences were found in the basic somatic features between the studied groups of male students. The men currently studying were 0.65 cm taller and 1.68 kg heavier than students ten years before. Men currently studying had better component endomorphy (by 0.39 points). Moreover, they had significantly lower mesomorphy (by 0.51 points) and ectomorphy (by 0.18 points). All differences in body components were statistically significant.

On the basis of mean absolute values and T scale points, the changes in physical fitness levels of students were determined (Figure 1, Table 2). Women currently studying had significantly better results in the 'standing broad jump' test (by 5.98 cm, i.e. 4.25 T scale points) than females studying a decade before. They also performed better in the 'sit-ups in 30 seconds' test (by 2.45 sit-ups, i.e. 6.97 points) and in the 'endurance shuttle run' test (by 5.73 shuttles, i.e. 3.65 points). Moreover, a slight (statistically insignificant) improvement was noted in the results of the '10 × 5 metre shuttle run' (by 0.42 s, i.e. 2.25 points), 'flamingo balance test' (by 0.18 trials, i.e. 0.88 points), 'sit-and-reach' test (0.24 cm, i.e. 0.44 points) and 'bent arm hang' (by 0.30 s, 0.33 points). However, they had significantly lower results in 'handgrip test' (by 3.80 kg, i.e. 7.68 points) and 'plate tapping' (by 0.85 s, 6.54 points).

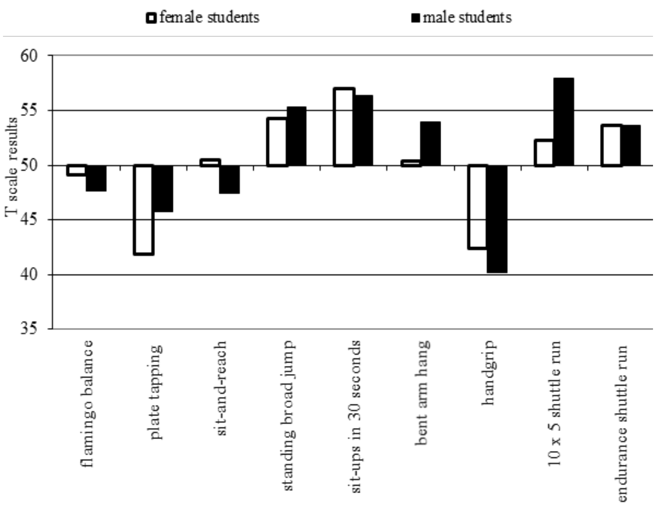

Figure 1. T scale results of Eurofit tests of male and female students from 2014 normalised to the results of students from 2004

Table 2. Results of Eurofit tests and Student's t-test of female and male students in the years 2004 and 2014

Eurofit tests	2004 $\bar{x}$	2004 SD	2014 $\bar{x}$	2014 SD	Student's t-test values	p-value
Females						
Flamingo balance test	2.26	2.04	2.44	2.07	0.63	0.529
Plate tapping	10.70	1.30	11.55	1.82	3.93*	0.001
Sit-and-reach	29.16	5.42	29.40	7.47	0.27	0.787
Standing broad jump	190.06	14.07	196.04	24.21	2.22*	0.027
Sit-ups in 30 seconds	24.79	3.53	27.25	3.79	4.87*	0.001
Bent arm hang	13.36	9.02	13.66	12.29	0.20	0.842
Handgrip test	38.18	4.95	34.38	5.32	5.36*	0.001
Shuttle run (10 × 5 m)	19.83	1.87	19.41	1.37	1.83	0.069
20 metre endurance shuttle run	60.30	15.68	66.03	14.79	2.71*	0.007
Males						
Flamingo balance test	3.40	2.53	4.01	2.76	2.64*	0.009
Plate tapping	9.93	1.43	10.54	1.58	4.63*	0.001
Sit-and-reach	26.95	7.12	25.10	7.94	2.80*	0.005
Standing broad jump	235.06	22.73	247.02	21.01	6.28*	0.001
Sit-ups in 30 seconds	28.36	4.61	31.28	4.25	7.58*	0.001
Bent arm hang	25.91	10.71	30.09	12.59	4.08*	0.001
Handgrip test	60.97	9.39	51.73	8.19	12.09*	0.001
Shuttle run (10 × 5 m)	18.88	1.60	17.61	1.22	10.33*	0.001
20 metre endurance shuttle run	86.99	15.43	92.66	12.30	4.70*	0.001

Note: $\bar{x}$ – mean, SD – standard deviation

* statistically significant differences at the level of $p \leq 0.05$ and $p \leq 0.001$

Bigger differences were noted when comparing the results of male students. In 2014 the participants performed better in the '10 × 5 m shuttle run' (by 1.27 s, 7.94 points), 'sit-ups in 30 seconds' (by 2.92 sit-ups, 6.33 points), 'standing broad jump' (by 11.96 cm, 5.26 points), 'bent arm hang' (by 4.18 s, 3.90 points) and in 'endurance shuttle run' (by 5.67 shuttles, 3.67 points).

However, they obtained significantly lower results in the remaining Eurofit tests, i.e. in the ‘handgrip test’ (by 9.24 kg, 9.84 points), ‘plate tapping’ (by 0.61 s, 4.27 points), ‘sit-and-reach’ (by 1.85 cm, 2.60 points) and in ‘flamingo balance’ (by 0.61 trials, 2.41 points).

Defining general fitness with the mean of the point differences from all the tests, it may be concluded that female and male participants of the 2014 research demonstrated a slightly higher level of physical fitness compared to their counterparts from a decade before. The differences were at the level of 0.31 points for females and 0.89 points for males, and were statistically significant.

Discussion and Conclusion

The entry requirements at sports universities result in PE students demonstrating higher levels of somatic features as well as physical fitness and efficiency than students from other fields of study [15, 21]. Changes which occurred in the years 2004 and 2014 and regarded body height and mass of female and male students reflect changes in the physical development of children and youth in the whole region of eastern Poland [19, 29]. The sustaining high secular trend in the somatic development of the youth from eastern Poland and the inhibition of this process in other regions of Poland [17] cause developmental differences to diminish.

Lower entry requirements, especially those concerning physical fitness combined with the demographic low led to a limited selection. This, in turn, resulted in the fact that each secondary-school graduate meeting those lowered requirements may become a student of the University of Physical Education. In the long-term these changes lead to an increase in endomorphy and a decrease in ectomorphy and mesomorphy. These tendencies are unfavourable in terms of educating future PE teachers. In the continuous research on American students (Andrews University) Pribis et al. [16] observed an increase in somatic build parameters (especially adiposity) with a simultaneous decrease in the level of physical fitness. Also, a high pace of increase in basic somatic features (height, mass and adiposity) with a simultaneous decrease in the results in a number of Eurofit test trials (FLB, PLT, SAR, SBJ, SUP, SHR) among Hungarian students at the University in Pecs and Kaposvir was noted by Kaj et al. [7].

Students surveyed demonstrated somatic build similar to their counterparts from the Medical University in Gdansk [8, 9] or Medical University in Lublin [10]. However, they presented higher physical fitness levels than students from the above-mentioned universities. Students surveyed obtained similar results in physical fitness tests to their peers from Zagreb [22], Kaunas [6] and Hungary [7] but had clearly lower results than students from typical sports universities, e.g. the University of Physical Education in Wroclaw [23] or the sports department at the University in Bratislava [20]. As long as a decade ago it was noted that somatic build of the candidates for the first year of physical education studies, and especially high adiposity accompanied by weak musculoskeletal system, differed significantly from the patterns noted in the youth from the same field of study at other universities or in individuals doing sports actively [28]. In the course of studies at sports faculties an increased number of practical classes exerts an influence on somatic features. Therefore, it may be presumed that more distinct differences between the groups of female and male participants might be noted in the case of older students since physical exercises may affect energetic balance of the system and body tissue composition. This correlation was also noted by Yildiz et al. [30] who observed students from the sports university in Aydın in Turkey. Also, the authors of publications devoted to the correlations between somatic features and the level of physical efficiency and sports results in various disciplines [24, 25] noted that apart from body build typical of a given sport, body composition as well as the proportion of fat tissue and lean body mass were particularly significant. At the same time they highlighted the fact that training effects differentiating tissue components depended on the specificity and duration of a training process, participants’ age and the discipline itself.

The analysis of changes in motor skills revealed that physical fitness of the students was similar to the results obtained ten years before and differences were noted only at the level of certain motor skills. It should be highlighted that bigger changes were noted in men than in women. It may have stemmed from the fact that young people adapted to the changing environment and to the requirements of the study programme. Similar changes could be noted among students at sports universities. Mleczko and Januszewski [13] emphasised the fact that students presently beginning studies at sports universities have better somatic features (e.g. adiposity) than motor skills, which is compliant with the national secular trends among the youth graduating from upper-secondary schools [17].

In general, the research revealing 10-year-long changes in body height and mass as well as physical fitness of students are in line with the conclusions of other authors. Contrary observations refer to an increase in adiposity, especially in men, with a simultaneous decrease in muscle and skeleton mass. The observed secular trends in body build and physical fitness of students may be interpreted as a confirmation of the lowering of biological potential of the youth originating from the areas where students live.

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ORIGINAL ARTICLE

TRENDS in
Sport Sciences
2020; 27(**1**): 35-39
ISSN 2299-9590
DOI: 10.23829/TSS.2020.27.1-6

Practical analysis of the metabolic response to a resistance training session in male and female sprinters

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Abstract
Introduction. **In modern sport, training individualization and detailed analysis of specific patterns of biochemical indices under certain exercises and training sessions is become more and more crucial.** Aim of Study. **This study aimed to concurrently evaluate the lactate and blood ammonia response during resistance training in four elite sprinters (two men and two women).** Material and Methods. **Blood samples were taken from the fingertip before and after the warm-up, after each exercise (power cleans, squat jumps, quarter squats and lunges), and at the 10th and 20th min of the cool-down.** Results. **In male athletes, maximum lactate concentrations were achieved after the power clean exercise, while peak blood ammonia concentrations after squat jumps. In female athletes, peak blood ammonia and lactate concentrations were noted more individually. The course of changes in lactate concentrations was very diverse in each athlete. The ammonia concentration in response to the performed exercises was much more consistent, however still different between individual athletes.** Conclusions. **A practical analysis of the metabolic response to different exercises in a resistance training session, using lactate and ammonia concentrations, offers vital information that can help coaches better understand internal training load experienced by the athlete and to better adjust the prescribed loads and rest periods to the training targets in future training sessions.**

KEYWORDS: ammonia, lactate, power, strength, elite athletes.

Received: 8 January 2020
Accepted: 19 February 2020

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Introduction

In modern sport, the biochemical monitoring of athletes is becoming more and more crucial in achieving the highest level of sports proficiency. With the use of wisely selected biochemical indices, coaches can, for example, receive detailed information about an athlete's metabolic response to different types of training and/or exercises. In a typical 100 m track sprint effort, the contribution of the anaerobic energy systems is about 90% concerning the lactate/phosphate creatine ratio, or 75-79% when calculated from the accumulated oxygen deficit [2, 18]. When, due to increased energy demand, ATP consumption exceeds its production and ADP concentration rises, adenylate kinase redirects the reaction towards the synthesis of ATP (2ADP = ATP + + AMP) and inosine monophosphate (IMP) to maintain the decreasing energy potential. This is why changes in adenosine monophosphate (AMP), and its direct metabolite – ammonia (NH_3), may reflect cellular energy metabolism more adequately than solely ATP or ADP concentration [5, 24]. In prolonged efforts, anaerobic glycolysis supports energy coverage, which is reflected by increased lactate concentration [4]. It was shown that the knowledge about actual levels of ATP breakdown and its restoration is based mainly on blood ammonia concentration, while the concentration of lactate – indicating the rate of anaerobic glycolysis – specifies the currently predominant ATP resynthesis pathway [11, 21]. Therefore, by concurrently measuring ammonia and lactate concentrations, which accumulate in blood in specific patterns [4, 8, 20, 23], coaches can precisely assess an athlete's response to different exercise types in terms of the magnitude of ATP degradation and the way it is restored [9, 20, 23].

The metabolic reaction to running exercise of different lengths (duration) and intensity, either in laboratory conditions [6, 9, 12, 14, 15, 16] or during real-time training [11, 21], was were earlier widely discussed. The shorter the distance (time) and the higher the intensity the more pronounced differences occur in the concentrations of blood ammonia and lactate [10, 15]. One hundred meters and longer distances cause a gradual and parallel increase in blood ammonia and lactate concentrations [5, 11]. Concerning the sex differences in metabolic response to exercise, it was previously shown that in most training tasks, irrespective of their character and intensity, blood ammonia and lactate concentrations are higher in men than in women [1, 3, 4, 7, 13, 22].

It is more difficult to anticipate the metabolic response to different resistance training exercises – an integral part of a sprinter's training plan. In each training session, there are exercise tasks of potentially opposing metabolic characteristics, one more strength-, power- and hypertrophy-oriented, others more focused on muscular endurance. Typically, higher blood lactate concentrations were observed after a session of moderate-intensity, a higher number of repetitions and decreased rest time between sets [14, 16]. It is of great importance to analyze in detail the patterns of blood ammonia and lactate changes to specific resistance exercises during real training sessions. Thus, this study aimed to concurrently evaluate the lactate and blood ammonia response in real-time resistance training of four elite sprinters.

Methods

Subjects

The study included two male and two female sprinters competing in the 100-m and 4 × 100-m relays at the national and international levels. The age and the competitive sports training background was 32 and 15 years, 23 and 5 years for males and 28 and 14 years, 25 and 11 years for female athletes. The study was approved by the Local Bioethical Committee at the Poznan University of Medical Sciences, Poland. The participants were informed of the procedures and gave their written consent prior to their inclusion in the study.

Procedures and measurements

The measurements were performed on the first day of a training camp. The training session started at 10 am and comprised of the exercises presented in Table 1. The warm-up before the strength training session consisted of jogging (10 min), dynamic stretching (15 min), and strength training preparation (15 min).

Table 1. Content of the main part of the strength training session

Exercise	Recovery time
Exercise 1 – Power cleans	5 min between exercises 1-4
Set 1: 6 × 60% 1RM	3 min between sets 1-2
Set 2: 5 × 80% 1RM	
Set 3: 2 × 90% 1RM	4 min between sets 2-3 and 3-4
Set 4: 2 × 95% 1RM	
Exercise 2 – Squat jumps	
Sets 1-3: 9 × 30% 1RM	4 min between sets 1-3
Exercise 3 – Quarter squats	
Set 1: 6 × 140 (75% 1RM)	4 min between sets 1-2 and 2-3
Set 2: 5 × 150 (80% 1RM)	
Set 3: 4 × 160 (85% 1RM)	5 min between sets 3-4 and 4-5
Set 4: 4 × 170 (90% 1RM)	
Set 5: 4 × 180 (95% 1RM)	
Exercise 4 – Lunges	
Sets 1-2: 10 × 35% 1RM (5 × right leg, 5 × left leg)	4 min between sets 1-2

Note: 1RM – one-repetition maximum in each athlete

Blood ammonia, lactate, and HR measurement

To analyze blood ammonia and lactate concentrations during the training session, blood samples were taken from the fingertip before and after the warm-up, 3 (or 2) min after each exercise set/repetition performed in the main part of the workout, and at the 10th and 20th min of the cool-down. To determine the blood ammonia concentration, 20 μl of whole blood was applied to a test strip and analyzed with a PocketChem BA (Arkray, Japan). To measure lactate accumulation, a Biosen C-line (EKF Diagnostics, Germany) was used. In brief, 20 μl of whole blood was drawn into a prefilled micro test-tube using a capillary. The L-lactate contained in the sample was enzymatically converted to pyruvate and hydrogen peroxide, which was detected by the electrode.

Results

The comparison of lactate and blood ammonia concentrations in both male and female sprinters during the training session is presented in Figure 1. Figures 2 and 3 separately show the individual courses of lactate and ammonia concentrations, respectively.

In male athletes, maximum lactate concentrations were achieved earlier than peak blood ammonia concentrations. After 20 min of recovery, blood ammonia concentrations

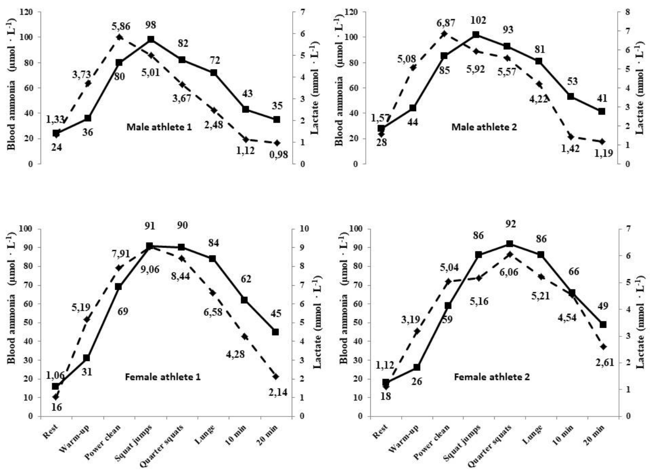

Figure 1. Blood ammonia (solid line) and lactate (dashed line) concentrations: comparison in each female and male athlete

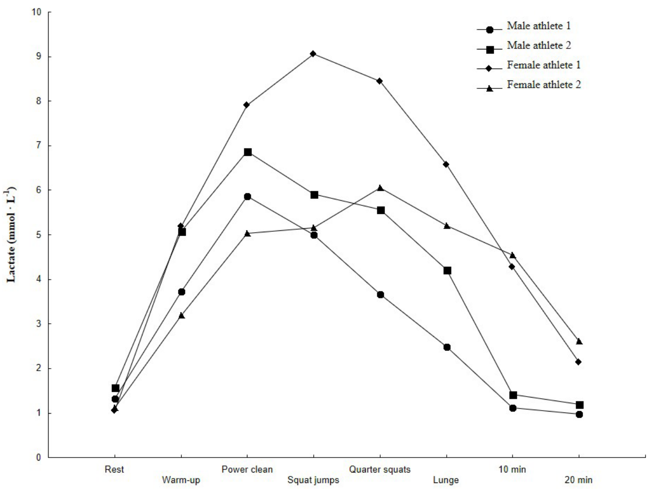

Figure 2. Lactate concentrations in all male and female sprinters during the strength training session

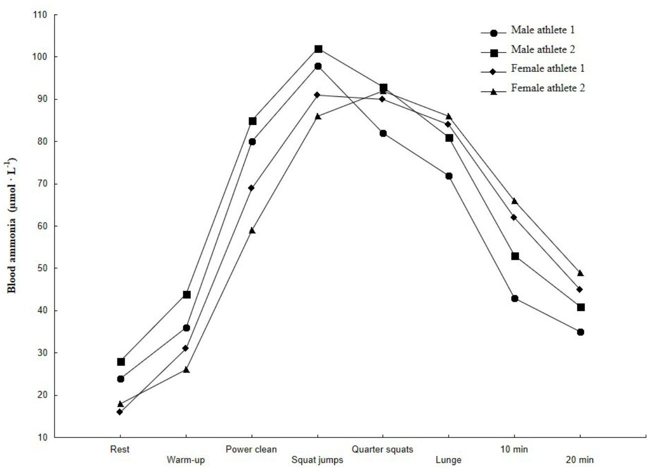

Figure 3. Blood ammonia concentrations in all male and female sprinters during the strength training session

but not lactate concentrations achieved resting values. In female athlete 1, peak blood ammonia and lactate concentrations were achieved at the same stage of the session 1 and the course of both biomarkers during the training workout was similar, too. In female athlete 2, the curve of lactate concentration was "irregular" and different from that of blood ammonia concentration. In both female athletes, after 20 min of recovery, blood ammonia and lactate concentrations did not achieve the resting values.

The values of lactate concentrations (Figure 2) were different in each sprinter. The highest concentrations were obtained by female athlete 2 and the lowest by male athlete 1. Also, peak concentrations were obtained in different phases of the training session. In the case of blood ammonia concentration, the differences between athletes were much less pronounced and the pattern of changes was similar. Male athletes were characterized by lower values at rest, higher peak concentrations, and lower values after 20 min of recovery compared to female sprinters.

Discussion

The aim of this study was to concurrently evaluate the lactate and blood ammonia levels during resistance training of four elite sprinters.

Blood ammonia concentration

Blood ammonia concentrations increased from rest until the squat jump and quarter squat exercise and then decreased up to 20 min after the workout. Blood ammonia concentrations were highest in both the squat jump exercise (highest) and quarter squat exercise (second highest) for all athletes (both male and female athletes). Since both squat jumps and quarter squats were performed for a higher number of repetitions, a high exertion (near muscular failure), and with a high level of intent (as fast as possible), this can explain the higher blood ammonia concentration. This is in line with Sánchez-Medina and González-Badillo [17] who measured blood ammonia concentration in resistance exercise leading to failure or not and concluded that sets taken closer to failure and with a larger number of repetitions lead to greater ammonia concentrations. Since blood ammonia concentration represents cellular energetic stress through AMP deamination [19], it is clear that higher levels of effort and exertion will lead to higher concentrations. Additionally, male sprinters achieved higher blood ammonia concentrations than female sprinters, possibly due to greater muscle mass, a greater percentage of fast-twitch muscle fibers (containing more AMP deaminase which leads to greater AMP deamination), and greater levels of strength leading to greater recruitment of muscle mass during resistance exercise (activating more fast-twitch muscle fibers during each repetition) [22]. The pattern of recovery also shows that male athletes achieved lower blood ammonia concentrations after quarter squats up until 20 min after the training session. After quarter squats, lunges were rather an accessory exercise and were not performed with maximum intent and exertion and therefore blood ammonia concentrations were lower. Although blood ammonia concentration courses were similar in all athletes, absolute values were different indicating that each athlete may have an individual metabolic response which is determined by an athlete's specific maximal exertion (to failure) or effort (highest intent) during exercise.

Blood lactate concentration

Blood lactate concentrations increased from rest until the power clean exercise and then varied depending on the athlete. For female athlete 1, lactate concentration increased greatly, while for female athlete 2, it increased slightly. For both male athletes, lactate concentration decreased with each subsequent exercise from the power clean. For the female athletes, concentrations varied in each exercise. Lactate concentration is an indicator of anaerobic glycolysis contribution during exercise [4]. Lactate concentration level, therefore, may indicate the level of anaerobic glycolysis utilization in each exercise, and individually for each athlete. The power clean is a complex movement and requires much coordination compared to the squat jump and quarter squat exercises, and therefore could trigger activation of more muscle groups causing greater lactate concentration. Interestingly, there were no visible patterns observed between male and female athletes regarding lactate concentration (male sprinters did not have higher lactate concentrations or vice versa).

If the goal of a strength training session is to increase maximal strength or power, then it would be of interest to avoid high lactate concentrations, which indirectly indicate neuromuscular fatigue [17]. Therefore, measuring lactate concentration in between sets can help coaches to monitor signs of muscle fatigue and optimally prescribe training parameters, like the number of repetitions or rest breaks, for each athlete individually to adequately target the training session goal (hypertrophy, strength, power). It is important to note, however, that lactate levels during a resistance training session are not comparable to ones achieved during a typical sprint training session. Blood lactate concentrations during a speed-endurance or special endurance session [5, 10, 11, 12] are much higher compared to those obtained in this study.

The limitation of this study is that we did not analyze ammonia and lactate concentrations in differently scheduled strength-oriented exercises. In the future, it would be interesting to compare the metabolic response of the same sprinters to differently scheduled resistance training sessions.

Practical applications

Measuring the metabolic response in sprinters using lactate and ammonia concentrations during a resistance training session offers vital information that can help coaches better understand the internal training load experienced by the athlete. Both lactate and ammonia concentrations can be used to monitor an athlete's response to resistance training exercises. Blood ammonia concentrations can be used to determine exertion and effort level after a set or after an exercise is completed. Blood lactate concentrations can help determine anaerobic glycolysis contribution after completion of a set or number of sets. Both ammonia and lactate can be used to determine individual athlete metabolic response, and help to determine if the resistance training session goal (hypertrophy, strength, power) is being targeted and if not, to individually adjust training parameters. In the future, it would be of interest to analyze more deeply the differences in metabolic response to strength training sessions of diverse training goals (hypertrophy, strength, power, endurance).

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UCP2	DD					ID					II				
Sex	*N*	$\bar{X}$	*SD*	*Min*	*Max*	*N*	$\bar{X}$	*SD*	*Min*	*Max*	*N*	$\bar{X}$	*SD*	*Min*	*Max*
F	42	45.65	*6.14*	32.30	59.00	36	45.66	*7.18*	30.60	59.80	7	45.07	*7.60*	35.00	54.80
M	72	54.01a	*6.20*	40.30	79.00	70	55.60	*7.32*	42.30	76.80	12	59.07a	*9.04*	49.70	74.90

Analysis of variance did not show statistically significant differences between mean values of recorded maximal oxygen uptake in groups represented by DD, ID, II genotypes. a - difference observed between DD and II genotypes at p value 0.052 in males.

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