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A HALF CENTURY OF SCIENTIFIC RESEARCH IN FIELD HOCKEY

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ABSTRACT
Purpose. Using databases available on the Internet, the number of scientific papers on the subject of field hockey were examined. **Basic procedures.** As a result, 208 scientific studies covering the fields of biochemistry, physiology, sport injuries, psychology and tactics were found, which were published within the last 50 years (from 1960 to 2010). Despite the popularity of field hockey and its status as an Olympic sport, the number of scientific studies which focused on field hockey was much smaller when compared to the amount of publications on other team sports, such as soccer, basketball, or baseball. **Main findings.** It was found that the greatest number of publications (61.06%) originated from five English-speaking countries (UK, USA, Canada, Australia, and New Zealand), with the majority focusing on sport psychology, injuries and biochemistry. What was discovered was that the vast majority of scientific studies used field hockey merely as a reference point in comparison to other team sports. **Conclusions.** The varying topic diversity of the scientific studies found among the databases significantly hinders an effective comparison of findings, especially considering that most of the studies focused on only a few selected aspects of the problem matter and were chiefly small sample studies, nor were they repeated.

Key words: biochemistry, physiology, tactics, nutrition, injuries, psychology

Introduction

Thanks in part to the Internet, searching for scientific information can begin from entering a few key words into a specialist database search engine, which hosts original research papers published in specialist community-wide journals, guaranteeing that the found texts are both accurate and of high quality. Such databases also feature a number of review works, which give critical analyses of research undertaken in various scientific fields.

Nearly every sport can be characterized by, among other things, what terms are applicable towards to what research findings in the biological sciences. In particular, the literature available on sports that have a long tradition, such as field hockey, could be expected to provide a comprehensive description of players' physical reactions to a specific physical exercise, as determined by the rules of the game. Having examined the available specialist literature, however, one needs to verify that assumption. The findings which have been published to date on the biological aspects of field hockey are rather random, incomplete, and usually do not allow for comparisons with the findings of our current research. Similar conclusions are drawn with respect to other scientific areas, which also include field hockey from a biological point of view. These include psychology, nutrition (especially the problems associated with supplementation), as well as tactics.

Thus, the aim of this paper is to examine and describe the current state of scientific research concerning the biological aspects of field hockey, including, but not limited to, questions regarding physical fitness, physiological and psychological comfort, as well as the techniques used to monitor these features in players.

Material and methods

The research materials consisted of scientific studies on field hockey hosted on a number of available databases. They were obtained by browsing for publications on a variety of topics in the PubMed and EBSCOhost databases, which include Academic Search Premier, SPORTDiscus, Hospitality & Tourism Complete, Health Source: Consumer Edition, Health Source: Nursing/Academic Edition, MEDLINE, Business Source Complete, Library, Information Science & Technology Abstracts, MasterFILE Premier, Newspaper Source, Regional Business News, Agricola, and Academic Search Complete. Moreover, in order not to omit other valuable studies relevant to this paper which have not been included in the above mentioned databases but are available on the Internet, www.scholar.google.pl was also used.

The search covered those publications entered into the databases between 1960 and 31 December 2010, which were accessed after entering the term "FIELD HOCKEY".

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This paper also takes into account studies published in Polish ($n = 6$) and Russian ($n = 1$) which had not been registered in the analyzed databases by the specified end date.

Thus, the spectrum of the obtained publications covered all areas of science which determine the biological profile of field hockey players. It consists not only of a description of physiological and biochemical indices, but also points to direct and indirect factors which may affect the value of such indices. They include, but are not limited to, improving various elements of the game which can affect a team's ability to succeed in matches and tournaments, the methods of preparing players for the competition season and maintaining players' fitness levels during that period, as well as numerous psychological and social aspects. The field hockey studies found in the databases have been divided into the following seven thematic groups:

– Biochemistry. Mostly studies describing research in which biochemical indices in the blood of field hockey players were determined, or describing changes in the concentration of selected biochemical parameters influenced by a given training load or physical performance tests.
– Physiology. Studies aimed at determining players' physical fitness and their predisposition to handle aerobic and anaerobic exercise.
– Tactics. Studies describing methods of improving players' training and effectiveness in matches. Works in this field also examined the objectivity of, or compared various endurance performance tests on, the basis of physical performance results obtained by field hockey players.
– Nutrition. Primarily studies characterizing the dietary habits of players or describing the influence of selected dietary supplements on their fitness.
– Anthropometrics. Studies discussing the structure and composition of the body and the differences between players of national or/and international clubs, or in presenting the found relationships within a single team.
– Injuries. Studies concerning the occurrence of trauma in field hockey players, discussing prevention methods, and presenting selected cases of injury.
– Psychology. Studies focusing on the psychological profile of players, interactions between them, and reactions to fear or aggression.

Results

EBSCOhost's browser showed 7459 results for "FIELD HOCKEY," a small number compared to other

Table 1. Number of citations found in EBSCOhost base after selecting a team sport

Search day – 31.12.2010

Team sport	No. of citations
Hockey	229133
Field Hockey	**7459**
Ice Hockey	12428
Lacrosse	22700
Basketball	570309
Volleyball	58495
Handball	13575
Baseball	570722
Softball	51755
Water Polo	7898
Cricket	182759
Soccer	258943
Football	1025038

team sports (Tab. 1). A search in the same database for lacrosse ("LACROSSE"), a less popular sport in many countries, is referred to over three times more frequently (22,700 times). Moreover, a detailed analysis of the articles concerning field hockey revealed that only 200 related directly to that sport. In other publications, field hockey was used as a comparative sport to those results obtained or observations made. 208 studies published in the last 50 years, from 1960 until 2010, were chosen for the purposes of this analysis.

It was found that over two-thirds of all analyzed studies concerning field hockey (142 out of 208, i.e. 68.27%) were published in the last ten years, from 2000 to 2010, which could indicate an increased interest in the sport (Tab. 2). The increase in the number of published papers was gradual and took place during years in which the Summer Olympics were held, in particular during those organized in Sydney (2000, 7 publications), Athens (2004, 24 publications), and Beijing (2008, 19 publications). However, such a dynamic rise in scientific studies concerning field hockey was still inferior to that of other team sports (Fig. 1).

An analysis of the 208 studies showed that a significant portion of them (68.60%) focused on research carried out exclusively on field hockey players. The remaining papers took into account other sports, usually soccer, basketball, cycling, rugby, or lacrosse, where field hockey players were a control group. Table 3 contains a division of the analyzed studies (n = 208) by thematic group as specified in the methodology section.

Out of the 208 studies on field hockey found in the databases, the most numerous were articles published

Table 2. Number of papers published in the last 50 years, from 1960 to 2010, on football, soccer, hockey and field hockey

Search day – 31.01.2011

Years	Summer Olympic Games (year)	Football	Soccer	Hockey	Field hockey
2008–2010	Beijing (2008)	296319	82327	62610	2172
2004–2007	Athens (2004)	362256	90719	60957	1757
2000–2003	Sydney (2000)	177251	45310	37713	732
1996–1999	Atlanta (1996)	78062	16275	24034	485
1992–1995	Barcelona (1992)	47978	9379	20317	332
1988–1991	Seoul (1988)	25675	4346	9322	360
1984–1987	Los Angeles (1984)	18960	3109	5581	300
1980–1983	Moscow (1980)	3591	1847	1655	300
1976–1979	Montreal (1976)	3099	1717	1975	196
1972–1975	Munich (1972)	1470	456	767	48
1968–1971	Mexico City (1968)	603	152	286	25
1964–1967	Tokyo (1964)	335	76	132	13
1960–1963	Rome (1960)	270	46	74	10

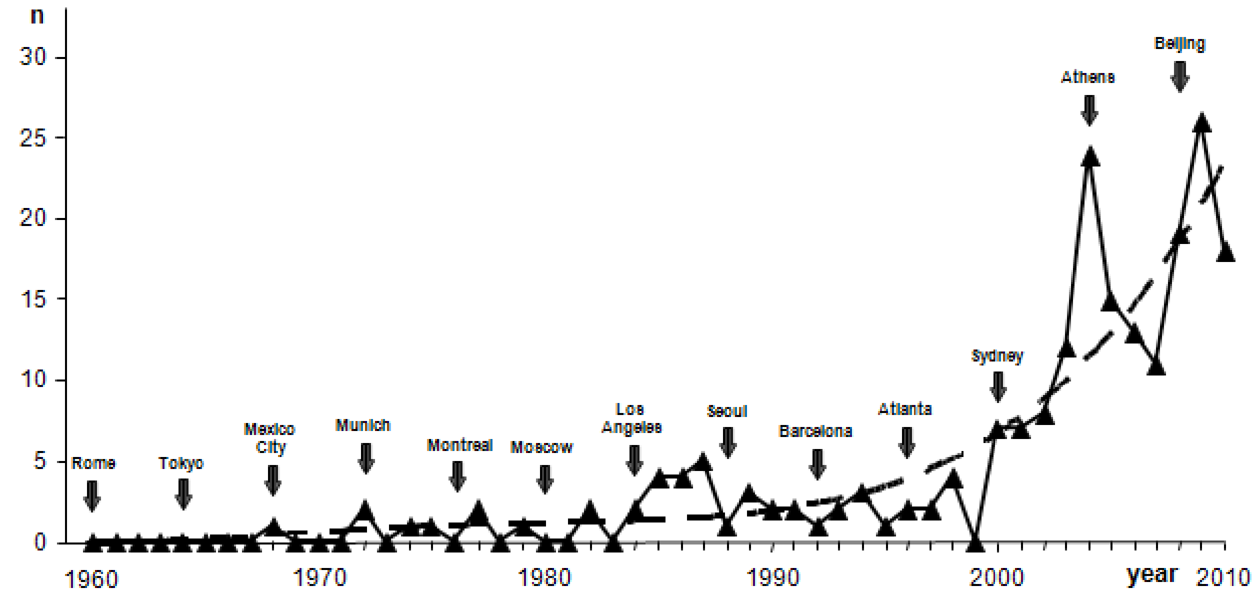

Figure 1. Number of papers published in the last 50 years, from 1960 to 2010. Arrows show the number of papers published in the year of the Summer Olympic Games. The discontinuous line shows an increasing trend in the number of publications

by authors from the United States (n = 44), the United Kingdom (n = 43), Australia (n = 29), Poland (n = 25), and the Netherlands (n = 12). A relevant comparison is presented in Table 4. Teams from two of those five countries, Australia (4 gold, 3 silver, and 4 bronze medals) and the Netherlands (4 gold, 2 silver, and 6 bronze medals), belong to the three most successful teams of the Olympic Games in the last 50 years. The third best team with the most medals (4 gold, 4 silver, and 1 bronze) is Germany (in both male and female categories). This fact, however, is not reflected by the number (n = 9) of scientific studies from that country found in the databases (Tab. 4).

In the analyzed studies on field hockey found within the databases, the largest research group composed of women (33.17%), followed by men (36.06%) and then with samples from both genders (30.77%). Some research, 6.25%, was carried out with respect to groups of school-age children and youths between the ages of 8 and 16. Eight studies (3.85%) described individual cases of injury, focusing on their causes, symptoms, and the most suitable methods of treatment.

Table 3. Percentage share of publication's theme groups (Number of publications = 208)

Theme group	No. of publications	Percent (%)
Anthropometrics	14	6.73
Biochemistry	32	15.38
Injuries	36	17.31
Nutrition	7	3.37
Physiology	43	20.67
Psychology	40	19.23
Tactics	36	17.31
Total	208	100.00

Table 4. Number of papers published in the last 50 years, from 1960 to 2010 on field hockey in several countries (Number of publications = 208)

Country	No. of publications	Percent (%)
Australia	29	13.94
Canada	7	3.37
Germany	9	4.33
India	7	3.37
Netherlands	12	5.77
New Zealand	4	1.92
Poland	25	12.02
South Africa	8	3.85
Spain	7	3.37
UK	43	20.67
USA	44	21.15
Others	13	6.25
Total	208	100.00

Discussion

Those studies on field hockey, as found in the databases, describe all aspects of the sport. They are presented according to the structure depicted in the "Material and methods" list of thematic groups:

Biochemistry

Studies in biochemistry (n = 32; 15.38%) are primarily concerned with issues related to the body's reactions to physical exercise and the characteristics of both aerobic and anaerobic metabolism in field hockey players as a response to physical activity. Compared with other team sports, such as soccer, there were a lack of articles offering a wider cross-section of research problems in the case of field hockey.

Typically, in order to monitor the level of fitness in sportsmen, biochemical indices were determined by using body fluid counts [1]. Blood tests were the most frequently performed on field hockey players (featured in 21 studies), used to measure the concentration of lactic acid. An evaluation of the changes found throughout a yearlong training cycle allows, according to Strzelczyk et al. [2], one to determine the level of a players' preparation for competition in terms of their fitness level. An increase in lactate concentration after a routine warm-up may also help assess the body's adaptation to anaerobic metabolism, and changes in the concentration of that factor allow one to determine a field hockey player's commitment to a match, according to Ghosh et al. [3]. It can be pointed out, however, that the high rate of lactate synthesis in working muscles significantly increases the concentration of hydrogen ions circulating in the blood, which leads to metabolic acidosis. That, in turn, led to a decrease in the ability to perform short-term physical exercises by female field hockey players [4]. According to Spencer et al. [5], such an adverse tendency may be, to a large extent, prevented in part by following a 7-week strength-training plan, which resulted in a significant reduction of hydrogen ion production in the body. At the same time, Bishop & Spencer [6] observed a decrease in the concentration of hypoxanthine, which is formed in the body as a byproduct of damage to purine nucleotides. It was observed that the quantity of this compound increases in the field hockey players' blood in proportion to their lactate content. Moreover, both decreased pH levels and the buffer capacity of blood was found in players after performing a single high-intensity physical exercise [6].

Research conducted by Kryściak et al. [7] in a different sample of field hockey players has also indicated an obvious post-exercise increase in the concentration of hypoxanthine and uric acid [8]. The above-mentioned authors discovered a highly negative correlation between VO_2max and the concentration of uric acid and the threshold for anaerobic metabolism, as well as negative correlation between the exercise-related concentration of xanthine and hypoxanthine ($p < 0.001$). Their data explicitly indicates that high-intensity exercise is associated with energetic stress, which in turn may lead to the damage of purines. The primary cause is usually associated to free radicals, themselves very reactive endogenic compounds produced during both aerobic and anaerobic metabolism. They stimulate the production of compounds which are adopted as determinants of oxidative stress. They include conjugated dienes and thiobarbituric acid-reactive substances (TBARS) [9], which are created as a result of fatty acids damage, and allantoin [10], which is a product of oxypurine and uric acid damage.

Iron is an integral component in both oxygen transport and storage as well as in the catalysis of several biochemical reactions. Concerns on the supply and circulation of iron in the body, which can permit the possibility of an athlete enduring a full exercise load, was discussed in 6 studies on field hockey. The relative lack of interest in iron stands in contrast to the extensive literature available on other team sports, particularly soccer [11]. Hinrichs et al. [12] showed that the total mass of hemoglobin correlated to VO_2max, but its level did not influence the actual iron status in field hockey players.

Athletes engaged in highly active sports are often diagnosed with so-called sports anemia, which manifests itself with, among other things, a reduction in the body's performance. This syndrome is usually caused by disturbances in iron balance resulting from insufficient iron intake from food, magnified by the fact that the body has an increased demand for that element. Douglas [13] found that the concentration of hemoglobin, the value of hematocrit, and the number of red blood cells in female field hockey and soccer players at the beginning, middle, and end of the season did not exceed any norms adopted for women of that age, and that the employed training cycle did not cause the occurrence of sports anemia symptoms. Different results were obtained in research carried out on a group of female field hockey players, where the level of ferritin concentration was measured during three consecutive seasons. The concentration of iron in their blood decreased with each competition season [14]. Thus, we can assume that playing field hockey may lead, in some athletes, to a decrease in the level of iron, especially as the deficiency of that element grew gradually in female field hockey players in proportion to the number of years of active team participation.

Such trends were not supported, at least in the precompetition period, by recent research concerning the concentration of iron and the total iron-binding capacity (TIBC) in field hockey players at rest and after exercising with increasing intensity on a treadmill until they reached maximum individual load [15, 16].

Physical exercise leads to a disturbance of homeostasis, which manifests from a change in the concentration of certain hormones. A higher activity of gastrointestinal hormones, including glucagon, gastrin, and pancreatic polypeptide, was found in the blood of field hockey players who were subjected to submaximal exercise at different stages of their sporting career [17]. However, no differences were found in the concentration of insulin. A minor upward trend was seen in better-trained field hockey players with respect to post-exercise increases in gastrin, while a major upward trend was shown with respect to pancreatic polypeptide [17]. Exercise on a cycle ergometer, which field hockey players and cyclists were subjected to, affected the activity of lysosomal enzymes in both the blood and urine [18]. The level of alkaline phosphatase, arylsulfatase and β-glucuronidase increased in both groups after exercise, however, a higher increase was observed in cyclists. According to the cited authors, the increased activity of lysosomal enzymes in urine may also be caused by a higher glomerular albumin filtration rate, and their secondary resorption in the proximal urethra.

The body's main defense mechanism against infections is immunoglobulin A (IgA), which occurs naturally in respiratory, gastrointestinal and genitourinary secretions. According to Mackinnon et al. [19], both high-intensity physical exercise and interval exercise, to which players were subjected to in training, significantly decreased the concentration of IgA in their saliva. Their research showed that field hockey players and squash players were more susceptible to upper airway infections. At the same time, it was demonstrated that the content of IgA in the saliva of infected field hockey players was lower by 20–25 percent in comparison to healthy athletes.

The level of biochemical and morphological indices is also affected by physical factors, such as heat and cold [20]. It was demonstrated that there was a temporary increase in the number of red blood cells, the value of hematocrit, and the concentration of hemoglobin in the blood of field hockey players after eighteen sessions held in a cryogenic chamber, lasting a maximum of three and taken twice a day. All values, apart from hemoglobin concentration, returned to their initial levels one week after the cycle of sessions in the cryogenic chamber were finished. Other parameters that measure immune response, i.e. the number of white blood cells and their fractions, and the level of interleukin 1 beta (IL-1β) did not change significantly as a result of such treatments, though the concentration of IL-1β increased in some field hockey players [21]. Research on the effect of cold temperature on athletes has been carried out to a much larger extent in other sports.

The results of biochemical tests may be also affected by injuries sustained during tournaments and matches. In such cases, one can expect a change in the level of interleukins and other inflammatory factors. Research carried out on the influence of increased physical exercise on the secretion of these substances has not been conducted on field hockey players. However, tests carried out on other athletes have shown, among other things, an increase in the concentration of pro-inflammatory interleukin 6 (IL-6) in a group of triathletes after competition [22], or the tumor necrosis factor alpha (TNF-α) in athletes after finishing a marathon [23].

These aspects remain largely absent in studies on field hockey as was found in the analyzed databases.

Physiology

The analyzed databases contained 43 studies on physiology which were conducted on field hockey players. These focused primarily on an athletes' endurance capacity, the characterization of their muscle fibers, and the effects of exercise tests on selected blood parameters.

Some authors conducted electrophysiological studies to establish specific reference values, which can be helpful in the training process and later in diagnosing sports injuries. Electromyography studies of elite field hockey players indicate different values of ulnar and tibial motor nerve conduction velocity compared to the values obtained by soccer and tennis players [24]. On the other hand, comparative electromyographic measurements of bicep femoris and semitendinosus muscle activity in field hockey players have shown that they have a much larger tolerance in maintaining an extended knee position without feeling any pain, when compared with those who do not practice any sport. According to Jaeger et al. [25], such an ability (or lack of it) is determined by the composition of muscle fibers. Research carried out on a group of female hockey players and on a control group revealed that the sportswomen had a higher percentage of oxidative-glycolytic muscle fibers (FTa), and their share and histochemical features were similar to those typically found in males. In the case of fast-twitch fibers (FTa), it has also been demonstrated that there is a direct relationship between the transverse section area of muscle fibers and their oxidative activity [26]. Moreover, Cochrane & Stannard [27] noted that high-intensity vibration training helps develop muscle mass and increases flexibility in female hockey players.

Muscle strength and body flexibility also depend on the quality of the connective tissue present, which forms, among other things, tendons and muscle attachments. The principal amino acid building connective tissue is hydroxyproline. According to Krawczyński et al. [28], the metabolism intensity of that amino acid correlates with the amount of training undergone. It has been demonstrated that hydroxyproline excretion in urine in cyclists with a few years of training (1–3 years) was higher than in field hockey players who underwent a longer period of training (over 6 years), both at rest and after exercise. The results of this research also suggest that the domination of certain endurance elements in the training process influences the metabolism of connective tissue.

An increased level of excreted creatine was found in the urine of well-trained athletes who were subjected to a medium-intensity exercise test. However, the physical fitness of field hockey players had a lesser effect on the level of creatinuria [29]. Therefore, one may assume that adapting more efficiently to long-term training coincides with the faster utilization of creatine that is generated in working muscles.

The mechanism of maintaining the correct acid-base homeostasis by the kidneys was investigated by Bittner et al. [30]. They demonstrated that a field hockey player's fitness level was not characterized by variations of renal balance during submaximal exercise, and that being more efficient in such regulatory activity, which was itself determined on the basis of blood pH, pCO_2, and pO_2 levels as well as on the concentration of hydrogen carbonate and ammonium ions, depended on the length of their sports career. Moreover, it was explained, with reference to the case of female field hockey players, that physical exercise, which does not cause metabolic acidosis, is able to induce regulatory processes in the kidneys [31].

A number of studies concerning the physiology of field hockey players mentioned that regular training and high physical activity cause changes to body composition, including bone mass. Bone metabolism may be subjected to sudden changes, especially in women, as it is connected with hormonal balance, particularly that of estrogens [32]. A comparison of bone composition in women practicing contact (basketball, netball), limited-contact (running, field hockey), and non-contact sports (swimming), and of a control group, revealed that there is a positive correlation between the degree of contact experienced in sport and the average bone density and higher mineralization of leg and arm bones. The results suggest that women who regularly participate in contact sports during the pre-menopause period have higher bone mineral density in comparison to women who do not practice any sport [33]. A team of researchers led by Sparling [34] compared three different methods of determining total bone mineral density and body composition of the 1996 United States Olympic Team for Women's Field Hockey: they were: dual energy X-ray absorptiometry (DXA), hydrostatic weighing, and the sum of seven skinfolds. The obtained results were very convergent. What was also demonstrated [35] was that forearm bone mineral density in female field hockey players increased during their training season. At the same time, the total amount of body fat decreased while the lean body mass increased. It was also determined that muscle strength and maximal oxygen uptake (VO_2max) increased during the training season [36], although this correlation could differ considering the position played by an athlete on the field. The highest value of VO_2max (59.9 ml · kg^{-1} · min^{-1}) was found in centre midfield players. It was 11.4 ml · kg^{-1} · min^{-1} higher than the value found in right back position players [37].

Horváth et al. [38] pointed out the beneficial effects of playing recreational field hockey as well as other forms of regular physical exercise. They carried out an electrocardiographic examination of 215 men and women, which demonstrated a significant reduction in the risk of hypertension in persons whose parents had high blood pressure.

Tactics

According to one definition, game tactics is the purposeful, effective and planned way of competing, which pits one's own and their rivals' skills during a match. It also defines the playing field and conditions of the competition, as well as the rules and regulations applicable to a given game [39–41]. Thus, with an idea of what tactics are, can allow several indices to be included, including those that are biochemical in regards to tests which measure a players' endurance capacity. It also touches upon several other physiological and biochemical issues, which frequently are only indirectly alluded to in regards to a players' fitness, such as their body position their ability to be in peak physical shape.

Even a rough analysis of the available studies reveals a lack of data resulting from a more in-depth motor analysis of field hockey players during matches and practices with respect to different age groups as well as regarding the gender or the length of one's sporting career. As in the case of the other thematic groups, field hockey is usually found in the background in other conducted research or plays only a minor role in the topic discussion.

Research carried out by Reilly & Seaton [42] showed that the typical body positions adopted when playing a field hockey match have an influence on overall posture shaping, e.g. such as having the spine shortening while running as well as on physiological test results. Field hockey players, depending on the position they play, cover a distance ranging from 9300 to 10870 meters [43, 44]. That distance may be divided into segments which vary in terms of motion intensity, i.e. the walking, jogging, standing, striding, and sprinting, and which have a share of 46.5 ± 8.1, 40.5 ± 7.0, 7.4 ± 0.9, 4.1 ± 1.1 and 1.5 ± 0.6 percent respectively in respect to the duration of a match [45]. Those time relationships are not fixed and are subject to significant alterations with each played game. For example, the stopover duration of three consecutive matches was, respectively, 7.4, 11.2 and 15.6 percent of game duration [46].

A similar time-motion analysis was also carried out during matches featuring female field hockey players [47]. The distances covered during three consecutive matches were significantly shorter than those covered by males, and amounted, on average, ranges between 3850 and 4250 meters [48]. Similar results were obtained from research carried out on a group of amateur field hockey players [49].

The art of keeping a field hockey player in peak condition involves using selected physiological parameters such as heart rate (HR), maximal oxygen uptake (VO_2max) or time to exhaustion. During competition, well-trained players subjected to high-intensity physical exercise demonstrate the highest values of VO_2max [50], furthermore, their exhaustion time is longer [51].

Analyzing the progress of a player's physical health, or obtaining information on their fitness levels during a competition season, is performed using a set of tests. It was statistically demonstrated that there are significant variations in the results of tests which a assess player's physical condition, dependant on the time when they are carried out, especially if conducted during the preseason and de-conditioning periods. It was also established that the extent of those differences depended on the sport played and athlete's gender. In the case of men, a lower variability was observed in Australian football, soccer, and rugby players, and a higher variability among softball players. For women playing soccer however, the seasonal variations of fitness levels, as found by a number of physical performance tests, was lower when compared to female field hockey players [52].

The wide range of physical performance tests allows for a greater degree of comparison and selection which is particularly helpful in determining a players' motor abilities. Sometimes, the aim of research in such a field as tactics is to compare the physical performance tests in order to define the optimal motor abilities of players. Lemmink et al. [53] evaluated the usefulness of a shuttle run test and a slalom run test in establishing the parameters of sprinting and dribbling in young field hockey players. Moreover, by using two varieties of the shuttle run test, the authors evaluated their influence on the aerobic and anaerobic metabolism of athletes [54]. It was shown that goalkeepers had the highest lower body strength and the lowest anaerobic capacity, while midfielders had the highest anaerobic capacity [55].

Bishop et al. [56] pointed out the importance of selecting the right test for evaluating a player's endurance capacity. On the basis of using a repetitive test (with a rep of 5 × 6-second maximal exercise) carried out on a cycle ergometer in order to determine an athlete's endurance capacity, they demonstrated that such a test needs to be modified and adapted to the specific characteristics of a given sport. Currently, new techniques based on global positioning satellite (GPS) systems can be used in analyzing the motion of all field hockey players during a single match. This method may be useful in the training process, especially in regards to maintaining correct load optimization as well as to an athlete's physiological welfare during competition [57]. Similar results can also be attained by analyzing selected camera recordings, including important parts of game play, such as penalty corners [58].

In determining the actual endurance capacity of field hockey players, a 5-meter multiple shuttle run test turned out to be the most useful [59, 60]. The advantage of this test was not only the ease with which it could be organized and the minimal equipment requirements, but also the short period of time during which an entire group of field hockey players can be assessed. A good measurement of training progress is also a multiple shuttle run test when measuring the total distance covered together with the heart rate. Another helpful device in determining the progress of team players is measuring the speed, time and, kinetic energy of a player during a 60-yard shuttle run test, using laser timing systems [61]. According to Boddington et al. [62], the evaluation of the average heart rate together with fragments of the 5-meter shuttle test are reliable measurements in assessing the endurance capacity of female field hockey players. However, they demonstrated that an evaluation of the degree of tiredness using the Borg scale and the difference between the longest and shortest distances of a shuttle run are not a reliable measurement of fitness of female field hockey players. Therefore, the authors suggested that the aforementioned parameters should be interpreted with caution, especially when players are taking the test for the first time. In addition, using a 40-meter shuttle test and running on a treadmill did not make it possible to find a correlation between the total running time and maximal oxygen uptake (VO_2max) in soccer and field hockey players [63]. Thus, the authors suggested modifying such tests in order to obtain results that are more satisfying. Lakomy & Haydon [64] postulated that the introduction of a delay into the 40-meter shuttle run test, which consisted of an enforced, rapid deceleration after crossing the finish line. They noticed that the group of athletes who participated in the test with enforced, rapid deceleration displayed a higher degree of fatigue. This may prove the validity of using such a method in a general training schedule, particularly in the case of team sports.

In order to choose the right exercise load for players in a training cycle, which is a key factor in preparing them for long-term high-intensity exercise, a method known as training impulse (TRIMP) is used, among other available techniques. A modification of this method, which consists by taking into consideration the weighting factor into account (TRIMPMOD), quantifies the training load of team sport athletes and may be useful in maintaining or increasing aerobic capacity during the season [65]. An one-week training impulse correlated ($p < 0.05$) with changes in VO_2max and a growth of the concentration of lactates, reaching 4 mmol/L while running on a treadmill.

The training methods used by athletes of a given sport were reflected by the results they achieved. Stagno et al. [66] examined two methods of training field hockey players, each with 11 persons who were subjected to extensive or intensive interval training for 12 weeks. An assessment of VO_2max, the speed required to reach the threshold of anaerobic metabolism (V_{OBLA}), and the time to exhaustion explicitly indicated that in the case of field hockey players, an intense interval training method proved more advantageous [66]. Registering the heart rate (HR) during training makes it possible to select the appropriate physical exercise needed to develop the desired motor features, endurance or strength of a player. Heart rate is an efficient and proven parameter which is helpful in designing training exercise loads [67]. Moreover, Lothian & Farrally [68] established that heart rate is a good intermediary parameter determining maximal oxygen uptake (VO_2max). However, the authors did not show a correlation between VO_2max and the activity of female field hockey players during a match. Other research [69] indicates a gradual increase in VO_2max during a training cycle. However, these changes were not statistically significant. Moreover, these changes did not translate into significant differences in heart rate.

Physical performance tests taken by field hockey players under conditions specified by the above methodology have recently been compared to energy expenditure measurements taken during a match by means of the so-called Sport Testers, which measure cardiac action. Boyle et al. [70] determined that the average energy expenditure of field hockey players during an entire match was 5.19 MJ. Moreover, they established that those values were significantly higher in midfielders (83 KJ/min) when compared to right- and left-wing players (61.1 KJ/min). The authors confirmed that a field hockey player primarily utilizes aerobic energy sources, and that their energy expenditure is at a relatively high level.

Attempts to improve the condition of field hockey players require a proper selection of new and innovative training methods and techniques. One of them is the use of training equipment, e.g. sled towing (a device which resists the motion of an athlete). When used in preparing field hockey, rugby and Australian football players; this increases an athlete's coordination and fitness. The resistance the sled gives must be carefully chosen to match the mass and height of the athlete [71]. What was also established was that the tactical skills of a field hockey player may also be improved by examining the power used when hitting a ball during a block [72] which can improve ball push, [73] or an analysis of the ball's direction during a shot [74]. One of the more recent methods of training field hockey players involves the audiovisual recording of matches and practices, and by analyzing this footage in order to determine a players' skill level [75] or a goalkeepers' abilities and potential [76]. Player progress may also be assessed on the basis of a testing battery, which is particularly useful in evaluating the skills of long- and short-training players [77, 78].

Nutrition

Seven out of the 208 analyzed studies on field hockey concerned themselves with nutrition. They focused on assessing the calorific value of meals eaten by athletes and on optimum hydration. Authors additionally raised the issue of using supplements and additives in nutrition and the physical performance enhancements they had on field hockey players.

The need to analyze the nutrient supply in players, which plays a fundamental role towards maintaining good physical fitness, has been documented. Such nutritional analysis, performed on the Canadian Olympic Women's Field Hockey team, revealed that the average 24-hour energy value of their meals was 1966.6 kcal, out of which 42.0% were carbohydrates, 38.7% fats, and 15.3% proteins. Such a diet, when combined with an average maximal oxygen uptake (VO_2max) of 51.0 mL/kg/min. and the associated energy expenditure, did not guarantee meeting the minimum energy requirements in a number of athletes. The nutritional deficiencies found among those players were, among other things, the lack of certain vitamins and iron [79]. Furthermore, Lee et al. [80] demonstrated that apart from iron deficiencies, inappropriate nutrition might also be the cause of calcium deficiencies. Successful attempts at preventing deficiencies by using specifically prepared iron supplements in sportswomen who were already lacking iron yet did not show any symptoms of anemia, explicitly indicated that iron injections were more effective than taking iron tablets. The concentration of ferritin (an iron storage protein) in the blood increased from 20 ± 2 to 63 ± 7 μg/L after a series of injections, while only from 27 ± 3 to 41 ± 5 μg/L in female athletes who took iron supplements orally [81].

The dietary supplement most frequently used by athletes is creatine, which usually increases the concentration of phosphocreatine in the muscles, a compound responsible for anaerobic metabolism. Research that was carried out among field hockey players provided ambiguous results in the usage of creatine supplementation [82]. In the search of supplements which could improve an athlete's fitness, some authors made reference to players using unusual diets or substances. An attempt to use an extract from lingzhi (Ganoderma lucidum), a fungus used for hundreds of years in traditional Chinese medicine for improving body strength and reducing body mass, was found to insignificantly improve a well-trained field hockey player's aerobic and anaerobic parameters [83]. In addition, the taking of a bovine colostrum preparation for eight weeks did not change the endurance performance results and body composition of the Dutch National Men's and Women's Field Hockey Teams [84]. The authors hypothesized that those substances, rich in proteins and antibodies, may stimulate a greater storage of phosphocreatine in the muscles as well as accelerate the dephosphorylation of ATP.

One of the essential elements of maintaining a high fitness level of field hockey players is ensuring appropriate hydration [85]. Dabinett et al. [86] pointed to certain methods which facilitate the monitoring of the proper hydration of athletes, such as evaluating average body mass fluctuations, heart rate measurements, and in taking a player's temperature from his eardrum during training. They also pointed out that the preferred liquids for athletes are specialized isotonic drinks and still water. Matches played during very hot and humid conditions should also encourage the match organizers to call for more time outs, and for athletes to take in more liquids and to cover their bodies with cold clothing [87]. By observing these recommendations a player can offset hyperthermia, which itself causes the reduction of stamina.

There were no differences between the average core, skin and ear canal temperatures between professional male and female field hockey players when exercising with an intensity of 50% VO_2max for 60 minutes. However, the dynamics of sweating, determined by body mass loss, was significantly higher in men than in women after the exercise period was concluded [88]. Goalkeepers, who wear special clothing, are especially at risk to their core temperature increasing [89]. Sunderland & Nevill [90] established that exercising in elevated ambient temperatures causes a rise in rectal temperature and increases the feelings of thirst and tiredness. The authors also noticed that an increase in temperature caused a reduction in the concentration of glucose and aldosterone in the blood, but did not affect the concentrations of cortisol, ammonia, lactates, and plasma volumes.

Anthropometrics

It cannot be ruled out that establishing a somatic and psychological profile for those wishing to practice a given sport may enable team managers to make the right choices when selecting future players [91]. Keogh et al. [92] pointed out that body physique and composition may affect tactical features, i.e. agility, running speed, and aerobic power, all of which factor in marking the difference between a well-trained and poorly prepared field hockey player. There is a large diversity in the physique of athletes who play field hockey. Most commonly, the players are slim (ectomorphic) with differing muscular builds (mesomorphic) [93, 94], with the different builds usually related to the position in which they play. Female goalkeepers are characterized by the highest body mass and the highest percentage of fat, while in players who play other positions the diversity of body build and composition was lower [95]. It was found that field hockey players have different physiques depending on their country of origin. A comparison of Asian and European field hockey players revealed that the former have not only a body type with stronger muscular features, but also a more massive skeleton [96].

Injuries

Injuries are discussed by authors ($n = 36$, 17.31%) in a variety of aspects, such as those resulting from the rules of field hockey, technical equipment (sticks, shin guards), and also local infrastructure (field surface). The occurrence of injuries also correlates with the intensity of physical effort during training, the number of matches played, the position a player plays, and what adopted tactics were used. Out of 36 studies, a small number ($n = 8$) describe individual cases of injuries in male and female field hockey players.

One aspect that played a significant role in injuries that field hockey players sustain is the field surface on which matches are played. The mechanics of players' motion and the pace of the game are different depending on what surface is used [97]. An analysis of field hockey players' subjective opinions during an intensive match on both an indoor surface and on artificial turf indicates that the latter is characterized by higher degree of hardness, which in turn led to an overall faster game play caused by higher ball rebounds [98–100]. It was also established that synthetic turf led to a higher frequency of acute injuries, which primarily resulted from the increased pace of the game [101], modified equipment, e.g. hockey sticks [102], or through an improvement of tactics used by means of training on smaller-scale fields. Coaches introduce such practices in order to improve the endurance capacity and effectiveness of players when playing in competitions [103]. Game dynamics may also be improved by introducing new elements to general field hockey rules. In particular, the risk of facial injuries caused by tossing the ball explains why an amendment to the rules on taking short corners, introduced by the International Hockey Federation on January 1, 2003, was quickly annulled after a few matches [104].

According to research carried out on a large group of school-aged children ($n = 7468$) who took part in team sports, injuries occur more frequently when playing field hockey and basketball. The injuries were mostly minor (concussions and slight joint sprains) and in three out of four cases normally occurred in the lower extremities [105]. At the same time, it should be pointed out that the risk of spraining an ankle was almost 1.5 times higher among female hockey players [106]. Yet field hockey was found to have the lowest injury rate when compared to ice hockey and lacrosse [107], as well as to Gaelic football, rugby, soccer, hurling and basketball [108].

An analysis of sustained injuries carried out during a period of 15 years among 5385 female field hockey players showed that the most frequent injuries included ankle sprains, knee disorders, and finger fractures. The likelihood of a concussion or head injury was 6 times higher during a match than during training [109]. What was also discovered was that the risk of injury was significantly reduced when female hockey players were appropriately prepared such as by taking part in neuromuscular balance programs or using ankle-stabilizing bands, or by using helmets and padded gloves. Moreover, dedicated educational programs on injury conducted from the very beginning of seasonal training significantly reduced the number of injuries as well as treatment costs [110].

Studies published to date indicate that of the level of contact field hockey players experience with the ball, a stick or another player may be the reason for injury, particularly to the upper body, the neck and the head. Authors noticed that goalkeepers and midfielders are the most susceptible to injuries [111]. It was estimated that only 20 percent of international field hockey players use intra-oral mouth guards on a regular basis. Consequently, there are frequent facial injuries which require a physician's and/or dentist's attention [112, 113] in addition to ocular injuries [114]. The cause of such injuries is the reluctant use of face shields by players, which they justify by the breathing difficulties experienced [115]. Players in the English Hockey League do use mouth guards during matches, but less frequently in training [116].

During the 2004 Summer Olympic Games in Athens, there were relatively few injuries among both genders in team sport disciplines (soccer, volleyball, basketball, handball, water polo, baseball, softball, and field hockey). 377 injuries were recorded in 456 matches, which was [117] calculated to average out to 0.8 injury per match or 54 injuries per 1000 players. The most frequent type of injury involved damage to a player's lower extremities which resulted from the direct contact with another player. It should be pointed out, however, that the degree of injury did not necessarily prevent players from training or participating in the next match. One issue, which remains unresolved, is the assessment, classification and standardization of bodily injuries sustained by players [118].

Problems connected with injuries triggered by overloading are described explicitly in a specific case study. A case of posttraumatic sacral spine fracture in a female field hockey player was presented in a study by Slipman et al. [119]. Wood-LaForte & McLeod [120] described the intense pain felt by a female field hockey player due to a bilateral femur fracture or another player who was diagnosed with a fracture of the superomedial surface of the acetabulum [121]. Radiating pain in the foot of a German National Team field hockey player during training and matches resulted in an arthroscopy procedure during which a torn ligament and the presence of scar tissue were revealed [122]. Overloading was also the cause of tendinitis and a posterior talus fracture of a female field hockey player [123]. An analysis of two further cases of female field hockey players did not explicitly demonstrate that increased exercise or viral meningitis [124] was the cause of an aneurysmal bone cyst of the femur [125].

In order to prevent injuries caused by overloading, authors of these various scientific studies recommended plyometric training, which increases leg muscle activity during a training cycle [126], and regular hamstring stretching [127], which effectively reduces the risk of tendon strain and knee and ankle joint injuries.

Research carried out by Mark F. Reinking [128] showed that leg pain found among players of numerous sports is closely related to physical exercise. The pain usually escalates during the competition period. The authors state that field hockey players and cross-country skiers are those who complain the most frequently of lower extremity pain, while soccer players complain the least. At the same time, it was not demonstrated that age, muscle length, dietary habits, BMI, menstrual cycle or bone mineral composition had an effect on athletes' differing experiences with pain reception.

Psychology

Studies concerned with psychology ($n = 40$, 19.23%) focus on the changes in the behavior and perception of athletes when faced with an important and at a given venue. They also discuss aspects on players' feelings and interpersonal relations when they win or lose. In the available literature, problems connected with the experiences and age of players, their origin and social status, religious faith, and sexual identity are raised quite frequently.

Psychological factors, apart from having an effect on physical activity, manifest themselves as changes in the biochemical parameters in an athlete's blood, usually n the form of hormones. It has been demonstrated that participation in sports tournaments unbalances the secretion of sex hormones in female field hockey players. The level of the luteinizing hormone (LH) increased across the period of time from pre-training to competition, the level of progesterone increased only during the training period, while the concentration of estradiol decreased during competitions. Only the concentration of the follicle-stimulating hormone (FSH) showed a high stability throughout the entire research period [129]. The results also demonstrated that female field hockey players experienced stronger reactions toward an approaching competition period, which manifested itself with an increase in the concentration of adrenaline and noradrenaline, but not cortisol, as was determined in saliva samples taken twenty-four, two and one hours before a tournament [130].

Measurements of anxiety experienced by the Japanese Women's National Field Hockey Team, which was carried out by means of questionnaires, showed that psychological stress during a World Cup qualifying tournament gradually decreased with each match [131]. It was also observed that there was no direct correlation between the body's emotional response and the final match score. Players with a strong belief in their abilities experienced significantly lesser physical and psychological stress than athletes who doubted their skills [132]. An analysis of data from soccer and field hockey players, presented by Sewell & Edmondson [133], revealed that goalkeepers displayed, statistically, a higher level of recognizable tension in comparison to players in other positions, and were more somatically anxious and less confident than defenders. Non-midfielders and forwards were more nervous than defenders and midfielders. The latter, in turn, were less confident than defenders [134].

What psychological stress a player experiences also depends on the venue. Female field hockey players were much more confident playing at home than away [135]. Arathoon & Malouff [136] recommend that after a lost match, field hockey players should not even try to recall the more positive moments during game play as this leads to a worsening of their state of mind and towards worrying even more about a defeat. Lamb [137] demonstrated that female field hockey players with low self-esteem are much more susceptible to injury. The author stated that the potential for injuries depends partly on the aggression displayed by the athletes.

An examination of Canadian female athletes found that women selected for the field hockey team were significantly more aggressive, had higher leadership ambitions and were psychologically stronger than team members in other sports. Moreover, female players in offensive positions accepted a coach's advice far more easily than those in defensive positions. In most cases, players selected for the team came from middle-class families that had both parents present, and were frequently the oldest child [138]. According to research done by Zamboanga et al. [139], one of the ways of maintaining unity in sports groups, e.g. female college field hockey teams, were get-togethers where alcohol was consumed. The authors pointed out that, depending on the sport, there were differences in the amount of alcohol consumed, yet the authors did not reveal which discipline had the highest amount of alcohol consumption.

Hockey players can acquire new abilities through physical and theoretical training. Doody et al. [140] demonstrated that experienced athletes are significantly better than inexperienced ones at perceiving and applying the instructions given by coaches and during visual presentations. It was also observed that field hockey and soccer players are much better at transferring information and strategies from other disciplines when compared to volleyball players [141]. Video analyses also reveal that the behavior of an experienced field hockey coach may change within as short of a period of time as one year. With time, his/her acceptance and willingness to give praise grows as the tendency to give orders and criticize decreases [142].

The improvement of fixed game play in field hockey can be improved the simple repetition of an exercise on a regular basis. Research has shown that even mentally projecting penalty shots by players, who underwent a period of seven weeks of research, was found to significantly improve the effectiveness of those game elements when compared to a control group [143]. Nieuwenhuis et al. [144] demonstrated that through using 16 kinanthropometric measurements, 6 motor skill assessments, and 2 psychological tests, one may effectively distinguish the difference between more or less talented female field hockey players. They stated that better hockey players had significantly better results in eight of these tests. At the same time, they indicated that such a method allows for the quicker identification of more talented players, which in turn shortens the length of time required for professional training [144]. Multiple task tests make it possible to obtain important information on the cognitive abilities and skills among field hockey players [145].

Two of the articles on field hockey available in the databases raised the topic of sexual identity and the tolerance of homosexual behavior. Roper & Halloran [146] did not observe any significant differences in athletes' attitudes towards gays and lesbians across a wide range of sports. The acceptance of homosexual athletes among female field hockey players was said to have been the cause of hem having contact with a homosexual female coach. Research by Shire et al. [147] showed that a small group of homosexuals was fully accepted by a team of female field hockey players. However, in the case where a majority of team, almost 84%, was homosexual or exhibited homosexual preferences, the heterosexual minority felt rejected and not accepted, which in turn had an adverse effect on relationship between individual female players.

Conclusions

1. An analysis of the scientific studies that focused on field hockey, as found in the analyzed databases, indicates that researchers have a wide scope of interests when it came to analyzing the sport of field hockey. However, due to the relatively small number of publications when compared to other team sports, the scientific information provided by them rarely allow for a comprehensive assessment of a given issue. Moreover, as found in numerous studies field hockey was only a reference point in research with regards to other team sports.

2. The consequence of their being such a small number of studies on field hockey is the difficulty in providing a comprehensive assessment of several issues, particularly when applying additional criteria such as gender, age, or the length of sample studies. This situation exacerbated by the lack of comparative research, especially in terms of the methodology and background information in which experiments were carried out, and/or the lack of research carried out on the same player population throughout a longer period of time.

3. The authors did not perceive any objective reasons why a sport as popular as field hockey has been so rarely subjected to more investigative research, especially in biological terms, particularly those in biochemistry, physiology, psychology, and nutrition.

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