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STUDENTS AND GRADUATES OF THE UNIVERSITY OF SZCZECIN AT THE 32ND OLYMPIC GAMES TOKYO 2020

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Abstract So far, in the history of the modern Summer Olympic Games, the event has not been organized only three times – due to World Wars – in 1916 (6th Olympic Games), 1940 (12th Olympic Games), and 1944 (13th Olympic Games). For the first time in its 124-year history, the International Olympic Committee decided (on March 24, 2020) to postpone the Games to the following year due to the pandemic caused by the SARS-CoV-2 virus. The 32nd Olympic Games Tokyo 2020 were held between July 23 and August 8, 2021, in a strict sanitary regime. The purpose of this paper is: to present the academic status of athletes – students and graduates of the University of Szczecin – who participated of the Olympic Games Tokyo 2020; to present key sports achievement to-date of these athletes; to analyze the sports results obtained by them in athletics in the context of medals won at the 32nd Olympic Games. The Polish Olympic team who participated in Tokyo 2020 included three athletes (runners), associated with the University of Szczecin: Patryk Dobek – 800 m run, Marcin Lewandowski – 1,500 m run, and Adam Nowicki – marathon. The coaching staff of Polish athletes included another graduate of the University of Szczecin, Jacek Kostrzeba. Additionally, Marek Kolbowicz, PhD – an employee of the Institute of Physical Culture Sciences at the Faculty of Health and Physical Culture of the University of Szczecin (INoKF WKFiZ US) – acted as a TV commentator/rowing expert. WKFiZ US' student – Patryk Dobek – won a bronze medal in the 800 m run, which was an unexpected surprise in the Polish Olympic team.

Key words students, graduates, Olympic athletes, Olympic Games, bronze medal, Tokyo 2020, Paralympics, University of Szczecin

Introduction

The choice of host of the 32nd Olympic Games was announced on September 7, 2013 in Buenos Aires, Argentina, during the 125th Session of the International Olympic Committee (IOC). Among the previously accepted three candidate cities – Madrid (Spain), Istanbul (Turkey), and Tokyo (Japan) – members of the Committee elected the capital of Japan. The date of this largest sports event was also determined: – July 24 – August 9, 2020. It is worth noting that Tokyo already hosted one such event: the 18th Olympic Games.

So far, in the history of the modern Summer Olympic Games, the event has not been organized only three times – due to World Wars – in 1916 (6th Olympic Games), 1940 (12th Olympic Games), and 1944 (13th Olympic Games). However, for the first time in the 124-year history, due to SARS-CoV-2 pandemic, '... and postulates submitted by national committees (including Polish Olympic Committee), the International Olympic Committee decided to postpone the Games to the following year with an approximate time frame of July 23 – August 8, but keep the original name ‘Tokyo 2020’ (Urbaś, 2020, p. 3). The decision of the IOC was consulted with and approved by the Japanese government and the Tokyo 2020 Organizing Committee (www.olimpijski.pl). The postponement of 32nd Olympics and the 16th Paralympics to 2021 significantly increased the financial costs of organizing the events (Banio, 2021a; Jastrząbek, 2021; Omorczyk, 2021; Urbaś, 2021).

The 32nd Olympic Games Tokyo 2020 were held between July 23 and August 8, 2021, in a strict sanitary regime. The participants came from 205 countries, and competed in 33 disciplines (339 competitions). Sports facilities were located in Tokyo and in its immediate vicinity, in the Tokyo Bay and in towns located far from the Japanese capital, e.g. Sapporo (*Przegląd Sportowy*, 2021).

The purpose of this paper is:

1. To present the characteristics of the academic status of athletes who participated in the 32 Olympic Games Tokyo 2020 – students and graduates of the University of Szczecin.
2. To present key sports achievement to-date of these athletes.
3. To analyze the sports results obtained by them in athletics in the context of medals won at the 32nd Olympic Games.
4. To continue research (sports analyzes and biographical ones) on the participation of these athletes in the Summer Olympic Games – students and graduates (athletes and coaches) of the Pedagogical University in Szczecin, University of Szczecin.

Materials and Methods

The study group consisted of five people – excellent sports personalities and participants of the Olympic Games, who also performed various functions during the 32nd Olympic Games Tokyo 2020. The group includes three athletes – runners Patryk Dobek, Marcin Lewandowski, and Adam Nowicki – as well as the athletics coach Jacek Kostrzeba, and sports expert in rowing and canoeing, Marek Kolbowicz.

In 2018, Patryk Dobek (Table 1) graduated with a Bachelor’s degree in Physical Education from the Faulty of Health and Physical Culture, University of Szczecin (WKFiPZ US). Currently, he is a Master’s student (2nd year) in the field of Physical Education at the Faculty of Health and Physical Culture, University of Szczecin (WKFiZ US – the current name of the faculty since October 1, 2019). He is a diligent student who skillfully combines professional sports and academic education. He is preparing a Master’s thesis on his running competition – men’s 800 m run (the supervisor of his Master’s thesis is the author of this article).

Table 1. Research material

First and last name*	Academic status	Function at the Olympic Games	Sports discipline – Olympic competition
Patryk Dobek	student	athlete	ATH** – 800 m
Marcin Lewandowski	graduate	athlete	ATH – 1,500 m
Adam Nowicki	student	athlete	ATH – marathon
Jacek Kostrzeba	graduate	coach	ATH – 1,500 m*** marathon
Marek Kolbowicz	graduate	sports expert	rowing and canoeing

* Alphabetic order.
** ATH – athletics.
*** Coach of Michał Rozmys.

Source: Documentation (2021); *Przegląd Sportowy* (2021); Urbaś (2021).

Patryk Dobek practices athletics; he specializes in 400 m run, 4 × 400 m relay, 400 m hurdles, and – since 2021 – in 800 m run. He is a multiple medalist of the World Junior Championships, Junior Championships, Youth European Championships, World Military Sports Games (except 800 m run). He participated in the 31st Olympic Games in Rio de Janeiro (400 m hurdles) and the 32nd Olympic Games in Tokyo (800 m run). In August 2020 in Bydgoszcz, at the 8th European Athletics Team Championships, Dobek twice obtained a result better than the PZLA's qualifying standard for the Tokyo Olympics in the 400 m hurdles (48.90) (Eider, 2019a). He scored 48.80 in the qualifying run, and 48.87 in the finals. These achievements ensured his participation in the 32nd Olympic Games Tokyo 2020 (he did not compete in this running competition in Tokyo, however).

Marcin Lewandowski was a student of a 4.5-year full-time studies in Physical Education (major: Teaching) (Eider, Eider, 2015a), at the former Institute of Physical Culture of the Faculty of Natural Sciences of the University of Szczecin. He wrote his Master's thesis on 'Annual preparation cycle of Marcin Lewandowski for the 800 m run', which he defended on October 17, 2011 at the Faculty of Physical Culture and Health Promotion at the University of Szczecin (Table 1). The supervisor of Lewandowski's thesis was also the author of this publication (Eider, Eider, 2017).

Currently, he is a member of AZS UMCS Lublin and represents the world level in 800 m and 1,500 m athletics running competitions. He participated four times in the biggest sports competition in the world – the Olympic Games. He made his debut in 2008 in Beijing, followed by London (2012), Rio de Janeiro (2016), and most recently Tokyo 2020 (which took place in 2021). During the previous Olympic Games, he competed in the 800 m run, while in Tokyo he took part in the 1,500 m run. He secured his qualifying standard for the 32nd Olympic Games Tokyo 2020 during, inter allia, the Diamond League in Paris (August 24, 2019), where he set the Polish record in the 1,500 m run at 3:31.95. The PZLA standard was 3:35.00 (Lewandowski, 2021).

In 2015, Adam Nowicki graduated with a Bachelor's degree in Physical Education from the Faculty of Medicine and Health Sciences at the University of Zielona Góra. Currently, he is a part-time Master's student (1st year) in the field of Physical Education at the Faculty of Health and Physical Culture at the University of Szczecin. He prepares materials for his Master's thesis on his Olympic discipline – marathon, which he writes under the supervision of professor PhD Leonard Nowak.

Since 2013, he has been a member of MKL Szczecin, as well as a professional soldier in one of the Command Battalions in Szczecin. He does long-distance running (10,000 m, half-marathon, marathon). He achieved the qualifying standard for the Olympic Games Tokyo 2020 during the NN Mission Marathon in Enschede, Netherlands (April 18, 2021), in which he set a life record with a time of 2:10.21 (PZLA requirement: 2:11.30). This is the seventh best result achieved in the history of the Polish marathon so far. On the last day of the 32nd Olympic Games Tokyo 2020 (August 8, 2021), Adam Nowicki took 38th place in the men's marathon (the highest rank among Poles). After two weeks, one of the marathon runners was disqualified for doping, which gave Nowicki 37th rank – the best result among Polish runners (Nowicki, 2021b).

Jacek Kostrzeba was a student of 4-year full-time studies in Physical Education at the Institute of Physical Culture, University of Szczecin. The institute operated as faculty until September 30, 1992. His Master's thesis on 'Athletes' maximum oxygen consumption depending on age and sport preparation in medium distance competitions' was supervised by professor PhD Zbigniew Jethon. He passed his diploma examination in 1990 (Eider, 2019b).

He is an athletics coach who trains female and male athletes in middle-distance and endurance runs in UKS Barnim Goleniów, the national team and the Olympic team. He was part of the coaching staff at the 31st

Olympic Games in w Rio de Janeiro (2016). He worked as a coach in the Polish Olympic team of endurance runners. His trainee, Krystian Zalewski (a student of WKFiPZ at the University of Szczecin) competed in the 3,000 m steeplechase, and was ranked 27th.

Marcin Kolbowicz was a student of a 5-year full-time studies in Physical Education at the Institute of Physical Culture of the Faculty of Natural Sciences of the University of Szczecin. His Master's thesis on 'The analysis of the development of leading features in rowing in the Olympic cycle 1992–1996 on the basis of the preparation program of the 4x' was supervised by prof. PhD Jan Jaszczanin. He passed his diploma examination in 1998. Currently, he works at the Institute of Physical Culture Sciences at the Faculty of Health and Physical Culture of the University of Szczecin. On June 26, 2012, the Council of the Faculty of Physical Education, Sport and Rehabilitation of the University of Physical Education in Poznań awarded Marek Kolbowicz with a doctoral degree in Physical Culture Sciences for his doctoral dissertation on 'The effectiveness of special physical preparation in the long-term process of sports training for Olympic rowers' (Eider, Eider, 2017). The doctoral dissertation was supervised by the author of this article. Marek Kolbowicz was an outstanding athlete who specialized in rowing. He practiced this Olympic discipline in 1986–2013. He won medals at major sports events, such as Olympic Games, World Championships, European Championships, and Polish Championships.

The analyzed research material was obtained through the author's and co-author's studies to date, the works of other authors, oral and written reports of athletes, the coach, expert, websites, biographical databases of athletes (data accessed on August 31, 2021).

Results

The Olympic competition in athletics (except for the marathon and racewalking) was held at the Olympic (national) stadium on July 30 – August 8, 2021. This stadium was the venue for the opening and closing ceremony of the 32nd Olympic Games Tokyo 2020. Patryk Dobek and Marcin Lewandowski competed in that beautiful sports facility, while the marathon runner Adam Nowicki competed on the streets of Sapporo (where marathon and racewalk took place).

The qualifiers for men's 800 m run took place on July 31, 2021. 48 players participated in six series – the top three competitors in each series qualified for the semi-finals, as well as six others with the best times. Patryk Dobek started in the 5th series, in which he was ranked 3rd with a time of 1:46.59. Another Polish representative, Mateusz Borkowski, came 2nd in the 6th series, with a time of 1:45.34. Both Poles advanced to the semi-finals, which took place on August 1, 2021 – in three series of 8 athletes. The top two competitors in each series and the other two with the best times in all three series advanced to the finals. Patryk Dobek competed in the first series, in which he was ranked 1st, with a time of 1:44.60, defeating an outstanding Kenyan athlete, Emmanuel Kipkurui Korir – a future gold medalist (Table 2). Unfortunately, in the second series, Mateusz Borkowski took the last place, and therefore did not advance to the finals. On August 4, 2021 nine runners took part in the finals; the winner was the aforementioned Kenyan athlete, Emmanuel Kipkurui Korir (1:45.06), while the second place was taken by his countryman, Rotich Ferguson Cheruiyot (1:45.23) (Table 2). Our titled runner secured a sensational bronze medal (1:45.39). He is the fourth Polish athlete who has competed in the finals of the 800 m Olympic run so far (thus he joined Paweł Czapiewski, Adam Kszczot, and Marcin Lewandowski), but he became first Polish Olympic medalist in this particular discipline.

It should be emphasized that during championships events (such as the Olympics, World and European Championships), athletes compete primarily for medals, and not for record times. The Tokyo final run was quite slow, and the times achieved by the finalists significantly deviated from the world and Olympic records of Kenyan Radish Dawid Lekut (1:40.91) (www.olympices.com; Dobek, 2021).

Table 2. Participation in the Olympic Games Tokyo 2020

First and last name	Discipline – competition	Score (time)	Rank	Medalists			
				medal	first and last name	country	score (time)
Patryk Dobek	ATH – 800 m	1:45.39	3rd	Gold	Kipkarui Emmanuel Korir	Kenya	1:45.06
				Silver	Cheruigot Ferguson Rotich	Kenya	1:45.23
				Bronze	Patryk Dobek	Poland	1:45.39
Marcin Lewandowski	ATH – 1,500 m	x	x	Gold	Jakob Ingebrigtsen	Norway	3:28.32
				Silver	Timothy Cheruigot	Kenya	3:29.01
				Bronze	Josh Kerr	England	3:29.05
Adam Nowicki	ATH – marathon	2:17.19	37th	Gold	Eliud Kipchoge	Kenya	2:08.38
				Silver	Abdi Nageeye	The Netherlands	2:09.58
				Bronze	Bashir Abdi	Belgium	2:10.00

x – interrupted the semi-final race due to a calf injury.

Source: Dobek (2021); Lewandowski (2021); Nowicki (2021b); www.olympices.com.

In 2021, Patryk Dobek started to compete in the 800 m run with great success – he obtained very good time results at competitions of various ranks (he won medals and achieved the qualifying standard for the Tokyo Olympics). In February, in Toruń's 65th Polish Indoor Athletics Championships, Patryk Dobek won the Polish Championships in the 800 m run with a time of 1:47.12, defeating, among others, a titled runner Adam Kszczot. In the same city, in March, the 36th European Athletics Indoor Championships took place. In his newly trained running competition – 800 m run – Dobek won a sensational gold medal, with a time of 1:46.81 (woj., 2021a). At the June athletics meeting held in Montreuil, France, he won the 800 m run with a very good time (1:44.76), and obtained the qualifying standard set by the Polish Athletic Association (1:45.20) for the 32nd Olympic Games Tokyo 2020. He achieved an even better result in Chorzów, during the 67th Janusz Kusociński Memorial – which was also held in June (June 20, 2021). He won with a time of 1:43.73, setting a new personal record, as well as the world record at that time (woj., 2021b). In June (June 26, 2021) he also participated in the 97th PZLA Polish Championships in Poznań, where he won the Polish championship in the 800 m run with a time of 1:48.21. He competed in the 32nd Olympic Games Tokyo 2020 only in the 800 m run and won unexpectedly a bronze medal with a time of 1:45.39 as a member of the Municipal Athletics Club (MKL) Szczecin.

A graduate of the University of Szczecin, Marcin Lewandowski, competed during the Tokyo 2020 Olympics in the 1,500 m run together with another Polish representative, Michał Rozmys (*Przegląd Sportowy*, 2021). Three qualifier runs (16-person each) took place on August 3, 2021. Michał Rozmys started in the first race and took the 6th place with a time of 3:36.28; thus, he advanced to the semi-finals (the top six runners advanced to the semi-finals from each qualifying race). Marcin Lewandowski participated in the second race, during which he fell (due to another competitor's fault), but ended this unfortunate race in the last place, with a time of 4:43.96. The protest submitted by the PZLA authorities was accepted and thus our representative found himself among the semi-finalists.

Two semi-final races (13 competitors each) took place on August 5, 2021. The first one was attended by Marcin Lewandowski; unfortunately, during the run, his injury of the left leg – which had not been completely healed – flared up. He was forced to leave the track; he did not finish the race and thus was disqualified. Jake Wightman from Great Britain won the race, with a time of 3:33.48. Michał Rozmys took part in the second semi-final race. He finished in last place – in one shoe (during the run one of the competitors stepped onto his shoe, which slipped off some time after). After the race was over, the judges positively responded to the protest submitted by the PZLA authorities, and as a result he was included into the final race (Kostrzeba; 2021; Lewandowski, 2021; www.olympices.com).

The final race (with 13 competitors) took place on August 7, 2021. The winner was an exceptional Norwegian runner, Jakob Ingebrigtsen, who ran 1,500 m in 3:28.32 (Table 2). Our finalist took the 8th place with a time of 3:32.67 – his new personal best. Marcin Lewandowski, who was in good health, without any injuries, and in a good pre-Olympic shape (on July 9, 2021, he set a Polish record – 3:30.42) could have fought for the coveted Olympic medal. Unfortunately, for health reasons, his fourth participation in the Olympics turned out to be unsuccessful.

In 2021 (the year of the postponed Olympics), he set other Polish records: indoors (3:35.71), at the Copernicus Cup meeting in Toruń (February 17, 2021) and at the stadium (3:30.42) during the Diamond League in Monaco (July 9, 2021). So far in his Olympic career, he was ranked 6th in the final race at the 31st Olympic Games in Rio de Janeiro (2016).

Marcin Lewandowski has won numerous medals, such as: World Championships (at the stadium), Indoor World Championship, the European Championships (at the stadium), the European Indoor Championships, the Super League of the European Team Championships, the World Military Sports Games, the European Military Championships, the Youth European Championships, IAAF World Relays, Polish Championships (juniors, youth, seniors) (Bała, 2019, 2021; Eider, Eider, 2015a, 2015b, 2017; Eider, 2020a, 2020b; Lewandowski, 2021; www.wikipedia.pl; *Przegląd Sportowy*, 2021).

So far, his greatest medal achievement is probably the bronze medal for the 1,500 m run (October 6, 2019) won at the 17th World Championships in Doha (Qatar) – "… the athlete calmly passed through the qualifying rounds and the semi-final, only to explode in the finals. On the final stretch he chased two front-runners, and did not surrender his 3rd rank to a couple of other competitors. He also secured an excellent time result for Poland – 3:31.46' (Bała, 2019, p. 14). Earlier – in 2018, at the World Indoor Championships in Birmingham, he also won a silver medal in the 1,500 m run. He is an eight-time medalist of the European Championships at the stadium and indoors in middle-distance running: 800 m, 1,500 m (www.wikipedia.pl).

Marcin Lewandowski is a titled athlete, who proudly represents Poland at the largest sports events in athletics. For his sports achievements he was decorated with the Knight's Cross of the Order of Polonia Restituta and the Golden Cross of Merit (Lewandowski, 2021).

WKFiZ US student, Adam Nowicki competed in the marathon (42.195 km), which took place on August 8, 2021 in Sapporo Odori Park, in the morning, at a temperature of 25–26°C and nearly 70% air humidity (Nowicki, 2021b). 106 competitors participated in that race – and only 76 completed it. The winner was Kenyan Eliud Kipchoge, with a time of 2:08.38. Among the three Polish marathon runners (Marcin Chabowski, Arkadiusz Gardzielewski, Adam Nowicki), Adam Nowicki turned out to be the best; he finished the Tokyo marathon in 2:17.19, taking the 38th place. When one of his competitors was disqualified for doping, our runner ended up at the 37th place (Nowicki, 2021b), while Arkadiusz Gardzielewski was ranked 63rd (2:22.50). Unfortunately, Marcin Chabowski was among the 30 competitors who withdrew from that very difficult marathon run (www.olympics.com).

In his sports career to date, Adam Nowicki has won five medals at the Polish Seniors Championships in the 10,000 m run – three silver medals (Postomin 2014, Białogard 2016, Rybnik 2017), and two bronze medals (Wieliczka 2015, Karpacz 2020). In the half-marathon, he won three medals: two gold ones (Piła 2014, Bydgoszcz 2020) and one silver (Piła 2018) (Nowicki, 2021a, 2021b; www.wikipedia.pl). In 2017, he took up the marathon, dreaming of competing in the Tokyo 2020 Olympics. He made his debut in 2018 in the Warsaw Marathon, and took the 3rd place with a time of 2:17.28 – he was the best Polish competitor in that event (Nowicki, 2021b; *Przegląd Sportowy*, 2021). At the Polish Championships, he won two medals: a silver one (Olesno 2020) and a bronze one (Warsaw 2019).

Apart from the two students of the University of Szczecin – Patryk Dobek and Adam Nowicki – and a graduate, Marcin Lewandowski, the Polish Olympic team included a graduate of our university, Jacek Kostrzeba in the coaching staff. Michał Rozmys, his club and staff runner successfully competed in Tokyo 2020; he took 8th place in the final 1,500 m, improving his life record. His trainee, Angelika Mach from AZS UMCS Lublin, also participated in the Tokyo marathon (August 7, 2021). She was among 73 competitors, and ultimately took 59th place; she finished the race in very difficult weather conditions (Kostrzeba, 2021). As a coach, Kostrzeba cooperated with other trainers who took care of Polish competitors of the Tokyo marathon.

His trainees won many medals at the Polish Championships, for example Krystian Zalewski won gold medals in the 3,000 m steeplechase, 5,000 m and 10,000 m run at the 95th PZLA Polish Championships in Radom (August 23–25, 2019). Zalewski, once the 2019 athletics season ended, and he summarized his sports achievements to-date, analyzed his running predispositions, and had professional conversations with his coach Jacek Kostrzeba, decided to prepare for the marathon and obtain the qualifying standard (PZLA requirement 2:11.30) which would guarantee his participation in the Tokyo Olympics (Zalewski, 2020). In 2021 (April 18, 2021) he competed in Dębno in the 91st PZLA Polish Marathon Championships. All three medalists of that championships: Arkadiusz Gardzielewski (2:10.31), Kamil Karbowiak (2:10.35), and Krystian Zalewski (2:10.58) ran the marathon in a shorter time than the PZLA standard (which was 2:11.30). In the previously mentioned Enschede marathon, better times were achieved by Marcin Chabowski (2:10.17), and Adam Nowicki (2:10.21). Of the five marathon runners mentioned, only three with the best times represented Poland at the 32nd Olympic Games in Tokyo – without Zalewski. In Dębno on April 18th, 2021, Angelika Mach, an athlete trained by Jacek Kostrzeba, took part in the 41st PZLA Polish Championships in Women's Marathon. She took 2nd place with a time of 2:27.48, which allowed her to participate in marathon run at the Olympic Games Tokyo 2020 (Kostrzeba, 2021).

Among the Olympians trained by the coach Jacek Kostrzeba, there is also a UKS Barnim Goleniów member (since 2015), Michał Rozmys – a professional soldier of the Polish Army. He is a repeated Polish representative in middle-distance running (800 m and 1,500 m). The coach from Goleniów significantly influenced the sports progress of this athlete, who in 2019 won the gold medal in the 1,500 m run at the Universiade in Naples. In the same year, he competed in the World Military Sports Games in Wuhan, where he won two gold medals: in the 800 m and 1,500 m run. He also won the gold medal in the 1,500 m run at the Polish Indoor Championships held in Toruń (February 16–17, 2019). He secured his qualifying standard for the 32nd Olympic Games Tokyo 2020 on June 9, 2021 during athletics meeting in Marseille. He completed the 1,500 m run in 3:34.96 (PZLA requirement was 3:35.00), which was his new personal record, and guaranteed participation in the Tokyo Olympics (Kostrzeba, 2021; www.pzla.pl; www.wikipedia.pl).

The titled rower, Marek Kolbowicz, PhD, an employee of the Institute of Physical Culture Sciences at the University of Szczecin, upon completing his sports career became an expert in rowing at the largest sports events (e.g. World and Europe Championships). He was in the 15-strong team of the Polish Olympic television ‘TVP’ (Urbaś, 2021; Tymiński, 2021) which broadcast sports competitions in Tokyo 2020, mainly in disciplines with the participation of Polish representatives. Dariusz Szpakowski, a long-time excellent sports journalist, was the commentator for rowing (and canoeing), while the expert was the Olympic champion of 4× in Beijing (2008) Marek Kolbowicz (Kolbowicz, 2021).

Marek Kolbowicz was an outstanding athlete specialized in rowing; he practiced this Olympic discipline in 1986–2013. He won medals at major sports events, such as Olympic Games, World Championships, European Championships, and Polish Championships. He is the Olympic champion (along with Michał Jeliński, Adam Korol, Konrad Wasielewski – a graduate of IKF WNP US) in 4× rowing in Beijing (2008), four-time world champion (Gifu 2005, Eton 2006, Munich 2007, Poznań 2009), European champion (Monte-o-Velho 2010), multiple Polish champion, and a five-time participant of the Olympic Games (Atlanta 1996, Sydney 2000, Athens 2004, Beijing 2008, London 2012) (Eider, Eider, 2015b, 2017; Eider, 2020b; Kolbowicz, 2021; Piechal et al., 2019). His numerous sports achievements have been described in detail in many studies (e.g. Eider, Eider, 2015a, 2015b, 2017), and the President of Poland, Bronisław Komorowski, awarded him with the title of the Athlete of the First Decade of the 21st Century (Urbaś, 2011).

Discussion

For the first time in the history of the Summer Olympics, the International Olympic Committee has postponed the event to the following year. The largest quadrennial sports competition took place in the odd year, between July 23 and August 8, 2021, without the participation of spectators. This decision was made due to the spreading SARS-CoV-2 pandemic. As it turned out later, it was the right decision, which prevented numerous infections, deaths among the local population, as well as the organizers and participants of the Tokyo Olympics. However, postponing such a large event to the following year, maintaining the sports facilities, the Olympic village, etc., significantly increased the costs of its organization (Banio 2021b, Jastrząbek, 2021; Urbaś, 2021). A survey conducted among numerous athletes showed their positive attitude to the decision to reschedule the Games to 2021 (Banio, 2021c).

The Olympic Games Tokyo 2020 (the name Tokyo 2020 was retained by the decision of the IOC) were conducted under strict sanitary restrictions, so as not to increase the number of COVID-19 infections.

There were three athletes in the Polish Olympic team participating in the Tokyo competition associated with the University of Szczecin (US), the largest university in the Western Pomerania region. Two of them, Patryk Dobek and Adam Nowicki, are current students of the Faculty of Physical Culture and Health of the US, who skillfully combine competitive sports with education, while Marcin Lewandowski is a graduate of the Faculty of Physical Culture and Health Promotion of the US (Documentation, 2021).

Polish athletes won 14 medals at the Tokyo Olympics, including 4 gold ones, 5 silver ones, and 5 bronze ones – which is the best result so far in the 21st century. Among the medalists is Patryk Dobek, who unexpectedly won a bronze medal in the 800 m run. This was the first Olympic medal won by a Pole, as well as a European, at this distance since 2004. His results during the most important athletics competitions, medals he won and the results he obtained in 2021 indicated that he could become a great surprise at the Olympics. The tactics of rather slow final run, which he developed with his coach, Zbigniew Król, proved to be very successful.

The other US student, Adam Nowicki, performed well in the marathon run. He was among 76 runners who finished the marathon, and took the 37th place (as many as 30 participants withdrew and did not reach the finish line). Atmospheric conditions (high temperature, high humidity) were the main factors that negatively affected the runners who decided not to finish the marathon. It should be noted that Adam Nowicki was included in the central training program only a few months before his Tokyo start (Nowicki, 2021b). Lack of participation in previous training camps abroad (acclimatization) probably had a significant impact on his sports level in his debut marathon run.

Marcin Lewandowski had a very unsuccessful start at the Olympic Games in the 1,500 m run. He fell down in the qualifying run, and his leg injury flared up in the finals. In 2021, before Tokyo 2020, he participated in several athletic events, where he demonstrated a high sports level (including a new life record of 3:30.42). Many years of track and field experience and his results in the 1,500 m run indicated that he stood a good chance of competing in the Olympic finals and fighting for a medal. However, at the Tokyo Olympics, he was not able to fulfill his dream of being among the medalists.

Perhaps at the 33rd Olympic Games in Paris (2024 – potentially his fifth Olympics – he will win an Olympic medal?

Not only athletes participate in the Olympic Games – other participants include coaches, judges, association authorities and activists, doctors, physiotherapists, psychologists, and media representatives. In Tokyo, the coaching staff included Jacek Kostrzeba, a graduate of the Institute of Physical Culture at the University of Szczecin, who trained many athletes in middle-distance and endurance running. One of his trainees is Michał Rozmys – finalist in the 1,500 m run. Media representatives included Marek Kolbowicz PhD, a graduate of the Institute of Physical Culture at the Faculty of Life Sciences of the University of Warsaw, who acted as an expert in rowing and canoeing (Kolbowicz, 2021). He is a titled gold medalist in 4× rowing (Olympic champion, four-time world champion, European champion, and multiple Polish champion in various competitions). As an academic teacher, he has great knowledge of rowing, sports theory, and nutrition. He used his professional and training-related expertise during TV broadcasts from Tokyo of rowing competitions.

Other outstanding athletes also played the role of experts in their respective Olympic disciplines in Tokyo (e.g. Otylia Jędrzejczak, Sebastian Chmara). It was very fortunate that the authorities of Eurosport and TVP selected titled sportsmen for the commentators; they enriched the broadcast with their expert knowledge (Urbaś, 2021; Tymiński, 2021).

Conclusions

1. The 32nd Olympic Games Tokyo 2020 were held in 2021 due to the spreading pandemic of COVID-19.

2. The Polish Olympic team who participated in the Tokyo 2020 Games included three athletes (runners) associated with the University of Szczecin: Patryk Dobek – 800 m run, Marcin Lewandowski – 1,500 m run, and Adam Nowicki – marathon.

3. The coaching staff of Polish athletes included another graduate of the University of Szczecin, Jacek Kostrzeba.

4. Marek Kolbowicz, PhD – an employee of the Institute of Physical Culture Sciences at the Faculty of Health and Physical Culture of the University of Szczecin (INoKF WKFiZ US), acted as a TV commentator/rowing expert.

5. WKFiZ US' student – Patryk Dobek – won a bronze medal in the 800 m run, which was an unexpected surprise in the Polish Olympic team.

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MOTOR CONTROL MECHANISMS AND THE PRACTICE OF KRAV MAGA – A NARRATIVE ANALYSIS

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Abstract Krav Maga ('contact combat') is an Israeli hand-to-hand combat discipline that originated in the early 19th century in response to life-threatening conflicts. Today, Krav Maga is a popular self-defense and martial art discipline practiced and taught throughout the world. One of the key features of Krav Maga that distinguishes it from other combat disciplines is its dependence on *reflexive defense* – a natural and immediate defensive reaction. However, the relevant literature has not discussed the motor control mechanisms that underlie reflexive defense in hand-to-hand combat or that account for its temporal characteristics. This introductory study argues that the reflexive defense at the core of Krav Maga is a genuine reflex mediated at the brainstem level. The paper also discusses some aspects of reaction in the context of self-defense and combat sports, and the implications for the debate on whether Krav Maga training should involve more than one combat response to any given threat.

Key words motor control, Krav Maga, reflexive defense, self-defense

Introduction

The term martial arts (MA) is commonly associated with Asian fighting arts, such as karate, kung fu, and taekwondo; however, surprisingly, the term is derived from Mars, the name of the Roman god of war, ergo the name 'Arts of Mars' which was used as early as the 1550s in Europe (Clements, 2006). Today, the term MA may also be used when referring to *combat sports* such as judo and *combat systems* from non-Asian locations such as the French savate (Loudcher, 2007) or the Russian sambo (DeMarco, 2016).

While combat disciplines, combat sports, and MA are varied and have many distinguishing aspects, including their goals, origin, culture, technical characteristics, and philosophy, they also share some similarities because their physical skills "all stem from using the body or weapons for combat purposes" (Johnson, Ha, 2015, p. 65). Accordingly, they all use self-defense techniques to overcome an opponent; thus, reaction time is a significant factor in determining the result of a match or confrontation (Gierczuk, 2017).

Combat systems may also be referred to as 'reality martial arts' or 'reality based fighting' when they focus on real-world situations (i.e. 'the street'), as in the case of the *Keysi Fighting Method* (Bowman, 2014), or are used for army and security purposes, such as *Systema,* which is a Russian combat system (DeMarco, 2016). Krav Maga, which is the scope of this paper, is a combat system originally developed to save lives in real combat situations; however, in recent years, it has also begun to be learned and practiced as an MA (Mor, 2018).

Krav Maga's origins may be traced back to the 1920s, when the current land of Israel was under British mandate and was part of the area known internationally as Palestine (Mor, 2019). Two rival communities shared the land: Jews and Arabs. These two communities were generally hostile to one another and engaged in frequent and violent physical confrontations fueled by cultural, political, and ideological differences. The use of guns and rifles was restricted by the British, so violent exchanges were usually limited to manual combat, knives, swords, stick fighting, and stone throwing (Gross, 2010).

A Jewish paramilitary organization (the Hagana) that was involved in these hostilities sought to develop an effective hand-to-hand combat method to counter these frequent physical threats after known methods such as jujitsu failed to save lives in real combat situations (Mor, 2019). One of Hagana's members, Dr. Moshe Feldenkrais, conducted photographic 'experiments' in which colleagues were subjected to surprise attacks with knives in order to observe their natural reactions. It was found that the combatants' spontaneous reactions were commonly to "substitute an arm for the head, the throat, the back" (Leri et al, 1977) to protect themselves. These responses are known today in Krav Maga terminology as *reflexive defenses* (Netzer, 2020; Vardi, 2020).

The combat system that was developed by Feldenkrais involved the learning and practicing of specific counter-attack routines, each designed to deal with a different type of attack. These routines were executed immediately after the reflexive defense was completed (Cohen-Gil, 2013). The idea of executing an initial unconscious response followed by an *acquired counter-attack routine* (ACAR) was to maintain a shorter reaction time than would be achieved by the initial unconscious reaction alone, while producing a more effective counter to the physical threat. Renden et al. (2017) demonstrated that "Police officers' performance in high-pressure arrest situations improved after reflex-based self-defense training." This improved performance was attributed, among other factors, to the conversion of primary responses into tactical movements. These findings are in line with Feldenkrais' approach of using reflexive defense together with ACARs for achieving tactical advantage in hand-to-hand combat.

The main focus of this paper is the examination of the motor control systems underlying the reflexive defense and the ACAR. In addressing this issue, we also shed light on a major debate that has arisen among instructors of Krav Maga: the question of whether training a single ACAR per threat is more effective than teaching several alternative responses per threat (from which the individual chooses the one that is most appropriate).

Mechanisms in motor control and essential definitions

Before exploring the operation of the motor control mechanisms, it is important to define some of the key terms and concepts:

Motor control refers to the neuromuscular activity responsible for the performance of a motor skill, i.e. the pattern of neural signals that activate and coordinate the muscles and limbs to produce movements (Anderson, 2010; Raiola, 2017). In general, human movements can be purposeful, directed, and coordinated or they can be spontaneous. Furthermore, they can be simple or complex. These movements are controlled by the central nervous system (CNS), which consists of the brain and spinal cord and is made up of three types of neurons: (1) sensory neurons which gather information and send it to the CNS, (2) inter-neurons which are found in the core of the CNS and process the information, and (3) motor neurons, which send neural impulses from the CNS to skeletal muscle fibers that can translate such impulses into movement (Anderson, 2010).

A *motor program* may be defined as a stored neural pattern which is used to control a specific and well-coordinated motor movement (Anderson, 2010). Such stored sequences are quite often compared to a computer program. *Generalized motor programs* (GMPs) are variants of the movement-specific motor program that consist of an abstract, memory-based representation of the generic features of a class of actions, allowing practitioners to adjust the non-generic features to a changing situation while maintaining short response times (Keslo, 1997).

Motor learning deals with the process of acquiring motor skills, including the behavioral and/or neurological changes that occur while learning, and the variables that influence those changes (Anderson, 2010). Motor learning may be described as a continuous process of repetition and feedback of the same movement in order to create a motor program. However, the learning process may also involve (limited) variations in the patterns of movement, thus enabling the practitioner to optimize the process of learning itself and to develop a GMP for a given movement, rather than repeating precisely the same solution over and over again (Raiola, 2017).

A wide variety of *reflexes* in humans have now been identified. Among these are primitive newborn reflexes, such as the grasp reflex (Futagi, Suzuki, 2010), cranial reflexes (Hall, Chilcott, 2018), and tendon reflexes (Lees, Hurwitz, 2019), as well as other reflexes such as coughing or sneezing. The startle reflex, which causes a defensive response to a sudden or threatening stimulus, is the most relevant for this paper (Ramirez-Moreno, Sejnowski, 2012). While conscious and deliberate actions are processed at the cortical level (Kobesova, Kolar, 2014) and require a longer time to initiate (Valls-Solé, 1999), the neural pathways that subserve reflex responses are shorter and do not reach the cortical level. Instead, they are organized at the spinal and brainstem level (Kobesova, Kolar, 2014). Thus, the startle reflex center is located in the brainstem (Blumenthal, 2015) and has been shown to involve the amygdala, which is central to the perception and processing of emotions and to the response to external threats (including the mediation of defensive responses) (LeDoux, 2003). Humans portray the startle reflex in unconscious flexor defensive movements such as raising and drawing forward the shoulders, abducting the upper arms, or bending the elbows and knees, all executed in response to a sudden or threatening stimuli and potentiated by fear (Hamm, 2015).

Reaction time (RT) may be defined as the interval between the onset of a stimulus and the initiation of a response. *Movement time* (MT) is the interval between the initiation of a movement and its completion, and *response time* (ResT) is the sum of the RT and MT (Baayen, Milin, 2010).

A *simple reaction* happens when a person is required to initiate a single predetermined response to a defined specific stimulus such as light or sound. A *choice reaction* occurs when there are at least two possible stimulus response alternatives and the subject must choose the best response to the presented stimulus (Proctor, Schneider, 2018). Choice reactions entail longer RTs than simple reactions (Baayen, Milin, 2010).

Reaction in combat "is anything but simple" (Hermann, Scholz, Vieten, Kohloeffel, 2008, p. 419); it involves RT, choice reaction, and ResT (Gierczuk, 2018). Research indicates that many factors affect human RT parameters, including "age, sex, … central versus peripheral vision, practice, fatigue, fasting, breathing cycle, personality types, exercise, and intelligence of the subject" (Jain, Bansal, Kumar, Singh, 2015, p. 124). As for ResT, research suggests that it may be affected by various disruptions, physical exertion (Gierczuk et al., 2018), movement velocity, and agility (Zemková, 2016). Given that reacting quickly is a critical factor which can determine whether one wins (or loses) in combat sports (Gierczuk et al, 2017; Hermann et al., 2008), it is not surprising that understanding the mechanism and the effect of training on both RT and ResT has been of interest for quite some time (Cojocariu, 2011a; Gierczuk et al., 2018; Hermann et al., 2008; Mori, Ohtani, Imanaka, 2002; Petri et al., 2019; Zemková, 2016). The notion that RT and ResT are trainable is supported by papers demonstrating that experienced MA practitioners attain better results in choice reaction tasks than novice or untrained practitioners (Cojocariu, 2011b; Mori et al., 2002; Zemková, 2016). Even within the same combat sport of karate, when comparing the influence of two different types of training (i.e. kata versus kumite), results show that the latter scored significantly better on choice reaction and agility time (Zemková, 2016).

Analyzing Krav Maga's reflexive defense and acquired counter-attack routine using motor control mechanisms

When a Krav Maga practitioner is attacked by surprise, the appropriate response consists of two elements: The first is a reflexive phase, in which he reacts spontaneously (as Feldenkrais described it); the second is a learned or acquired set of movements by way of a counter-attack (the ACAR). In the following sections we discuss the motor control mechanisms of these elements.

Krav Maga's reflexive defense and the startle reflex

A surprise attack or a surprise physical menace is generally very intimidating and may cause physiological and behavioral responses. The nature of the initial response to the threat or attack is critical in determining whether the attacked person can escape intact or with minimal damage.

In 1927 Ivan Pavlov referred to the reflex of self-defense:

> The strong carnivorous animal preys on weaker animals, and these, if they waited to defend themselves until the teeth of the foe were in their flesh, would speedily be exterminated. The case takes on a different aspect when the defense reflex is called into play by the sights and sounds of the enemy's approach. Then the prey has a chance to save itself by hiding or by flight. (Pavlov, 1960)

It seems that what Pavlov referred to as the 'reflex of self-defense' and Feldenkrais identified as 'spontaneous movements' (later termed reflexive defense) are the unconscious flexor defensive movements of the startle reflex. The startle reflex is a response to sudden and extreme stimulation in visual, tactile, or auditory modalities (Blumenthal, 2015). It is represented by a variety of muscular contractions and autonomic responses (Blumenthal, 2015), which may serve to prevent injury (Hamm, 2015) and act to either prepare the body to escape or activate defensive responses (Blumenthal, 2015).

It is believed that the startle reflex is related to the Moro reflex found in newborns, which consists of abduction of the arms in response to sudden sensory stimuli. This response disappears at the age of about four months and is replaced by a generalized contraction of facial and limb muscles (Gómez-Nieto 2020).

Loud acoustic stimuli are commonly used in researching startle reactions. The acoustic startle reflex (ASR) has been shown to involve involuntary muscle contraction with an EMG response latency of about 10 ms. The ASR facilitates a defensive stance that will enable fast movement or escape if required (Gómez-Nieto, 2020). Given the very short latency of the ASR, and similar observations of the startle reflex in anencephalic infants, it is widely accepted that the startle reflex occurs via a subcortical reflex mechanism (Valls-Solé, 1999) and is mediated in the brainstem (Blumenthal, 2015; Gómez-Nieto, 2020).

The startle reflex is dominant in the first stages of the natural defense reaction when attentional factors are in play, and it is restrained in later phases when behavioral factors predominate. It has been shown that the startle reflex is amplified when a person is in an aversive emotional state and constrained when a person is in a positive emotional state (Vial, 2001). This is reflected physiologically in the behavior of the amygdala, which responds to aversive stimuli by neural transmission to various areas of the hypothalamus, midbrain, and brain stem, which in turn produce expressions of fear, including a potentiated startle response. An intense startle reflex of this kind can be associated with freezing, while escape behavior is associated with inhibition of the startle reflex (Hamm, 2015).

The startle reflex is also affected by other parameters such as the task situation, personality characteristics, clinical conditions, physical conditioning, and situational factors (Blumenthal, 2015).

Speed of response and ACAR

Minimizing ResT is an important factor in many sporting activities, but as mentioned, in the context of combat it may be critical to survival or to the avoidance of injury. However, the reduction of ResT alone may not be sufficient; the generated response must also be relevant to the menace and an effective counter to the threat.

We note that the fastest RTs occur in simple reactions when the subject is presented with only one stimulus and required to make a single, pre-determined response. As the number of alternatives increase, in accordance with Hick's law (Pavão, 2016), RT also increases; this is because discrimination between a number of stimuli and selection of one of a set of response alternatives take time. The increased latency of a choice reaction means that, in the context of self-defense, training combatants to use only one ACAR for a specific menace may serve as a means of reducing RT, due to the decrease in the number of response alternatives.

Alertness and readiness to respond have also been shown to reduce RT. Thus a warning signal that is temporally close to the stimulus requiring action reduces the RT. However, if the interval between the warning and the 'go signal' is too long, the RT increases (Magill, Anderson, 2010).

Training to perform an ACAR in conjunction with the startle reflex may also shorten a process known as the psychological refractory period (PRP). When an action involves two stimulus response chains in sequence, the RT to the second stimulus may be extended due to the operation of the PRP; that is, there may be a delay due to the time required to complete the selection of the first response before selecting the second (Pashler, 1994). This is the situation that presents itself in hand-to-hand combat because a series of stimuli (attacks, movements, noises) must be responded to in rapid succession. It follows that if combatants are given training in generating an ACAR immediately after the startle reflex, as proposed by Feldenkrais, the PRP (after the startle reflex is performed) may be shortened or even eliminated.

Finally, once an ACAR has been successfully coupled with a specific reflex response, and the pairing has been sufficiently practiced, it is possible that the neural mechanisms underlying the movements will enable the creation of a GMP, which will in turn reduce the total ResT.

Discussion

In combat sports, matches are often decided in a split second. Athletes need to quickly identify stimuli, process their significance, and choose the best response which will allow them to gain an advantage and hopefully win the match (Badau, Baydil, Badau, 2018; Pavelka et al., 2020) Thus, provoking instinctive reactions which will allow athletes to react automatically is a major part of training (Mladenovic, Educati, 2015) for athletes and combatants alike. What seems to a bystander to be spontaneous, semi-reflex blocking, attacking, or evasion in combat sports is actually the result of years of accumulated training targeting reaching these specific automated responses (Ericsson, 2014). The importance of accumulated training is evident when comparing combat sport athlete training to police personnel hand-to-hand combat training. The length and magnitude of the latter is limited due to time and budget constraints. For example, “Dutch police officers train their arrest and self-defense skills only four to six hours per year” (Renden, 2015, p. 1496). In such short periods of training, reaching automatization of reactions without relying on ‘reflex-based training’ is most likely impossible.

As discussed, combat sports and real-life fighting share some similar characteristics as the need for short RT and ResT, practice of block-attack combinations, training for automatization of response and the need for agility. However, there are also some significant differences which should be noted such as: (1) the length of self-defense training is usually much shorter; therefore, creating automated response through numerous repetitions is irrelevant. (2) “attacks on the street differ substantially from the ones confronted with in the training environment” (Staller, 2017, p. 71), simply because in combat sports attacks must follow competition rules. Thus, training and transferring motor skills to the ‘street’ requires adaptations to varied conditions of dissimilar contexts (Collard, 2007). (3) anxiety plays a dominant role in real combat situations and may negatively affect perceptual-motor performance (Renden, 2015). Though combat-sports athletes may also encounter some levels of anxiety, pre and during matches; it is different than the one arises from real violent confrontations where outcomes maybe fatal.

It seems that by harnessing the startle reflex to an ACAR, Feldenkrais created a motor pattern which optimizes the tradeoff between the speed of the reaction and the effectiveness of the counter-attack. Since this motor pattern is reflex-based, i.e. based on the startle reflex, it seems that it enables the automatization phase to be reached in a shorter training time than that required for encoding a motor pattern based on repetitions alone. The downside may be that when a single ACAR is practiced and generated automatically as a motor pattern in response to a threatening stimulus, it exposes the combatant to the risk that the acquired routine may not be the best option to counter that specific menace. In contrast, practicing several movement patterns for each specific menace may achieve better relevance but at the cost of an extended RT. Thus, there is a tradeoff between relevance (i.e. effectiveness) and response latency.

The choice between teaching one ACAR or several options is one of the commonly debated issues among Krav Maga instructors. Training in one ACAR is mostly favored by military personnel, whereas teaching several options per threat is preferred by civilian Krav Maga instructors. A commercial factor may be at play here, as it is considerably easier to maintain interest and preserve civilian student numbers over a long period if a variety of techniques is associated with each type of physical threat.

Additional issues for consideration in this context are:

1. The length of training required to embed multiple automated responses. This will be longer than for the single ACAR approach and therefore renders the multiple response model less acceptable when training time is restricted. However, for training civilians, this may not be a constraint.
2. There are benefits arising from the multiple response approach. These include the contribution to practitioner coordination; enhanced interest in and enjoyment of the training process; and enabling the practitioner to choose a response pattern best suited to his or her body type and characteristics.

To summarize this point, while it is clear that teaching a single ACAR response minimizes RT and takes less time to assimilate (which may be crucial for combat professionals), this should be balanced against the benefits of providing multiple-response training for any given threat. These benefits, as set out above, may be more salient for civilians who engage in Krav Maga training as a form of MA.

An additional issue arises from the reciprocal relationship between RT and the timing of the go signal. As noted, if the go signal is unduly delayed, RT will be extended, thus generating a significant disadvantage in the context of hand-to-hand combat. In such situations we argue that a proactive response might be a better option than waiting for the assailant to initiate an attack. This idea is reflected in one of the basic principles of the Israeli combat discipline dating back to the mid-1940s that initiating attack is preferable to a responsive defense (Unknown). However, initiation of an attack brings with it moral, professional, and legal issues that require additional consideration.

Conclusion

Our analysis demonstrates that key elements of the Krav Maga combat system – the importance of pairing acquired responses with the initial automatic startle reflex, the advantage of anticipatory responses, the impact of training on reducing refractory periods, and the logic behind training one ACAR per given threat - have a rationale grounded in contemporary motor control theory. This provides a retrospective justification for principles that were articulated in the early 20th century, before the physiological mechanisms were fully understood.

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RELATIVE AGE EFFECT: A SYSTEMATIC DISCRIMINATION AGAINST BIOLOGICALLY YOUNGER ATHLETES

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Abstract Physical differences associated with birth-date among athletes of the same selection year have been described as the Relative Age Effect (RAE). The aim of this study was to examine whether RAE still exists in soccer and running sport disciplines as well as to evaluate its progress among different gender, age, and sport context and if it has an effect on performance. Using official archives of the international sports' associations (World Athletics-UEFA), birthdates and performance were collected for 7,226 athletes (4,033 males; 3,198 females) who participated in soccer and running events. A chi-square test was used to assess differences between observed and expected birth date distributions. The study showed an over-representation of athletes born in the first quarter of the selection year for both soccer and running events. RAE is more obvious in younger age groups and in sports that require higher explosive speed, strength, power and anaerobic capacity such as soccer and short distance sprints. It was also found that RAE is associated with performance. In conclusion, athletes of younger age groups with greater biological age have a physical advantage in explosive sports (i.e. soccer and short distance running) that probably does not predict their future development.

Key words RAE, talent, soccer, running

Introduction

Within youth sports, athletes are generally assigned to groups according to their chronological age for the purpose of providing them the appropriate and equal opportunities of training and competition (Cobley, Baker, Wattie, McKenna, 2009; Kearney, Hayes, Nevill, 2018). These competitive opportunities are used for talent identification processes and can potentially provide equal learning experiences (Mohamed et al., 2009). Although, grouping athletes in categories according to their chronological age appears to be a practical, equitable and safe process, the research has shown that relatively older athletes within such groups are supposed to be advantaged (Smith, Weir, Till, Romann, Cobley, 2018). However, even if youngsters belong to the same chronological group they may differ markedly with respect to biological maturation (Baxter-Jones, Eisenmann, Sherar, 2005; Lloyd, Oliver, Faigenbaum, Myer, Croix, 2014). Furthermore, these differences are also heightened due to the two year chronological range that many sports use to classify young athletes into groups (Sherar, Esliger, Baxter-Jones, Tremblay, 2007). Literature review confirms this suggestion by highlighting a disproportionate number of athletes born shortly after the cut-off date of the age group compared to the ones born shortly before it. This phenomenon is defined Relative Age Effect (RAE) which refers to the asymmetry of birth distribution within each sport population.

The RAE phenomenon is observed in several team and individual sports, including soccer (Práxedes, Moreno, García-González, Pizarro, Del Villar, 2017), basketball (Arrieta, Torres-Unda, Gil, Irazusta, 2016), swimming (Nagy, Földesi, Sós, Ökrös, 2018), tennis (Gerdin, Hedberg, Hageskog, 2018), track and field (Brazo-Sayavera, Martinez-Valencia, Mueller, Andronikos, Martindale, 2018). The underlying causes of RAE are potentially multifactorial due to the differences in physical, physiological, cognitive, psychological and social characteristics (Smith et al., 2018). According to the maturation-selection hypothesis, relatively older athletes within the age group indicate more favorable anthropometrical and physical characteristics which may provide them with various performance advantages (Cobley et al., 2009; Lovell, Towlson, Parkin, Portas, Vaeyens, Cobley, 2015). Although the initial advantage of relatively older athletes is already known, most of the trainers strengthen the developmental advantages by providing them with greater opportunities of supplementary coaching and accessibility to higher level of competition that probably influences their progress and participation in later years (Cobley et al., 2009; Hancock, Adler, Côté, 2013). Consequently younger athletes are more likely to feel failure, frustration and finally dropout of sports and talent pools due to less sport experiences, enjoyment, rewards and success (Delorme, Chalabaev, Raspaud, 2011; Hollings, Hume, Hopkins, 2014). On the other hand, the remaining younger athletes are more likely to excel as adults and have a longer and a more successful career than their older peers (Deaner, Lowen, Cobley, 2013; McCarthy Collins, 2014).

It is clear that youths born early in the year are more experienced and physically superior than their peers who were born later (Milić, 2016). Literature review showed that as sport contexts rely on different technical, cognitive and gross motor abilities, they may show relative age effects at different trainable aspects (Kearney et al., 2018). It seems that the strength of RAE depends on sport, gender, age category and skill level factors (Cobley et al., 2009; Smith et al., 2018). In particular, although gender makes a little difference to the overall RAE distribution, it has been found that the highest level of RAE is associated with the youngest age categories in females but with the adolescence in males. This difference is probably explained by the earlier biological growth of females and their faster development in motor coordination, body control and physical characteristics (Smith et al., 2018). In total, RAE progressively increased from the child (<11 yrs) to the adolescent age (15–18 yrs) before reduced within the senior age (>18 yrs). This reduction is probably explained by several mechanisms such as higher rates of dropping out of younger athletes (Lemez, Fraser-Thomas, 2018; Penna, Campos, Gonçalves, Godinho, Lima, Prado, 2018), reduction of physical maturity differences (Cobley et al., 2009), and transfer from one sport to another depending on the compatibility of performance requirements (Baker, Cote, Abernethy, 2003). Regarding the relationship between RAE and competition level, it has been found an increased magnitude of RAE at higher competition levels (Cobley et al., 2009; Lovell et al., 2015; Romann, Cobley, 2015). As far as the association between sport context and RAE, it seems that technical/skill-based or weight-categorized sports were generally not associated with RAE (Albuquerque, Fukuda, Da Costa, Lopes, Franchini, 2016; Côté, MacDonald, Baker, Abernethy, 2006; Delorme, Raspaud, 2009). On the other hand RAE is extremely high in team sports, where athletes' comparisons appear on the field of play, as well as in sports emphasizing on individual anthropometric and physical differences characteristics. Therefore greater RAE occurs in physical demanded sports such as basketball, volleyball, soccer, track and field (Cobley et al., 2009; Romann, Fuchslocher, 2014; Smith et al., 2018).

It is obvious that RAE occurs mostly in physical based sports in which biological maturation may affect performance. This phenomenon frequently leads on increases of dropping out rates and a reduction of potentially youth talented athletes, which in long term contributes to a performance reduction of top level and national teams (Pizzuto, Bonato, Vernillo, La Torre, Piacentini, 2017; Jiménez, Pain, 2008). Furthermore, in order to monitor the youths' development, trainers and coaches have to take into consideration the performance characteristics of each sport so as to identify strengths and weaknesses of their athletes, prescribe and evaluate training, as well as to select the real talents instead of the more mature (de Freitas, Werneck, de Souza, de Castro, Figueiredo, de Lima, 2020). In particular, soccer and running are commonly considered as physically demanded sports that coaches evaluate similar characteristics such as physical size, strength, flexibility, coordination, speed, aerobic and anaerobic capacity to identify potentially future talents (Furley, Memmert, 2016; Henriksen, Stambulova, Roessler, 2010; Hollings et al., 2014; Kruger, Pienaar, 2009; Pandi, 2018; Sarmento, Anguera, Pereira, Araújo, 2018). Although running requires higher individual physical development due to the single attributes it includes (i.e. sprinting), the majority of RAEs' studies focus on team sports (Cobley et al., 2009). Therefore, the purpose of the current study was to determine RAE prevalence and magnitudes across soccer and running and its relationship with performance. Furthermore, in order to identify moderators of RAE magnitude, identified samples were examined in subgroups according to gender, age, and sport discipline. Based on existing literature, we hypothesized that RAE was prevalent across both soccer and running with a greater magnitude in physically demanded running disciplines. RAE was also expected to be stronger within male population but lower in older age groups. As the evidence relating to the relationship between RAE and performance within sport disciplines is equivocal, no predictions were made.

Material and Methods

Participants

Data were acquired from the official web-sites of World Athletics and UEFA. These databases provide information about athletes' performance and age as well as teams' performance. Participants were collected from different individual and team sport events, which represent the core athletic disciplines, such as running (100 m, 800 m, 1,500 m, 3,000 m, 5,000 m, 10,000 m, hurdles), and soccer. In total the researchers recorded the date of births of 7,226 athletes (n = 4,033 males; 3,198 females) who had been selected to participate in IAAF world championships throughout 2011–2018 and UEFA 2020 European championships. The participants who were recorded derived from U-18 and U-20 running events as well as U-17 and U-19 soccer events. As previously suggested, athletes who ranked in multiple events were only counted within the event in which they ranked most highly (Kearney et al., 2018). Furthermore, although an informed consent was not needed as the reported data were available online, the researchers reported them anonymously.

Procedures

Athletes were classified by birthdates according to the international cut-off date of 1st January. Although, most of the athletes who are selected to participate in youth national teams organized within a one or two-year difference for each age band, in soccer some were even younger. For each of the two age categories, the birth month of each athlete was recorded within a three month birth quarter (Q1: January, February, and March; Q2: April, May, and June; Q3: July, August, and September; Q4: October, November, and December; Q5: January, February, and March of the next years etc). Performance was evaluated by qualification, semi-final and final ranking for runners individually and by final ranking, total points, and qualification attainment for soccer teams. The study was conducted according to the Declaration of Helsinki, and the protocol was approved by the University Ethics Committee of the School of Physical Education and Sport Science before the beginning of this study.

Data analysis

Frequencies were obtained for each birth quartile to record the total distribution of the sample (Brazo-Sayavera et al., 2018).Then, chi-square test was used to assess differences between observed and expected relative age distribution according to gender and age category. Linear regression analyses using performance as the dependent variable considering gender, age, and disciplines was performed. Correlation coefficients (r), adjusted coefficients of determination (R^2), standard estimate errors (SEE) and analyses of variance were calculated. Finally, residuals were assessed for normality, independence, linearity, and homoscedasticity, whereas all statistical assumptions for linear regression were met. The magnitude of the correlation coefficients (r) was examined according to Hopkins (2006) as follows: very small <0.1, small 0.1–0.3, moderate 0.3–0.5, large 0.5–0.7, very large 0.7–0.9, nearly perfect >0.9 and perfect r = 1. The statistical package IBM SPSS v.23 was used for analysis and the level of significance was set at $p < 0.05$.

Results

A total of 7469 participants were recorded of which 243 excluded (3.25%) due to missing data. The following table presents sample details of the remaining 7,226 participants (Table 1).

Table 1. Sample details according to age, gender and sport

Age	Gender	Sport									Total
		100 m	100/110 m hurdles	400 m hurdles	800 m	1,500 m	3,000 m	5,000 m	10,000 m	soccer U-17/U-19	
U-18	males	286	151	161	–	–	–	–	–	894	1492
	females	238	141	122	–	–	–	–	–	758	1259
U-20	males	215	222	197	324	271	105	87	95	1025	2541
	females	188	170	159	269	211	121	65	–	751	1939
Total		927	684	639	593	482	226	152	95	3428	7226

Figures 1 and 2 show the birth-date proportions within quartiles of all the participants according to their gender and age category. In particular, Figure 1 shows that: 37% males and 20% females of the U-17 or U-18 sample born in the 1st quartile of two years; 25% males and 18% females of the U-17 or U-18 sample born in the 2nd quartile of two years; 16% males and 16% females of the U-17 or U-18 sample born in the 3rd quartile of two years; 11% males and 12% females of the U-17 or U-18 sample born in the 4th quartile of two years; 5% males and 11% females of the U-17 or U-18 sample born in the 5th quartile of two years; 4% males and 10% females of the U-17 or U-18 sample born in the 6th quartile of two years; 1% males and 7% females of the U-17 or U-18 sample born in the 7th quartile of two years; 2% males and 6% females of the U-17 or U-18 sample born in the 8th quartile of two years (Figure 1).

Similarly, Figure 2 shows that: 25% males and 15% females of the U-19 or U-20 sample born in the 1st quartile of four years; 20% males and 13% females of the U-19 or U-20 sample born in the 2nd quartile of four years; 14% males and 12% females of the U-19 or U-20 sample born in the 3rd quartile of four years; 11% males and 10% females of the U-19 or U-20 sample born in the 4th quartile of four years; 10% males and 13% females of the U-19 or U-20 sample born in the 5th quartile of four years; 7% males and 11% females of the U-19 or U-20 sample born in the 6th quartile of four years; 6% males and 9% females of the U-19 or U-20 sample born in the 7th quartile of four years; 4% males and 8% females of the U-19 or U-20 sample born in the 8th quartile of four years; whereas the rest 4% males and 8% females of the U-19 or U-20 sample born in the following two years (Figure 2).

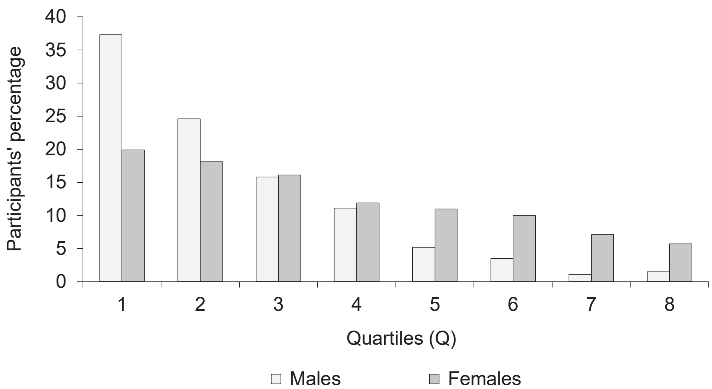

Figure 1. Birth date proportions within quartiles and gender for U-17 or U-18 participants

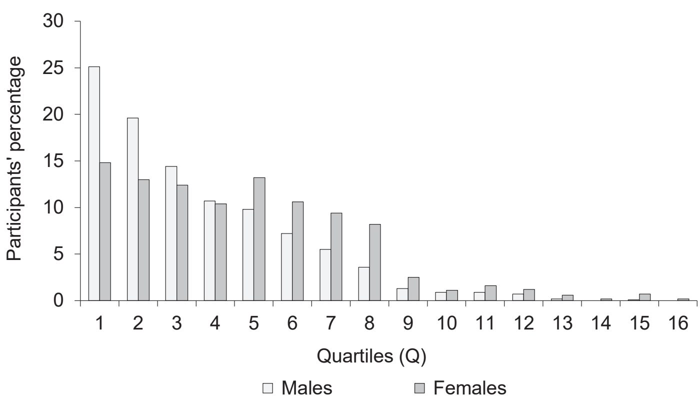

Figure 2. Birth date proportions within quartiles and gender for U-19 or U-20 participants

Table 2 shows the quartile distributions and chi-squares subdivided according to gender, age category, and sport discipline. The results showed significant differences between quartiles for both U-18 and U-20 100 m males and females (U-18 males: $\chi^2 = 154.84$, $p = 0.000$; U-18 females: $\chi^2 = 24.19$, $p = 0.001$; U-20 males: $\chi^2 = 104.40$, $p = 0.000$; and U-20 females: $\chi^2 = 66.04$, $p = 0.000$), U-18 and U-20 110 m hurdles males and 100 m hurdles females (U-18 males: $\chi^2 = 128.68$, $p = 0.000$; U-18 females: $\chi^2 = 39.82$, $p = 0.000$; U-20 males: $\chi^2 = 144.58$, $p = 0.000$; and U-20 females: $\chi^2 = 100.12$, $p = 0.000$), U-18 and U-20 400 m hurdles males and females (U-18 males: $\chi^2 = 8.21$, $p = 0.000$; U-18 females: $\chi^2 = 46.79$, $p = 0.000$; U-20 males: $\chi^2 = 136.26$, $p = 0.000$; and U-20 females: $\chi^2 = 113.16$, $p = 0.000$), U-20 800 m males and females (U-20 males: $\chi^2 = 87.40$, $p = 0.000$; U-20 females: $\chi^2 = 76.02$, $p = 0.000$), U-20 1500 m males and females (U-20 males: $\chi^2 = 114.44$, $p = 0.000$; U-20 females: $\chi^2 = 54.79$, $p = 0.000$), U-20 3,000 m males ($\chi^2 = 73.67$, $p = 0.000$), U-20 5,000 m males and females (U-20 males: $\chi^2 = 40.76$, $p = 0.000$; U-20 females: $\chi^2 = 27.86$, $p = 0.000$), U-20 10,000 m males ($\chi^2 = 55.84$, $p = 0.000$), but not significant relative age distribution for U-20 3,000 m females ($\chi^2 = 10.28$, $p = 0.591$). Finally, the results showed significant differences between quartiles for both U-17 and U-19 soccer males and females (U-17 males: $\chi^2 = 1074.81$, $p = 0.000$; U-17 females: $\chi^2 = 112.63$, $p = 0.000$; U-19 males: $\chi^2 = 1,321.98$, $p = 0.000$; and U-19 females: $\chi^2 = 381.78$, $p = 0.000$) (Table 2).

A significant regression equation was found for 100 m hurdles U-18 female athletes ($F_{(1, 139)} = 4.533$, $p = 0.035$), with and R^2 of 0.032. Participants' predicted performance is equal to 2.818 + 0.072 (age) ranking when age is measured in quartiles. Participant's performance reduced 0.072 ranking for each quartile of age. A significant regression equation was found for 100 m U-20 male athletes ($F_{(1, 212)} = 2.679$, $p = 0.103$), with and R^2 of 0.012. Participants' predicted performance is equal to 3.201 + 0.031 (age) ranking when age is measured in quartiles. Participant's performance reduced .031 ranking for each quartile of age. A significant regression equation was found for 100 m U-20 female athletes ($F_{(1, 186)} = 4.401$, $p = 0.037$), with and R^2 of 0.023. Participants' predicted performance is equal to 3.038 + 0.037 (age) ranking when age is measured in quartiles. Participant's performance reduced 0.037 ranking for each quartile of age. A significant regression equation was found for 100 m hurdles U-20 male athletes ($F_{(1, 220)} = 2.875$, $p = 0.091$), with and R^2 of 0.013. Participants' predicted performance is equal to 3.215 + 0.037 (age) ranking when age is measured in quartiles. Participant's performance reduced 0.037 ranking for each quartile of age. A significant regression equation was found for 1,500 m U-20 male athletes ($F_{(1, 149)} = 7.858$, $p = 0.006$), with and R^2 of 0.050. Participants' predicted performance is equal to 2.798 + 0.052 (age) ranking when age is measured in quartiles. Participant's performance reduced 0.052 ranking for each quartile of age. A significant regression equation was found for 5,000 m U-20 male athletes ($F_{(1, 85)} = 7.539$, $p = 0.007$), with and R^2 of 0.081. Participants' predicted performance is equal to 2.008 + 0.028 (age) ranking when age is measured in quartiles. Participant's performance reduced 0.028 ranking for each quartile of age. A significant regression equation was found for 5,000 m U-20 female athletes ($F_{(1, 63)} = 2.395$, $p = 0.127$), with and R^2 of 0.037. Participants' predicted performance is equal to 1.942 + 0.023 (age) ranking when age is measured in quartiles. Participant's performance reduced 0.023 ranking for each quartile of age. A significant regression equation was found for 10,000 m U-20 male athletes ($F_{(1, 93)} = 2.017$, $p = 0.006$), with and R^2 of 0.077. Participants' predicted performance is equal to 2.017 + 0.031 (age) ranking when age is measured in quartiles. Participant's performance reduced .031 ranking for each quartile of age. A significant regression equation was found for 800 m U-20 male athletes ($F_{(1, 167)} = 3.041$, $p = 0.083$), with and R^2 of 0.018. Participants' predicted performance is equal to 1.388 + 0.023 (age) ranking when age is measured in quartiles. Participant's performance reduced 0.023 ranking for each quartile of age.

Table 2. Relative age distribution by gender, age category and sport discipline

	100 m				100 m hurdles				400 m hurdles				800 m		1500 m		3,000 m		5,000 m		10,000 m	Soccer			
	U-18		U-20		U-18		U-20		U-18		U-20		U-20		U-20		U-20		U-20		U-20	U-17		U-19	
	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	M	F	M	F
Q1	86	51	36	22	57	36	41	28	45	29	45	16	35	17	19	8	36	7	16	9	24	368	135	296	127
Q2	66	33	29	10	36	30	33	28	36	27	28	21	26	11	25	16	18	3	15	10	17	229	138	255	104
Q3	36	30	22	22	19	17	27	16	33	26	32	24	24	18	30	13	23	8	7	7	10	148	130	155	89
Q4	39	23	18	21	14	12	27	15	18	9	14	23	10	14	19	13	9	5	7	6	18	95	106	110	68
Q5	26	34	23	21	10	15	31	22	10	9	24	27	22	18	16	18	9	6	11	13	8	31	81	83	110
Q6	21	24	22	15	6	13	28	21	10	6	22	20	18	15	13	12	4	5	4	4	3	15	83	51	84
Q7	5	25	23	18	4	10	13	13	4	9	18	6	9	11	10	12	3	5	6	3	5	3	46	40	82
Q8	7	18	17	19	5	8	8	7	5	7	4	8	8	18	8	11	3	4	8	4	6	5	39	24	74
Q9			5	14			3	6			6	7	6	4	2	6		2	3	4	3			5	5
Q10			5	3			6	3			2	1	2	2	4	4		4	1	1				2	3
Q11			7	7			2	4			1	2	5	5	2	5		4	3					3	3
Q12			5	4			2	5				2	4	2	1	2		3	4	3				1	2
Q13			2	5				1				1		3	1				2	1					
Q14							1							2		1		1							
Q15			1	5				1			1	1		4	1	2									
Q16				2										1		1					1				
Total	286	238	215	188	151	141	222	170	161	122	197	159	169	145	151	124	105	57	87	65	95	894	758	1025	751
Expected	35.8	29.8	15.4	12.5	18.9	17.6	17.1	12.1	20.1	15.3	16.4	11.4	14.1	9.1	10.8	8.3	13.1	4.4	6.7	5.4	9.5	111.8	94.8	85.4	62.6
X^2	154.84	24.19	104.40	66.04	128.68	39.82	144.58	100.12	86.21	46.79	136.26	113.16	87.40	76.02	114.44	54.79	73.67	10.28	40.76	27.86	55.84	1074.81	112.63	1321.98	381.78
P	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.591	0.000	0.003	0.000	0.000	0.000	0.000	0.000

Table 3. Performance distribution according to birth quartile

Sport		U-18 equation	U-18 r	U-18 R^2	U-18 SEE	U-18 F	U-18 P	U-20 equation	U-20 r	U-20 R^2	U-20 SEE	U-20 F	U-20 P
100 m	males	3.367 + 0.030	0.067	0.004	0.845	1.238	0.267	3.201 + 0.031	0.112	0.012	0.865	2.679*	0.103
	females	3.333 + 0.004	0.010	0.000	0.897	0.024	0.876	3.038 + 0.037	0.152	0.023	0.882	4.401**	0.037
100 m hurdles	males	3.164 + 0.015	0.030	0.001	0.929	0.132	0.717	3.215 + 0.037	0.114	0.013	0.857	2.875*	0.091
	females	2.818 + 0.072	0.178	0.032	0.893	4.533**	0.035	3.055 + 0.026	0.090	0.008	0.898	1.377	0.242
400 m hurdles	males	3.057 + 0.034	0.069	0.005	0.913	0.756	0.386	3.214 + 0.021	0.060	0.004	0.884	0.697	0.405
	females	2.875 + 0.018	0.042	0.002	0.928	0.211	0.646	2.990 + 0.028	0.083	0.007	0.902	1.102	0.295
800 m	males							1.388 + 0.023	0.134	0.018	0.498	3.041*	0.083
	females							3.182 + 0.016	0.063	0.004	0.929	0.566	0.453
1,500 m	males							2.798 + 0.052	0.224	0.050	0.623	7.858***	0.006
	females							2.566 + 0.007	0.037	0.001	0.671	0.164	0.686
3,000 m	males							2.480 + 0.046	0.126	0.016	0.677	1.656	0.201
	females							1.926 + 0.014	0.137	0.019	0.368	1.052	0.309
5,000 m	males							2.008 + 0.028	0.285	0.081	0.322	7.539***	0.007
	females							1.942 + 0.023	0.191	0.037	0.374	2.395*	0.127
10,000 m	males							2.017 + 0.031	0.278	0.077	0.284	7.805***	0.006
	females												

* p < 0.10; ** p < 0.05; *** p < 0.01.

The following table shows the relationship between relative age effect measured by the medians of each team with team performance measured by ranking, points, and qualification. Statistical testing of this relationship revealed significant correlations for U-17 male players between rank, points and qualification with RAE medians (Spearman's $r = 0.306$, $p = 0.038$; $r = -0.379$, $p = 0.009$; and $r = 0.317$, $p = 0.032$, respectively), and a linear regression analysis ($F_{(1, 44)} = 5.118$, $p = 0.029$; $F_{(1, 44)} = 6.615$, $p = 0.014$; $F_{(1, 44)} = 5.753$, $p = 0.021$, respectively) with R^2 of 0.104; 0.131; 0.116 respectively. Teams' predicted performance is equal to 1.103 + 0.670; 8.292 + 1.934; 0.835 + 0.329 revealing that having a median earlier quartile is associated with an advantage of 0.670 ranks, 1.934 points, and 0.329 qualification. Statistical testing of this relationship revealed significant correlations for U-17 female players between rank, points and qualification with RAE medians (Spearman's $r = 0.403$, $p = 0.009$; $r = -0.346$, $p = 0.027$; and $r = 0.391$, $p = 0.011$, respectively), and a linear regression analysis ($F_{(1, 39)} = 7.097$, $p = 0.011$; $F_{(1, 39)} = 4.541$, $p = 0.039$; $F_{(1, 39)} = 6.419$, $p = 0.015$, respectively) with R^2 of 0.154; 0.104; 0.141 respectively. Teams' predicted performance is equal to 0.877 + 0.462; 8.126 + 1.085; 0.791 + 0.200 revealing that having a median earlier quartile is associated with an advantage of 0.462 ranks, 1.085 points, and 0.200 qualification. Statistical testing of this relationship revealed significant correlations for U-19 male players between rank, points and qualification with RAE medians (Spearman's $r = 0.353$, $p = 0.010$; $r = -0.389$, $p = 0.004$; and $r = 0.256$, $p = 0.067$, respectively), and a linear regression analysis ($F_{(1, 50)} = 7.149$, $p = 0.010$; $F_{(1, 50)} = 9.445$, $p = 0.003$; $F_{(1, 50)} = 2.983$, $p = 0.090$, respectively) with R^2 of 0.125;

0.159; 0.256 respectively. Teams' predicted performance is equal to 1.452 + 0.407; 7.466 + 1.233; 1.186 + 0.122 revealing that having a median earlier quartile is associated with an advantage of 0.407 ranks, 1.233 points, and 0.122 qualification. Statistical testing of this relationship revealed significant correlations for U-19 female players between rank, points and qualification with RAE medians (Spearman's r = 0.404, p = 0.012; r = –0.285, p = 0.083; and r = 0.292, p = 0.076, respectively), and a linear regression analysis ($F_{(1, 36)}$ = 6.893, p = 0.013; $F_{(1, 36)}$ = 3.568, p = 0.067; $F_{(1, 36)}$ = 3.236, p = 0.080, respectively) with R^2 of 0.161; 0.090; 0.082 respectively. Teams' predicted performance is equal to 0.647 + 0.331; 8.609 + 0.725; 0.821 + 0.123 revealing that having a median earlier quartile is associated with an advantage of 0.331 ranks, 0.725 points, and 0.123 qualification (Table 4).

Table 4. Impact of the RAE on Performance variables

Soccer		Age											
		U-17						U-19					
		Equation	r	R^2	SEE	F	P	Equation	R	R^2	SEE	F	P
Ranking	males	1.103 + 0.670	0.323	0.104	1.030	5.118	0.029	1.452 + 0.407	0.354	0.125	1.067	7.149	0.010
	females	0.877 + 0.462	0.392	0.154	1.044	7.097	0.011	0.647 + 0.331	0.401	0.161	0.862	6.893	0.013
Points	males	8.292 + 1.934	0.362	0.131	2.616	6.615	0.014	7.466 + 1.233	0.399	0.159	2.814	9.445	0.003
	females	8.126 + 1.085	0.323	0.104	3.066	4.541	0.039	8.609 + 0.725	0.300	0.090	2.629	3.568	0.067
Qualification	males	0.835 + 0.329	0.340	0.116	.477	5.753	0.021	1.186 + 0.122	0.237	0.256	0.495	2.983	0.090
	females	0.791 + 0.200	0.376	0.141	.475	6.419	0.015	0.821 + 0.123	0.287	0.082	0.467	3.236	0.080

Discussion

Given the necessity to understand and isolate the mechanisms causing RAE, and to suggest appropriate solutions to eliminate this diachronic phenomenon the researchers examined relative age effect in two high physical demanded individual and team sport contexts and its relationship with performance. Although past research has long documented the need for changes in the registration of players in sports so as to reduce the effects of RAE, the current findings indicate that this issue still remains unsolved.

RAE magnitude and age

The analyses in our study showed that greater RAEs were found at U-17–U-18 age category compared to the U-19–U-20 category. The higher RAE of younger athletes has been corroborated by previous studies which suggest that it weakens across time from U-18 to U-20 in running (Brazo-Sayavera et al., 2018; Hollings et al., 2014) and from U-17 to U-19 in soccer (Helsen, Van Winckel, Williams, 2005) sport contexts. The reduction of RAE at the older age category is difficult to explain, with various mechanisms possibly affecting RAE in the early stages of commitment but reducing during the later years. In particular, differences due to physical maturity become redundant at later development stages, allowing players of older age groups to perform on a more equal way (Cobley et al., 2009). In addition, parents, coaches and/or athletes all amplify the RAE at a different way especially in younger ages (Hancock, Ste-Marie, Young, 2013). For example, parents may affect RAE through enrolling in sports relatively older players whereas coaches might place greater expectations and advantage to relatively older athletes (Brustio et al., 2019). Finally, the larger RAE in U-18 group of track and field athletes might be due to the unique scheduling of World Athletics championships. Specifically, older athletes of U-18 group have an advantage that reverses when they become the younger athletes of the U-20 group the following year. Respectively, the disadvantaged younger U-18 group athletes enjoy the advantage of competing at the U-20 group three years later. These reversals possibly reduce the RAE of older age categories (Hollings et al., 2014).

RAE magnitude and gender

Moreover, an overall RAE was evident across all participants, with males showing a stronger effect than female athletes in both track and field sport disciplines and soccer. This finding has been supported by studies which revealed that RAE is evident, albeit is less pronounced in female events (Hollings et al., 2014; Saavedra-García, Gutiérrez-Aguilar, Sa-Marques, Fernández-Romero, 2016). Several speculative explanations support this finding such as the popularity of sports and the consequent more chances to be selected or/and self-selected (Till et al., 2010), or early maturation reasons (Brazo-Sayavera et al., 2018). More specifically, according to maturation selection hypothesis (Tanner, 1981), females tend to experience puberty earlier than males. It is well established that after adolescence strength is still increasing in males but tends to be stabilized in females due to hormone effects (Papaiakovou et al., 2009). Females are presumably closer to physical maturity than males and probably gain less than males from a year difference (Hollings et al., 2014). Furthermore, genetic reasons (i.e. genu valgum, tendon viscoelastic properties) which are more prominent after puberty might influence movement coordination and sprint speed of females (Hewett, Myer, Ford, 2004; Kubo, Kanehisa, Fukunaga, 2003; Papaiakovou et al., 2009).

RAE magnitude and sport discipline

More specifically, RAE was stronger for sprinting events and soccer than for middle distance events finding that is also supported by past studies (Brustio et al., 2019; Kearney et al., 2018).This finding may suggest that endurance capacity was less affected by the relative age of athletes. In particular, from athletic context the disciplines of 100 m sprinting, 100/110 m and 400 m hurdles were more affected. All these disciplines require strength, speed and a developed muscle mass (Hollings et al., 2014). This may suggest that relatively older athletes might be advantaged by more developed anthropometric characteristics which produce greater levels of strength and speed (Brustio et al., 2019; Hollings et al., 2014; Kearney et al., 2018). Also in soccer, players may be benefited more by speed and strength abilities than by endurance capacity. Consequently, sports that require anaerobic capacity, as well as explosive speed, strength and power, such as short distance runs and soccer, follow similar training strategies, and influenced more by RAE.

RAE magnitude and performance

Regarding the relationship between performance and RAE the analyses showed that RAE predicted performance in several sport disciplines. In particular, within U-18 age category, the relatively older females showed significantly greater performance than younger athletes in 100 m hurdles. Correspondingly, within U-20 age category relatively older males showed greater performance than their younger counterparts in 100 m, 110 m hurdles, 800 m, 1,500 m, 5,000 m and 10,000 m. Similarly, U-20 relatively older females showed greater performance than younger athletes in 100 m and 5,000 m disciplines. Generally, literature review supports our findings about the relationship between RAE and track and field sports (Brustio et al., 2019; Romann, Cobley, 2015). Although RAE is not so obvious in older age category such as in younger, it affects more players' performance in the older one. It can probably be explained by several social, physiological and psychological factors which might be affected by physical differences across the previous years. In general, although at this age the physical differences have disappeared, older players have already experienced superior training guidance and conditions which benefited various motor-physical skills, such as coordination, balance, strength and speed. Furthermore, they experienced greater success, and, they consequently have higher levels of competence and intrinsic motivation than their younger counterparts. Adding that drop-out rate was higher for relatively younger athletes we conclude that the combination of these indices confer an effect on performance (Cobley et al., 2009; MacDonald, Baker, 2013). Regarding soccer, the results showed a significant relationship between RAE and performance indicators taken as final ranking, total points, and qualification status. In particular, there was a significant relationship between RAE and all the performance indicators of both U-17 males and females. Similarly, in U-19 age category there was a significant relationship between RAE and ranking in both males and females, as well as between RAE and total points of male soccer players. Only the indicators of total points for females as well as qualification status for both males and females failed to indicate a significant relationship with RAE. Current findings support past research that confirmed the relationship between RAE and performance in U-17 elite soccer players (Augste, Lames, 2011). Although achieving success in team sports is affected by several variables' interference it seems that physical maturity consist a crucial factor that benefits team performance. Similarly to individual sports, although the physical differences among players have been eliminated in older age categories, relatively older players have already taken advantage compared to younger ones (Costa, Albuquerque, Garganta, 2012; Delorme, Boiché, Raspaud, 2010).

The critical question is how this preference for early born youngsters could be changed and if that contributes to greater success. Researchers have proposed several solutions to address RAEs, including rotating cut-off dates, shorter age categories bandwidths, physical and/or maturation classification schemes and educating trainers, coaches and parents (Andronikos, Elumaro, Westbury, Martindale, 2016; Cumming, Lloyd, Oliver, Eisenmann, Malina, 2017; Haycraft, Kovalchik, Pyne, Larkin, Robertson, 2018). Furthermore, regarding sprinting events, it has been suggested the application of corrective adjustments to youth results so as to remove RAE from top rankings (Cobley et al., 2019; Romann, Cobley, 2015). However, as long as there is no agreement for organizational changes against RAE, coach and parental education seems the recommended solution. Based on current findings, future research is suggested to further examine how a limitation of birthdates on the number of athletes that participate in sport events (i.e. 25% per birth semester) would reduce RAE. Furthermore, still a question exists that is if the biologically older athletes differ also in technical, tactical and cognitive characteristics.

Conclusion

In conclusion, RAE was evident within the majority of subpopulations of running sport disciplines and soccer. The results showed that selecting athletes with a higher relative age benefits individual and team success in competition against other athletes or teams. Thus it is obvious that trainers and coaches tend to prefer relative older athletes who are probably physically more mature at the time of selection. However, talent identification systems aim to promote the most promising athletes at adult age which is more important than the temporary success at younger ages. Sports should be considered as a long-term talent development process whereas winning constitutes a short term temporal goal which is frequently set by environmental factors, such as social agents including parents, coaches and athletes who are propagating RAE. Thus, trainers and coaches should focus to give equal opportunities to athletes to compete and increase the commitment for a long and successful career in sports.

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NORMAL LEVELS OF TSH AFFECT THE METABOLIC PROFILE DIFFERENTLY IN PHYSICALLY ACTIVE MALES AND FEMALES

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Abstract Our study was aimed at the evaluation of relationships between thyroid stimulating hormone (TSH) within the normal range and metabolic risk factors (glucose, insulin, HOMA-IR and lipoprotein profile) in physically active male and female students. In 219 students circulating TSH, glucose, insulin and lipoproteins were measured in blood under fasting conditions. Insulin resistance was expressed as HOMA-IR (homeostasis model assessment for insulin resistance). For further procedures 99 males and 97 regularly menstruating females with TSH 0.4–4.0 μIU/ml were accepted. In male students no correlations between circulating TSH, anthropometric and biochemical variables were noted. In females TSH within the normal range was slightly but significantly correlated with the triglyceride (TG) level ($p < 0.03$). However, step-wise multiple regression analysis revealed that the effect of TSH was small ($p < 0.046$) in relation to that found for HOMA-IR ($p < 0.0009$). No relationships between biochemical variables and normal levels of TSH were noted in male students. However, surprisingly normal range TSH in males was slightly but significantly correlated with the percentage of body fat and this issue needs further studies concerning measurements of different fat depots. The above data suggests that in active females TG synthesis and export from the liver is more sensitive to TSH action than in active male counterparts.

Key words normal range TSH, glucose, insulin, HOMA-IR, lipoproteins

Introduction

Numerous studies have shown that variability in circulating TSH within the normal range affects circulating lipids (Asvold, Vatten, Nilsen, Bjøro T, 2007; Lee et al., 2019). However, this issue was studied mostly in middle-aged and older adults as a consequence of increased thyroid gland disease with age (Chen et al., 2018; Lo Sasso, Vidali, Scazzone, Agnello, Ciaccio, 2019). Data concerning metabolic effects of variability in normal level circulating TSH in young adults are scarce and their results are interpreted for combined male and female participants (Joseph, Chettuvatti, Yadav, Bharadwaj, Kotian, 2017; Rahbar et al., 2017). On the other hand, it is well documented that sex hormones significantly contribute to the regulation of thyroid function due to functional associations between the hypothalamic-pituitary-thyroid axis (HPT) and the hypothalamic – pituitary gonadal axis (HPG) at least in part due to estrogen and androgen receptor expression in thyroid glands (Schaefer, Geelhoed, Dadu, 1986; Marugo et al., 1991). Thus, the above data suggest that studies concerning TSH effects on metabolic processes have to be interpreted separately in males and females due to differences in sex hormone status.

Additionally, many data have provided discordant results concerning associations of circulating TSH and physical activity. In young men both no changes and significant elevation in circulating TSH were noted immediately after maximal aerobic exercise (Ciloglu et al., 2005; Huang et al., 2004; Beyleroglu, 2011). In addition it was shown that long term exercise may have different impacts on TSH levels than an acute exercise program (Hawamdeh, Baniata, Mansi, Nasr, Aburjai, 2012). However, no changes in circulating TSH were observed in elite athletes who underwent regular training (Healy, Gibney, Pentecost, Wheeler, Sonksen, 2014; de Souza et al., 2019; Ceresini et al., 2019). With this background in mind our study was undertaken and was aimed at evaluation of relationships between circulating TSH within the normal range with metabolic risk factors (glucose, insulin, lipoproteins) separately in male and female physical education students engaged in regular physical activity due to their studies. In 112 male and 107 female students circulating TSH, glucose, insulin and lipoproteins were measured in blood under fasting conditions. For further procedures exclusively those with TSH 0.4–4.0 μIU/ml were selected.

Material and methods

Subjects

Physical education students were recruited by word of mouth and advertisements in student dormitories. Exclusively regularly physically active healthy non-smokers not taking supplements on a regular basis were accepted. None of them were high-performance athletes, however, all volunteers had been active for at least 3 months and were engaged in different forms of physical activity due to their study program (gymnastics, swimming, basketball, dance for 6 hours/week). Finally 112 males and 148 females were accepted and underwent further procedures. All 148 female students were asked about oral contraceptive (OC) use and 25 OC users were excluded from the study. Thus 123 females were asked to provide information concerning menstrual cycle regularity. In consequence exclusively 107 females with cycle length 21–35 days were accepted for participation (Dasharathy et al., 2012). All participants provided written consent for participation in the study and the study protocol was accepted by the local Ethics Commission.

Anthropometry

In 112 male and 107 female subjects mass and height were determined in barefooted participants wearing light clothes using standard medical equipment. The precision of body mass and height determination was 0.1 kg and 0.1 cm, respectively. Body fatness was determined using measurements of 4 skinfolds (biceps, triceps, suprailiac and subscapular) with Harpenden caliper (British Indicators, Burges HILL, UK) and calculated according to Durnin and Womersley (1974). All measurements were done twice by a trained technician and in the case of discrepancy were repeated for the third time. Lean body mass (LBM) was also calculated.

Biochemical analysis

A total of 112 males and 107 females were accepted for blood analysis. All subjects were asked to refrain from physical activity for at least 8 h and to eat their last meal at least 12 h before blood withdrawal. Blood was taken under aseptic conditions into plastic tubes with anticoagulant and centrifuged 15 min to obtain plasma which was stored at – 70°C until analysis. Plasma glucose was determined using the GOD-PAP method. Triacylglycerols (TG), total cholesterol (TC) and HDL-cholesterol (HDL-C) were assayed with colorimetric methods and commercial kits (Randox Laboratories, UK). Coefficients of variation for all variables did not exceed 5%. The plasma concentration of LDL-cholesterol (LDL-C) was calculated according to the Friedewald, Levy, Fredricson (1972) formula. Plasma insulin was measured using a standard radioimmunoassay (RIA) with human monoclonal antibodies against insulin and commercial kits (BioSource, Belgium). Inter- and intra-assay coefficients of variation for insulin determination did not exceed 7%. All measurements were done in duplicate. Insulin resistance index (HOMA-IR) was calculated according to the Mathews et al. (1995) formula:

$$\text{HOMA-IR} = [\text{glucose (mmol/L)} \times \text{insulin } (\mu\text{IU/ml})]/22.5.$$

Subjects' classification according to normal plasma TSH

Circulating thyroid hormone (TSH) was assayed using a standard immunoassay method (RIA) and commercial kits (BioSource (Belgium) Inter- and intra- assay coefficients of variation for TSH determination did not exceed 7%.

The results of circulating TSH were used to identify subjects with normal circulating hormone TSH levels established between 0.4–4.0 μIU/ml according to Pearce et al. (2013). In consequence, a total of 99 males and 97 regularly menstruating females participated in the analysis of TSH relationship with other metabolic variables (glucose, insulin, HOMA-IR and lipoproteins) (Figure 1).

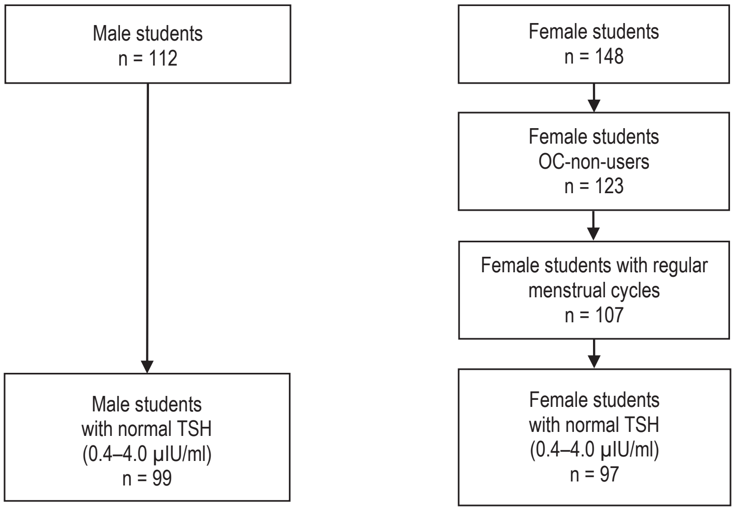

Figure 1. Classification of study participants according to circulating TSH.

Statistical analysis

Data were tested for normality using the Shapiro-Wilk test. The differences between male and female students were evaluated using the Mann-Whitney test. In both male and female students Pearson's correlation was used to test the association between TSH and other variables. In addition, in females step-wise regression analysis was performed to determine the contribution of TSH to the variability of the TG plasma levels. Both analyses were performed for logarithmically transformed data (base 10). Descriptive statistics are presented as mean ± SD. Significance of differences was established at $p < 0.05$. All calculations were performed using STATISTCA for Windows, v.12.0 (Stat Soft, USA).

Results

Body composition and metabolic variables in male and female participants with normal TSH are presented in Table 1 with males with significantly higher body mass, body height but lower percentage of body fat in comparison with females ($p < 0.001$ for all variables). Females were characterized by significantly higher circulating insulin vs. males ($p < 0.001$) In consequence, HOMA-IR in females was markedly higher in comparison with males (1.480 vs. 1.128, $p < 0.005$). There were no sex-related differences in plasma levels of TG, TC and LDL-C. However, circulating HDL-C in females was higher by 28.5% than in males ($p < 0.001$). In male students a slight, but significant correlation was found between circulating TSH and the percentage of body fat ($p < 0.03$) but no correlations of TSH with biochemical variables were noted (Table 2). On the contrary, in female students circulating TSH was not related to the percentage of body fat but a slight and significant correlation was noted with plasma TG ($p < 0.03$).

Table 1. Anthropometric and biochemical characteristics of physically active male and female students with normal TSH levels (0.4–4.0 μIU/ml)

Variables	Males (n = 99)	Females (n = 97)
Age (years)	21.1 ±2.1	21.1 ±1.5
Weight (kg)	78.4 ±10.0	62.2 ±8.5[a]
Height (cm)	182.0 ±6.7	167.9 ±5.7[a]
Fat (%)	11.6 ±4.8	25.2 ±5.2[a]
Fat (kg)	9.1 ±4.7	15.7 ±6.0[a]
LBM (kg)[^]	69.3 ±7.7	46.5 ±4.1[a]
TSH (μIU/ml)[#]	2.3 ±0.8	2.2 ±0.8
Glucose (mmol/L)	4.7 ±0.3	4.5 ±0.3[a]
Insulin (μIU/ml)	5.4 ±2.4	7.4 ±4.8[a]
HOMA-IR	1.128 ±0.535	1.480 ±0.932[b]
TG (mmol/L)	0.9 ±0.4	0.8 ±0.3
TC (mmol/L)	4.3 ±0.8	4.4 ±0.6
HDL-C (mmol/L)	1.4 ±0.3	1.8 ±0.3[a]
LDL-C (mmol/L)	2.2 ±0.6	2.2 ±0.6

[^] LBM – lean body mass; [#] TSH-thyroid stimulating hormone.
HOMA-IR – insulin resistance; TG – triacylglycerols; TC – total cholesterol; HDL-C – HDL-cholesterol; LDL-C – LDL-cholesterol.
[a] P < 0.001; [b] P < 0.005 – significantly higher vs. males.

Table 2. Pearson's correlation coefficients between normal TSH level, anthropometry and biochemical variables in active male and female students

Variables	Males (n = 99)	Females (n = 97)
Fat (%)	**0.226**[a]	0.002
Glucose (mmol/L)	–0.020	0.090
Insulin (μIU/ml)	0.040	0.105
HOMA-IR	0.001	0.113
TG (mmol/L)	–0.120	**0.230**[a]
TC (mmol/L)	–0.040	0.001
HDL-C (mmol/L)	0.080	0.178
LDL-C (mmol/L)	–0.050	–0.150

Abbreviations: see Table 1; [*] all data were logarithmically transformed (base 10) before calculation; [a] P < 0.030.

In females step-wise multiple regression analysis revealed that circulating TG was positively and significantly correlated with HOMA-IR (p = 0.0002) with slight but significant contribution of plasma TSH to the variability of TG (p = 0.046) (Table 3). In the case of male students all data were excluded from step-wise multiple regression model.

Table 3. Step-wise multiple regression analysis for the relationship between TG and HDL-C with TSH and HOMA-IR in active female students with normal TSH levels

Dependent variable	Independent variables	ß	SD	t	p
TG*	HOMA-IR	0.359	0.094	3.820	0.0002
	TSH	0.189	0.094	2.017	0.0460
Corrected $R^2 = 0.162$, $F (2.94) = 10.338$, $p < 0.00009$					

For abbreviations – see Table 1; * – all data were logarithmically transformed before analysis (base 10).

Discussion

The most important finding of our study indicated that active female subjects differ in respect to the relationship between normal level TSH with circulating TG vs. their male counterparts.

In male students no correlations between circulating TSH, anthropometric and biochemical variables were noted. This is in agreement with other data indicating a direct effect of thyroid hormones on hepatic lipid metabolism (Sinha, Singh, Yen, 2018; Duntas, Brenta, 2018). In addition there are data which noted that in middle age subjects TG efflux from the liver is to a greater extent stimulated by TSH in females than in males (Tognini et al., 2012). However, multiple regression analysis indicated that TSH contribution is close to the limit of significance, with powerful contribution of insulin resistance expressed as HOMA-IR. It is well documented that TG synthesis in the liver is markedly stimulated in response to elevated insulin resistance (Scherer et al., 2016; Pramfalk et al., 2016). Thus, it could be postulated that in active females the role of insulin resistance in the regulation of circulating TG is more pronounced than that of blood TSH within the normal range. On the other hand, it could be tentatively postulated that the effect of TSH on TG will be more pronounced with an increase in its plasma level observed with age in both sexes (Ehrenkranz et al., 2015; Wang et al., 2018). In this context the role of TG in the development of cardiovascular disease in women has to be taken into consideration (Boullart, de Graaf, Stalenhoef, 2012; Budoff, 2016). Interestingly, data for active male students did not demonstrate any relationship between circulating normal range TSH with TG. Thus it could be suggested that different steps of TG metabolism in active males are less sensitive to variability of TSH within the normal range. Therefore, the age and sex of the subjects, as well as the range of TSH level in the blood, seem to be of key importance for the assessment of its influence on the metabolism of hepatic lipid metabolism.

Surprisingly, a slight but significant associations of TSH with the percentage of body fat was found exclusively in male students, thus in subjects with significantly lower fatness vs. their female counterparts. The reason for this finding could be only speculated and further studies are needed concerning regional fat distribution (e.g. visceral and/or epicardial) in both active males and females in the context of normal circulating TSH (Korkmaz et al., 2013; Belen et al., 2015; Sayin et al., 2016).

Conclusions

In summary, our study indicated that circulating TG in physically active females is more sensitive to variability in TSH within the normal range in comparison with their male counterparts. However, the contribution of TSH although significant is much lower than that of insulin resistance expressed as HOMA-IR. According to our best knowledge this study is the first which focused on the effect of normal TSH levels on the metabolic profile in young, active participants of both sexes. However, the limitations of our study have to be underlined and are focused on the lack of the determination of adipokines (e.g. leptin and adiponectin) but also of the adipo-myokine irisin which possibly affect circulating TSH and whose levels differ with respect to sex. Moreover, it seems that in males more precise determination of body fat is of importance.

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EFFECT OF MODIFIED HIGH INTENSITY INTERVAL TRAINING ON FAT LOSS

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Abstract Exercise has multiple health benefits and is a critical component in managing overweight and obesity. High Intensity Interval Training (HIIT) involves brief high-intensity anaerobic exercise followed by rest or very low intensity exercise. 24 men and women (age 18–60 years) volunteered to participate in a 6 weeks of modified HIIT exercises program where whole body functional training exercises was provided. Their body weight, body mass index, waist to hip ratio and skin fold fat were measured at the beginning and at the end of the 6 weeks duration . Statistical significance was found between the variables at $p < 0.05$. The results showed that a Modified HIIT exercise Program based on Body weight training results in considerable decrease in level of sub-cutaneous adiposity up to 77.8%. Obesity and overweight have become complex pandemic disorders where in physical inactivity and lack of time to exercise plays a major role leading to various complications. Reduction in adiposity through structured exercises protocols will improve body composition and Cardio-metabolic health . Novel interventions such as modified HIIT serve as the perfect pathway to address the time factor and enhancement of physical activity as well.

Key words Modified HIIT, Functional Training, Obesity, Fat Loss

Background and aims

In a clinical context, the term ‘overweight’ usually connotes adiposity, an excess of body fat (Billewicz, Kelsey, Thomson, 1962). WHO defines obesity as abnormal or extensive fat accumulation that negatively affects health (Stenholm, Harris, Rantanen, Visser, Kritchevsky, Ferrucci, 2008). Obesity is a complex chronic disorder that results from the interaction of genotypic and environmental factors and involves multifaceted interactions among numerous potential determinants such as humoral, neural, metabolic, psychological etc. (Poirier, Despres, 2001).

The incidence of obesity and its related diseases has dramatically increased worldwide in the last few decades, mainly as a result of a physically inactive lifestyle and exercise. Currently, along with behavioral and nutritional counseling, involvement in regular physical activity serves as the first line of defense in preventing obesity (Zhang, Tong, Qiu, Wang, Nice, He, 2015). There is robust evidence that long term exercise at moderate intensity could improve body composition, cardiovascular fitness and other health-related parameters including insulin sensitivity and lipid profile in healthy and obese people (Donnelly et al., 2009); (McInnis, Franklin, Rippe, 2003). Despite the well-established benefits of routine physical activity for improving such cardio-metabolic health, it remains difficult for health care professionals to get individuals to adhere to current physical activity guidelines of at least 30 min per day of moderate intensity exercise 5 days per week or vigorous exercise for 20 min per day 3 days a week (Trost, Owen, Bauman, Sallis, Brown, 2002). Therefore, given that 'lack of time' is the most commonly cited barrier to exercise adherence, more recent studies have focused on identifying a more time-efficient mode of exercise training (Fisher, Brown, Brown, Alcorn, Noles, Winwood, Resuehr, George, Jeansonne, Allison, 2015). A high-volume, moderate-intensity continuous training (MICT) protocol has been shown to be a powerful strategy for inducing loss of abdominal fat, including visceral fat (Irwin et al., 2003; Ross, Dagnon Jones, Smith, Paddags, Hudson, Jenssen 2000).

However, in recent years, a growing body of literature has shown that high-intensity interval training (HIIT) could induce similar favorable metabolic adaptations associated with MICT (Nybo et al., 2010). HIIT involves brief high-intensity anaerobic exercise followed by brief but slightly longer bouts of very low intensity exercise (Trapp, Chisholm, Freund, Boutcher, 2008) or separated by a short rest interval (Gibala, McGee., 2008). Such high intensity training provides fitness and health improvements in less time per week than the recommended exercises guidelines (Heinrich, Patel, O'Neil, Heinrich, 2014). HIIT exercises significantly reduce subcutaneous fat, total body mass while improving VO2 max and insulin sensitivity (Shiraev, Barclay, 2012). This apart, many studies have examined the effects of HIIT in fat loss and health of special population such as overweight adolescents, older adults, diabetic individuals, paraplegics, intermittent claudication, chronic obstructive pulmonary disease and cardiac rehabilitation patients (Boutcher, 2011). Though authors have reported fat loss due to HIIT exercises, yet, such reports do not isolate the amount of adiposity lost due to these exercises. Moreover, the efficacy of such exercises responsible for loss in adiposity is a point to ponder.

Currently, the world is experiencing an extraordinary, life altering challenge with COVID-19 (Hall, Laddu, Phillips, Lavie, Arena, 2020), where self-isolation and quarantine requirements are leading to decreased physical activity. Sustained physical inactivity and sedentary behaviour can be deleterious; for example, a 2 weeks reduction in daily steps from 10,000 to 1,500 steps leads to impaired insulin sensitivity, lipid metabolism, increased visceral fat and decreased fat free mass and cardiovascular fitness in healthy individuals (Pinto, Dunstan Owen, Bonfa, Gualano, 2020). Interestingly a bout of moderate intensity exercises does not counteract the detrimental effects of even 4 days of physical inactivity, suggesting that individuals can become 'resistant' to well-known exercise induced metabolic adaptations (Akins, Crawford, Burton, Wolfe, Vardarli, Coyle, 2019).

Considering all these factors, we aimed to induce a home based exercise program where a modified HIIT exercise involving whole body functional training was prescribed.

Material and methods

A total of 12 men and 12 women participated in this study. Participants (n = 24) were recruited from Saveetha Medical College & Hospital, SIMATS and surrounding community to participate in our exercise program. General screening guidelines were used. A detailed medical diagnosis was performed. Parameters such as history of symptoms, recent illness, familial history of disease and illness, orthopaedic problems, lifestyle habits, exercise history, work history and usage of medications and drug allergies were assessed for each of the participants. The study was ethically cleared by the institutional ethical committee of SIMATS, Chennai.

People who were overweight and obese were considered for the study. Unhealthy people with co-morbids(such as musculo-skeletal injuries, cardiac patients, etc.) and unwilling participants were excluded from our study. All participants participated voluntarily and adequate knowledge regarding the study setting was explained to them. Information about the level of physical activity and health condition was obtained using a Physical Activity Readiness questionnaire (PAR-Q). Participants were stratified on a median age of 18 to 60 years and a BMI of ≥26. They were prescribed HIIT exercise for four days per week until six weeks. The participants (both females and males) characteristics included age (M = 37.63 ±12.79 years), height (M = 163.42 ±10.04) weight (M = 80.58 ±12.90 kg), Body Mass Index (30.30 ±2.62 kg/m^2), waist to hip ratio (M = 1 ±0.10) and sum of skin folds fat (M = 160.08 ±24.65). Overall subject characteristics of pre-test and post-test values on individual variables of the participants (both men and women) had significant changes as seen on Tables 2 and 3 respectively.

Skin folds were measured using a Harpenden skin fold caliper and a seven-site ISAK method (biceps, triceps, subscapular, abdomen, supra iliac, mid-thigh and calf) was used to calculate the sum of skin fold fat value. All the population were considered as overweight/ obese according to the BMI and skin fold measurements.

The exercises consisted of floor based high intensity functional exercises followed by a short period of complete rest. Each participant underwent a series of exercises protocol as follows:

1. Warm up = 5 minutes.
2. Modified HIIT exercises = 15 minutes.
3. Stretching and cool down = 5 minutes.

The modified HIIT exercises were designed as whole body functional workouts. After completing the warm up session, the participants would perform a series of whole body modified HIIT exercises comprising of jumping jacks, squats, pushups, crunches, triceps dips, plank, same spot high knee running, lunges, side plank, v-sit hold, mountain climber and burpees. These are short, rapid series of exercises using one's own body weight. The participants performed these exercises for a time period of 30 seconds followed by 15 seconds of rest interval throughout the exercise regimen time of 15 minutes, for 4 days per week for 6 weeks. As the week progressed the participants were encouraged to repeat this exercise cycle as many as possible within the maximum stipulated time of 15 minutes.

A rating of perceived exertion was measured using the modified Borg scale, so as to ensure that the participants were within the exercise tolerance limits, as devised by the scale. The participants were given the right to stop the exercise session if they felt the intensity was reaching beyond their limit.

As this was an exercise intervention based study, participants were counselled to take a nutrient rich food intake not giving particular emphasis to their daily caloric intake, nor calculating macro/micro nutrient levels. However, participants were strictly advised to avoid junk food and processed food.

Data Analysis

At the end of six weeks, all participants were measured with a post data comprising of weight, BMI, WHR and skin fold fat levels. Data was analyzed using SPSS statistical software. Paired t-test was performed to identify the intergroup comparison. The significance level was considered at $\alpha = 0.05$.

Results

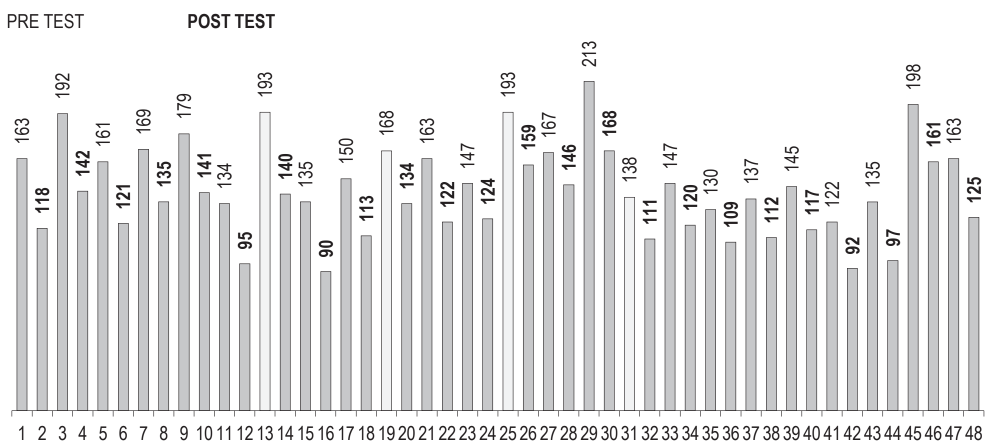
The aim of this study was to implement a home based effective weight loss program through whole body functional exercises. As can be seen in Table 1, the variables such as body weight, waist-hip ratio (WHR), body mass index (BMI) and sum of skin folds were analysed for an inter group comparison. Statistical significance was found between the variables of BMI, WHR, body weight and sum of skin fold values.

Table 1. Subject's anthropometric variables (mean ± standard deviation) before and after exercise intervention

Paired Samples Test									
		Paired Differences					t	df	Sig. (2-tailed)
		mean	std. deviation	std. error mean	95% confidence interval of the difference				
					lower	upper			
Pair 2	Weight_1–Weight_2	3.83333	1.00722	0.20560	3.40802	4.25865	18.645	23	0.000
Pair 3	WHR_1–WHR_2	0.02958	0.02836	0.00579	0.01761	0.04156	5.111	23	0.000
Pair 4	BMI_1–BMI_2	1.72292	1.30812	0.26702	1.17055	2.27529	6.452	23	0.000
Pair 5	Sum_SF_1–Sum_SF_2	35.41667	8.84119	1.80470	31.68336	39.14997	19.625	23	0.000

* p = ≤ 0.05 significance of pre-test vs post-test.
For age and height, t-test cannot be computed because the standard error of the difference is 0.

The results showed that after exercise interventions there is considerable decrease in the level of adiposity and body weight as well. Moreover, we noticed that there was 77.8% decrease (Figure 1) in the subcutaneous skin fold fat levels after the completion of 6 weeks of exercise regimen.



The total participants are n = 24; combined data of pretest data and post test for sum of skin fold equals to n = 48.

Figure 1. Shows the decrease in the sum of skin fold fat after the exercise regimen in all the participants

Discussion

The results of the current study showed that six week modified high intensity interval training led to a significant decrease in the body's adiposity. There was a considerable reduction in the BMI, WHR and the sum of skin folds post the six weeks of our exercise protocol. The direct effect of exercise on level of adiposity is unknown still. Yet, studies have made successful attempts in identifying the amount of fat lost due to exercise. Boudou et al. (2003) and Mourier et al. (1997), showed 18% reduction of subcutaneous fat. Similarly, Trapp et al. (2008), found 10% decrease and Tremblay et al. (1994), found 15% decrease in adiposity. Our study showed 77.8% decrease in subcutaneous fat levels. However our result was interpreted using the sum of skin folds rather than using any kind of radiological imaging source as supported by some of these authors.

Majority of our research goal was focused on estimating the amount of fat lost due to HIIT exercises than identifying the right pattern of exercise. Many authors have devised exercise strategies based on aerobic and anaerobic exercises (Tjønna et al., 2008; Park et al., 2003; Johnson, Sachinwalla, Walton, Smith, Armstrong, Thompson, George, 2009). Some authors used different exercises forms to combat obesity (Strasser, Schobersberger, 2011; Schoenfeld, 2011). We narrowed our approach towards HIIT exercises that covered whole body rather than isolated set of muscular exercises. This apart, several studies have proved the advantages of HIIT exercise (Zhang et al., 2015; Heinrich et al., 2014; Kordi, Choopani, Hemmatinafar, Choopani, 2013), of which, short term HIIT exercises have found to produce better results in fat reduction than any other form of exercise (Lanzi et al., 2015; Panissa, Alves, Salermo, Franchini, Takito, 2016). Such short term exercise of high intensity pattern, if delivered accurately, has shown better results in losing adiposity.

All the HIIT exercises mentioned in our study are compound multi-dimensional workouts. They provide collective benefit to the participant rather than focusing on individualizing the muscle/body part worked. There are no consensus literature available as to what constitutes a true HIIT protocol (Hood, Little, Tarnopolsky, Myslik, Gibala, 2011). Thus, we designed a modified HIIT protocol which would be realistic for our participants to complete, and also is evidence based (Chandler, Stringer, 2020) .

Adiposity is a complex multifactorial mechanism involving genetic, metabolic, physiological, psycho-social and environmental cross links. The adipose tissue, though considered a ‘toxic tissue’ is found fundamental to the primary life-history functions of the human body (Wells, 2012). Hence, identifying the accurate ways to enhance such functions is essential. Though HIIT exercises provided ways to reduce excess adiposity, the efficacy of such exercises are still a point to ponder. One way to identify such efficacy was by estimating the aerobic capacity through Vo2 max, which in turn might be a costly factor. There is sufficient evidence to prove the effectiveness of HIIT on aerobic and cardiovascular factors (Garcia-Hermoso, Cerrillo-Urbina, Herrera-Valenzuela, Cristi-Montero, Saavedra, Martinez-Vizcaino, 2016). We however aimed at estimating the adiposity alone, cost effectively, rather than measuring aerobic or cardio vascular factors that require usage of various technology and gadgets. Hence, the anthropometric indices such as BMI, skin fold fat and WHR served as a better feedback in estimating the acute responses to HIIT exercises. We found considerable difference in the BMI and WHR post our exercises regimen.

Decrease in body composition can be considered as a key factor in delivering HIIT programs. Though there is sufficient evidence on reduction of body composition in young and adolescent participants (Costigan, Eather, Plotnikoff, Taaffe, Lubans, 2015), this study presents a diversified age group (Table 2 and Table 3) showing variance in body composition measures post the exercise period.

Table 2. Men Group Comparison – Pre and Post Test

	AGE	HEIGHT	WEIGHT	BMI	WAIST	HIP	WHR	BICEPS	TRICEPS	SUBSCAPULAR	ADBOMEN	SUPRA ILIAC	THIGH	CALF	SUM OF SKF
MEN – PRE TEST VALUE															
MEAN	36.90	171.70	89.80	30.50	41.08	40.50	1.01	13.30	20.80	24.66	37.75	29.33	24.00	18.50	168.41
SD	12.85	5.97	7.34	2.36	4.14	3.26	0.05	2.70	4.06	4.18	8.83	5.61	3.41	3.26	25.38
MEN – POST TEST VALUE															
MEAN	36.90	171.70	85.60	29.10	37.33	37.70	0.98	9.00	15.08	19.08	30.16	23.90	18.33	15.08	130.66
SD	12.85	5.97	6.86	2.48	3.51	3.28	0.04	2.20	3.14	3.15	6.68	4.77	3.66	3.20	20.07

Table 3. Women Group Comparison – Pre and Post Test

	AGE	HEIGHT	WEIGHT	BMI	WAIST	HIP	WHR	BICEPS	TRICEPS	SUBSCAPULAR	ADBOMEN	SUPRA ILIAC	THIGH	CALF	SUM OF SKF
WOMEN – PRE TEST VALUE															
MEAN	38.33	155.04	71.33	30.10	38.16	39.50	0.97	13.00	18.08	22.75	27.08	27.91	23.00	19.90	151.75
SD	12.71	4.52	9.91	2.83	2.63	4.51	0.13	3.46	3.45	3.24	3.61	5.49	2.97	4.73	20.87
WOMEN - POST TEST VALUE															
MEAN	38.33	155.04	67.83	28.10	34.41	36.60	0.94	9.66	13.16	17.41	21.25	22.91	18.41	15.80	118.66
SD	12.71	4.52	9.57	3.11	2.88	3.83	0.11	3.22	3.46	3.77	3.29	5.54	2.95	3.50	21.05

Various studies have utilized the option of diet interventions in their program (Clark, 2015; Arad, DiMenna, Thomas, Tamis-Holland, Weil, Geliebter, Albu, 2015). We did not recommend any nutritional or dietary recommendations to our participants. All our participants were advised to follow their regular dietary pattern without any specific caloric intake recommendations/restrictions. This served as a highlight to determine the effectiveness of our program specifications which was devoid of any diet prescription. Our present study may be used as a preliminary research in estimating the level of adiposity loss using modified HIIT exercises.

Limitations

The key limitation of our study is the mode of measuring the level of adiposity. Though it is a proven fact that radiological imaging provides congruent evidence in estimation of body fat, we chose a cost effective way through measuring the skin fold fat levels. It did precisely provide body's adiposity levels, yet, specific adaptations to the exercise demands are unknown. Another limitation is the estimation of the effectiveness of the modified HIIT exercises offered to the participants. The exercises mentioned were scientifically proven/accepted list of exercises used by various researchers. However, individual efficacy of these exercises looks immeasurable. This is mainly due to the multi-dimensional benefit of each exercise. For example, doing a plank not only improves the core muscle strength, also, it provides equal support to the arms, elbows, back and toes. Hence, analyzing the micro effect of such multi-dimensional exercise is impractical. The diversified age group did show significant decrease in adiposity levels. Yet, age wise classification was harder to achieve without radiological investigations. Considering the technological advancement in today's world, we believe that these sustained adaptations such as fat loss due to modified HIIT exercises would become a handy tool in the days to come.

Conclusion

This preliminary study suggests that supervised six weeks of high intensity interval training connotes in achieving loss of adiposity among a diversified age group. The subcutaneous fat lost due to modifications in musculoskeletal parameters through six weeks of exercise training was firmly supported by significant decrease in anthropometric parameters as well. A multi-dimensional exercise regimen such as this could pave way for more time saving yet result oriented protocols in controlling obesity in the near future.

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BEETROOT JUICE – LEGAL DOPING FOR ATHLETES?

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Abstract Nitric oxide (NO) is a physiologically important signaling molecule that promotes the expansion of blood vessels and thus facilitates the transport of oxygen (O_2) and energy substrates to the muscles. Research shows that nitric oxide (NO) also improves the effectiveness of mitochondrial respiration, which is manifested by reduced oxygen consumption during exercise. Until recently, it was thought that nitric oxide (NO) could only be formed as a result of the endogenous pathway of oxidative transformations L-arginine. Recent research results indicate, however, that an alternative to the endogenous pathway of nitric oxide (NO) formation may be the exogenous supply of inorganic nitrates (NO_3^-) with food.

The aim of the study was to review the current literature on the properties of beetroot juice as an important source of nitrates (NO_3^-) and its effectiveness in improving the exercise capacity of physically active people.

A systematic review of the research, published from 2005 to January 31, 2021, was made on the basis of searching bibliographic databases such as: PubMed, Elsevier and Web of Science. The following keywords were used: “beetroot”, “beetroot juice”, “nitrates”, “nitrites”, “nitric oxide”, “supplementation”, “ergogenic substances”, “sports nutrition”.

Although there are conflicting data, it appears that beetroot juice supply may be a cheap, natural, and promising nutritional strategy for improving sports performance in both endurance and intermittent high intensity (start-stop) exercise. More detailed studies are analyzing the effect of dietary nitrate (NO_3^-) supply in anaerobic exercise – especially in high-volume resistance training – are needed. It is also emphasized that further research is needed to elucidate the effects of specific factors on the variability of ergogenic effects after beetroot juice consumption, which may be of the greatest importance in terms of the effectiveness of this nutritional intervention.

Key words beetroot juice, ergogenic compounds, sports, nitrates, nitrites

Introduction

The introduction of novel training stimuli allows athletes to achieve optimal performance during exercise (Campbell, Winiewski, 2017). It is increasingly observed that adaptations initiated by physical activity can be enhanced by appropriately selected nutritional strategies, which include guidelines for the type, quantity and timing of meals or fluids intake, and in specific situations, the use of supplements and sports nutrition (Jeukendrup, 2017). The aim of these strategies is, among other things, to cover individual energy needs taking into account the training periodization, to maintain carbohydrate availability especially during endurance exercise, to increase post-workout glycogen resynthesis, to regulate muscle protein synthesis and body water management (Belval et al., 2019; Thomas, Erdman, Burke, 2016; Vitale, Gatzin, 2019).

According to the American College of Sports (ACSM), Academy of Nutrition and Dietetics (AND), and Dietitians of Canada (DC), proper adjustment of nutrient supply in relation to the exercise performed is essential for improved athletic performance (Thomas et al., 2016). Consequently, much of the current research, focuses on the effects of the intake of specific foods, including the use of isolated food ingredients and dietary supplements to improve not only health but also exercise capacity (Clements, Lee, Bloomer, 2014).

Based on current research, the Australian Institute of Sport (AIS) has classified food ingredients and dietary supplements for athletes into four groups while determining whether they are safe, legal, and effective in improving excercise performance. In category A, which includes food ingredients and dietary supplements with proven effects on improving exercise capacity, the AIS included beetroot juice (Australian Institute of Sport [AIS], 2020; Maughan et al., 2018). Undoubtedly, its use has gained great popularity among physically active people in recent years and appears to be a cheap, natural and promising nutritional intervention for enhancing physical performance. The ergogenic effect induced by beetroot juice consumption is related to its high content of inorganic nitrates (NO_3^-), converted in the body to nitric oxide (NO), which is a physiologically important signaling molecule that dilates blood vessels and thus can increase blood flow to muscles, facilitating oxygen (O_2) transport. In addition, studies have shown that nitric oxide (NO) improves the efficiency of mitochondrial respiration, so that the oxygen cost of exercise is significantly reduced (Dominguez et al., 2017).

Objective of the work

The aim of the study was to review the current literature on the properties of beetroot juice as an important source of nitrates (NO_3^-) and its effectiveness in improving the exercise capacity of physically active people.

Methodology

A systematic review of studies published from January 1, 2005 to January 31, 2021 was performed. For this purpose, bibliographic databases such as PubMed, Elsevier and Web of Science were searched. Keywords were used: “beetroot”, “beetroot juice”, “nitrates”, “nitrites”, “nitric oxide”, “supplementation”, “ergogenic substances”, “sports nutrition”. The information considered relevant was included in this review.

The mechanism of the nitric oxide (NO) formation

Beetroot juice is used as an ergogenic substance due to its high content of inorganic nitrate (NO_3), which is the precursor for nitric oxide (NO) in the human body (Lundberg, Weitzberg, Gladwin, 2008). Until recently, it was thought that nitric oxide (NO) could only be formed by the endogenous pathway of oxidation of L-arginine, catalyzed by several isoforms of nitric oxide synthase (NOS), in the presence of molecular oxygen and such chemical reaction cofactors as NADPH, FAD, BH_4 (Ignarro, Fukuto, Griscavage, Rogers, Byrns, 1993). However, recent findings indicate that an alternative to the endogenous pathway of nitric oxide (NO) formation, may be the exogenous supply of inorganic nitrate (NO_3^-) with food. This means that large amounts of nitrate (NO_3^-) present in beetroot juice are able to increase nitric oxide (NO) levels in the human body (Bailey et al., 2009; DeMartino, Kim-Shapiro, Patel, Gladwin, 2019).

Other food products rich in inorganic nitrates (NO_3^-) include, among others green leafy vegetables, such as savoy cabbage, Chinese cabbage, endive, fennel, lettuce, spinach, rucoli, a well as vegetable and fruit juices, e.g. carrot juice or pomegranate juice, and drinking water. It is estimated that the content of nitrates in the aforementioned vegetables is in the case of with cabbage, Chinese cabbage, fennel and endive drom 500–2,500 mg (9–40 mmol)/1 kg of fresh vegetables, while in the case of lettuce, spinach, rucoli and beetroot (including beetroot juice) – 2,500 mg (40 mmol)/1 kg of fresh vegetables, respectively. It should be noted that the content of nitrates in plant product varies depending on their type and largely depends on environmental factors such as climate, soil conditions or the time elapsed from harvesting (Hord, Tang, Bryan, 2009; Santamaria, 2005).

It should also be mentioned that the source of nitrates in the diet may be meat products in which nitrates are used as a preservative (Murphy, Eliot, Heuertz, Weiss, 2012).

The average food intake of nitrates among adults in the United States, Europe and Australia is 60–120 mg/day (1–2 mmol/day). Based on the data obtained, it is estimated that vegetables are the main source of this compound in the diet of adults (80–85%). Researchers also suggest that vegetarians and people who follow nutritional models such as the DASH (Dietary Approaches to Stop Hypertension) diet are likely to achieve higher intakes of nitrates with food (AIS, 2020; Clements et al., 2014).

In the initiation of the exogenous pathway of "nitrate – nitrite – NO" metabolism, an important role is played by the oral microbiome, specifically, commensal, anaerobic bacteria residing in crypts distributed on the surface of the tongue, which degrade 25% of the nitrate (NO_3^-) ingested with food to nitrite (NO_2^-) via nitrate reductase enzymes (Qu, Wu, Pang, Jin, Qin, Wang, 2016). Subsequently, part of the nitrite (NO_2^-) is converted to nitric oxide (NO) in the stomach by a non-enzymatic mechanism that is dependent on low pH (Lundberg, Carlström, Larsen, Weitzberg, 2011), and the remainder is absorbed from the small intestine, from which it enters the systemic circulation, where it can be reduced to nitric oxide (NO) in the blood or in other body tissues, with the involvement of deoxyhemoglobin, among others, under conditions of low oxygen availability (hypoxia) (Lundberg et al, 2008). Importantly, researchers have observed that skeletal muscle probably contains the largest storage of nitrate (NO_3^-) in the body. Nitrate (NO_3^-) stored in muscle tissue, under hypoxic and acidic conditions resulting from the accumulation of lactic acid accumulated during exercise, is used to produce nitrite (NO_2^-) and subsequently form nitric oxide (NO), which may explain the potential benefits for athletes in terms of improved exercise capacity (Piknova et al., 2015; Piknova, Park, Kwan, Lam, Schechter, 2016).

Nitric oxide (NO) is a physiologically relevant signaling molecule that has important hemodynamic and metabolic functions (Dominguez et al., 2018; Ferguson et al., 2013; Jones et al., 2021; Larsen, Weitzberg, Lundberg, Eklbom, 2007). Studies have shown that it plays an essential role in the regulation of blood flow and, more specifically, favors vasodilation (Furchgott, Jothianandan, 1991), resulting in increased transport of oxygen and, among others, energy substrates i.e. glucose and lipids to the muscles, thus supporting exercise performance and post-exercise recovery speed (Puype, Ramaekers, Thienen, Deldicque, Hespel, 2015).

Furthermore, nitric oxide (NO) has been found to induce gene expression, enhancing biogenesis and mitochondrial efficiency, through a cGMP – dependent mechanism, thus improving mitochondrial efficiency in skeletal muscle (Dejam, Hunter, Schechter, Gladwin, 2004; Pinna et al., 2014). These effects benefit from increased efficiency of oxidative metabolism, manifested by reduced oxygen consumption during exercise, or more productive phosphocreatine resynthesis (Ahluwalia et. al., 2016; Allen et al., 2010; Larsen et al., 2007; Larsen, Schiffer, Weitzberg, Lundberg, 2012).

The efficiency of mitochondrial oxidative phosphorylation is classically measured as the amount of oxygen consumed per amount of ATP produced, referred to as the P/O ratio (Hinkle, 2005). The research results indicate an improvement in the mitochondrial P/O ratio as a result of the exogenous supply of nitrates (NO_3^-). There are several possible interactions between nitrate (NO_3^-), nitrite (NO_2^-), nitric oxide (NO), and the mitochondrion. Perhaps the best characterized effect of NO is its binding to cytochrome C oxidase (COX) and the terminal electron acceptor in the electron transport system (ETS) (Brown, Cooper, 1994). Research results indicate that nitrates mechanically contribute to (NO_3^-) reduction in the expression of ATP/ADP translocator, a protein involved in proton conduction, which has a profound impact on the basic function of mitochodndria in skeletal muscle (Larsen et al., 2011).

The importance of beetroot juice in the nutrition of people with increased physical activity

The results of research concerning the influence of nitrates (NO_3^-) as a precursor of nitric oxide (NO) and the resulting benefits for the human organism have led scientists to analyze the influence of an increased supply of nitrates (NO_3^-) together with food, i.e. beetroot juice on the performance of athletes of various sports (Larsen et al., 2007). In addition, the enormous workload of exercise, during which athletes often balance between training hard enough and achieving their goals and at the same time avoiding the risk of injury, has given rise to the need to look for new ways, including nutritional, that could protect the athlete's body. The aim of these interventions would be, among other things, to reduce the risk of delayed onset muscle soreness syndrome (DOMS), which potentially increases the risk of injury (Flores, Gomez, Estrada-Catrillion, Smitaman, Pathria, 2018), or to improve post-workout recovery, allowing athletes to compete at the highest possible level of performance.

The first study conducted in this area to verify whether nitrate (NO_3^-) has any effect on metabolic parameters during exercise was conducted by Larsen et al. (2007). The authors, in a randomized double-blind crossover study, examined the effects of a three-day supply of nitrate (NO_3^-) in the form of sodium nitrate, at a dose of 0.1 mmol/kg b.w./day, on physiological and metabolic parameters of male athletes. Based on the results obtained after tests performed on a cycle ergometer at submaximal intensity, they showed that the aerobic cost of exercise decreased after sodium nitrate supply compared to the placebo group. Furthermore, in this study, there was no increase in lactic acid concentration in muscle tissue, which would indicate more efficient energy production during exercise.

Given the results of the above study, Bailey et al. (2009) set out to determine if similar effects could be achieved through the administration of nitrate (NO_3^-) rich beetroot juice. This is an important question given that sodium nitrate is a pharmaceutical, whereas beetoot juice is a natural food product that can easily be included as part of a balanced diet. The researchers therefore hypothesized that beetroot juice supply is able to reduce the aerobic cost of moderate-intensity exercise and increase exercise tolerance during high-intensity exercise. An additional goal was to determine the effects of beetroot juice, and thus nitrate (NO_3^-), on plasma, blood pressure, and muscle oxygenation in athletes. In a crossover double-blind study, the athletes were given beetroot juice for six days at 500 ml/day, equivalent to 5.5 mmol/NO_3^-, and in addition, the athletes were asked to refrain from consuming other products containing nitrate (NO_3^-), according to a list provided. On the last three days of the experiment, the athletes were subjected to exercise testing. Based on the results, the supply of nitrate (NO_3^-) along with beetroot juice resulted in an increase in plasma nitrite (NO_2^-) concentration, a decrease in systolic blood pressure, as well as an improvement in muscle oxygenation indices and a decrease in VO_{2max}. The authors of this study suggested that increased dietary nitrate (NO_3^-) intake could potentially increase exercise tolerance during prolonged endurance exercise.

A study by Rokkendal – Lausch et al. (2019) confirmed the beneficial effects of high nitrate intake – 12.4 mmol NO_3^- along with beetroot juice among trained cyclists. In a randomized, crossover, double-blinded trial, it was shown to improve the athletes' performance during 10 km of cycling. Similar results were obtained by researchers at Maringa State University (de Castro, de Assis, Figueiredo, Machado, 2019), who showed that a three-day supply of 42 ml (8.4 mmol NO_3^-) of beetroot juice among recreationally trained long-distance runners was able to effectively increase the average speed and final time during the athletes' 10 km run.

On the other hand, in a systematic review of studies, Dominguez et al. (2017) showed that nitrate (NO_3^-) supply, in the form of beetroot juice, can have ergogenic effects on cardiorespiratory fitness, and furthermore increase energy production at the same VO_{2max} values, in trained athletes under normoxia and hypoxia. This is important, due to the fact that such a nutritional strategy could be a factor in potentially increasing energy efficiency, in athletes training for endurance sports. Moreover, the researchers concluded on the basis of the obtained data that beetroot juice consumption should be started about 90 minutes before exercise, because after this time the maximum increase in plasma nitrite (NO_2^-) concentration is observed. Most of the studies analyzed by the authors indicated that the optimal supply of nitrates (NO_3^-) with beetroot juice was between 6–8 mmol NO_3^-, although as it turned out, this is not a fully justified dose in such sports disciplines as kayaking or rowing. Based on the data obtained, the researchers suggested that nitrate supply should be higher when performing exercise involving the upper extremities. In addition, this review of studies confirmed that a chronic supply (up to 15 days) of beetroot juice may be equally effective in improving cardiorespiratory fitness as a single dose.

Another review of studies was also published in 2020 that proved the efficacy of nitrate supply with diet, and although a small increase of only 3% in exercise performance was shown, in the context of athletic participation, this small increase can significantly affect athletes' performance and determine victory (Senefeld et al., 2020). Indeed, research indicates that even a 0.6% improvement in performance can change the state of sports competition (Paton, Hopkins, 2006). The cited study noted the lack of research among women, which may have contributed to the authors' results of a lack of significant benefits regarding increased physical performance. The same lack of effect was noted among professional athletes and among athletes performing prolonged efforts (>15 minutes) of lower intensity. The optimal nitrate supply proposed by the authors of this study was between 5 and 25 mmol NO_3^-, taken 2–3.5 hours before training (in none of the analyzed studies was an ergogenic effect obtained at values below 5 mmol NO_3^-) (Senefeld et al., 2020).

Peacock et al. (2012) in their studies, the aim of which was to analyze the impact of the consumption of nitrates (NO_3^-) with a diet on the improvement oh the efficiency of cross – country skiers during 5 and 10 km run, also showed that the short – term supply of nitrates (NO_3^-) in the diet may not be an effective strategy for reducing the aerobic cost of exercise during submaximal exercise, and it does not increase the performance of endurance exercise among highly trained endurance athletes.

Similar results were obtained by Cermak Res, Stinkens, Lundberg, Gibala, van Loon et al. (2012) who showed no improvement in exercise capacity among traing cyclist after the supply of nitrates (NO_3^-) wuth beetroot juice at a dose od 8.7 mmol compared to group of placebo.

In turn, researchers from a research center in Spain did not confirm improvements in such analyzed variables as cardioventilation variables, VO_{2max} level, economy of exercise performed, or effects on time trial among male triathletes, during a bicycle ergometer test (Garnacho-Castano et al., 2018).

There are several theories due to which both the degree of training and the intensity of exercise may affect the ergogenic effect of the use nitrates (NO_3^-) with beetroot juice (Wilkerson et al., 2012). It has been shown that in the case of highly trained athletes, the exogenous „nitrate – nitrite – NO" pathway may be less important due to the high activity od the endogenous L-arginine oxidation patwahy (NOS) (McConell et al., 2007). Moreover, the response to the standard dose of nitrate (NO_3^-) along with beetroot juice may be less effective in highly trained athletes due to the higher starting nitrite (NO_2^-) level in the blood plasma, compared to people who lead a sedentary lifestyle (Poveda et al., 1997). It should also be mentioned that nitrites (NO_2^-) are reduced to nitric oxide (NO) under hypoxic conditions, while due to the greater capliiarity of skeletal muscles in highly trained athletes, muscle tissue hypoperfusion may be minimized during physical exertion, thus leading to a reduction in demand on the production of nitric oxide (NO) by the reduction of nitrite (NO_2^-). The above mechanism also explains the reduced effectiveness of nitrate (NO_3^-) in low – intensity endurance exercise, due to the fact that highly trained athletes who performed endurance traning usually work with optimal blood flow and O_2 distribution levels (Jensen, Bangsbo, Hellsten, 2004).

Due to the above data, Wilkerson et al. (2012) proposed that, based on the NO_2^- response in the blood plasma, athletes should be divided into two groups – "responders" and "non-responders" to the supply of nitrates (NO_3^-) along with beet juice. It should be emphasized that factors such as the dose of nitrates (NO_3^-) with beetroot juice, the intensity of exercise or the individual response of the body are important factors that may affect the effectiveness of a nutritional intervention, which is the supply of beetroot juice in relation to improve exercise capacity. It has been suggested that an increased dose may be required among elite athletes to obtain similar performance enhancement benefits as for intermediate level athletes (Garnacho-Castano et al., 2018).

Based on the research conducted by Logan – Sprenger, Logan (2016), it was shown that women consuming higher amounts of nitrates (NO_3^-) with the diet per 1 kg of body weight (2.4 mg NO_3^-/kg b.w.) showed an increased response on the supply of nitrates (NO_3^-) with beetroot juice, compared to men (1.3 mg NO_3^-/kg b.w.). The results of the research indicate that athletes are characterized by a higher daily intake of nitrates (NO_3^-) with their diet compared to the general population. Therefore, the researchers point out that the elevated starting values of nitrite (NO_2^-) in the blood plasma of highly trained individuals may be partially the result of consuming more foods that are naturally rich in nitrates (NO_3^-).

There is also scientific evidence that contradicts the claim that nitrate (NO_3^-) supply along with beetroot juice would bring benefits in terms of improving sports performance even among less trained. Such conclusions were reached by Hurst, Saunders, Coleman (2020), who in their study showed no difference between the time running performance over a distance of 5 km in recreationally trained runners taking nitrate-rich beetroot juice (70 ml, 4.1 mmol NO_3^-) compared with the placebo group.

Currently, an area of interest for researchers is the use of nitrate (NO_3^-) rich beetroot juice in team sports characterized by periods of high intensity activity interspersed with periods of relative recovery (start-stop exercise). Thompson, Vanhatalo, Jell, Fulford (2016) undertook to investigate the effect of nitrate (NO_3^-) on the performance of this type of exercise using the Yo-Yo Intermittent Recovery level 1 test. In a randomised, crossover, double-blind study, a control group of recreationally trained athletes received, for five days, 70 ml of concentrated beetroot juice (6.4 mmol NO_3^-), while a placebo group received 70 ml of nitrate (NO_3^-) depleted beetroot juice, also. Based on the data obtained, the supply of NO_3^- rich beetroot juice improved maximum performance in sprint and high-intensity interval running among athletes. The authors of the study suggested that this effect may translate into performance not only in individual sports but also in team sports.

Similar conclusions were reached by researchers in the Netherlands, who showed that a supply of beetroot juice improved athletes' performance during the Yo-YoIR1, and also lowered the heart rate of athletes in the control group compared to the placebo group (Nyakayiru et al., 2017). The researchers inferred that a six-day supply of 140 ml (12.9 mmol NO_3^-) of beetroot juice was effective in improving the performance of intermittent high-intensity exercise, including high-intensity running and sprinting series, in trained soccer players. It should be noted that the nature of this type of exercise is dependent on the contribution of type II muscle fibers. This issue has been addressed by researchers from the United States and Sweden. Ferguson et al. (2013) using an animal model in their study evaluated the effect of dietary nitrate supply on blood flow during submaximal exercise. The authors observed that the increase in blood flow and vascular conductance in the limbs involved in the exercise was increased primarily in fast twitch muscle fibers. On the other hand, Hernandez et al. (2012) demonstrated that dietary nitrate supply influences increased calcium (Ca^{2+}) reuptake from the endoplasmic reticulum, in type II muscle fibers in mice, which translates into increased muscle contraction force, and thus may indicate an ergogenic effect of nitrate (NO_3^-) for efforts involving the above type of muscle fibers.

Daab, Bouzid, Lajri, Bouchiba, Saafi, Rebai (2020) conducted an experiment in which the effects of beetroot juice consumption on the kinetics of fitness recovery, levels of markers of muscle damage and perceived muscle soreness were analyzed among athletes after a simulated soccer game. Reduced levels of creatine kinase (CK) and lactate dehydrogenase (LDH), indicative of muscle damage, were noted. In addition, they also showed reduced acute phase protein – CRP levels and no onset of delayed onset muscle soreness syndrome (DOMS) among football players who took nitrate-rich beetroot juice (NO_3^-), compared to the placebo group. A review of studies by Rojas-Valverde, Montoya-Rodriquez, Azofeifa-Mora, Sanchez-Urena (2020) also confirmed the benefits of beetroot juice intake, applied both in a single dose (250 ml to 500 ml) 2.5–3 hours before exercise and taken 3–6 days before the exercise test, in the amount of 70 ml. Based on the results, an improvement in the athletes' resistance to exhaustion during repeated sprints was observed, which manifested itself in an increased number of running repetitions. Other conclusions were reached by researchers from Spain (Lopez - Samanes, Parra, Moreno-Perez, Courel-Ibanez, 2020), who analyzed the effect of beetroot juice supply on the improvement of neuromuscular efficiency, among basketball players. The authors in their experiment did not demonstrate the effectiveness of this type of nutritional intervention. Similar results were obtained by Fernandez-Elias et al. (2020), who showed that a single 70 ml supply of beetroot juice appears to be an ergogenic agent of little value for improving the performance of physical exercise performed by professional tennis players.

The cross-section of research on the effects of beetroot juice intake on athletes of endurance and speed sports is quite wide, while there are limited data on the evaluation of ergogenic potential in resistance training i.e.

weightlifting. A meta-analysis conducted by San Juan, Dominguez, Lago-Rodriguez, Montoya, Tan, Bailey (2020), on nitrate (NO_3) supply along with beetroot juice on improving muscle strength, contraction velocity and muscular endurance during weightlifting, showed that beetroot juice supply may be a promising nutritional intervention in improving contraction velocity and the ability of athletes to perform more repetitions during weightlifting, however, it was emphasized that further research is needed in this area.

Also published in 2020 were the results of a randomized double-blind study that evaluated the effects of beetroot juice supply on muscular endurance and concentric movement velocity during resistance training, specifically during exercises performed by athletes in the form of back squat and bench press (Ranchal-Sanchez, Diaz-Bernier, De La Florida-Villagran, CLlorente-Cantarero, Campos-Perez, Jurado-Castro, 2020). The data obtained confirmed the effectiveness of the nutritional strategy used by increasing the maximum number of repetitions during the squat, but these benefits were not observed when the athletes performed the test in the form of bench press.

Nitrates (NO_3^-) from beetroot juice vs supplementation with sodium nitrate (NIT/$NaNO_3^-$)

Undoubtedly, a very important issue is also the assessment of the effectiveness of the use of an increased supply of nitrates (NO_3^-) with beetroot juice compared to supplementation with sodium nitrate (NIT/$NaNO_3^-$) in terms of improving exercise capacity.

Flueck, Bogdanova, Mettler, Perret (2016) conducted a study to compare the effects of sodium nitrate (NIT) and nitrate (NO_3^-) ingested with beetroot juice fo oxygen (O_2) consumption in male athletes during moderate to high intensity exercise. Twelve men took part in the study, who were subjected to an exercise test on a bicycle ergometer for seven days and received various doses of nitrates (NO_3^-) in the form of concentrated beetroot juice or sodium nitrate (NIT) dissolved in pure water (3, 6, 12 mmol NO3-). The concentrations of nitrates (NO_3^-) and nitrites (NO_2^-) in the plasma were measured before, three hours after consumption and after the exercise test. Oxygen (O_2) consumption of the moderate – intensity exercise test did not differ significantly between exercise over the seven days.However, with high – intensity exercise, oxygen (O_2) consumption was approximately 4% lower when 6 mmol nitrate (NO_3^-) was consumed in beetroot juice compared to the same dose of sodium nitrate (NIT). The authors of the study concluded that beetroot juice can reduce oxygen consumption to a greater extent than sodium nitrate (NIT), and thus more effectively improve the exercise capacity of physically active athletes.

In turn, Clifford, Howaston, West, Stevenson (2017) conducted a study to compare the effects of nitrate (NO_3^-) consumed with beetroot juice and a drink containing only sodium nitrate (NIT/$NaNO_3^-$) on exercise-induced muscle injury rates (EIMD). Thirty recreational men were divided into three groups, each of which received a different type of supplementation (concentrated beetroot juice, sodium nitrate or isocaloric placebo) immediately after the exercise test and 24 and 48 hours after. To assess muscle damage, maximal isometric voluntary contractions (MIVC), pressure pain threshold (PPT), creatine kinase (CK), and high-sensitivity-reactive protein C (hs-CRP) were measured immediately after exercise, 24, 48 and 72 hours after exercise test. Based on the obtained data, the authors of the study suggested that the supply of nitrates (NO_3^-) with beetroot juice is more effective than sodium nitrate (NIT) in relieving EIMD-related muscle pain, and any analgesic effects are most likely related to the content of beetroot juice. phytonutrients other than nitrates (NO_3^-) or due to their interaction.

Toxicity of nitrates (NO_3^-) and nitrites (NO_2^-)

Based on the results of research carried out in previous years, it was found that nitrates (NO_3^-) and nitrites (NO_2^-) have a negative effect on the human body, contributing to the formation of N-nitroso compounds (NOCs) – potentially carcinogenic compounds (Mirvish, 1995; Tannenbaum, Sinskey, Weisman, Bishop, 1974).

Studies on the effect of beetroot juice consumption on the production of N-nitroso compounds (NOCs), and thus analyzing its consumption in relation to the risk of cancer, are limited. In a randomized controlled trial, the aim of which was to analyze the endogenous formation of N-nitroso compounds after consumption of beetroot juice and the effect of vitamin C supplementation on the excretion of the above-mentioned. compounds with urine, it was shown that in 29 healthy adults, recreationally active, consumption of concentrated beetroot juice in a dose of 70 ml (400 mg (NO_3^-) caused a significant increase in the level of N-nitroso compounds (NOCs) in the urine, measured as ATNC (Apparent Total Nitrosamine Content) after one day and in the next seven days. Based on the data obtained, it was found that vitamin C supplementation was able to inhibit the excretion of N-nitrosamine compounds (NOCs) after consuming one dose of beetroot juice, but not for a longer period. The authors of the study concluded that caution should be exercised with long-term use of beetroot juice as an intervention to support exercise capacity, and signaled the need for more extensive research to rule out possible long-term adverse health effects (Berends et al., 2019).

The Australian Institute of Sport (AIS) points out the adverse health effects of consuming beetroot juice (especially in higher doses and in concentrated form) in the form of mild gastro-intestinal complaints, and therefore recommends that this nutritional intervention be checked by competitors during the preparation period, and not immediately before or during the competition. AIS also indicates the possible occurrence of temporary pink discoloration of the urine and stools, which in turn is a completely harmless side effect (AIS, 2020).

Although there is insufficient evidence confirming the harmfulness of consuming high doses of nitrates (NO_3^-) with beetroot juice, numerous epidemiological studies can be found in the literature on the subject, analyzing the possible risks to human health related to the consumption of nitrates (NO_3^-) and nitrites (NO_2^-) along with other foods that are rich in this compound.

Studies assessing the impact of consuming red or processed meat with a high content of nitrates (NO_3^-) and nitrites (NO_2^-) have shown that its consumption causes the endogenous formation of N-nitroso compounds (NOCs) (Habermeyer et al., 2015; Hebels et al., al., 2012; Hughes, Cross, Pollock, Bingham, 2001; Linseisen et al., 2006). Moreover, the results of prospective cohort studies show an association between red meat consumption and an increased risk of colon (Cross et al., 2011), stomach (Tannenbaum, Correa, 1985) and bladder cancer (Mirvish, 1995).

It is also worth mentioning the increased risk of methaemoglobinaemia with the use of too high doses of nitrite salts (Lundberg, Larsen, Weitzberg, 2011).

Scientists from the World Cancer Research Fund and the American Institute for Cancer Research (2018) observed that the supply of nitrates (NO_3^-) in the form of vegetables and fruits correlated with a lower risk of cancer development, which is probably the result of the high content of bioactive compounds in in particular the antioxidants of the above-mentioned food groups. It is also believed that vitamin C present in vegetables is able to inhibit the formation of N-nitroso compounds (NOCs) by reducing $2HNO_2$ to nitric oxide (NO), while itself being oxidized to dehydroascorbic acid (World Health Organization [WHO], International Agency for Research on Cancer [IARC], 2010). Bahadoran, Mirmiran, kabir, Azizi, Ghasemi (2017) also pointed out that it is unlikely that the acceptable daily intake of nitrates (0.3–7 mg/kg body weight/day) will be exceeded by consuming vegetables and fruits, unless they are consumed daily in concentrated and extremely high doses.

Taking into account the above data, consumption of beetroot juice containing a high content of nitrates may pose a potential threat to human health, mainly due to the formation of N-nitroso compounds (NOCs). However, it is important to emphasize the beneficial role of bioactive substances contained in fruits and vegetables, including beetroot juice, which may, in turn, positively affect the reduction of the risk of cancer development. However, the above issue requires further research (Zamani et al., 2021).

Variability of the ergogenic effects of the supply of nitrates (NO_3^-) along with beetroot juice

Due to the controversy surrounding the potential effectiveness of a nutritional intervention such as nitrate (NO_3^-) supply along with diet, and more specifically with beetroot juice, researchers undertook a study to isolate the factors influencing the variability of ergogenic effects. It has been proven that it can be influenced by several factors i.e. the level of aerobic capacity of the athletes, the time of use, and the proposed nitrate (NO_3^-) dose, the inter-individual variability in pharmacodynamics (Wylie et al., 2013; Wylie et al., 2016), gender (Wickham, Spriet, 2019), and environmental factors (Shannon et al., 2017). Furthermore, ergogenic potential may be dependent on the oral microbiome, which is responsible for the reduction of nitrate (NO_3^-) to nitrite (NO_2^-), and which is shaped by many oral substances such as antibiotics, chewing gum, or antibacterial mouthwashes (Govoni, Jansson, Weitzberg, Lundberg, 2008; Qu et al., 2016).

Conclusion

In conclusion, although there are conflicting data, it appears that the use of beetroot juice rich in inorganic nitrate (NO_3^-) may be an effective nutritional strategy in improving exercise performance, especially in recreational exercisers. Among competitive athletes, there is a need for further research to determine an appropriately higher dose or timing of beetroot juice supply to achieve the desired effect of increased exercise capacity.

There is scientific evidence demonstrating the ergogenic effect of beetroot juice intake in both endurance and intermittent high intensity start-stop exercise. However, more detailed studies analyzing the effect of dietary nitrate (NO_3^-) supply on anaerobic exercise - especially high volume resistance training – are needed. Further research is also needed to elucidate the effects of specific factors on the variability of ergogenic effects after beetroot juice consumption, which may be most relevant to the effectiveness of this nutritional intervention. In addition, the impact of an extended period of nitrate (NO_3) delivery with food beyond the relatively short period that the scientific data present (i.e., up to 15 days) needs to be evaluated to determine whether stronger ergogenic effects can be observed with a longer duration of beetroot juice application, and thus, an in-depth investigation of the long-term safety profile of increased nitrate (NO_3^-) delivery, in this case in the form of beetroot juice, should also be considered.

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IDENTIFICATION OF THE MAPPING MODELS OF THE PLAYERS COOPERATION IN SERVE RECEPTION IN VOLLEYBALL

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Abstract **Introduction.** Identifying cooperation in team games is a difficult process to implement. Thanks to the development of methods and techniques of game observation, it is possible to reliably and accurately identify and evaluate the actions of players. The collections of various analyzes are used to create pragmatic game models. There are several types of such models. The paper presents models representing effective cooperation in the game on the example of volleyball. **Aim of the study.** The aim of the study was to identify mapping models of effective cooperation in the game, in the game positioning phase – in the element of receiving-passing the ball (serves). The second goal was to present the differences and similarities between observed teams. **Material and methods.** The work uses a method called qualitative study of unique cases, the research material consists of the four highest-ranked teams from Rio de Janeiro 2016 Olympic Games. **Results.** Four different models of cooperation in receiving-passing the ball (serve) were identified. Each of them contains characteristic features visible in the figures. **Conclusions.** Various models of cooperation have been identified. Each team has a specific model of receiving-passing the ball (serve) due to the spatial flexibility. The models presented in the paper are effective because they show the cooperation of the best teams in the world.

Key words volleyball, cooperation, mapping models, service reception, game models, Olympic Games

Introduction

Nowadays, thanks to the great possibilities and continuous development of methods and techniques of game observation, the development of technology in sport, as well as paying more attention to the processes of monitoring and evaluation of the game, it is possible to more objectively and reliably evaluate players. The analysis covers different elements like: players motor skills, psychological and mental sphere, but most of all – their efficiency in the game. The analysis of the collected data allows for identification of actions taken by the players and assessment of their efficiency. The collections of such analyzes can be used to create various types of game models, which seem to be the best tool for presenting and identifying cooperation in team sports. Game models are based on the praxeology and the theory of sports games. Praxeology is regarded as an applied science, which means that the obtained research results can be used in sports practice and constitute a beneficial value. The praxeological model defined by Pszczołowski (1978) is a complex object that reflects a complex, existing or projected fragment of reality for cognitive purposes.

In order to best understand the idea of using game models in identifying the processes of action and cooperation in the game, it is necessary to organize their types and ways of using them in practice. Game models are pragmatic models, i.e. models of players' actions, which allow the rationalization of processes aimed at their improvement. Panfil (2006) characterized six types of game models. There are two types of cognitive models: ideal mapping and ideal designing models, as well as two types of practical models: real mapping and real designing models. There are also promotional models (mapping and designing) that are used to improve the image of a sporting event and increase its attractiveness.

The ideal mapping models allow for some kind of re-creation and identification of the actions in the game taken by the observed players – representing the highest possible sports level (championship level). The main characteristic of ideal mapping models is, above all, the lack of influence on the monitored players. These type of models are created without time pressure, and there are no other restrictions on players monitoring when creating them. In addition, the monitoring of activities takes place on the basis of specific efficiency criteria (resulting from game theory and praxeology). Perfect models imitating the game of the best teams are created with the help of the so-called detailed mapping models – that is, various types of activity tables, graphics, charts, etc. Ideal mapping models allow for the identification of actions and cooperation of players in sports teams. Thanks to these models, it is possible to draw conclusions and create rational practical directives, which can then be used in the creation of ideal design models as well as practical (mapping and design) models.

Ideal game-design models are a set of assumptions, rules and conclusions resulting from the praxeology, the theory of the sports game, and above all from the observation of the best teams (championship level) and ideal models reflecting this game. Ideal design models can be helpful in sports practice. Such models are also often used in the development of long-term team and discipline development strategies. It should be noted, however, that the ideal game design models result from the objective and reliable monitoring of the best players and may constitute some kind of pattern or scheme.

Real mapping and designing models are a kind of practical models. This type of models are used in the process of managing various teams. Their characteristic features are the ability to influence the actions of players, and the observation criteria result primarily from the tasks set for the players. Real models are created by constantly comparing the real mapping model with the real designing model. Real models are therefore a kind of a loop, where the design model is subject to observation, and by means of the mapping model, by comparing and evaluating the actions taken, corrections are made to this design model.

In this work, mainly ideal mapping models representing the game of the masters were used. The game at the highest sports level is characterized by the use of the ability to surprise the opponent. All actions taken by the players come down to the element of surprise, so as to be able to achieve the full possibility of acting while achieving the goals. The surprise of the opponent is achieved through the conscious or intuitive use of various solutions (Panfil, 2012). The opponent is surprised by creativity of actions, by the choice (variety) of action or its speed (and change of speed of action). The criteria for assessing creative solving of a situation are, on the other hand, accuracy of action, flexibility or the creation of a new quality. The interoperability models can also be described as flexible. The flexibility of the model is then understood as the ability to adapt the actions taken to the current situation of the game, i.e. in this case to adjust the interaction to the requirement of an effective game. The flexibility of the model can be considered here in three elements. It is:

– flexible use of various combinations, where players perform various methods of cooperation, adjusting them to a given situation, so as to surprise the opponent and score a point,
– flexible use of the game space, where players interact with each other in different places of the game space, using various methods of interaction,
– flexible differentiation of the speed of cooperation, where the players interact with each other using combinations with different tempo of displaying the ball (1, 2 and 3 tempo).

The flexibility of interaction in the offensive game increases the possibilities of surprising the opponent. That is why sports teams, in order to be able to compete effectively, use flexible (differentiated) models of cooperation in the game. The work attempts to show the possibility of formulating models of various manifestations of team synergy occurring in a sports game.

Aim of the study

The aim of this study was to identify game-mapping models of effective cooperation based on the examination of the links between the skills of players cooperation in the phase of game positioning – serve receive and pass phase, and the effectiveness of male sports teams playing volleyball in the competition classified at the highest level of sports championship. Moreover, the author attempted to present the differences and similarities between identified models.

Due to the main aim of this research it is possible to formulate the following research questions:

1. What are the characteristics of the various models representing the cooperation of players in receiving-passing the ball (serve), due to the criterion of flexibility of cooperation?
2. What are the differences and similarities between the identified models representing the interaction of players in receiving-passing the ball (serve)?

Material and methods

Research method

In this research work, a research method called a qualitative study of unique cases was used. This method is an original research procedure that allows for a pragmatic perception of research, as well as a pragmatic perception of its results together with their interdisciplinary dimension (Panfil, Superlak, 2011). The method should be used precisely when analyzing complex, exceptional and unique entities, and such are sports game teams. When identifying the various ways in which players interact, an observation technique was used.

Research tool

The study used an original observation sheet of cooperation in serve reception in volleyball (Figure 1). The cooperation observation sheet in serve reception is a research tool which aims to graphically identify the interaction between the player passing the ball (i.e. who receives the service) and the player on the field (who makes the second hit – sets the ball). The sheet is a representation of a volleyball court. The line in the middle of the figure (black in bold) is the center line of the court, dividing it into two halves. The bold black lines to the right and left of the center line are the 3 m lines that separate the frontcourt from the backcourt according to the rules of the game. The sheet marks the place where the receiving player hits the ball, and then the place where the player hits the ball. The pitch was divided into 18 equal areas (3 m × 3 m squares). The designated places also allow you to define the division of the court zones, which is in force in the FIVB regulations. Thanks to this, it is visible where on the court the player performs a reception pass and from which zone the ball is played.

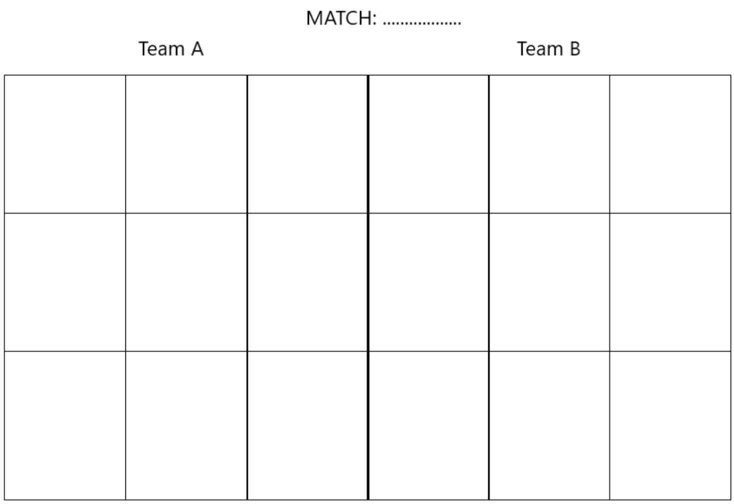

Figure 1. Original sheet for identifying cooperation in serve reception in volleyball

Research material

The material consists of sports teams playing volleyball at the highest level of classified sport. The research material consists of the teams that took the first four places during the Olympic Games in Rio de Janeiro in 2016. Moreover, these are the teams that are currently in the top positions of the FIVB ranking (data as of 1.08.2018). These teams meet the effectiveness criterion, because the Olympic tournament is one of the most important tournaments in international volleyball competitions (its significance is also confirmed by the maximum number of possible points for the world ranking (100 points for a victory, 90 for 2nd place, etc.) The selected teams are:

– Brazil national team: 1st place in the Olympic tournament (1st place in the FIVB ranking),
– Italy national team: 2nd place in the Olympic tournament (3rd place in the FIVB ranking),
– US national team: 3rd place in the Olympic tournament (2nd place in the FIVB ranking),
– Russia national team: 4th place in the Olympic tournament (5th place in the FIVB ranking).

Description of the research procedure

The research was conducted by observing the matches played during the volleyball tournament of the Olympic Games in Rio de Janeiro in 2016. Each of the teams was observed during the three matches. Mainly matches from the final stage of the tournament (quarter-final and semi-final matches, as well as the final and the match for 3rd place) or from the group stage, also with teams presenting a high sports level. List of watched meetings:

Brazil national team:

– Brazil–USA – Group A match, date: August 11, 2016, result: 1 : 3 (20 : 25; 23 : 25; 25 : 20; 20 : 25),
– Brazil–Russia – semi-final on August 19, 2016, score: 3 : 0 (25 : 21; 25 : 20; 25 : 17),
– Brazil–Italy – final, date: August 21, 2016, result: 3 : 0 (25 : 22; 28 : 26; 26 : 24).

Italy national team:

– Italy–Iran – quarter-final, date: August 17, 2016, results: 3 : 0 (31 : 29; 25 : 19; 25 : 17),
– Italy–USA – semi-final, date: August 19, 2016, result: 3 : 2 (30 : 28; 26 : 28; 9 : 25; 25 : 22; 15 : 9),
– Italy–Brazil – final, date: 21.08.2016, score: 0 : 3 (22 : 25; 26 : 28; 24 : 26).

The US national team:

– USA–Brazil – Group A match, date: August 11, 2016, result: 3 : 1 (25 : 20; 25 : 23; 20 : 25; 25 : 20).
– USA–Italy – semi-final, date: August 19, 2016, result: 2 : 3 (28 : 30; 28 : 26; 25 : 9; 22 : 25; 9 : 15).
– USA–Russia – match for 3rd place, date: August 21, 2016, result 3 : 2 (23 : 25; 21 : 25; 25 : 19; 25 : 19; 15 : 13).

The Russia national team:

– Russia–Poland – group B match, date: August 13, 2016, result: 3 : 2 (25 : 18; 16 : 25; 25 : 18; 22 : 25; 15 : 13).
– Russia–Brazil – semi-final on August 19, 2016, score 0 : 3 (21 : 25; 20 : 25; 17 : 25).
– Russia–USA – match for 3rd place, date: August 21, 2016, result 2 : 3 (25 : 23; 25 : 21; 19 : 25; 19 : 25; 13 : 15).

The source of data collection were matches recorded in the form of digital video recordings. All matches were captured with a video camera, placed centrally behind one of the end lines, on the dais, in such a way that the two halves of the volleyball court were visible. The location of the camera while recording matches remained the same throughout the game.

Each of the selected games was observed twice using the observation sheet of cooperation in serve reception (Figure 1) to identify interaction between the receiving and setters. When identifying cooperation in accepting the service, each of the actions observed in the video was recorded on the observation sheet as follows: place where the service was received (the place where the player touched the ball) – marked with a dot, the place where the ball was played (the place where the player touched the ball) – was marked dot. Then the dots were connected with a solid line. Thanks to this, after observing the entire game, a "map" of receiving-passing the ball (service) was created, along with the places where it was played. It should be noted that only passes where the ball was moving towards the net were recorded on the sheet (no passes where the ball was directed backwards, towards the end line or outside the recording area).

Results

The data collected on the identification sheets for cooperation in receiving-passing the ball (serve) allow for the identification of certain patterns in terms of spatial flexibility. The Brazilian team most often directed the ball to zone III of the pitch. The players of this team tried to direct the ball into the space located as close as possible to the net. In the match which ended with a negative result for this team (Figure 2), the most receptions were directed to the space between the court axis and the border of zones II and III. This space is marked in red. In this game, a second area was also designated, where the service was directed, located in zone III, approx. 1.5 m from the net, behind the identified first area of the most frequent admissions – passes. In matches that ended with a positive result for this team (figures 3 and 4), the space for receiving the service is larger, it covers mostly zones II and III, which proves a high spatial flexibility in their cooperation in receiving-passing the ball (serve), and then effectively creating point situations (these areas are marked in red in the figures). In the match with the Italy national team has also designated an area (marked in green) located on the border of the attack line (3 m line), between zones III and VI.

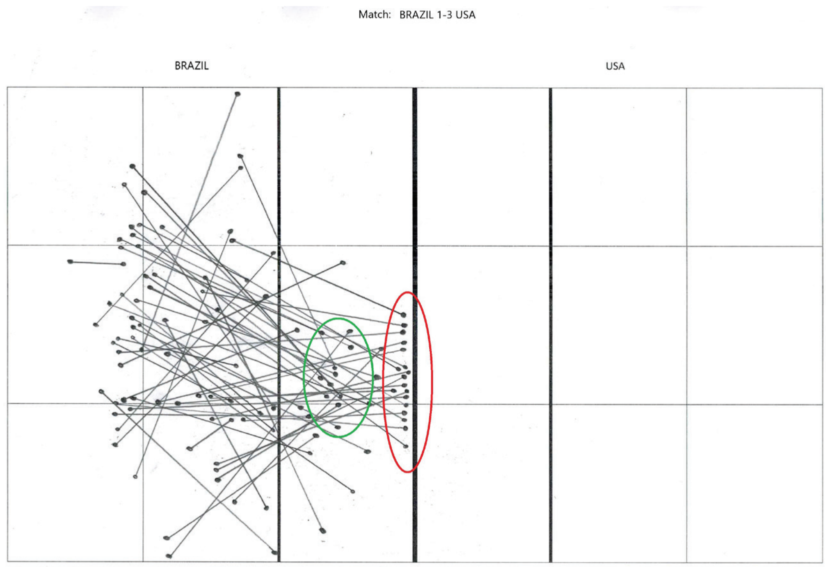

Figure 2. Analysis of cooperation in the field of spatial flexibility in the Brazil–USA – Group A match, result: 1 : 3 (20 : 25; 23 : 25; 25 : 20; 20 : 25)

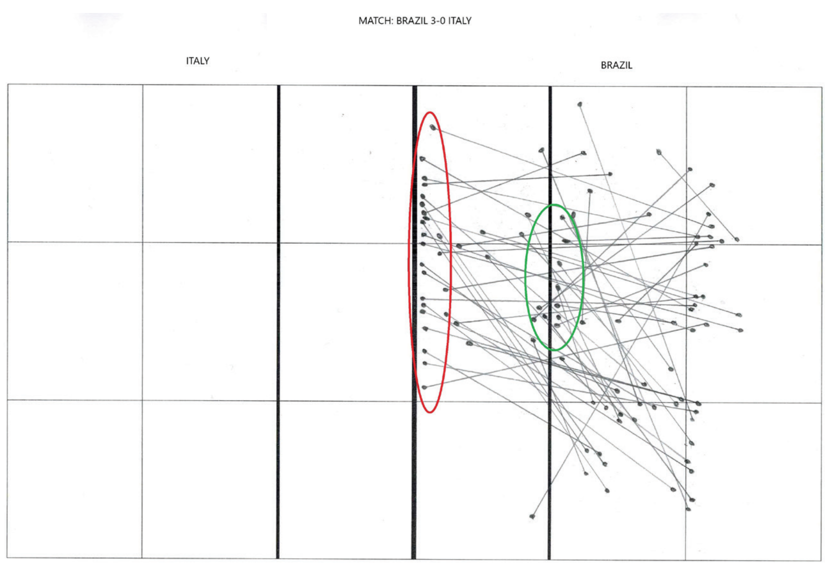

Figure 3. Analysis of cooperation in terms of spatial flexibility in the Brazil–Italy – final match, result: 3 : 0 (25 : 22; 28 : 26; 26 : 24)

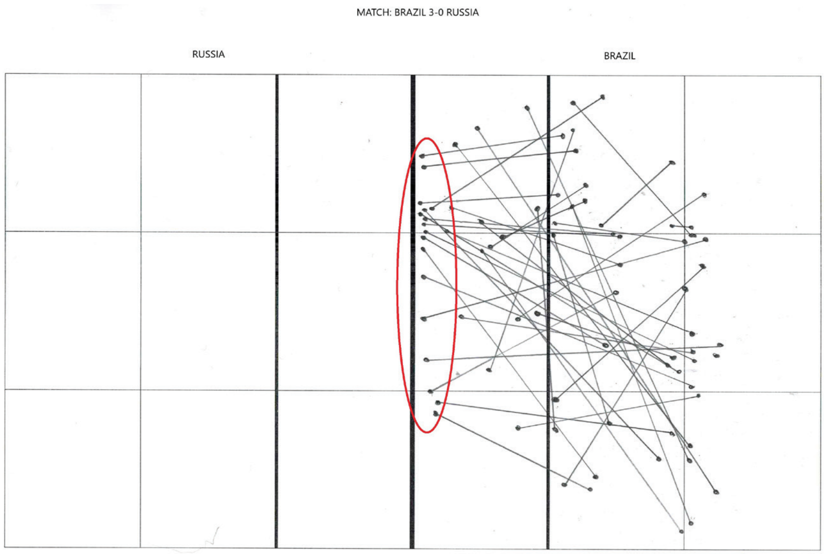

Figure 4. Analysis of cooperation in terms of spatial flexibility in the Brazil–Russia – semi-final match, result: 3 : 0 (25 : 21; 25 : 20; 25 : 17)

Analyzing the reception-pass ball (serve) phase of the Italy national team, it is noticeable that generally the first pass was directed to the zone III. In figures 5, 6 and 7, the space marked in red has been identified, which is in close proximity to the net and is located within the axis of the court. This team tries to direct the ball as close as possible to the pitch axis, from where it then creates point situations. During the analysis of selected matches, a second area was designated where the serve reception was directed. This space is located behind the first reception-pass area, approx. 1.5 m from the net and mostly covers zone III of the court, as well as part of zone II. This space is marked in green in the figures.

By analyzing the spatial flexibility of the United States team, we can determine the areas to which the ball is most often directed after receiving a service. In figures 8, 9 and 10, the area in close proximity to the net, which is located in zone III of the court and also covers a small part of zone II, is marked in red. It was there that the most reception-pass were identified. The green color in the figures also marks the area where some of the balls were directed after the service reception. In all analyzed games, this area is similar and is located on the border of zone II and III of the court, approx. 1.5 m from the net. It is also worth paying attention to the area marked in blue in Figure 9. In the match with the Italian national team, some of the plays were accepted there, which may be a pattern in the team's tactics. It is noteworthy that a similar area located in this place was identified in the research of Mazur (2017), in a match with the Canadian national team, also played at the Olympic tournament in Rio de Janeiro, where cooperation in the reception-passing of the US team was analyzed.

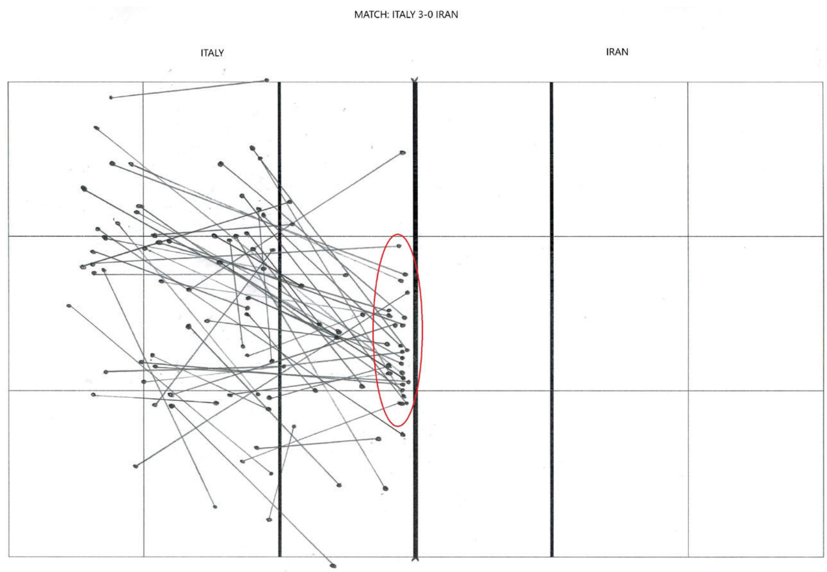

Figure 5. Analysis of cooperation in terms of spatial flexibility in the Italy–Iran – quarter-final match, results: 3 : 0 (31 : 29; 25 : 19; 25 : 17)

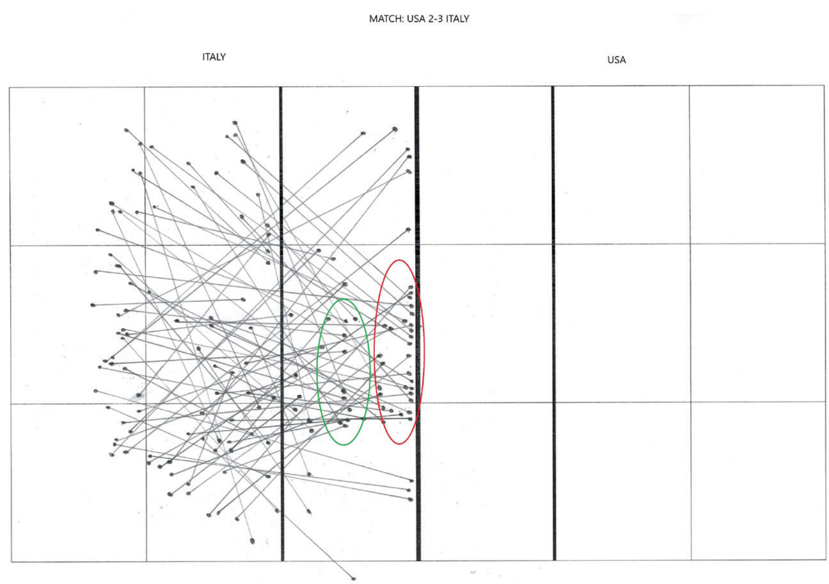

Figure 6. Analysis of cooperation in the field of spatial flexibility in the Italy–USA – semi-final match, result: 3 : 2 (30 : 28; 26 : 28; 9 : 25; 25 : 22; 15 : 9)

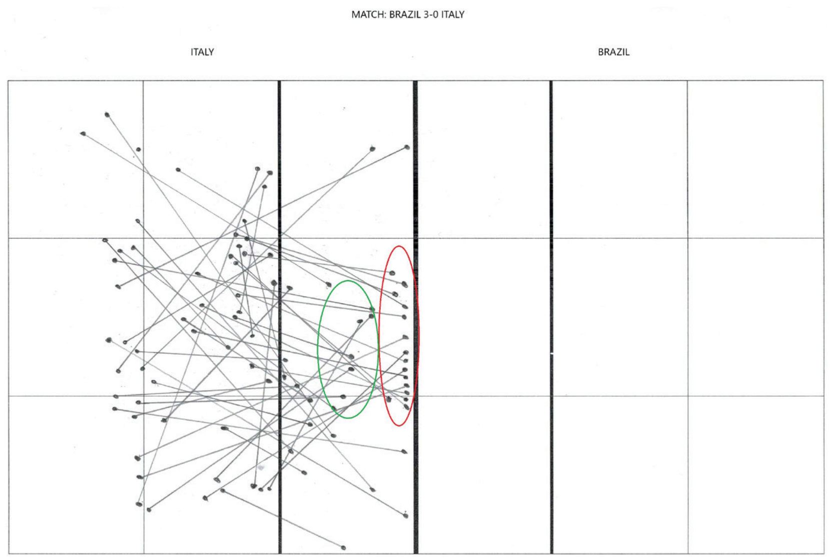

Figure 7. Analysis of cooperation in terms of spatial flexibility in the Italy–Brazil – final match, result: 0 : 3 (22 : 25; 26 : 28; 24 : 26)

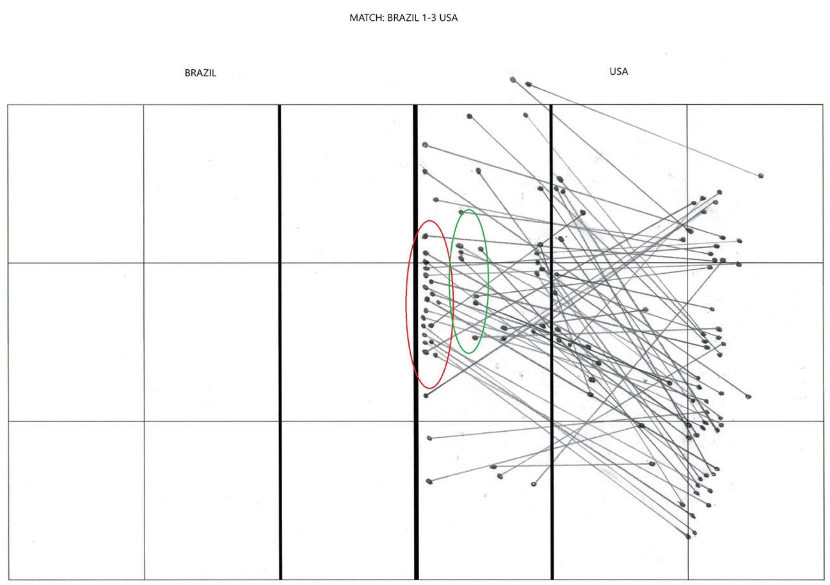

Figure 8. Analysis of cooperation in the field of spatial flexibility in the USA–Brazil – Group A match, result: 3 : 1 (25 : 20; 25 : 23; 20 : 25; 25 : 20)

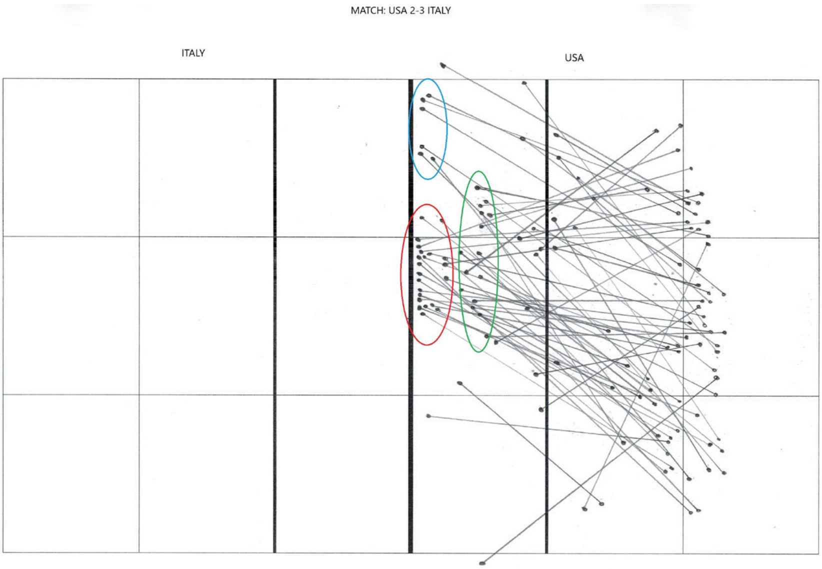

Figure 9. Analysis of cooperation in the field of spatial flexibility in the USA–Italy – semi-final match, result: 2 : 3 (28 : 30; 28 : 26; 25 : 9; 22 : 25; 9 : 15)

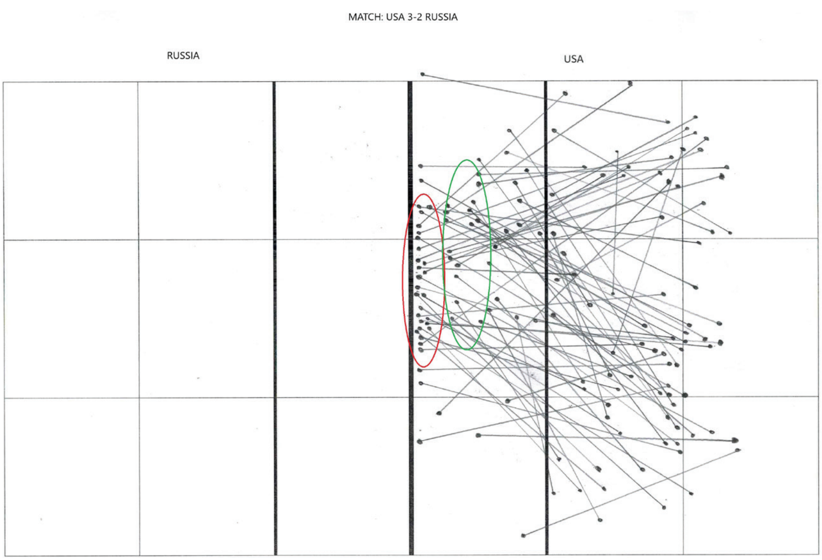

Figure 10. Analysis of cooperation in the field of spatial flexibility in the USA–Russia – 3rd place match, result 3 : 2 (23 : 25; 21 : 25; 25 : 19; 25 : 19; 15 : 13)

The analysis of the spatial flexibility of cooperation in receiving-passing the ball (serve) of the Russian national team allowed for the designation of several zones in this phase of the game. After receiving the service, the most of the balls were directed to the space located in close proximity to the net and between zones II and III of the court. This area is marked in red in figures 11, 12 and 13. Figures 11 and 12 also show the green area to which the serves were also directed. This space is not less than 1.5 meters from the net and is located on the border of zones II and III of the volleyball court. Figure 11 also identified two more smaller areas of reception-pass serves, where the ball was directed in the match with the Brazilian national team, however, the pattern of receiving-passing to this place was not repeated in other observations, which can be treated as a coincidence.

When analyzing the positioning phase in receiving-passing the ball (serves), differences between the teams are visible. Comparing teams due to the spatial flexibility criterion is difficult, because each of them implements their own, unique strategy of cooperation in this phase of the game. Each of the models presented in this research, however, has some specificity that distinguishes them from the others. It should be emphasized that all selected teams try to receive the ball (serve) as close as possible to the net. The model of receiving-passing the ball of the Brazilian national team is characterized by the widest area of cooperation in this phase of the game. The model of receiving-passing the ball of the Russian team, unlike the Brazilian team, is characterized by a narrow area to which the service is directed. It can be seen in the graphics that this team tries to steer the ball more pointly, near the border of II and III pitch zones, focusing more on accuracy. The remaining spaces marked out in the graphics appear irregularly. The greatest similarity among the models of cooperation during the receiving-passing phase was observed among the Italy and US national teams. The players of these teams tried to steer the ball to zone III. The areas indicated in the graphics cover the space both to the right and left of the pitch axis. The reception-pass the ball (serve) models are very similar in these two cases.

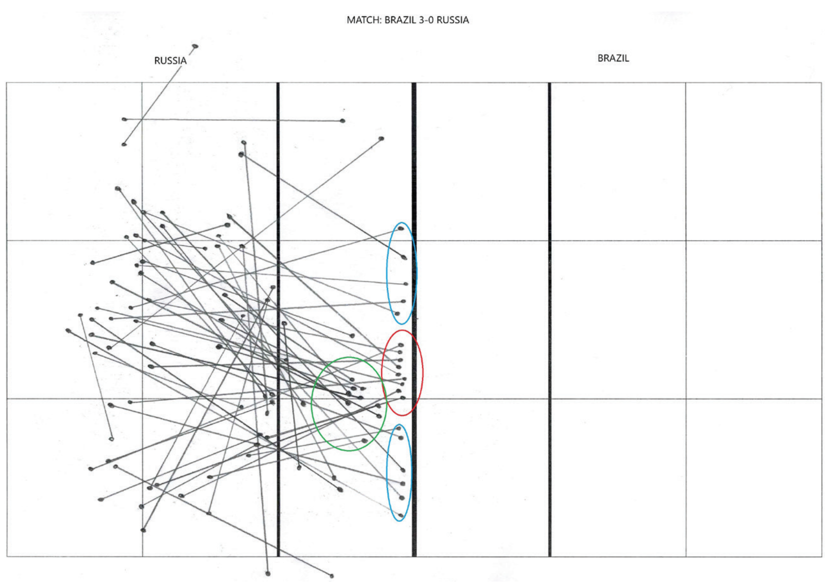

Figure 11. Analysis of cooperation in the field of spatial flexibility in the Russia–Brazil – semi-final match, result 0 : 3 (21 : 25; 20 : 25; 17 : 25)

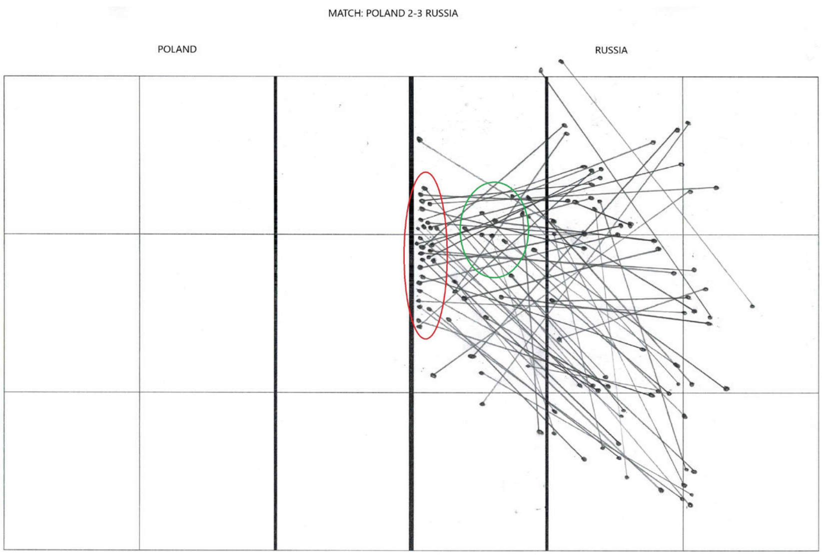

Figure 12. Analysis of cooperation in the field of spatial flexibility in the Russia–Poland – group B match, result: 3 : 2 (25 : 18; 16 : 25; 25 : 18; 22 : 25; 15 : 13)

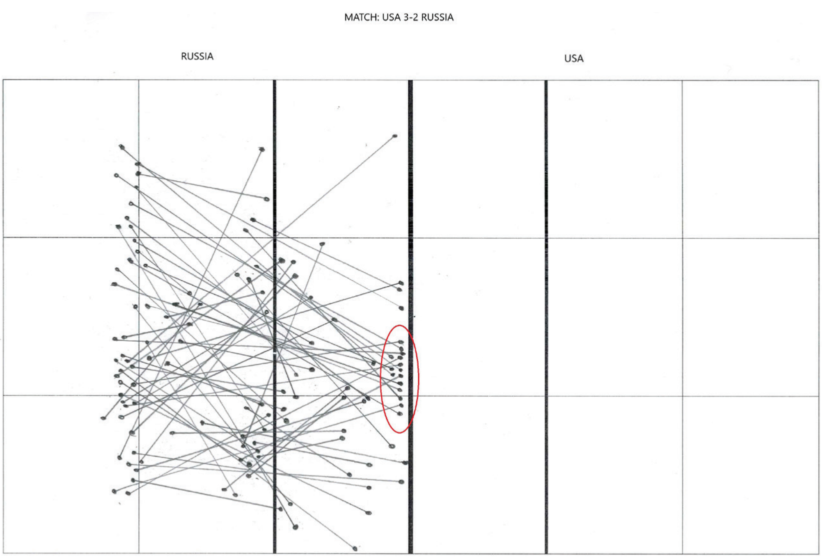

Figure 13. Analysis of cooperation in the field of spatial flexibility in the Russia–USA – 3rd place match, result 2 : 3 (25 : 23; 25 : 21; 19 : 25; 19 : 25; 13 : 15)

Discussion

Trying to identify cooperation in team games is very important, but also innovative. Still few scientific works focus on a holistic view of cooperation processes, assessing players usually through the prism of individual actions. Scientific publications are most often based on the assessment of individual activities, referring them to the final result of the game, without taking into account the influence of other team players on enabling these activities to be performed during the game An example may be works such as: Drikos (2018), Hayrinen, Hoivala, Luhtanen (2000), Kountouris, Drikos, Angelonidis, Laios, Kyprianou(2015), Costa Freire (2017), Costa Freire, Evangelista, Pedrosa, Ugrinowitsch, Catro (2018), Pena, Rodríguez-Guerra, Buscà, Serra (2013), Palao, Santos, Urena(2007), Mesquita, César (2007) and many more. The main purpose of this work is to draw attention to cooperation in the game. Identifying the players cooperation allows to look at the team functioning as a one system. Research methods should be sought that will allow for the evaluation and analysis of cooperation in team sports. One of such methods is the presentation of cooperation in the form of mapping models. Thanks to the models, it is possible to actually represent the various ways of cooperation that occur in teams. Some authors have already taken up the issue of identifying cooperation in the form of pragmatic game models.: Panfil Paluszek. (2005), Becella (2005), Nowak (2014), Nowak, Panfil (2012), Mazur, Superlak (2015), Mazur, Superlak (2018) and others. This work is a continuation of this kind of trend in research. The issue of identifying the model of cooperation in the positioning phase of a volleyball game was already undertaken by Mazur (2017). This work is a kind of extension of that data which was published.

An analysis of the spatial flexibility of selected teams allows us to designate areas on the pitch where selected teams most often passed the ball after receiving a service. The main goal of all teams is to direct the ball into a space as close as possible to the net. This is due to the fact that the setters can then surprise their opponent with much greater efficiency, creating various point situations with their teammates. The speed of the combinations performed then is very high, which causes the block and defense of the opponent to be surprised, and thus it is easier to score points. However, differences in the spatial flexibility of the studied interaction among teams were observed. In the presented research results, the Brazilian national team mainly tried to steer the ball into the space located between zones III and II. An interesting fact is that in matches that ended in a positive result for this team, the area to which the ball was directed is larger than the area marked in the match which they lost. This may mean that this team tries to position the game using as much space as possible in order to surprise the opponent by flexible use of combinations in the phase of creating point situations, in different places on the court. Thanks to the large area to which the ball is directed after receiving a service, it is easier to surprise the opponent by using a variety of ways to create point situations at different places on the pitch. However, when the opponent effectively prevents by efficiently performing the service, then the space of cooperation in receiving-passing the ball decreases. In the observed games, areas further away from the net were also designated. They were located mainly in the III zone of the court, near the 3 m line. These areas differ from one match to the other, but this was due to the quality of the opponent's service, i.e. the scale of its difficulty.

Cooperation in receiving-passing the ball is not always successful, and the ball is not directed to the place chosen by the receiver. The opponent always tries to make the positioning phase of the game as difficult as possible, which is why there are other areas of receiving-passing the ball, located further away from the net, so achieving the goal of surprising the opponent is more difficult. Differences in spatial flexibility between the studied teams were observed in the cooperation of the Russian team. The players of this team try to steer the ball as close as possible to the net, but this area is quite small and in all observed games, it was located between the II and III field zones. The space between these two zones is often referred to by discipline experts as the “perfect reception zone” or “zone 0”. For many years, this place was recognized as the best place to effectively create point situations. It can be assumed that this team is trying to steer the ball into this space, because in the observed games, areas also between these two zones of the court (II and III), but further away from the net, have also been marked. After analyzing these spaces, the direction of receiving-passing the ball by the players of this team is noticeable. The teams from the USA and Italy had the most similar models of cooperation in terms of spatial flexibility. You can see a great similarity in the cooperation of these teams in this phase of the game. Both teams tried to direct the ball as close as possible to the net, into the space close to the court axis, in zone III. Outside this area, both teams have designated areas further away from the net (more than 1.5 m), including the area of II and III pitch zones. These teams try to direct the ball towards the axis of the court, which also seems to be the right choice, because then the distance to the individual players performing the attack is comparable, and then the players of these teams can surprise the opponent by choosing the appropriate combinations and players performing them.

Conclusions

The analysis of the research results allows to conclude that the main goal of the work, which was to identify mapping models of effective cooperation in the game, was achieved. Various models of cooperation have been identified, based on the performance of the top four teams of the 2016 Olympics in Rio de Janeiro in volleyball, in the positioning phase – where cooperation in the element of receiving-passing the service ball was observed. The models presented in the paper could be treated as effective, because they show the cooperation of the best teams in the world in volleyball. It should be emphasized that the work was not intended to assess the effectiveness of individual activities, but to present how the cooperation is actually implemented by the most effective teams competing in this discipline. The obtained research results allow for the formulation of answers to the research questions posed, which can be used as practical directives for other sports teams :

1. Each team has a specific model in receiving-passing the ball (serve) due to the spatial flexibility.
2. All teams try to direct the ball as close as possible to the net.
3. The model representing the reception-pass of the team of Brazil is characterized by a large width of the area to which the ball is directed after the serve reception, the model of the Russian team has the smallest width of the area to which the service is received. The most similar models in the receiving-passing the ball (serve) have the teams of the United States and Italy, which direct the ball around the axis of the court.

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THE IMPACT OF IMPLICIT AND EXPLICIT TRAINING METHODS ON THE ACQUISITION OF PERCEPTUAL EXPERTISE IN YOUNG ATHLETES

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Abstract This study examined the effectiveness of implicit and explicit learning methods on the acquisition and retention of the decision-making skill in low and high complexity situations. 60 novice students were divided into explicit, implicit, and control group. Experimental groups followed 12 training courses. A pre-test, a post-test, and a retention test were used to evaluate the effectiveness of the instructional methods. All participants were evaluated in decision-making speed and accuracy in laboratory tests under simulated conditions. A three-way factorial ANOVA was conducted (3 Group X 2 Complexity X 3 Measurement periods) with repeated measurements on the last factor for the accuracy and reaction time. The analysis showed a significant improvement in decision-making accuracy, in low complexity for both experimental groups. In high complexity situations, the explicit method improved over time and was better than the implicit for decision accuracy. No differences were found among groups or measurements for the decision speed in either low or high complexity situations. It seems that in complex sport conditions, the use of explicit learning helps novices to develop decision-making accuracy more than the implicit learning method, since guided discovery may guide the participants to process contextual information from the sports environment more effectively.

Key words attention demands, decision-making, complexity, speed, accuracy, dual sports

Introduction

Decision-making is the ability to make the right and quick decision and is important for athletes when performing a sport skill, especially in a changing environment such as in team sports (Lola, Tzetzis, 2020) or maybe in dual sports. In racket sports players have to make correct decisions for the direction of the ball according to their or their opponents' position on court within a very short time (Raab, 2005).

Many researchers have attempted to discover instructional methods that will improve perceptual expertise in sport; however, knowledge is sparse about when, whether, or how perceptual skills such as decision-making can be developed through instruction and practice (Votsis, Tzetzis, Hatzitaki, Grouios, 2009). Whilst the effectiveness of implicit and explicit learning strategies has been debated in the motor learning literature (Masters, 1992; Masters, Maxwell, 2004), few researchers have attempted to investigate whether the typical conclusions reported for motor skills also relate to perceptual and cognitive skills such as decision-making (Williams, Ward, Smeeton, 2004).

The explicit learning method is the most common training method, used by coaches especially for novices. In this instructional method, the coach sets out clear rules and gives verbal instructions on how to execute a particular movement or skill (Lola, Tzetzis, 2020). The acquisition of knowledge via the explicit learning process results in consciously accessible declarative knowledge that can be articulated (Tzetzis, Lola, 2010). However, the explicit use of rules places a heavy load on working memory resources. These limitations, under some conditions, will impede learning since working memory is extremely limited in both capacity and duration (Maxwell, Masters, Eves, 2003). When execution requires simultaneous processes of motor response and analyzes the environment using multiple sources of information to make the correct decision, the control system is overloaded and this may reduce sports performance (Maxwell, Masters, Eves, 2000).

According to the implicit learning method, the coach does not give instructions of execution but distracts the attention of the trainees using a secondary stimulus (Jackson, Farrow, 2005; Williams, Ward, Chapman, 2003; Votsis, Tzetzis, Hatzitaki, Grouios, 2009), to develop procedural knowledge, bypassing working memory processing (Masters, 1992; Kleynen et al., 2014). Thus, skills that are learned implicitly are thought to be less reliant on declarative knowledge than skills that are learned explicitly (Maxwell, Masters, Eves, 2000), and instead capitalize more strongly on automatic processes (Lola, Tzetzis, 2020; Chauvel et.al., 2012). The advantage of implicit practice is that working memory is not involved in the implicit process, which allows the athlete to perform other functions in parallel, such as decision-making (Baddeley, 2003). Research in the area of decision-making has demonstrated that implicit practice has a positive effect on developing and improving decision-making since it enables the use of multiple sources of information that help to make correct decisions (Tzetzis, Lola, 2010; Poolton, Maxwell, Masters, Raab, 2006; Jackson, Farrow, 2005; Smeeton, Williams, Hodges, Ward, 2005; Raab, 2003a; MacMahon, Masters, 2002).

The omission of explicit rules seems to have a positive effect on performance; however, the results of the performance depend on the complexity of the situations too (Maxwell et al., 2003; Liao, Masters, 2001). In more realistic scenarios, as in fast racket sports, the athletes are faced with dozens of complex situations. Raab (2005) mentions that several factors, such as movement efficiency, task complexity, uncertainty, and speed, influence the effectiveness of movements. Complexity in decision-making includes two dimensions that may exist simultaneously in the game: (a) the simultaneous demand on perception and motor response (tactical information), and (b) the game conditions, which can have an intense effect on both motor selection and execution of the appropriate response (e.g., Fitts, Posner, 1967). Regarding the first dimension (a), in real conditions, sports performance involves both motor and decision-making components translated into tactical information. Raab (2005) suggests that tactical information is characterized as complex and is usually supplied once movement production has been mastered. Raab (2003a) also suggests that a methodical description of game tactics is to categorize the complexity of the game (more difficulty – less difficulty) formed by the combination: stimulus – analysis and processing – appropriate kinetic response. In another study, Raab (2003b) mentions that there is a distinction between motor skill learning versus cognitive skill learning. Masters, Poolton, Maxwell and Raab (2008) and Poolton, Masters, and Maxwell (2006) investigated the benefits of implicit learning on cognitive efficiency in a task involving both motor and decision-making components. They concluded that explicit learners exhibited performance decrements when performing a decision-making task and a high complexity task concurrently. The concept behind these techniques is based on the processing of declarative (acquisition via explicit methods) and procedural knowledge (acquisition via implicit methods) (Anderson, 1983; Fitts, Posner, 1967; Schneider, Schiffrin, 1977). As Raab (2005) mentions, the processing of declarative knowledge depends on limited attention resources, whereas procedural responses are less attention-demanding, and the point is to gradually free up attention resources that can then be devoted to more complex variations of the skill. However, several researchers argue that is possible to achieve parallel development of declarative and procedural knowledge (e.g., Gentile, 1998; Raab, Masters, Maxwell,2005; Maxwell, Masters, Eves, 2003) and hint that a combination of decision and behavioral training may be beneficial. The second dimension (b) is the game conditions, which are determined by the variety of stimuli and responses in each environment (Siemann, Gebhardt, 1996). The complexity of the game conditions can also take other forms, such as the time available to perform the skill, the emotional charge of the participant (Masters, 1992), or the analysis of the primary and secondary goals (DeShon, Alexander, 1996). Raab (2003a) also states that the degree of complexity of a gaming condition increases as the number of options increases, while the detection time of stimuli decreases. Additionally, Raab (2003a) identified that the degree of decision-making complexity depends on game conditions 1V1, 2V2, 3V3, 4V4. Conditions one against one – 1V1, and two against two – 2V2 were characterized as low complexity game conditions. Conditions three versus three – 3V3 and four versus four – 4V4 were characterized as conditions of high complexity.

Very few studies (Masters et al.2008; Jackson, Farrow, 2005; Raab, 2003a, b; Gomez, 1997) examined the effect of instruction methods on the improvement of decision-making in different task complexity conditions. The present study compared directly some of the most common techniques on perceptual training -the explicit and implicit method of instruction, in different complexity situations. A novelty is that in the present study participate young athletes.

It was hypothesized that both implicit or explicit methods would positively affect the decision-making task – in terms of reaction time and accuracy – in low complexity conditions; however, taking the literature into account (Lola, Tzetzis, 2021; Raab, 2003a; Smeeton, Williams, Hodges, Ward, 2005; Tzetzis, Lola, 2015; Masters, Maxwell, 2004), we expected the implicit method of learning to have better results in high complexity conditions, in a decision-making task.

Material and methods

Participants

The sample consisted of 63 students, aged 11 to 12 years (M = 11.5, SD = 0.5). 42 were girls and 21 were boys. All participants were perfectly healthy with no serious eye disorders. Participants were divided into three equal groups (N = 20). Two groups were experimental (explicit and implicit learning), and the third was the control group (Farrow, Abernethy, 2002). All participants were beginners, with no previous experience of racket sports. Their parents signed a consent form and they were enrolled in the program with the right to retire at any stage. All rules of ethics and the anonymity of the participants were followed throughout the investigation.

Research design

All participants performed an initial measurement (pre-test). The experimental groups then followed the intervention program (12 courses: three times a week for four weeks). The post-test followed and, two weeks later, the retention test was implemented. All tests were laboratory tests in simulated playing conditions in badminton. Independent variables were the groups with three levels (explicit, implicit, and control group), the measurement with three levels (pre-test, post-test, retention test), and the complexity of the game conditions with two levels (low and high complexity). Dependent variables were a) the accuracy of the responses / total number of attempts X 100 and b) the reaction time (in msec).

Testing procedure

In each test (pre-test, post-test, retention test), there was a trained person who verbally explained the test procedures, gave additional written instructions, and demonstrated the laboratory tests. To assess the ability to make decisions in low-complexity game conditions, 23 video game phases with different game-phase conditions were presented to the participants on a large screen through a projector (Smeeton, Williams, Hodges Ward, 2005). The first three attempts were trials and then the participants had 20 attempts to respond accurately and speedily. The videos lasted from 3.5 to 5 seconds and presented a game condition. The instruction on how to decide on options was balanced for speed-accuracy effects ("decide as quickly and accurately as possible"). The participants watched two athletes in a badminton court, and they had to assume that they were the athlete facing the participant, who was about to perform a badminton serve. The video stopped one frame before the hit. The participants had to react, by stepping (front or back) on a platform according to where it would be better in their view to serve in court. For the low complexity conditions, there were only two possible responses (Gomez, 1997; Raab, 2003a), while for the high complexity, the possible responses were six – each area in the video corresponding to a specific area on the platform. Particular attention was always paid to the participant, to ensure that they would not predict the hit but react according to they believed would be best for them to do. Thus, the decision-making but not the anticipation skill was assessed. The accuracy and speed of the response were evaluated.

Intervention program

The experimental groups attended 12 training courses which included theoretical (20 min) and practical phases (30 min), three times a week, for four weeks, following a different method (implicit or explicit) to improve their decision-making skill in badminton.

During the theoretical courses of the explicit group, the participants were given verbal explicit rules and written instructions regarding: a) the kinematic characteristics of the movement (Paup, Fernhall, 2000), b) instructions for the concentration of attention on the key points of the movement (Starkes, Deakin, JLindley, Crisp, 1987; Farrow, Abernethy, 2002), c) a brief report on the differences between experts and novices in decision-making strategies (Abernethy, Gill, Parks, Packer, 2001). They also watched videos with expert athletes and received feedback on right or wrong decision-making (Starkes, Lindley, 1994). None of the videos used in the tests were used during the training period and vice versa. During the theoretical courses, the implicit group did not receive any explicit instructions on decision-making skill, but they were instructed to watch the videos and memorize the decision-making tactical scenarios like a memory game. None of the videos used in the tests were used during the training period and vice versa. The situations, the options, and the number of correct and incorrect decisions were balanced for the training procedure so that the videos presented the same number of correct and incorrect decisions for all options.

During the practical courses, the explicit group followed the guided discovery learning method (Smeeton, Williams, Hodges, Ward, 2005), which contained instructions for the participant to pay attention to key points regarding how to perform the skill and its result. For each verbal instruction related to a key point of the skill, a question was asked about how these points were related to the result of the skill. An example is "Observe the direction of the racket at the time of the racket-shuttle contact, where do you think the shuttle will go?" The implicit group was trained via a secondary dual cognitive task through random letter generation (MacMahon, Masters, 2002; Gröpel, Mesagno, 2017). The participants had to respond and simultaneously indicate the next letter of the alphabet that was presented to them (dual-task). The control group did not take any theoretical or practical training.

Statistics

A three-way factorial ANOVA was conducted (3 Group X 2 Complexity X 3 Measurement periods) with repeated measurements on the last factor for the accuracy and reaction time of the decision. A post-hoc Tukey test was used to analyze significant differences ($p < 0.05$). The required sample size was calculated a priori with the help of G-power software (v. 3.1.9.7). For three groups and three measurements, with effect size 0.25, alpha error 0.05 and power 0.8 the suggested minimum sample was 36. Therefore the study's sample of 63 was deemed sufficient for the analysis. The criteria of Field (2019) were utilized in order to assess normality based on the calculation of Z Skewness and Z Kurtosis. The normality assumption was not violated for any of the study's variables.

Results

The accuracy of the decision-making skill

Mauchly's W was found to be significant ($W(2) = 0.470$, $p < 0.001$) and Greenhouse-geisser statistic was below 0.75 (0.654) therefore the Greenhouse-Geiser correction was applied. The main effect and interaction analysis of the accuracy of the decision-making skill showed that there was a statistically significant main effect among the three measurement periods ($F_{(1.307, 156.852)} = 291.338$, $p < 0.001$, Partial $\eta^2 = 0.708$), the two degrees of complexity ($F_{(1, 120)} = 99.190$, $p < 0.001$, Partial $\eta^2 = 0.453$), and the three groups ($F_{(2, 120)} = 20.530$, $p < 0.001$, Partial $\eta^2 = 0.255$). There was statistically significant interaction ($F_{(2.614, 156.852)} = 100.970$, $p < 0.001$, Partial $\eta^2 = 0.627$) among the three measurement periods and the three groups, the two degrees of complexity and the three groups ($F_{(2, 120)} = 7.150$, $p = 0.001$, Partial $\eta^2 = 0.106$), the measurement periods and the complexity ($F_{(1.307, 156.852)} = 47.813$, $p < 0.001$, Partial $\eta^2 = 0.285$). Finally, there was also a statistically significant interaction ($F_{(2.614, 156.852)} = 19.497$, $p < 0.001$, Partial $\eta^2 = 0.245$) among the measurement periods, the groups, and the complexity. The mean accuracy of the decision-making skill is depicted in Table 1.

Table 1. Mean accuracy (%) of the decision-making skill

Measurement	Complexity	Group	Mean	SD	Post hoc
Pre-Test	Low	explicit	40.00	4.18	E = I = C F(2, 31.964) = 2.135, p = 0.135 (Welch Anova, Games-Howell)
		implicit	40.95	13.00	
		control	45.48	11.28	
		total	42.14	10.35	
	High	explicit	33.81	6.87	E = I = C F(2, 60) = 0.381, p = 0.685 (Fisher's Anova, Tukey HSD)
		implicit	32.86	5.82	
		control	34.76	8.29	
		total	33.81	7.00	
Post-Test	Low	explicit	63.81	7.05	E = I, E > C d = 1.84, I > C d = 1.57 F(2, 60) = 22.123, p < 0.001 (Fisher's Anova, Tukey HSD)
		implicit	63.10	9.93	
		control	46.19	11.61	
		total	57.70	12.60	
	High	explicit	53.81	6.31	E > I d = 3.00, E > C d = 2.78, I = C F(2, 60) = 55.138, p < 0.001 (Fisher's Anova, Tukey HSD)
		implicit	35.48	5.90	
		control	32.62	8.75	
		total	40.63	11.76	
Retention Test	Low	explicit	60.48	7.23	E = I, E > C d = 1.48, I > C d = 1.53 F(2, 60) = 17.747, p < 0.001 (Fisher's Anova, Tukey HSD)
		implicit	62.86	10.07	
		control	46.19	11.61	
		total	56.51	12.17	
	High	explicit	51.90	7.50	E > I d = 2.61, E > C d = 2.58, I = C F(2, 60) = 49.540, p < 0.001 (Fisher's Anova, Tukey HSD)
		implicit	35.00	5.24	
		control	31.90	7.98	
		total	39.60	11.23	

The reaction time of the decision-making skill

Mauchly's W was found to be significan ($W(2) = 0.629$, $p < 0.001$) and Greenhouse-geisser statistic was below 0.75 (0.73) therefore the Greenhouse-Geiser correction was applied. The main effect and interaction analysis of the reaction time of the decision-making skill showed a statistically significant main effect among the three measurement periods ($F_{(1.459, 175.092)} = 10.807$, $p < 0.001$, Partial $\eta^2 = 0.083$) as well as between the two degrees of complexity ($F_{(1, 120)} = 7.562$, $p = 0.007$, Partial $\eta^2 = 0.059$). However there was no statisticaly significant effect between the three groups ($F_{(2, 120)} = 0.14$, $p = 0.869$, Partial $\eta^2 = 0.002$). There was no statistically significant interaction ($F_{(2.918, 175,092)} = 0.698$ $p = 0.550$, Partial $\eta^2 = 0.012$) between the three measurement periods and the three groups, the two degrees of complexity, and the groups ($F_{(2, 120)} = 1.172$, $p = 0.313$, Partial $\eta^2 = 0.019$), the measurement periods and the complexity ($F_{(1.459, 175.092)} = 0.145$, $p = 0.797$, Partial $\eta^2 = 0.001$). Finally, there was no statistically significant interaction ($F_{(2.918, 175.092)} = 0.209$, $p = 0.885$, Partial $\eta^2 = 0.003$) among the measurement periods, the groups, and the complexity. The mean reaction time of the decision-making skill is depicted in Table 2.

Table 2. Mean reaction time (msec) of the decision-making skill

Measurement	Complexity	Group	Mean	SD	Post hoc
Pre-Test	low	explicit	2,879.80	599.17	E = I = C $F_{(2, 60)} = 0.148$, $p = 0.863$ (Fisher's Anova, Tukey HSD)
		implicit	2,892.80	469.13	
		control	2,970.30	662.30	
		total	2,914.30	574.38	
	high	explicit	3,115.60	877.42	E = I = C $F_{(2, 36.828)} = 1.353$, $p = 0.271$ (Welch Anova, Games-Howell)
		implicit	3,316.85	428.83	
		control	3,050.00	661.54	
		total	3,160.82	679.66	
Post-Test	low	explicit	2,714.70	494.96	E = I = C $F_{(2, 60)} = 0.772$, $p = 0.467$ (Fisher's Anova, Tukey HSD)
		implicit	2,672.70	458.35	
		control	2,885.10	760.19	
		total	2,757.50	584.62	
	high	explicit	2,979.55	624.64	E = I = C $F_{(2, 60)} = 0.084$, $p = 0.920$ (Fisher's Anova, Tukey HSD)
		implicit	3,037.60	396.61	
		control	2,972.85	637.58	
		total	2,996.67	555.51	
Retention Test	low	explicit	2,661.10	470.49	E = I = C $F_{(2, 60)} = 1.134$, $p = 0.328$ (Fisher's Anova, Tukey HSD)
		implicit	2,655.45	462.17	
		control	2,857.90	550.72	
		total	2,724.82	497.14	
	high	explicit	3,002.45	674.34	E = I = C $F_{(2, 60)} = 0.678$, $p = 0.511$ (Fisher's Anova, Tukey HSD)
		implicit	3,114.15	415.00	
		control	2,900.75	656.47	
		total	3,005.78	590.75	

Discussion

There are shreds of evidence showing that the implicit learning method is more effective than the explicit, in perceptual skills such as decision-making skills (Lola, Tzetzis, 2021; Poolton, Masters, Maxwell, 2006; Raab, 2003a, b). The present study aimed to examine the effect of explicit and implicit learning methods of instruction on the accuracy and speed of the decision-making skill, for novice badminton athletes in different levels of complexity. Limited studies evaluated directly the two training methods on the development of decision-making skill, using young participants (Lola, Tzetzis, 2021).

Accuracy among groups and measurements measurements in low and high complexity situations

In low complexity situations comparison among measurements showed that both the implicit and the explicit group improved over time their accuracy from the pre-test to the post-test and maintained their performance in the retention test. The control group did not appear to have any significant difference between the measurements. Similar results were found by Raab (2003a). The comparison among groups in the retention test showed that both the implicit and the explicit groups were more accurate than the control group. It seems that both the explicit (conscious) and the implicit (unconscious) learning method improve the accuracy of the responses.

More specifically, in low complexity situations, the accuracy of the responses of the explicit group improved, possibly because the declarative knowledge acquired provided specific, relatively stable goals in well-defined tasks. The participants of the explicit group, based on the game conditions presented to them theoretically, analyzed the key points of the environment and the opponent, recalled the correct response from memory and selected the best solution. Vickers, Reeves, Chambers, Martell, (2004) state that explicit knowledge helps participants to create the procedure to discover the correct response.

The implicit learning group also improved its decision-making accuracy. Raab and Johnson (2008) explain that the implicit learning method results in the knowledge of situation-action relations that cannot be verbalized. This knowledge may lead to the improvement of decision-making accuracy. Masters, Law, and Maxwell (2002) assert that implicit cognitive learning helps to build judgments about the relation between stimuli and what movement should be carried out.

There was no difference in the accuracy of the decision-making skill between the explicit and implicit group. It seems that both methods allowed the participants to create a set of decision-making processes differently and respond accurately. Raab (2003a, b) also reported that both implicit and explicit processes may lead to improvements in decision-making skills. Raab and Johnson (2008) explain that the distinction between implicit and explicit learning plays a key role in the first two stages of Orasanu's and Connolly's (1993) protocol, which is: a) the presentation of the problem, and b) the identification of the constraints, resources, and goals. The presentation of the problem is the focus of a great deal of research on judgment and decision-making (e.g., Tversky, Kahneman, 1981), and the next step is the identification of the constraints, resources, and goals. The combination of theoretical courses (the presentation of videos, the photos highlighting technical points of the skill, the photos focusing on the tactics of the game), and the practical training, possibly improved critical thinking and developed the appropriate knowledge of the participants implicitly or explicitly, especially in the low complexity situation.

The advantage of the implicit over the explicit method is that it does not overload WM. In this research, the participants performed an easy, low attention demand task (choose between only two responses) in an easy condition, which was to step in the correct direction without executing any particular movement form. Raab (2003a) argued that implicitly learned decisions are advantageous in low-complexity situations; however, he used the traditional explicit learning method with possibly more attention demands. In this research, the explicit learning group followed the guided discovery method, which uses fewer attention resources compared to the traditional explicit learning method, and this might be another reason for the different results. It is concluded that both implicit and explicit processes are effective for decision accuracy in low complexity situations.

In high complexity situations the retention test results showed that in high complexity situations the explicit learning group was more accurate than the implicit group and both of them were better than the control group. Also, only the explicit group seemed to show an improvement over time. Possibly, the verbal guidance through the explicit (guided discovery) method helped novice participants to judge what information they should focus on or ignore, and to focus on the regulatory points of the environment or the players. The implicit learning mechanism of judgment in high complexity situations was not as helpful as the verbal instructions acquired through the guided discovery method. Raab (2002) also found similar results: in high complexity situations, the explicit process leads to better decisions than the implicit process. In another study, Raab (2003a) also argues that in high-complexity situations explicit learning enhances a selection of the necessary stimuli and uses these to make judgments about which option is the best. According to Magill (1998), in the complex environment of sports, athletes should be guided to “information-rich areas” to decide correctly. Explicit instructions could direct the attention of the novices to the information-rich or significant areas, leading to accurate decisions. This basic finding was also reported by Raab (2003b) in different sports (basketball, handball, volleyball) in which allocation decisions had to be made quickly. However, Raab et al. (2005) found contradictory results in another study using elite athletes. More specifically, they found that the unconscious mechanism (implicit) was better than the conscious (explicit) in complex situations such as a series of strokes in different playing conditions. The difference with the present study is probably due to the participants’ level of expertise, since our participants were novices, so the level of expertise is probably a mediating factor. It is concluded that in high complexity situations when training novices, the application of the explicit learning method is better than the implicit learning method. However, several researchers (Bennet, 2000; Beek, 2000; Masters, 2012; Jackson, Farrow, 2005) have claimed that when training elite athletes, the application of the implicit learning method may be as or even more effective than the explicit learning method. Future studies should examine the effect of these two methods on different expertise levels.

Reaction time among groups and measurements in low and high complexity situations

The decision-making speed did not improved over time and there were no differences among the groups in low or high complexity situations. One possible explanation may be that even if novice participants were instructed to react fast and correctly, they probably tried to respond correctly as a matter of priority and did not improve the speed of their decision. Speed-accuracy effects between groups could not be found, as expected, due to the balanced instructions to decide as quickly and accurately as possible; however, it seems that they probably placed more emphasis on the correctness of their decisions than their speed. The participants were novices following 12 training sessions and they probably considered it more important to decide correctly than quickly. If the training were longer and they felt more confident recognizing known patterns, perhaps their decision speed would improve.

Another crucial point is that their reaction with their whole-body movement might increase the complexity of the situation even in the easy condition. The participants had to respond quickly by stepping on a platform with their lower limbs using multiple degrees of freedom to coordinate their whole body, increasing the complexity and speed of the response. Even if the task was easy (two choices), the whole body reaction seemed to be difficult. The lower limb response involved a whole-body motor response, which resulted in a considerable increase in reaction time, while the coordination and control of the body required the activation of even more muscles.

The results of the present study are also supported by previous research on perceptual skills where the accuracy of the response in the experimental group was improved but the reaction time was not, in sports such as volleyball (Adolphe, Vickers, Laplante, 1997), football (Franks, Hanvey, 1997) various skills in squash (Abernethy, Wood, Parks, 1999), and American football (Christina, Baressi, Shaffner, 1990).

Conclusions

It seems that in complex sport conditions when the environment is constantly changing and there is the possibility of multiple motor response options, the use of verbal instruction through guided discovery helps to develop decision-making accuracy more than the implicit learning method. The explicit learning method was found to be better compared to the implicit learning method, in young novice athletes, for decision accuracy but not for decision speed. It seems that the guided discovery learning method is an effective method of learning for novice athletes. Additionally, both implicit and explicit learning methods were effective for decision-making accuracy in low complexity conditions which means that there is no "process-pure approach". Neither the explicit nor the implicit learning method had any effect on the speed of decision for the novice participants. The level of expertise probably affects the effectiveness of these methods. Before deciding on the best training method to follow to improve decision-making, the level of complexity and the athletes' expertise must be taken into account.

Limitations

The results should be generalized with caution since the simulated evaluation process in the laboratory included creating self-produced video clips selected by three experts as being most typical of real situations. It is not certain that we would have the same results if the evaluation were done on the field. Secondly, the platform used in the laboratory may have increased the complexity of the conditions. No simulation can 100% match the real conditions and what the athlete experiences on the field. Field measurements enhance ecological validity and perhaps give a better picture of the effectiveness of practice methods (Lola, Tzetzis, 2021), and are recommended in future studies. Finally, the participants in this study were tested on a dual sport (badminton) with two opponents, and results may be different in team sports with more players.

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NEWER PERSPECTIVES IN LACTATE THRESHOLD ESTIMATION FOR ENDURANCE SPORTS – A MINI-REVIEW

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Abstract Lactate threshold (LT) estimation in endurance sports continues to be a widely controversial field amongst sports scientists and students despite beyond 50 years of research. With the advent of technology and superior sensors, LT research has ventured into newer fields involving wearables and artificial intelligence. Still, there is a felt need to understand the focused areas of LT research and to guide the students, sports scientists and coaches. The main aim of this mini-review is to identify research categories in a descriptive manner and to synthesize broad themes for future research from latest literature. A comprehensive electronic search in three databases was performed including only original free full text research articles conducted in athletes and heathy subjects, published in English between 2016 and 2020 following PRISMA guidelines. Out of screened 466 articles, 14 articles were finally shortlisted as per inclusion criteria and the findings were summarized. Five research categories were identified and reviewed. To conclude, there is a need for consensus in Graded Exercise test protocols used, LT concepts validity for specific sports and the application of valid, reliable noninvasive LT estimation methods in endurance sports. Synthesized broad themes would help guide sports scientists, students and researchers for future research.

Key words anaerobic threshold, physical endurance, athletic performance, exercise testing, lactate threshold

Introduction

In 1808, Jons Jakob Berzelius described lactate for the first time in muscles of hunted stags and postulated the relation between lactate concentration and exercise performed (Kompanje, Jansen, van der Hoven, Bakker, 2007; Needham, Carnis, 1971). Lactate research has evolved since then and has played a prominent role in understanding the bioenergetics during endurance exercise and sporting activities (Brooks, 2018; Gladden, 2008). The blood lactate curve, which is the proportional increase in the blood lactate concentration when plotted against the incremental work rate or time of the activity performed, illustrates the lactate kinetics during graded exercise (Beneke, Leithäuser, Ochentel, 2011; Hall, Rajasekaran, Thomsen, Peterson, 2016).

The understanding of the underlying mechanisms has also evolved over the years with the advent of medical science. The hypothesized concept had begun with muscle anoxia as a cause for increasing lactate through lactate shuttle and use of lactate as an alternative fuel to lactate accumulation due to inability of the physiological mechanisms to clear the formed lactate from the active muscle and hence the lactate accumulation in the blood (Brooks, 2000; Poole, Rossiter, Brooks, Gladden, 2021). This disproportionate rise in blood lactate was called various names like lactate threshold (LT), aerobic threshold, anaerobic threshold, ventilatory threshold etc. in literature. This has been researched widely in endurance sports and is of immense value in training evaluation, prescription and performance prediction (Faude, Kindermann, Meyer, 2009). According to the Kindermann model, the blood lactate curve has been divided into three different phases (Meyer, Lucia, Earnest, Kindermann, 2005). The first rise of lactate above baseline is known as Aerobic threshold or $LT_1/LT_{AER.}$ Maximum Lactate Steady state (MLSS) is the highest constant work rate during which the lactate remains steady not more than 1 mmol/l than previous level and a second disproportionate rise compared to the work rate is called the Anaerobic threshold or LT_2/LT_{ANER}. (Faude et al., 2009; Meyer et al., 2005)

LT has been controversial not only with the terminologies used but also with multiple proposed methods given its complex variability (Faude et al., 2009; Hall et al., 2016). Blood lactate curve inherently is determined by various physiological factors like age, gender, type of sports, training level of athletes, sleep, glycogen stores, muscle fibre composition, metabolic enzyme activity, capillary density and mitochondrial density (McArdle, Katch, Katch, 2017). In addition, extrinsic factors like measurement methods used; incremental testing protocols including mode of testing, stage duration and length of the test have also added more complexity to LT estimation (Faude et al., 2009; Foxdal, Sjödin, Sjödin, Ostman, 1994; Jamnick, Botella, Pyne, Bishop, 2018). Several described multiple terminologies and LT concepts have created further confusion among researchers and sports scientists over the years. In a review done by Faude et al. (2009), around 29 LT concepts have been identified (Faude et al., 2009).

Despite the controversies and influence of multiple determinants, estimation of LT in endurance sports has been considered one of the important parameters in sports training and high performance sports owing to its immense value and application. During the early days of research, the LT estimation was considered as a point where the individuals physiological system failure commenced hypothesized as either due to lack of oxygen or due to reduced lactate clearance. However, lately LT estimation is considered as a point where the individual's physiological system integrates and responds to the stress of the exercise (Poole et al., 2020). Interpretation of the LT estimation provides valuable feedback on the metabolic adaptations that occur with sports training, an important input to the coaches (Kraemer, Fleck, Deschenes, 2011). The estimation of the LT point where the aerobic anaerobic transition happens in endurance sports is nowadays considered a more decisive parameter more than maximal oxygen consumption (VO_{2max}) when assessing performance in elite competitive as well as recreational runners (Baron et al., 2008; Etxegarai, Portillo, Irazusta, Arriandiaga, Cabanes, 2018; Meyer, Gabriel, Auracher, Scharhag, Kindermann, 2003). This is generally attributed to the fact that in highly trained endurance athletes, peripheral adaptive changes to training result in improvement in LT percent of VO_{2max} as compared to VO_{2max} per se that may become static with training after a certain level in these athletes (McArdle et al., 2017). Approximating the LT point with work rate or speed as well as with time, provides an input to prescribe training intensity to the athlete in an easily understandable and measurable parameter to help improve performance. Assessed individually using other than fixed lactate level LT concepts provides an Individual Anaerobic Threshold (IAT) which generally is used as a benchmark parameter with progression of the training cycle when evaluated longitudinally (Meyer et al., 2000; Poole et al., 2020). The estimation of LT_{AER} and LT_{ANER} have been used widely in prescription of training intensity and to periodize the training microcycle by appropriate load monitoring. LT has been prescribed as ranges of percent of VO_{2max}, Heart rate reserve (HRR), maximum heart rate (MHR) or rating of perceived exertion (RPE) for practical application of the LT zones in training by coaches and athletes (Etxegarai et al., 2018; Pallarés, Morán-Navarro, Ortega, Fernández-Elías, Mora-Rodriguez, 2016).

However, certain practical difficulties still exist in LT estimation and pose a challenge to the sports scientists and the coaches. Measurement of blood lactate involves an invasive sample collection technique, which is by far the most difficult challenge that generally inhibits athletes to participate whole-heartedly in the evaluation (Onor et al., 2017; Sun, Yi, Li, Li, 2017). Moreover, the sophisticated equipment required for the LT estimation is costly and conduct of the test requires expertise. In addition, with multiple LT concepts and the lack of a standard graded exercise testing (GXT) protocol poses further operational constraints (Faude et al., 2009; Jamnick et al., 2018; Pallarés et al., 2016). In the last few years, with technological advances in lactate analyzers using capillary blood and biomedical sensors with micro-electromechanical systems, the LT estimation research is now focused to develop noninvasive, valid and reliable methods for performance prediction (Amann, Subudhi, Foster, 2006; Bunc, Heller, 1989; Cambri et al., 2016; Candotti et al., 2008; Etxegarai et al., 2018; Onor et al., 2017). There is a felt need to update the sports scientists, researchers, coaches and athletes on the latest area of research in LT concepts and update on the validity and reliability of the commonly used LT concepts in various endurance sports. The main aim of this systematic mini-review is to synthesize latest focus areas in LT concepts research and identify broad research themes for future research studies in endurance sports performance.

Methods

Computerized literature searches following the Preferred Reporting of Items for Systematic Review and Meta-Analyses (PRISMA) guidelines were performed (Moher, Liberati, Tetzlaff, Altman, PRISMA Group, 2009). Search strategy included original research articles only since that was the aim of the study. Free full text articles in English language published between 2016 and 2020 were searched in three scientific databases namely PubMed, Science Direct and Google Scholar. The following keywords were used – 'Lactate threshold', 'Anaerobic threshold', 'sports', 'athletes'. The bibliographies of all located articles were screened and a forward citation search was performed. The search was completed on 20 Nov 2020. Ethical approval was not obtained, as the study essentially was a review of previously published literature.

Study Eligibility

The study eligibility criteria after screening included the following – Free full text, English language, original research article and healthy or actively sporting study population. The exclusion criteria were any type of review articles, systematic reviews and meta-analyses, conference papers, thesis/dissertation works, letters to editors, unpublished data, book chapters and duplicate publications from search databases. Studies not adhering to the inclusion criteria were excluded after assessment for eligibility. Two reviewers did this independently and in case of a difference of opinion, a third reviewer opined on the same.

Data Extraction and Synthesis

A single reviewer did the initial article identification and screening from all three search databases. Two reviewers did screening of 21 free full text articles for study eligibility using the predetermined eligibility criteria. Out of the screened articles, both the reviewers independently without any difference in opinion excluded 07 as per exclusion criteria. Finally, 14 research articles published between 2016 and 2020 were included in this Mini-review. Figure 1 shows the method of study selection as per PRISMA guidelines (Moher et al., 2009). Descriptive summary of the extracted data from these articles were explained with the help of tables and graph.

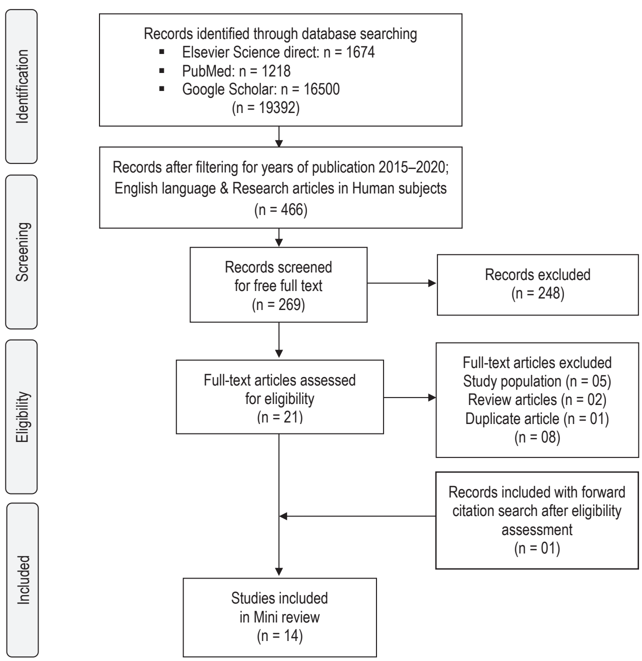

Figure 1. Study Selection as per PRISMA Guidelines
Source: Moher et al. (2009).

Results

Two reviewers thoroughly reviewed all fourteen included research articles. The main purpose of the study being to identify key research areas in LT estimation, resulted in classifying the research areas based on the extracted information from the articles into five broad categories. These broad categories of research area and distribution of number articles among these categories are depicted graphically in Figure 2. Analysis of the country of publication of the articles showed that more than 50% i.e. 08 out of 14 research studies were conducted in Europe. With respect to the study design, we observed 11 cross sectional, 01 post analysis of a Randomized control trial, 01 case report and 01 randomized repeated measure design. Summary of Aim and Key findings of the included research articles grouped under the identified broad research categories is as per Table 1.

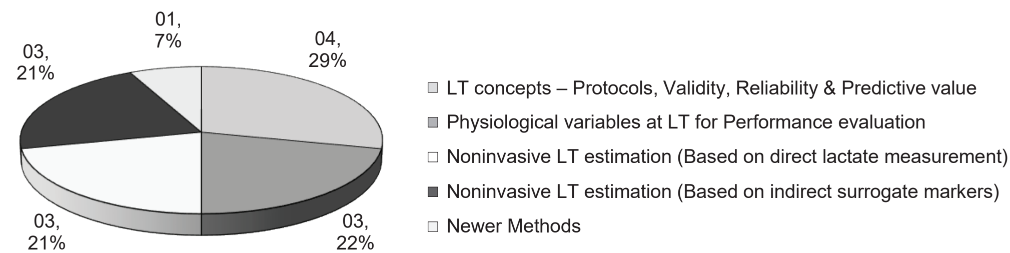

Figure 2. Research Categories: LT estimation in Sports derived based on the included research articles from 2016 to 2020 shown as actual number of articles under each category and percentage out of total included articles (n = 14)

The two main confusing and controversial areas of LT research namely LT concepts to be employed and Graded Exercise testing protocols (GXT) to be used were extracted from the included research articles and hence has been tabulated in Table 2. Moreover, the study also aimed at recommending future research themes deriving from the latest broader concepts including the sports type and athletes' type that were studied and hence these findings are tabulated in Table 3 separately.

With respect to LT concepts, we identified as many as 25 LT concepts from these last 5 years of original research after excluding the duplication of concepts. These 25 LT concepts include 22 direct LT concepts with 04 newly studied LT concepts. Three LT concepts were indirect methods to estimate LT using surrogate markers namely Heart rate inflection point (HR_LT), Ventilatory gas Thresholds (VT_1 & VT_2) and Electromyogram ($EMGth_1$ & $EMGth_2$) thresholds. GXT protocols used in these articles have been extracted and synthesized in a structured format namely mode, stage, rest interval, load increment and blood lactate (BLa) sampling technique used for easy comprehension. None of the GXT protocols used in these 14 research articles was similar as shown in Table 2.

In 12 studies out of 14, either competitive or recreational athletes were the study subjects. The sports studied were running (n = 05, 35.7%), cycling (n = 03, 21.4%), swimming (n = 1, 7.1%), ice skating (n = 01, 7.1%), wheelchair basketball players (n = 01, 7.1%) and multiple sports including track & field athletes, basketball and football (n = 01, 7.1%). Two studies included healthy active subjects (Table 3).

Table 1. Details of Research areas derived from the included articles from 2016 to 2020

S. No.	Research areas derived	Study	Year of study	Country where research was done	Study Design/Study Population	Aim	Main Findings
1	2	3	4	5	6	7	8
1	Lactate Threshold (LT) concepts – Protocols, Validity, Reliability & Predictive value of Endurance performance	Fernandes et al.	2016	Brazil	Exploratory laboratory cross sectional study/ 27 Male runners of different training level	To evaluate different LT methods and to determine most reliable LT method for level of conditioning and training program	Differences in LT methods between Low and Highly trained endurance runners Onset of Blood lactate Accumulation ($OBLA_{4mmol/L}$) method underestimated LT in Low trained groups
		Pallarés et al.	2016	Spain	Cross Sectional Study/ 14 Male well trained cyclists	To assess the validity and reliability of critical workloads found using various LT methods with Ventilatory threshold (VT)	D_{max} method was not reliable, even though it coincided well with VT_2 Both Reliable and Valid LT methods were LT + 2.0 mmol/L and $OBLA_{4mmol}$ LT + 0.5 mmol/L coincided with Maximum Lactate Steady State (MLSS) workload Deduction of Heart Rate reserve (HRR) / Maximum Heart rate ($HR_{max)}$ / rating of Perceived exertion (RPE) based training zones based on the LT (VT_1), LT + 0.5 (MLSS) and LT + 2.0 (VT_2)
		Heuberger et al.	2018	Netherlands	BLC used from a Randomized Placebo controlled single blinded single centre RCT study/ 48 male cyclists	To compare various LT concepts for their repeatability and predictability of endurance performance	(a) Mod D_{max} was the best LT concept with both predictive and repeatability (b) D_{max}, Minimum Lactate equivalent (La/ Power) + 1.5 mmol/L (LT_3) and $OBLA_{4mmol/L}$ also performed well.
		Jamnick et al.	2018	Australia	Cross sectional study/ 17 Male cyclists	To determine the validity of the lactate threshold (LT) and maximal oxygen uptake ($VO2_{peak}$) determined during graded exercise test (GXT) of different durations and using different LT calculations	(a) The LT varied with all the GXT stage durations. (b) The closest to LT – MLSS values were Modified D_{max} method – developed in this study namely Exponential D_{max}, Log-log Modified D_{max} and Log-log Exponential Mod D_{max} LT methods. (c) The closest to LT MLSS was Log – Poly Mod D_{max} of GXT4 (d) GXT protocol need to be customized based on the outcome parameter namely $VO2_{max}$ or LT as stage duration designed may influence both. Initial speed as well as increment load need to be formulated individually based on predicted VO_{2max} rather than Fixed load protocols. (e) Verification Exhaustion bout may not be useful in identifying the $VO2_{peak}$ if the GXT duration is longer. Ideal duration of GXT for VO2max estimation is 8 – 12 min

1	2	3	4	5	6	7	8
2	Physiological variables at LT Performance evaluation	Pelarigo et al.	2016	Brazil	Cross sectional study/ 10 Elite Female Middle & Long distance competitive Swimmers	To examine the relationship between bioenergetics variables and biomechanical variables while swimming at various percentage of MLSS intensities (97.5%, 100% and 102.5%)	In all the three testing MLSS intensities, Bioenergetics variable namely Oxygen uptake, Energy cost (C) and Energy Expenditure except HR were constant throughout the test timings. At 97.5% & 100% MLSS, Bioenergetics variables did not change as a function of time. However, Biomechanical factors namely Stroke Rate increased and Stroke length decreased with increasing MLSS intensities. At 102.5% MLSS, although VO_2 and C were constant, VE and HR increased with time resulting in reduced Oxygen efficiency. Increased VE and Blood Lactate would be a reason for early fatigue and non-completion of full 30 min swim by subjects
		Scheer et al.	2019	Germany	Cross sectional study/ 25 male trail runners	To examine established LT concepts in Trail running and evaluating in two different Trail distances for performance prediction	(a) LT correlated with race performance in short trail running (21km – XXS format) (b) LT predicted performance in slower runners compared to faster runners. (c) $OBLA_{4mmol/L}$ predicted better than IAT in these runners.
		Otto et al.	2019	Germany	Randomized repeated measure design/ 08 competitive wheelchair basketball players	To compare arm crank ergometer with treadmill wheelchair propulsion ergometer using physiological parameters at peak performance and Individual Anaerobic threshold (IAT) to provide with optimal training prescription recommendations	(a) Treadmill group showed significantly higher VO_2, HR, and Energy Expenditure at peak performance as well as at IAT. (b) Blood Lactate values were significantly lower than Arm crank ergometer group
3	Noninvasive LT estimation (Based on direct lactate measurement)	Onor et al.	2017	Italy	Cross sectional Experimental study/ 5 Healthy volunteers (2 males and 3 females)	To validate non-invasive method of measurement of lactate levels in sweat during cycling exercise	(a) Non-invasive Sweat lactate measurement using Screen Printed Carbon Electrodes (SCPE) using potentiometric sensor technology correlated linearly with Sweat samples analysed using High Performance Liquid Chromatography (HPLC)
		Etxegarai et al.	2018	Spain	Cross sectional study/ 143 recreational runners	To create an intelligent machine learning system that is capable of estimating LT in endurance running sports	(a) Machine learning (ML) method used to estimate Lactate curve was found to be more homogenous than the actual blood lactate curve, thus ML may predict the LT accurately overcoming the problems in blood lactate measurement error that are inherent to LT tests. (b) ML estimated LT correlated well with actual LT measured and running performance in recreational runners.

1	2	3	4	5	6	7	8
		Etxegarai et al.	2019	Spain	Experimental study/ 50 Recreational runners	To propose heuristic method as an accessible LT method and integrate in Training decision making of recreational runners	(a) D_{max} method though more commonly used has individual error due to various reasons. Increasing the number of Lactate points decreases the variability (b) LT is highly dependent on V_{peak} (maximum workload) which is again variable between individuals. So developing method without V_{peak} may reduce the error. (c) Heuristic approach with equation, LT = 60 % of endurance running speed reserve + Initial running speed on treadmill during GXT can predict the LT workload.
4	Noninvasive LT estimation (Based on indirect surrogate markers)	Borges et al.	2016	New Zealand	Cross Sectional study/ 14 adult recreational and highly trained athletes (7 males and 7 females)	To determine the levels of agreement between the Wearable device derived LT (WLT) and traditional LT methods and the inter & intra device reliability of WLT (Near Infrared Spectroscopy)	(a) WLT method was not significantly different from the traditional LT methods. (b) The correlation of WLT method was high to very high between these methods, with highest being $OBLA_{4mmol/L}$ LT method. (c) The error of measurement between WLT method and OBLA LT method was the lowest. (d) Inter-device as well as Intra-device reliability of WLT was high (r=0.97 in both the cases)
		Sun et al.	2017	China	Case report/ 4 healthy volunteers (02 males and 02 females – among them 02 young athletes and 02 adults)	To introduce a novel noninvasive individual lactate threshold Heart rate prototype as an alternative for invasive LT tests using a T-shirt integrated with conductive fabric ECG electrodes and LT HR computing algorithm	(a) Noninvasive fabric based indirect method to identify the LT training zone using HR inflection method used by Modified Conconi method. (b) Voice command based on the LT-HR achieved to instruct the athlete to adjust the pace to delay fatigue
		Piucco et al.	2020	Canada	Cross sectional study/ 10 well trained ice skaters	To assess the validity of first and second breakpoints in EMG signal from 6 different lower limb muscles using visual and mathematical models and compare them with VT_1 and VT_2 during skating	(a) $EMGth_2$ can be identified compared to $EMGth_1$ in 80% of the cases using both the methods. (b) $EMGth_2$ was not different from VT_2 using mathematical model as compared to visual method. (c) 2-level regression fitting of Blood lactate curve yielded better validity of $EMGth_2$ than other methods. (d) Among the 6 muscles studied, Knee extensors and hip extensors presented highest $EMGth_2$ detection.
5	Newer Concept: Inter Threshold Area (ITA)	Capellá et al.	2018	Spain	Cross sectional study/ 606 male adult athletes and PE students	To examine the Inter threshold area between VT_1 and VT_2 for individuals with different endurance capacities	(a) ITA values were higher in endurance predominant sports (Cyclists > Triathletes > Basketball > Football > Track & Field > Artistic Gymnasts (b) It is not convenient to express VTs as percentage of VO2max. Rather, absolute values of VTs and ITA must be used to compare between individuals.

Table 2. LT concepts and Graded Exercise testing (GXT) Protocols employed in the included Research articles

Study	Aim of the study	GXT Methods/ protocol used	LT concept employed (Direct & Indirect)
1	2	3	4
Fernandes et al. (2016)	To evaluate different LT methods and to determine most reliable LT method for level of conditioning and training program	**GXT Mode:** Continuous Treadmill running **Stage duration:** 4 min **Load Increment:** 1km/h speed every stage with constant 1% grade **Blood Lactate (BLa) sampling:** Finger tips capillary blood (CPL) without interruption after every stage	– Baseline + 1mmol/L, – $OBLA_{4mmol/L}$, – Semi-log method of blood lactate and intersection of the two linear segments
Pelarigo et al. (2016)	To examine the relationship between bioenergetics variables and biomechanical variables while swimming at various percentage of MLSS intensities (97.5%, 100% and 102.5%)	**GXT Mode:** Intermittent 25m Indoor Swimming **Stage:** 200m swim lap **Rest:** 30s in between 200m lap **Load increment:** 0.05m/s until voluntary exhaustion **BLa Sampling:** Ear lobe CPL at rest, during 30 s rest interval between stages and 2 min after voluntary exhaustion	LT: Intersection between a linear and exponential regressions of BLC
Pallarés et al. (2016)	To assess the validity and reliability of critical workloads found using various LT methods with VT	**GXT Mode:** Ramp protocol Cycle ergometer **Stage:** 1 min **Load increment:** 25W/min until exhaustion **BLa Sampling:** CPL collected every 2 min without interruption	– LT defined as the highest workload without rise in Blood lactate above baseline, – LT + 1mmol/L, – LT + 0.5; LT + 1.5; LT + 2.0; LT + 2.5 and LT + 3.0 mmol/L, – D_{max} method – Point on the 3rd order polynomial regression curve of Blood lactate that yields the maximum distance from the line joining the two end points of the curve, – $OBLA_{4mmol/L}$
Borges et al. (2016)	To determine the levels of agreement between the Wearable device derived LT (WLT) and traditional LT methods and the inter & intra device reliability of WLT	**GXT Mode:** Continuous Treadmill running **Stage:** 3 min **Load increment:** Starting with 4.8 km/h and increased to 9.3 – 11.7km/h in 2nd stage and further stage increment by 0.3 to 1.1 km/h until exhaustion. **BLa Sampling:** Fingertip CPL obtained 10 seconds before the end of every stage and 1 min post exercise during recovery	– Linear spline fitting method, – Dmax method, – Modified Dmax method, – First rise of blood lactate > 1 mmol/L method, – $OBLA_{4mmol/L}$, – WLT patented LT estimation algorithm **(Indirect)**

1	2	3	4
Sun et al. (2017)	To introduce a novel noninvasive individual lactate threshold Heart rate prototype as an alternative for invasive LT tests using a T-shirt integrated with conductive fabric ECG electrodes and LT HR computing algorithm	**GXT Mode:** Continuous Treadmill running **Stage:** Not described **Load increment:** Initial speed of 16km/h and 15-degree gradient until identification of HR inflection point (LT -HR) or 75% of age predicted Max HR if no inflection happened. With identification of LT- HR, a voice command from the mobile app instructs the individual to adjust the pace to delay onset of fatigue **BLa Sampling:** Not described	Modified Conconi HR_LT Inflection point **(Indirect)**
Onor et al. (2017)	To validate non-invasive method of measurement of lactate levels in sweat during cycling exercise	**GXT Mode:** Continuous Cycle ergometer **Stage:** 3 min **Load increment:** Maintaining a cadence of 70 - 75 rpm until 18 min of exercise. **Lactate Sampling:** Sweat Lactate samples collected at the end of every stage.	Not used. Only validation of sweat lactate with HPLC done.
Etxegarai et al. (2018)	To create an intelligent machine learning system that is capable of estimating LT in endurance running sports.	**GXT Mode:** Intermittent Treadmill running **Stage:** 4 min **Rest:** 1 min **Load increment:** 1% slope and 9 km/h to start with and increased by 1.5 km/h every 4 min until 13.5 km/h and there after 1 km/h till exhaustion **BLa Sampling:** Earlobe CPL collected at each stage during 1 min rest phase after each stage.	D_{max} Method with at least 5 lactate sample points during the test
Jamnick et a.l (2018)	To determine the validity of the lactate threshold (LT) and maximal oxygen uptake (_VO2max) determined during graded exercise test (GXT) of different durations and using different LT calculations	**GXT Mode:** Customised Cycle ergometer (05 GXTs performed) **Stage:** 1- min, 3-min , 4-min, 7-min and 10-min in 5 GXTs were tested for suitability for LT estimation followed by a Verification Exhaustion bout after cessation of GXT for estimation of VO_{2peak} **Load increment:** Calculated based on the demographic and Physical activity readiness derived VO2 max data **BLa Sampling:** Antecubital venous blood sampling at the end of each stage	– Log –log method, – OBLA – 2.0, 2.5, 3.0, 3.5, 4.0 mmol/L, – Baseline + Absolute value – B + 0.5, 1.0, 1.5mmol/L, – Dmax, – Mod Dmax, – Respiratory Compensation point (VT), Newer LT concepts: – Exponential Dmax, – Log-log Modified Dmax, – Log-log Exponential Mod Dmax, – RCP_{MLSS} – Estimated MLSS from regression equation based on RCP from GXT_1

1	2	3	4
Heuberger et al. (2018)	To compare various LT concepts for their repeatability and predictability of endurance performance	**GXT Mode:** Continuous Cycle ergometer **Stage:** 5 min **Load increment:** initial resistance 75W with increment of 25W/stage till exhaustion **BLa Sampling:** Antecubital vein sample between 4:15 min to 4:45 min of each stage	– LT1 – Observer determined first rise in BLa, – LT2 – B + 1mmol/L, – LT3 – Minimum Lactate equivalent (La/ Power) + 1.5 mmol/L, – LT4 – First BLa value that shows > 1mmol/L between two BLa values, – LT5 – Min Lactate Equivalent (La/VO2), – $OBLA_{4mmol/L}$, – D_{max}, – Mod D_{max}
Scheer et al. (2019)	To examine established LT concepts in Trail running and evaluating in two different Trail distances for performance prediction	**GXT Mode:** Continuous Step test **Stage:** 3 min **Load increment:** Start with 8 km/h and increment of 2km/h every 3 min until exhaustion or task failure **BLa Sampling:** Ear lobe CPL after each stage and at termination	– LT_{AER} – Bla > baseline value, – IAT – BLa > 1.5mmol/L above LT_{AER}, – $OBLA_{4mmol/L}$
Etxegarai et al. (2019)	To propose heuristic method as an accessible LT method and integrate in Training decision making of recreational runners	**GXT Mode:** Intermittent Treadmill running **Stage:** 4 min **Rest:** 1 min **Load increment:** 1% slope and 9 km/h to start with and increased by 1.5 km/h every 4 min until 13.5 km/h and there after 1 km/h till exhaustion **BLa Sampling:** Earlobe CPL collected at each stage during 1 min rest phase after each stage	D_{max} Method with at least 5 lactate sample points during the test
Otto et al. (2019)	To compare arm crank ergometer with treadmill wheelchair propulsion ergometer using physiological parameters at peak performance and IAT to provide with optimal training prescription recommendations	**GXT Mode:** Intermittent Arm Crank ergometer Vs Intermittent Treadmill Propulsion **Stage:** 3 min in both protocols Rest: 30s in both protocols **Load increment:** Starting 50W and 20W/3min at 60rpm till exhaustion Vs Starting 6kmph/ 1% slope with 1.5kmph increment every 3 min until exhaustion **BLa Sampling:** Earlobe CPL collected at each stage during 30s min rest phase after each stage	Minimum lactate equivalent + 1.5 mmol/L (Dickhuth LT concept ref)
Piucco et al. (2020)	To assess the validity of first and second breakpoints in EMG signal from 6 different lower limb muscles using visual and mathematical models and compare them with VT1 and VT2 during skating	**GXT Mode:** Continuous Skating test on a slide board of polyethylene surface **Stage:** 3 min **Load increment:** Starting with 30 push offs per minute (ppm) and increased by 3 ppm every stage until exhaustion **Sampling:** Breath to breath metabolic analyser for expired gases was done	VT_1 and VT_2 by visually detected by Ventilatory Equivalent method (VE/VO_2 and VE/VCO_2) **(Indirect)**

Table 3. Broad Themes Identified in LT estimation for endurance sports performance for future research

S. No.	Study	Population for which applicable	Sports for which applicable	Research Area derived	Broad Themes identified for future research
1	Fernandes et al. (2016)	Runners	Middle and Long distance Running	Lactate Threshold (LT) concepts – Protocols, Validity, Reliability & Predictive value of Endurance performance	1. Development of LT estimation specific GXT protocol including appropriate stage duration, length of the test, load increment and minimum lactate samples required. 2. Validity & Predictive value of LT concepts for competitive endurance sports based on training level and competitive level using common GXT protocols. 3. Validation and Reliability testing of Newly developed Modified D_{max} LT method (Log-Poly Modified Dmax method) in both cycling as well as other endurance sports. 4. Identification of Sports-specific valid LT concept and most acceptable LT concept for multiple sports
2	Pallarés et al. (2016)	Well Trained Male Cyclists	Cycling		
3	Heuberger et al. (2018)	Well trained cyclists	Cycling		
4	Jamnick et al. (2018)	Trained Cyclists	Cycling		
5	Pelarigo et al. (2016)	Competitive female Swimmers	Middle and Long distance Swimming	Physiological variables at LT Performance evaluation	1. Comparison of LT estimation based on gender within various endurance sports. 2. Correlation of other performance indicators with LT estimation to comprehensively evaluate and predict endurance performance. 3. Development of Sports specific LT methods for Paralympic sports
6	Scheer et al. (2019)	Male Trail Runners	Trail running		
7	Otto et al. (2019)	Competitive Wheelchair basketball players	Wheelchair Basketball		
8	Onor et al. (2017)	Active Healthy Adults	Any sports	Noninvasive LT estimation (Based on direct lactate measurement)	1. Validation studies of Sweat lactate analysis in endurance athletes against Blood lactate assessment methods. 2. Machine learning models in competitive endurance athletes and validation against gold standards like MLSS and Race performance. 3. Noninvasive ML models in special populations like military personnel and recruits for performance prediction where expertise and sophisticated equipment is an operational constraint
9	Etxegarai et al. (2018)	Recreational Runners, triathlon and Trail runners	Long distance Running		
10	Etxegarai et al. (2019)	Recreational runners	Running		
11	Borges et al. (2016)	Recreational and Highly trained athletes	Running	Noninvasive LT workload estimation (Based on indirect surrogate markers – Near Infrared Spectroscopy (NIRS), Heart Rate (HR) and Electromyogram (EMG)	1. Validation of noninvasive LT workload estimation based on indirect surrogate markers in competitive endurance athletes using Gold standard LT tests like MLSS and Race performance. 2. Validation and Reliability of HR_LT zone based computing algorithm in exercise prescription among recreational as well as competitive runners using standard methods
12	Sun et al. (2017)	Active healthy individuals	Any sports		
13	Piucco et al. (2020)	Well trained long track Speed Skaters	Ice skating		
14	Capellá et al. (2018)	Athletes	Cycling, Running, Swimming, Track & Field, Basketball and Football	Newer Concept: Inter Threshold Area (ITA)	Practical application of ITA using LT methods in various competitive as well as recreational endurance sports in training prescription and performance evaluation

Discussion

The main findings of this review showed that five broad research categories (Table 1) have emerged over the last 5 years of LT research with the focus of research skewing more towards noninvasive LT estimation using wearables and artificial intelligence (Figure 2). Most of these research studies were conducted in European countries and developed nations signifying the present research trend and highlighting the need of pursuing focused research on LT in sports in other parts of the world. The common sports in which LT research was conducted are running and cycling, contributing more than 50% of the other endurance sports. A recent study employed LT estimation in performance assessment of wheelchair basketball players also, thereby applying the LT concepts in para-athletes too.

Although in the last decade, many review articles on lactate kinetics and LT training were published, it was seen that most of these review articles focused on either the evolving lactate kinetics or LT concepts (Beneke et al., 2011; Galán-Rioja, González-Mohíno, Poole, González-Ravé, 2020; Hall et al., 2016; Poole et al., 2021; Rogatzki, Ferguson, Goodwin, Gladden, 2015; Sarma, 2018). Hence, our main aim was to identify broad research categories in recent LT research especially in athletes and healthy individuals over the last 05 years for identification of focused areas and to synthesize broad themes for future research in sports. The eligibility criteria was also designed accordingly.

GXT Protocol Design

Graded exercise test (GXT) protocols in terms of stage duration, continuous or intermittent between stages, load increment with each stage as well as the method of lactate measurement have been considered as independent variables that influence the LT estimation irrespective of the concepts that are employed. (Bentley, McNaughton, 2003; Bentley et al., 2007; Jamnick et al., 2018). As shown in Table 2, amongst the 14 research studies included, each study has followed a different protocol design. There has been no clear consensus with respect to appropriate use of GXT for LT estimation in terms of all the protocol components (Jamnick et al., 2018). Jamnick et al. (2018) have studied the validity of almost 16 LT concepts in about five different GXTs with respect to the stage duration using customised load increments based on demographic and Physical activity readiness scale scoring (Jamnick et al., 2018). LT estimation varied with all the GXT duration and the closest LT concepts to MLSS were newer modified Dmax methods employed in this study namely Exponential D_{max}, Log-log Modified D_{max} and Log-log Exponential Mod D_{max}. Log – Poly Mod D_{max} of GXT with 4 min stage duration was the closest to LT_{MLSS}. Moreover, customization of load increment with stages as well as based on the outcome parameters have been recommended by the authors of this study (Jamnick et al., 2018).

LT concepts – Validity, Reliability and Predictive value

Faude et al. (2009) have carried out a comprehensive review on validity of various LT concepts (Faude et al., 2009). According to this review, validation of the LT concepts was done either with MLSS or competition performance. LT_4 or $OBLA_{4mmol/L}$ and IAT (Stegmann, Kindermann, Schnabel, 1981) were by far the most commonly studied LT concepts against MLSS for validation in various endurance sports (Faude et al., 2009). As summarized in Table 1 (S. No. 1), we found four research studies conducted with the aim of evaluating validity, repeatability and predictive value of LT concepts (Fernandes et al., 2015; Heuberger, Gal, Stuurman, Keizer, de Muinck, Miranda, Cohen, 2018; Jamnick et al., 2018; Pallarés et al., 2016). Three studies were conducted in cyclists (Heuberger et al., 2018; Jamnick et al., 2018; Pallarés et al., 2016) and one study in runners (Fernandes et al., 2015). To summarize these findings, LT_4 or $OBLA_{4mmol/L}$ again fared well in all the studies with respect to validity, repeatability and predictive value. However, use of LT4 underestimated LT in low-trained athletes (Fernandes et al., 2015). Controversy in D_{max} LT concept was observed between these studies (Heuberger et al., 2018; Pallarés et al., 2016). However, Jamnick, Botella, Pyne, Bishop (2018) with newer LT concepts of modified D_{max} found them to be closest to LT_{MLSS}. Apart from these LT concepts, LT + 2.0 mmol/L and Minimum Lactate equivalent (La/ Power) + 1.5 mmol/L have also been studied in these studies with good validity and predictive value in cyclists (Heuberger et al., 2018; Pallarés et al., 2016).

Physiological variables at LT for performance evaluation

Under this research area, we could identify three articles as shown in Table 1. All these three studies were done in different endurance sports like swimming, trail running and wheelchair basketball players. Pelarigo, Greco, Denadai, Fernandes, Vilas-Boas, Pendergast (2016) have studied the relationship of bioenergetics variables and biomechanical variables of female swimmers at various percentages of MLSS. They have found that at 100% MLSS, bioenergetics variables were constant but biomechanical variables namely stroke rate increased and stroke length reduced. This study compared biomechanical variables and their relationship with physiological variables at various MLSS intensities for performance evaluation (Pelarigo, Greco, Denadai, Fernandes, Vilas-Boas, Pendergast, 2016). We identified a similar study relating biomechanical variables of running with energy cost or running economy at LT mainly in runners (Joubert, Guerra, Jones, Knowles, Piper, 2020). Scheer, Vieluf, Janssen, Heitkamp (2019) examined established LT concepts in Trail runners of varying distances for the first time and evaluated LT estimation for performance prediction (Scheer et al., 2019). Otto, Reer, Holtfreter, Riepenhof, Schröder (2019) compared arm crank ergometer with treadmill wheelchair propulsion ergometer using physiological parameters at peak performance and IAT to provide optimal training prescription recommendations in wheelchair basketball players (Otto et al., 2019). All these three research studies provide the latest insight into the utilization of LT concepts and physiological variables at LT in performance evaluation and more so importantly application of LT for training prescription even in para-athletes.

Noninvasive LT estimation (Lactate related)

Because of the major drawback of invasive methodology used for obtaining blood samples, various research studies have focused on noninvasive LT estimation in an attempt to negate this major drawback. The noninvasive LT estimation can be broadly divided into two major research areas as Lactate related i.e. using alternate source of lactate or by using machine learning methods and Indirect i.e. using surrogate markers for lactate itself to identify the LT indirectly. We identified three research studies under this research area. Onor, Gufoni, Lomonaco, Ghimenti, Salvo, Sorrentino, Bramanti (2017) have validated sweat lactate level measurement during cycling exercise with High Performance liquid chromatography in healthy volunteers (Onor et al., 2017). However, LT using sweat lactate method if validated with conventional LT estimation would prove to be of immense value in future LT research. Etxegarai, Portillo, Irazusta, Arriandiaga, Cabanes (2018) from Spain have tried developing machine learning based LT prediction algorithm and validated with blood lactate LT estimation in recreational runners (Etxegarai et al., 2018). In addition, using heuristic approach, the same research group has developed an equation for recreational runners for LT workload estimation based on running speed reserve and initial running speed on treadmill during a GXT (Etxegarai, Portillo, Irazusta, Koefoed, Kasabov, 2019). These methods if further researched and validated would prove very useful for athletes and active individuals where expertise and facilities for LT estimation are not available.

Noninvasive LT estimation (Indirect)

This category of research idea included noninvasive LT estimation using surrogate markers that was popular since the years of Wasserman and Conconi using ventilatory thresholds and heart rate inflection as indirect markers of LT (Conconi, Ferrari, Ziglio, Droghetti, Codeca, 1982; Conconi et al., 1996; Wasserman, McIlroy, 1964). In this review, we located three research articles in this area of LT research, one each from New Zealand, China and Canada. Borges, Driller (2016) in their study had evaluated a wearable device based LT estimation (WLT) using the Near Infrared Spectroscopy principle in runners (Borges, Driller, 2016). The device that was worn over the calf, has an algorithm to predict the LT, and was shown to be valid and reliable in this study. The correlation of WLT was highest with $OBLA_{4mmol/L}$ and both inter-device as well as intra-device reliability were high ($r = 0.97$ in both the cases) (Borges, Driller, 2016). Sun, Li, Li (2017) from China had published a case report to introduce a novel noninvasive individual lactate threshold Heart rate prototype as an alternative for invasive LT tests using a T-shirt integrated with conductive fabric ECG electrodes and HR_LT computing algorithm (Sun et al., 2017). In this study, they had devised an indirect HR_LT based algorithm to identify the LT training zones using modified Conconi's method of heart rate inflection point using the ECG electrodes. Despite the inherent accuracy issues with heart rate due to various confounding variables, heart rate based exercise & sports training is popular and commonly used in wearable technology. Hence, this noninvasive indirect LT estimation research category still merits focus among researchers. Piucco, Diefenthaeler, Prosser, Bini (2020) have assessed the EMG_{th1} and EMG_{th2} breakpoints from 6 different lower limb muscle sites with VT_1 and VT_2 in Ice skaters (Piucco et al., 2020). This study though did not directly use LT methods to validate was still included to bring out the importance of noninvasive LT research using indirect surrogate markers even for validation, here VT_1 and VT_2.

Newer Methods

A final research category as Newer methods was framed to include research studies that were not fitting into any of the above four categories. Capellá et al. (2018) from Spain had presented a new concept of inter threshold area between VT_1 and VT_2 among individuals with varying endurance capacities (Capellá, Peinado, Moro, Revenga, Esteves, Montero, 2018). Further application of this new concept in training and performance evaluation of athletes are promising research areas for future research.

Future research themes

One of the objective of this review was also to suggest broad research themes for future research to sports scientists, students, coaches and physical education professionals. Table 3 shows the synthesized broad themes based on the categorized research areas and included original research studies under the respective categories. Despite more than 50+ years of Lactate Research in sports (Poole et al., 2020), consensus in GXT protocol, LT concept for specific sports, validation of common LT sports in endurance sports other than running and cycling, gender difference in LT estimation and LT research in Para-sports, validated noninvasive lactate measurement techniques are lacking. There is certainly immense scope of future research in these broad research themes.

Even though the aim of the review was to identify research categories and provide a roadmap for future research in LT estimation in sports, there were few limitations in terms of the search being restricted to freely available full text articles in the databases. This would have limited the number of research ideas in the field. In addition, since the search was restricted to athletes and healthy active adults, this review lacks research themes done in patient population and clinical research.

Conclusion

Lactate threshold, despite a long research history, is still an actively researched area globally in sports due to its varied applications. The researchers are focused mainly on GXT study protocols, evaluating validity & predictive value of LT concepts and developing noninvasive methods for LT estimation using wearable technology and machine learning arena for performance enhancement in competitive as well as recreational sports. This review has laid the roadmap for future research themes to guide the sports scientists, students and researchers and future research based upon the suggested themes will shed more light upon the conundrum that is LT research.

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SURGICAL MASK USE IN PHYSICAL EXERCISE IN YOUNG HEALTHY SUBJECTS SUME TRIAL

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Abstract In the context of the COVID-19 pandemic, the use of surgical masks has become the new normal. The use of these devices in exercise and medical situations has been advocated with the purpose of reducing contagions, but some concerns exist regarding its impact of physical fitness and safety of use. If the use of mask while exercising can cause decreased functional capacity or dangerous hypoxemia is still something we know little of. Therefore, we performed maximal treadmill stress tests in 12 healthy young subjects, with and without surgical mask use, and measured exercise capacity, oxygen saturation (rest, peak exercise and post-exercise) and electrocardiographic changes on a standard treadmill test. Exercise capacity and oxygen saturation levels decreased in peak exercise vs rest in a statistically significant manner when mask was used. ECG changes, although not significant, were present in 3 subjects when mask was used and disappeared when the test was made unmasked. We concluded that masked exercise has the potential to cause decreased exercise load and oxygen saturation and potentially cause diagnostic errors in medical exams.

Key words surgical mask, exercise, treadmill test, stress test, oxygen saturation, Covid-19, EC

Introduction

In the present SARS-COV-2 pandemic, one of the measures that has been progressively implemented by the various nations is related to the mandatory use of a mask in order to reduce the spread of the pathology (CDC, 2020; ECDC, 20202). The locations in which the use of a mask is mandatory vary, with some nations having mandatory use in any public space and others only in non-ventilated places (Greenhalgh, 2020).

An issue that proves to be important has to do with physical exercise. Given that exercise has the potential to generate high levels of aerosols, it has been advocated that a use of a mask should be kept during all activity in order to potentially reduce the risk of viral transmission (Chandrasekaran, Fernandes, 2020). The effect of such mask in physical activity, however, is not clear. Concerns exist on its effect on exercise capacity (decreasing exercise load) and possibility of causing significant hypoxemia. A study by Fikenzer et al. (2020) showed significant negative changes in ventilation parameters in an cycle ergometer test in healthy subjects wearing surgical and FFP2 masks. During our study, a paper published by Shaw et al (Shaw, Butcher, Ko, Zello, Chilibeck, 2020) showed that time to exhaustion during a cycle ergometer test was not different with or without surgical mask use, neither was arterial oxygenation.

On the other hand, in the context of the COVID-19 pandemic, specific exams in cardiology such as the electrocardiogram (ECG), stress test (treadmill or cycle ergometer), are sometimes done with masked patients in order to avoid possible viral spread, given that this test produces significant amounts of aerosols. We do not know, however, whether the use of a mask causes significant changes in cardiovascular parameters in order to interfere in the interpretation of the exam.

We, therefore, aimed to evaluate the impact of the use of a standard surgical mask in a treadmill stress test in young healthy volunteers, in terms of ECG changes, oxygen saturation and total exercise capacity.

Material and Methods

The study protocol was presented to the Ethics Commission of Hospital Particular do Algarve, that approved its methodology and objectives and confirmed that the study was in accordance with the Declaration of Helsinki.

12 self reported healthy volunteers (medical students and nurses), 4 male and 8 female, with average characteristics presented in Table 1, were asked to perform a Treadmill Stress Test – Bruce protocol, a widely used protocol for evaluation of physical fitness and cardiovascular risk (Bruce, Blackmon, Jones, Strait, 1963; Fletcher et al., 2013; Garner, Pomeroy, Arnold, 2017) – while wearing a standard surgical mask in which total physical capacity, ECG changes and oxygen saturation were evaluated. The tests were stopped after the subjects considered that they had reached exhaustion, therefore requesting termination of the exam. Subjects were asked for a personal opinion if they believed the use of surgical mask interfered with their performance. Two weeks after the first exam, a second one was done, this time without surgical mask (two days before they were required to have a negative SARS-COV-2 test).

The treadmill test was performed in a BTL-770M device, with blood pressure measurements done with a Heine Gamma XXL LF device. Oxygen saturation was evaluated by pulse oximetry with a Sangool FS20D device. A cardiologist and a cardiology technician were present at all times during the tests.

In terms of ECG changes, they were interpreted by a cardiologist in accordance with ACC guidelines (Gibbons et al., 1997). Arterial saturation was measured directly in one of the fingers of the subject before exercise, at peak exercise and post-exercise (5 minutes after the end of the exam), and total physical capacity estimated from the total time of exercise. Since different stages are involved in Bruce Protocol[7] (The BRUCE protocol uses different elevations of the treadmill and speeds used – associated to a specific Metabolic Equivalent (MET) per stage – for instance, stage 1 of the Bruce protocol is performed at 1.7 miles per hour (mph) and a 10% inclination gradient, stage 2 is 2.5 mph and 12%, while Stage 3 goes to 3.4 mph and 14%, and so on. Each of these stages has a corresponding MET value, which meant that a subject increasing 10 seconds in total exercise time while finishing the test in stage 3 would do significant more workload than one increasing those seconds in stage 1), we created a MET-Score in which the result was obtained by multiplying the seconds of exercise done by the METs associated with the stage in which the exercise was done, then we made the sum of all stages, therefore corresponding to an estimate of the full load of exercise performed.

All data was delivered to a data manager for post-processing.

All subjects received a document explaining the study and signed a consent form authorizing use of their data and agreeing to participate in the study.

In order to maintain consistency, we provided surgical masks to all patients. The mask was an OP-MASK B, a type IIR medical device.

Table 1. General characteristics of the sample (SD – Standard Deviation, BSA – Body Surface Area)

	Male	Female	Total	p-Value
n	4	8	12	
Age (mean ± SD)	30.5 ±5.69	27.3 ±3.80	28.3 ±4.60	0.283
BMI (mean ± SD)	24.9 ±3.22	22.0 ±1.95	23.0 ±2.70	0.214
Weight (mean ± SD)	78.0 ±7.44	57.6 ±5.00	64.4 ±11.50	**0.004 < 0.05**
Height (mean ± SD)	1.8 ±0.10	1.62 ±0.02	1.6 7±0.09	**0.004 < 0.05**
BSA (mean ± SD)	**1.10 ±0.12**	**1.6 ±0.07**	**1.7 ±0.19**	**0.004 < 0.05**

Statistical analysis

We performed a statistical analysis using mean and standard deviation. Hypotheses tests were executed for independent samples – Mann-Whitney U test – and for paired samples – Wilcoxon signed rank test and Chi squared test to test association between categorical variables.

IBM SPSS version 27 software was used for the statistical analysis.

Results

All but one of the subjects had a higher MET-Score while exercising without a mask. Comparing groups, there was a slight but statistically significant increase in MET-Score when subjects performed without a mask, showing that the subjects were able to increase exercise load when the mask was removed (Figure 1).

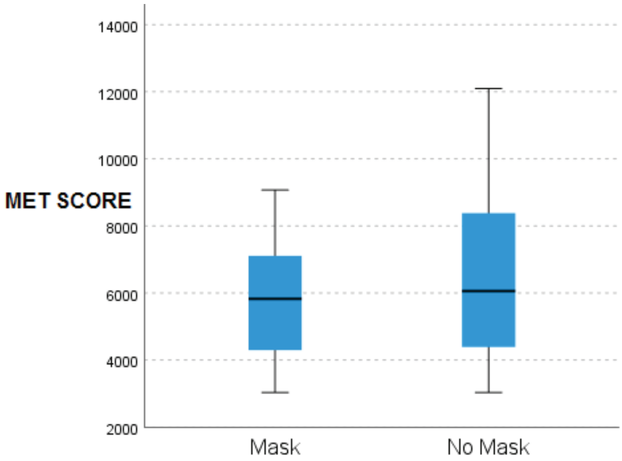

Figure 1. Increased MET-Score mean in No Mask group (p = 0.023)

Half of the participants declared feeling a sensation of discomfort while wearing the mask. This was also a statistically significant result.

Saturation levels were evaluated in rest, peak exercise and post-exercise (5 minutes after stopping the test). We compared basal and peak levels in one variable (ΔSAT1, difference between basal saturation and peak exercise saturation) and peak and post-exercise levels in another (ΔSAT2, difference between peak exercise saturation and post-exercise saturation). We found that the decrease of ΔSAT1 was more apparent in the masked group, and this finding had statistical significance (Figure 2). This was closely related with a statistically significant difference in peak exercise saturation (Figure 3). ΔSAT2 was not statistically significant.

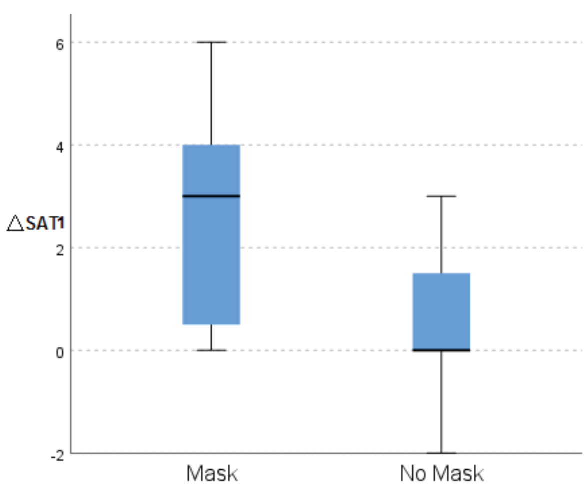

Figure 2. Clear difference between ΔSAT1 means in both groups (lower the better) (p = 0.021)

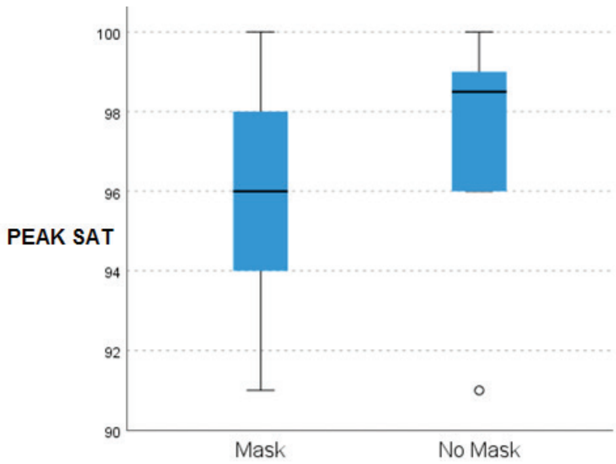

Figure 3. Lower saturations observed in peak exercise when the subjects wore mask (higher the better) (p = 0.049)

ECG changes were evaluated by a trained cardiologist. In the masked group 3 subjects, all female, had ECG changes that albeit not diagnostic for coronary ischemia, were at least doubtful. Two subjects had slight ST depression (one in inferior leads, the other in V4–V6 leads, neither reaching 1 mm depression but over 0.5 mm) and the other had premature ventricular beats (figures 4, 5 and 6). There changes were not the typical “upslope ST segment” expected in exercise, but a more horizontal change with less than 10 mm/second upstroke. Also relevant, none of these changes appeared in peak exercise (two in recovery, another at medium level of effort). When the subjects repeated the test unmasked, these alterations were no longer present.

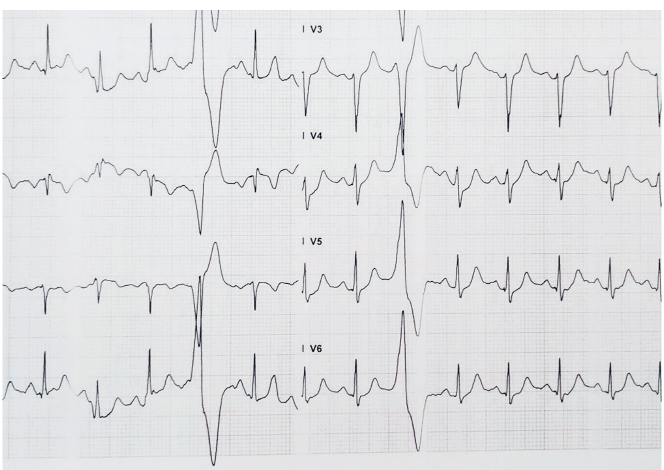

Figure 4. Premature ventricular beats in recovery phase (masked group)

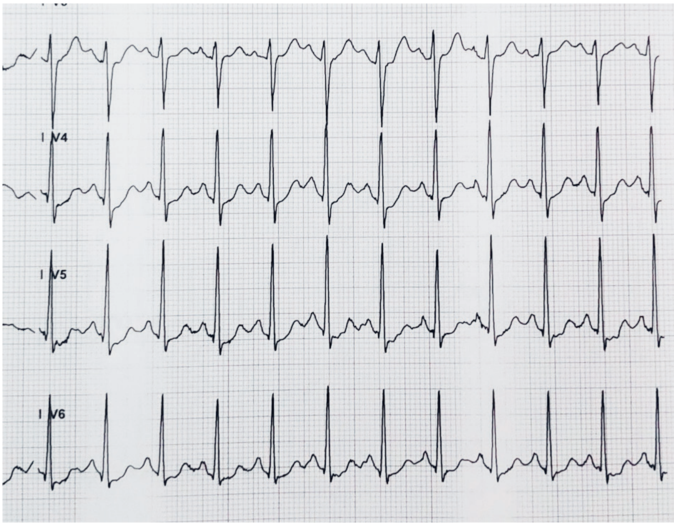

Figure 5. Slight ST depression V4–V6 leads during exercise (masked group)

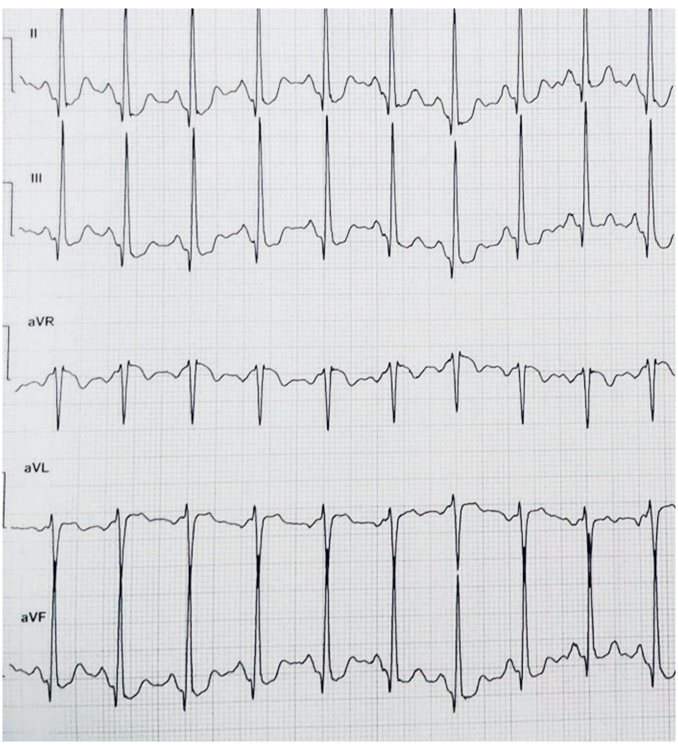

Figure 6. Slight ST depression in Inferior leads, recovery phase (masked group)

Discussion

The current study provides valuable insights regarding use of surgical masks in exercise. While we have some limitations, the results still are relevant. The small number of subjects is important to consider, but the previous studies reported are also with small numbers (maximal 14 subjects) and the need to evaluate the research question rapidly in the context on a Pandemic Crisis made us prefer less subjects but a faster conclusion. There is a majority of males in our evaluation, but this can simply be a representation of the number of people exercising, not a bias *Per Se*. We chose young healthy volunteers since, assuming the possibility of harm with mask use while exercise, we did not considered ethical to test patients with cardiac pathology already diagnosed. Also, our volunteers did at least some physical activity, so the adaptation to the treadmill test was easier. Health status was reported by our subjects, but all were health professionals, so we accepted the claim. In our study subjects were not required to control their average physical activity, to abstain from exercise in specific periods or to control their eating habits before the study. This had the purpose of not interfering with the daily routines of our subjects and, since they were acting as their own control, obtain a result with higher external validity. Performing the tests in the same location with the same machine in a 2 week difference also contributed to the validity of the results, since this rules out interfering aspects like exercising in different weather patterns, at different times of the day or in different environments (roads, sports track, etc). The study by Fikenzer et al. (2020) did showed changes in respiratory parameters like forced expiratory volume and peak expiratory flow, but neither oxygen saturation nor physical activity performed was evaluated. Shaw et al (2020) however, did test oxygen saturation levels between rest and peak exercise and total physical activity performed. In this study neither of these parameters was statistically significant. In our study this was not the case. Both the physical load performed (estimated by our MET-Score) and oxygen saturation (O2Sat) show clear differences when subjects wore masks. Physical capacity and O2Sat at peak exercise were decreased when subjects wore a mask compared to not wearing one, showing that indeed the use of mask can cause measurable respiratory and exercise capacity changes even in healthy volunteers doing exercise. When we compare our data with the one from Shaw et al. (2020) it is possible that the fact that we used a treadmill test and not a cycle ergometer might have affected the results regarding O2Sat. Since higher muscle mass is used in a treadmill that in a cycle ergometer (Kisan, Kisan, Or, Sp, 2012) this could theoretically cause a higher oxygen demand. The notion is not without its merits, if we considerer that at least for patients with chronic obstructive pulmonary disease a treadmill test has been described as eliciting lower oxygen saturation levels at peak exercise *vs* a cycle ergometer (Hsia, Casaburi, Pradhan, Torres , Porszasz, 2009). It has been shown that the maximal oxygen consumption (VO_{2max}) is higher in treadmill stress tests compared with cycle ergometer stress tests in trained individuals (Basset, Boulay, 2000) which in theory would convey a higher aerobic capacity and therefore a possible higher exercise capacity in that time of activity. Although our methods are different, we clearly had a difference with the use of a mask. We preferred a treadmill because it´s more commonly used in our country and we believe replicates more accurately the type of leisure exercise most healthy subjects do (jogging), so we believe our results can be more relevant to the general population, notwithstanding the small numbers used.

Eliciting the same results we had doing a different strategy, like performing a high intensity period of exercise done in a short amount of time, replicating protocols like those of High Intensity Interval Training (Tabata, Irisawa, Kouzaki, Nishimura, Ogita, Miyachi, 1997) could be an option to verify the changes we saw in a less time consuming matter. Further studies might be helpful in this matter.

A quite surprising result obtained, although not reaching statistically significance, was the appearance of non diagnostic but doubtful ECG changes in subjects while doing the test with a mask that disappeared when the test was repeated without mask. Since all subjects were self-reported healthy, asymptomatic, and the unmasked exam was done two weeks later, without any medication or change in habits, we do not believe this was related to ischemia. While we could speculate that an unusually high change in O2Sat between rest and peak could be that cause of this, that did not happen in our subjects, since the changes were slight. Also, it is questionable that such hypoxic effect could cause such changes unless it´s quite significant (Entwistle, Sommerville, Tandon, Jones, 1994; Coustet, Lhuissier, Vincent, Richalet, 2015) These subjects will perform further evaluations to rule-out the possibility of other alterations.

Since the beginning of this pandemic period, it has been regular practice to perform treadmill tests for diagnosis of coronary artery disease with the patients wearing masks. Considering our findings regarding the ECG changes and the exercise capacity (Roger et al., 1998) the possibility of diagnostic interference with mask use exists and has to be taken into account, and cardiologists should be aware of this while interpreting studies. Most subjects that do a treadmill stress tests do so to evaluate cardiovascular parameters in order to diagnose pathology. If the use of a mask can cause healthy volunteers to perform less exercise (and, as we saw, elicit ECG changes), than lower exercise levels performed might make a cardiologist believe a problem exists where he is simply detecting limitation caused by the use of a mask, and so the false positive results might increase.

Another relevant issue is, since we did detect significant changes in exercise capacity, oxygen saturation and reported discomfort with mask use, if this might impact the amount and level of exercise performed by the everyday subject if a mask is mandatory in these situations: While for the trained athlete the decrease in exercise load is the main issue (this might be relevant also for the casual subject that does leisure physical activity, since it might demoralize someone that´s starting to exercise), the discomfort and the decrease in O2Sat might be much more significant for the casual person, and might cause an increased abandonment of exercise.

From our results, if viable from the epidemiological perspective, exercise should be done without a mask, and consideration for exercise stress tests without masks has to be considered.

Conclusion

Our study shows that young healthy subjects have significant decreases in exercise capacity and oxygen saturation when performing exercise using surgical masks, besides reporting discomfort with its use. Also, there were slight ECG changes only present with mask use, which could cause difficulties in diagnosis of ischemia. A study with a higher number of subjects might clarify these findings, but we believe exercise should be done without a mask and consideration for exercise stress tests without masks should be discussed in the Medical Community.

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