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Original Articles

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A tribute to Antonin Rychtecky – his European legacy in youth sport and Olympic education studies

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My first meeting with Antonin Rychtecky is dated back to October 3rd in 1988, some months before the Velvet Revolution in Czechoslovakia. It was my colleague Hans-Georg John who invited me to join him on his Prague trip to be introduced to his friend Miroslav Pliva and to be introduced to a new colleague who worked in the same area of my academic work: Antonin Rychtecky. This 1988 October trip was well prepared: I was invited by Antonin Rychtecky to present a paper on how sport pedagogy as a discipline may offer support and advice to elite athletes. The presentation was given at the old faculty facilities, downtown by the river Vltava, just beside the Tyrs Museum. I was invited to join a group of faculty scientists who investigated Prague school children of regular schools and special sport schools to compare their physical fitness and motor development profiles. In the 1980s empirical studies in PE with physical fitness test batteries were not common and almost unknown in West Germany. We recorded by video tape everything we saw, in which way the test items were conducted by children and how measurements were taken by the Prague faculty team.

We took the video tapes back to Essen, where I had been working since 1980. We trained our team of colleagues and students to apply the same test battery to children of the same age group, in regular Essen school classes, according to the protocol applied to the Prague children by the Prague faculty team in doing their measurements. The outcome was the first co-authored three year longitudinal comparative study of West German and Czech school children regarding their motor and physical fitness profiles. The fresh results were reported at the International Comparative PE and Sport conference in Bishop Abbey, London, 1990, and published later, co-authored

by Antonin Rychtecky, Miroslav Pauer and Roland Naul (1991). That was our first co-authored international publication. Only a year later, in 1992, the overall results of our Prague-Essen monitoring project on physical fitness and motor development were presented at the ICSSPE Pre-Olympic Scientific Congress in the city of Malaga, published later in Spanish (Naul, Neuhaus, & Rychtecky, 1995). As a research co-ordinator of the International Society of Comparative Physical Education and Sport (ISCPES) I supported the bid of the Faculty of Physical Education and Sport (FTVS) submitted by Bohumil Svoboda and Antonin Rychtecky to host the next ISCPES Congress in Prague, in 1994. The outcome of the congress was very successful, as reflected in the proceedings of the Congress documents (Svoboda & Rychtecky, 1995).

The Olympic Year of 1994 became the real turning point for Antonin to join a greater European research project which included the monitoring of Olympic ideals for the first time in 12 and 15 year-old adolescents. It was a European six-country project (BEL, CZE, EST, FIN, GER, HUN) launched by the International Committee of Sport Pedagogy (ICSP) with a grant from the IOC. It was a study of around 7,000 students to investigate coherent development between physical fitness, active lifestyle behaviour and the assessment of moral principles as Olympic ideals. Some of the earliest comparative results were published in Acta Universitatis Carolinae – Kinanthropologica (Naul, Telama, & Rychtecky, 1997) and the full range of results were published in a book, volume 11 of the "Sport Science Studies" series of ICSSPE (Telama et al., 2002).

One international highlight performed by Antonin Rychtecky in his Olympic education studies was the result of a so-called "four Olympic ideal factors as behaviour patterns" project (Rychtecky & Naul, 2005) which became well referenced later in international publications, just like the "Olympic Questionnaire" of the ICSP-study which was developed in cooperation with him. The "Olympic Questionnaire" was later applied worldwide in Hong Kong, Singapore, USA, South Africa and even more frequently in some European countries, particularly in Poland and Ukraine. The structure and frame of the ICSP study design were also taken later by Prof. Rychtecky himself (2011, 2013, 2021) for two more national cohort studies on physical activity and Olympic ideals of adolescents in the Czech Republic.

A second big European project with FTVS and Antonin Rychtecky as an important partner network emerged in 2003, when a European research consortium of scholars, representing 11 EU member states was selected by the European Commission to conduct an EU-wide study on young peoples' physical activities and sedentary lifestyles (Naul & Brettschneider, 2005). The considerable income generated by the German lead partner was fairly distributed and shared between all partners of the review study in which Antonin Rychtecky represented the Czech partner. In total, we received more than a dozen national review studies including many national research results which had previously only been published in very different national EU languages like Czech, Portuguese, Finnish, etc. In this project, these different national sources, which had up until then remained largely unknown to an international audience because of language barriers, were brought to an international level of recognition and knowledge in Europe. A major contribution was made by Prof. Rychtecky. He not only wrote his report for the Czech Republic, but also became our mentor and translator to get in contact with scientists in Poland, Slovakia and Slovenia for their national reports

in English. Finally, Antonin summarized the outcome of the four national country reports on physical activity development and physical fitness from Central & Eastern Europe in a special volume (Rychtecky, 2004).

The final report of this study, stored at the European Commission library, caused some further activities after 2005: the first European Union Working Group on Sport and Health was established in Brussels (2006). Only eight EU countries sent their national delegates. Antonin Rychtecky represented the Czech Republic in this group. This group had a remit to draft the EU-Physical Activity Guidelines and brought up HEPA again on the EC agenda after 1999/2000. In the mid of the 2000s Antonin was also an invited and elected member of some other EC projects: he was a member of numerous research consortia linked to commissioned studies for the European Union (e.g. COMPASS Study; Study on Young People's Lifestyle and Sedentariness; VOCAsport; ARCTOS; AEHSIS).

As a part of the so called "Preparatory actions in the field of sport", another EU-project grant was awarded in 2009 up to 2011 by DG EAC (the Commission department in charge of sport, inter alia) and managed by us on behalf of ENGSO Youth and the German Sport, Youth with support of the Prague Faculty as a partner. A strong Czech sample of secondary school children of the city of Prague and two more schools in the town of Vrchlabí were included in cooperation with CSTV. Antonin Rychtecky served as the head of the Czech national HCSC-study (healthy children in sound communities) which results are documented in the final report of the EC-project.

Finally, another big world-wide project was launched about 10 years ago, but only came to life in 2012, and has been finished only in 2017. It is a 20-country study around the world with 9 EU-partners representing countries like Czech Republic, France, Germany, Greece, Poland, Russia, Spain, UK and Ukraine (Naul, Binder, Rychtecky & Culpan, 2017). With a comparative set of about 15 items of review criteria in total 20 national country reports have been written with additional 8 chapters of introduction and international analysis of the reported review results. Besides the Czech national country report, written by Antonin, four chapters of the anthology have been written together in international co-authorship with Prof. Rychtecky.

In the same year of 2017 Antonin, "Tonda", helped us as our international fellow of the Willibald Gebhardt Research Institute at Münster, to celebrate the 4th Olympic Education Symposium at the Charles University. We intended to dedicate the proceedings of the symposium to Anton Rychtecky's 75 birthday in September 2020. However, before printing of the final manuscript started, Prof. Rychtecky passed away. We just dedicated the book as a tribute to the life-work of Antonin Rychtecky (Binder et al., 2021) with inclusion of a review paper of Prof. Rychtecky which he gave at the symposium in Prague. It will be printed as a part of the proceedings posthumously (Rychtecky, 2021).

Without the support of my friend Tonda at the faculty in Prague, we never would have had access to sources and materials written by our Russian and Ukrainian Olympic scholars in this world-wide project. In many research projects Prof. Rychtecky with his perfect Russian academic language skills opened doors to Eastern Europe with involvement of Slavonian language countries. As a teacher he lectured as a member of the Czech National Olympic Academy frequently on Olympic education items at the International Olympic Academy in Ancient Olympia.

With the passing of Prof. Rychtecky, the FTVS lost one of their most prominent academic representatives in Europe and within the Olympic family world-wide. The Willibald Gebhardt Research Institute will keep our memories of Tonda as a friend and international fellow alive after more than 30 years of academic cooperation.

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Looking back at Professor PhDr. Antonín Rychtecký, DrSc.

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With grief, all of us who knew our colleague Antonín Rychtecký and were able to work with him received the news of his death. He died on December 6, 2020 after a long illness at the age of 75.

Antonín Rychtecký was born on 19. 9. 1945 in Vysoké Studnice in the district of Jihlava. After completing primary and secondary education, in accordance with his sporting interests, which also shaped his personality, he chose the Institute of Physical Education and Sport, the current Faculty of Physical Education and Sport, as the place of his university studies. This decision was, to a certain extent, a "fateful" decision, as he spent not only his student years at this faculty, but subsequently his entire professional career. The meeting with prof. Miroslav Vaněk, an internationally recognized representative of sport psychology, whose lectures on psychology and sport psychology aroused his interest in these fields. These subsequently played an important role in his further professional and vocational focus, as after graduating from the faculty he continued his scientific development within the internal postgraduate course, similar to current doctoral studies, as evidenced by his first research work focused on free effort in physical activity.

Subsequently, as a member of the constituted department of sport psychology FTVS, he significantly contributed to its development into an important workplace both in the faculty, national and international contexts. His pedagogical and scientific work showed a tendency to set high goals, diligence, the effort to achieve his goals. It can be said that he devoted a substantial part of his life to the faculty, he lived by the faculty, he worked for the faculty, always to the fullest.

In his pedagogical and scientific research work, he gradually and increasingly focused on the issue of psychological contexts, especially school physical education, where he was interested in issues of motor performance, the role of motivation in physical education and subsequently the issue of Olympism. His scientific contribution to this area is evidenced by numerous publications, both domestic and foreign, and includes, for example, the book "Didactics of School Physical Education" or "Lifestyle of the Youth Population", which also brings standards and norms of motor performance of youth that will influence physical education practice also in the following years. During his research activities, he has published more than 200 publications of a book and journal nature published at home and abroad, which proves both his diligence and contribution to Kinanthropology.

His pedagogical and scientific work was also reflected in his professional growth in obtaining the rank of doctor of pedagogical sciences and subsequently in 1997 in his appointment as a professor in the field of Kinanthropology, in the creation and development of which he participated for a long time.

In addition to his pedagogical and scientific activities, Professor Rychtecký played a significant role in the direction of the faculty as a member of the faculty management in the position of vice-dean for science and vice-dean for external and international affairs, which he held at various stages of faculty development. He was also active in scientific societies and editorial boards of professional journals, among others he was the chairman of the Czech Kinanthropological Society and a long-time editor-in-chief of the journal Acta Universitatis Carolinae Kinanthropologica. Chairman of the Editorial Board of the journal Czech Kinanthropology and Chairman of the Olympic Academy. The professional community loses a significant and respected personality in him, but thanks to his lifelong efforts he has left a significant mark that goes beyond the scope of his life.

In prof. Rychtecký will be remembered permanently and with respect not only by his former colleagues, but also by several generations of graduates of the Faculty of Physical Education and Sports for his diligence, openness to both colleagues and students, willingness to discuss anything at any time, for his helpful attitude and willingness to cooperate and help even in the difficult situations that not only academic but also everyday life brought.

Honor his memory.

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A hot mess: basketball coaches' perceptions of ability versus actual performances of their athletes

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ABSTRACT

Data analytics are an increasingly popular method for talent identification, and are used for a variety of decision making purposes, such as rotations and playing time. However, coaches often rely on their perceptions and experiences to identify talent and player attributes that are important to success. Therefore, the purposes of this study were to evaluate differences between coach perceptions of player ability against actual performances as well as to determine whether these perceptions differed as a head or assistant coach. Participants were six (two head; four assistant) college coaches who were asked to collectively identify the five most important attributes when evaluating a basketball player. Then, before the season began, all coaches were asked to independently score each of their athletes on these attributes using a 100mm Visual Analog Scale. These scores were compared to player performances during the season. Results were mixed, and while there were correlations between some player performance variables and coach perceptions, they varied wildly, and coaches' perceptions of their athletes had little consistent correlation to their performances. Furthermore, there were few agreements between head coaches and their assistants or between assistants. Findings suggest that while coach perceptions and talent identification have their place, the use of data analytics in sports may provide additional support when making coaching decisions such as playing time. Therefore, coaches should recognize their own limitations of player talent and balance these "feelings" with statistical evidence.

KEYWORDS

data analytics; sport analytics; coaching; coach; Visual Analog Scale

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INTRODUCTION

Coaches, at every level and in all sports, rely on their perceptions to make athlete-related decisions, such as roster selection, playing time, and tactical strategies. A perception represents an individual's ability to recognize an environmental stimulus using the senses (McFarland et al., 1999). In coaching, perceptions need to be recognized and accepted by the coach (Das & Phookun, 2013) if decision making is to be effective.

Unfortunately, perceptions can conflict with and cloud reality (Das & Phookun, 2013; Rickersten, 2012), especially when attitudes are taken into consideration (Pickens, 2005). Therefore, someone in an evaluative situation (e.g., coach, scout, manager) will likely have perceptions of an athlete's effectiveness based on a variety of circumstances, such as their prior performances, relationship with the player, and conversations with those associated with the player (e.g., former coaches, parents). These variables can influence how decisions are made. For example, in a recent documentary of Sunderland Football Club, owner Stewart Donald confessed to having purchased a striker for a record price, not because that was what he was valued at, but because he felt pressured into purchasing a striker before a transfer deadline. As days, then hours, then minutes ticked by, the player's perceived effectiveness and value to the club was progressively augmented by the urgency the owner felt to purchase a player prior to the transfer deadline and appease the club's fanbase (Pearlman & Turner, 2020).

Coaches are also required to make quick and often significant decisions based on their perceptions. Therefore, when judging performance or a situation, it is important that both coach and athlete share the same perceptions. For example, the feedback on a basketball player's jump shot technique provided by a coach might not be well-received or adopted by the player that does not perceive a problem exists. In many cases, such a discrepancy may exist; Oliver and Robins (1994) identified a bias in performance perceptions, noting that individuals perceived themselves more positively than their peers. Since self-perceptions and perceptions of others are often at odds, a single perspective may be an inadequate representation of reality (Vazire et al., 2008).

Cook (2015) found discrepancies between coaches' and athletes' perceptions of performance, highlighting how important it is that coaches be aware of potential differences in performance perceptions when offering athletes constructive feedback. Although a lack of research exists on coaches' perceptions of athletes, numerous studies have examined athletes' perceptions of coaches. Smoll and Smith (1989) created a model of sport leadership behaviors to provide a framework for examining the cognitive and affective processes to help mediate an athlete's reaction to their coach's behavior. The variables of this model include: 1) situational factors (e.g., nature of the sport, level of competition, practice vs. game setting), 2) coach and athlete individual difference variables (e.g., age, sex, perceived coaching norms, goals/motives), and 3) the coach's perception of athletes' attitudes. They found coaching effectiveness to be mediated by an athlete's perception and recall as "leader effectiveness resides in both the behaviors of the leader and the eyes of the beholder" (p. 1544).

Turnman (2006) investigated how a coaching reward and power system can influence athletes' overall satisfaction with sport participation. Palmer (2013) investigated NCAA Division I female basketball players' perceptions of coaching behavior in

relation to team cohesiveness and success. Findings indicated that players from both winning and losing teams selected the same top and bottom leadership functions of their coaches but rated the functions differently (Palmer, 2013).

Perceptions and analytics

Analytics and the use of statistics have become ubiquitous among professional sport teams, especially in the National Basketball Association (NBA; Fry, 2012). Analytics within the NBA has greatly impacted the way the sport is played and how player performance is measured. For example, it is used to study allocative and dynamic efficiency in decision making. Recent studies have demonstrated the growing use of athlete tracking data, which essentially tracks and numerically analyzes every aspect of an athlete's performance (Skinner & Guy, 2015). Player tracking data has been used with teams in the NBA to measure statistical improvements in player and team performance (Sampaio et al., 2015).

Tracking player movements in basketball has become important in overall performance of the team (Sarlis & Tjortjis, 2020). These tracking movements include statistics such as, speed, distance, player separation, and ball possession. Yet, much of the sport analytics produced and critiqued by statisticians can be overwhelming and there is inherent difficulty in understanding how to use this information effectively (Steinberg, 2015); coach perceptions may still hold some value.

Studies on coaching and analytics have been more prevalent than inquiry on coaching perceptions. In one study, game related statistics of basketball guards, forwards, and centers in three professional leagues were analyzed (Sampaio et al., 2006). Findings suggested that coaches perceived player's contributions to team performance differently according to the position of the player as either a guard, forward, or center rather than their contributions as a player in general. Therefore, there remains a challenge for coaches to balance analytical data, data that may fail to explain the story behind it (e.g., unusual circumstance, player injury, pressure moment), against their own perceptions that may be flawed.

Head coaches and assistant coaches

To date, there is no research evaluating the perceptions of head coaches against those of assistant coaches, which is a purpose of the present study. This is important, as with differing roles and responsibilities, each may view a given situation or athlete differently. According to Young (2020), head coaches in the NBA have a responsibility to establish and maintain a positive team culture, review and assess metrics associated with each game plan, allocate time for media events, participate in front office executive meetings, juggle demands from players about playing time and positions, and negotiate with a player's agent. Assistant coaches may be expected to establish and maintain a positive team culture, review and assess metrics associated with each game plan, allocate time for media events, participate in front office executive meetings, and also juggle demands from players about playing time and positions (Young, 2020).

Although most head coaches are responsible for making playing time decisions based on player performance, assistant coaches are often called upon to offer their input on player and team performance. As noted, with differing roles and responsibilities within the team, perceptions can differ. For example, perceptions by a basketball

coaching staff can be influenced by a range of variables including physical characteristics such as height, weight, and athleticism, to more skill-based evaluations involving a player's specific offensive or defensive abilities (Turcott & Pifer, 2019). Furthermore, in stressful competitive games, assistant coaches may be placed in a situation where the power dynamic between head and assistant coach leaves them feeling incompetent (Zakrajsek et al., 2019). Consequently, an assistant coach may have a valuable observation or perception, but it may differ from the perception of the head coach and be ignored, unwanted, or withheld.

Study purpose

Perceptions are an important component of a coach's decision making. However, there is little research investigating this topic. In basketball and many other sports, analytics have become increasingly prevalent, yet a coach's perceptions that rely on immediate observations remain an important component of a coach's decision making. While some research exists on the perceptions of head coaches, little research exists to evaluate differences to assistant coaches. Therefore, the primary objective of this study was to determine whether head and assistant coaches' perceptions of their players correlated to their basketball performance. We hypothesized that perceptions of head coaches would be better predictors of basketball performance compared to assistant coaches. Our secondary aim was to determine the congruency between head and assistant coaches' perceptions of basketball performance. We hypothesized that the head coach and assistant coaches would have similar perceptions.

METHOD

Participants

Participants ($N = 6$) consisted of members of one women's and one men's basketball coaching staff at a NCAA Division I institution ($n = 2$ head coaches, $n = 4$ assistants). The head women's coach was an African-American female with six years of NCAA Division I head coaching experience, one year as an interim NCAA women's head coach, four years as a NCAA Division I assistant coach and two years as a NCAA Division I graduate assistant coach. The first assistant women's coach was an African-American female with seven years of NCAA Division I associate head coaching experience, eight years of NCAA Division I assistant coaching experience and one year of NCAA Division I graduate assistant experience. The second assistant, a Caucasian female, had one year of NCAA Division I assistant coaching experience and two years as a NCAA Division II assistant coach. At the time of data collection, the first assistant had two years of experience working with the head coach; the second assistant had been a member of the coaching staff for one year.

The head men's coach was an African-American male with two years of NCAA Division I head coaching experience, five years of NCAA Division I associate head coaching experience, and had seven years as a NCAA Division I assistant coach. The men's first assistant coach was an African-American male a with one year of experience as a NCAA Division I assistant coach, two years of experience as a junior college assistant coach, and two years of experience as a graduate assistant at the NCAA Division I level. The second assistant, an African-American male, had two years of

NCAA Division I assistant coaching experience with the current head coach. At the time of the investigation, the first assistant had one year of experience working with the head coach; the second assistant had been a member of the coaching staff for two years.

Instruments

Player Evaluation and the Visual Analog Scale (*VAS*). Head coaches and assistant coaches were collectively asked to identify the five most important attributes when evaluating a basketball player. After one hour of deliberation together, the following five attributes were selected: 1) Overall Basketball IQ (the ability of a player to impact the game), 2) Offensive IQ (a player's offensive ability), 3) Defensive IQ (a player's defensive ability), 4) Anticipation Ability (the ability of the player to anticipate the play), and 5) Passing Ability (the player's ability to pass the ball). Beyond the descriptions provided, coaches did not provide a more exact definition.

All coaches were asked to independently score each of their athletes on a 100mm Visual Analog Scale. The VAS is a scale that looks like a ruler, and had only two labels of "none" to "highest ever seen" at the extreme edges. Coaches were asked to make a perpendicular mark on the line that best represented their perception of each player's specific ability for each of the five dependent variables: Overall Basketball IQ, Offensive IQ, Defensive IQ, Anticipation Ability, and Passing ability. A VAS provides an accurate measure of subjective perceptions and has been used extensively in prior studies (e.g., Boolani, 2017; Jacobson, 2010; Wittwer, 2016). Two research assistants scored the VAS and entered the scores into SPSS. If a dispute occurred, the average of the two scores was utilized.

Performance Statistics. Player statistics were collected for an entire season and included: games started and played; total and average minutes played per game; field goals and three-point field goals attempted, made, and field goal percentage; free throws attempted and made; offensive, defensive, and total rebounds per game; personal fouls and ejections accrued; assists and assists per field goal attempt; turnovers and assists per turnover ratio; blocks, steals, and steals per assist ratio; points scored, scoring average per game, and Unadjusted Player Efficiency Rating (uPER). These season statistics were then averaged per 30 minutes of playing time for each athlete to standardize differences in playing time across the season. This process is similar to that used Klusemann et al. (2013), who used a 30-minute timeframe to standardize statistics across a basketball season.

Unadjusted Player Efficiency Rating (*uPER*). The uPER is a measure of basketball performance using a formula that calculates an individual performance rating per minute of playing time. This formula produces an unadjusted player efficiency rating (PER) and may be normalized and adjusted to the pace of play. Since college teams play against teams in multiple conferences, uPER was calculated, which has been used in multiple studies (Hwang, 2012; Rosenthal, 2014; Solieman, 2006; Zhang, 2011). uPER is unadjusted for the pace of the game whereas PER is adjusted by pace of the game. Therefore, because data extended beyond a team's conference schedule, and included teams from other conferences and competitive divisions, uPER was used.

Procedure

Following institutional review board approval, the head coaches and assistant coaches of a NCAA Division I team at the same university were approached and asked to participate in a study about basketball talent identification. Upon agreement, participants were asked to meet and determine the most important attributes of a basketball player. At the end of preseason practice, but prior to the commencement of competitions, coaches from both the men's and women's teams were asked to complete a 100mm Visual Analog Scale (VAS) for each of their players for the five different attributes they had identified as critical. The men's coaches rated 7 players and the women's coaches rated 11 players. Following this process, data were collected on players' performances throughout the season to allow for comparisons between coaches' perceptions and on-court performances.

Analysis

To determine whether head and assistant coaches' perceptions of their players accurately predicted individual basketball performance a pairwise Pearson's correlation was calculated between the head and assistant coaches' perceptions of players' attributes (i.e., Overall Basketball IQ, Offensive IQ, Defensive IQ, Anticipation Ability, and Passing Ability) and actual performance statistics. A secondary aim was to determine the congruency between head and assistant coaches' perceptions of basketball performance. This was tested using pairwise Pearson's correlations among head and assistant coaches' perceptions of their players. Analyses were conducted separately for the men's and women's teams and significance was set at $p \leq 0.05$.

RESULTS

The purposes of this study were to evaluate differences between coach perceptions against actual performances as well as to determine whether these perceptions differed as a head or assistant coach. Results are broken down by men's and women's team as well as by whether the participant was a head or assistant coach.

Men's team

Tables 1–3 present the analyses for the men's team. Tables 1 and 2 present the correlations between the head coach and assistant coaches' perceptions of player attributes. Assistant coaches perceived player attributes in the same way as the head coach, as correlations were significant for almost all perceptions (Table 1). This was also true for comparison between assistant coaches, where the only correlation not significant was Offensive IQ (Table 2).

Table 3 presents the correlation between players' real performance statistics and coaches' perceptions. Points, Defensive Rebounds, Blocks, and Steals had no significant correlations to any categories. However, Total Minutes (i.e., playing time) was determined based on the Head Coach's perception of Offensive IQ ($r = 0.76$) and Passing Ability ($r = 0.77$). Offensive Rebounds were negatively correlated to Defensive IQ for the head coach ($r = -0.70$), first assistant coach ($r = -0.80$), and second assistant coach ($r = -0.70$). Assists appeared to be important for all coaches for all categories except Anticipation Ability, but interestingly it was significantly, positively correlated

to Defensive IQ by the head coach ($r = 0.89$) first assistant coach ($r = 0.84$), and second assistant coach ($r = 0.77$). Fouls were significantly, negatively correlated to Overall IQ by the assistant coaches ($r = -0.80, -0.80$) whereas it was tied to Offensive IQ by the head coach ($r = -0.90$).

Women's team

Findings were different for the coaches of the women's team, which are presented in Tables 4–6. Tables 4 and 5 present the correlations between the head coach and assistant coaches' perceptions of player attributes. There was little agreement overall; significant correlations were found between the head coach and first assistant coach for Overall IQ and Offensive IQ, and there was a significant correlation on Passing Ability with the second assistant coach. Assistant coaches had little agreement between themselves, with no significant correlations between their perceptions of players' attributes.

Table 1 Correlation between men's team head coach and assistant coaches' perceptions of player attributes

		Head Coach				
		Overall IQ	**Offensive IQ**	**Pass. Ability**	**Ant. Ability**	**Defensive IQ**
Assistant Coach 1	Overall IQ	0.95*				
	Offensive IQ		0.82*			
	Pass. Ability			0.93*		
	Pass. Ability				0.90*	
	Defensive IQ					0.87*
Assistant Coach 2	Overall IQ	0.95*				
	Offensive IQ		0.60			
	Pass. Ability			0.97*		
	Ant. Ability				0.91*	
	Defensive IQ					0.92*

* Significant at 5% level

Table 2 Correlation Between Men's Team Assistant Coaches' Perceptions of Player Attributes

		Assistant Coach 1				
		Overall IQ	**Offensive IQ**	**Pass. Ability**	**Ant. Ability**	**Defensive IQ**
Assistant Coach 2	Overall IQ	0.95*				
	Offensive IQ		0.61			
	Pass. Ability			0.90*		
	Ant. Ability				0.89*	
	Defensive IQ					0.90*

* Significant at 5% level

Table 3 Correlation of Men's Team Coaches VAR Scores Against Season Statistics

Head Coach					
Variable	**Overall IQ**	**Offensive IQ**	**Pass. Ability**	**Ant. Ability**	**Defensive IQ**
UPER	−0.30	0.00	0.00	−0.30	−0.20
Total minutes	0.58	0.76*	0.77*	0.27	0.48
Points/30min	0.29	0.15	0.64	0.42	0.23
Offensive Rebounds/30min	−0.60	−0.50	−0.20	0.00	−0.70
Assists/30min	0.90*	0.86*	0.86*	0.43	0.89*
Turnovers/30min	0.59	0.37	0.83*	0.65	0.51
Defensive Rebounds/30min	−0.40	−0.30	0.00	−0.20	−0.50
Fouls/30min	−0.70	−0.90*	−0.50	−0.10	−0.60
Blocks/30min	−0.60	−0.10	−0.40	−0.40	−0.70
Steals/30min	0.24	0.27	0.61	0.10	0.12
Assistant Coach 1					
Variable	**Overall IQ**	**Offensive IQ**	**Pass. Ability**	**Ant. Ability**	**Defensive IQ**
UPER	−0.40	−0.50	−0.10	−0.50	−0.10
Total minutes	0.52	0.53	0.62	0.28	0.36
Points/30min	0.11	0.26	0.42	0.16	−0.10
Offensive Rebounds/30min	−0.70	−0.30	−0.30	−0.40	−0.80*
Assists/30min	0.82*	0.63	0.83*	0.58	0.84*
Turnovers/30min	0.41	0.53	0.69	0.48	0.19
Defensive Rebounds/30min	−0.60	−0.40	−0.20	−0.50	−0.60
Fouls/30min	−0.80*	−0.70	−0.60	−0.40	−0.70
Blocks/30min	−0.50	−0.40	−0.40	−0.50	−0.40
Steals/30min	0.16	0.32	0.35	0.00	−0.20
Assistant Coach 2					
Variable	**Overall IQ**	**Offensive IQ**	**Pass. Ability**	**Ant. Ability**	**Defensive IQ**
UPER	−0.20	−0.20	0.00	−0.40	−0.10
Total minutes	0.59	0.49	0.74	0.45	0.29
Points/30min	0.14	0.38	0.74	0.57	0.00
Offensive Rebounds/30min	−0.70*	−0.30	0.00	−0.20	−0.70*
Assists/30min	0.91*	0.51	0.74	0.63	0.77*
Turnovers/30min	0.41	0.45	0.89*	0.82*	0.26
Defensive Rebounds/30min	−0.50	0.00	0.09	−0.20	−0.60
Fouls/30min	−0.80*	−0.40	−0.40	−0.30	−0.50
Blocks/30min	−0.50	−0.40	−0.30	−0.50	−0.50
Steals/30min	0.18	0.62	0.71	0.36	−0.20

* Significant at 5% level

Table 4 Correlation Between Women's Team Head Coach and Assistant Coaches' Perceptions of Player Attributes

		Head Coach				
		Overall IQ	**Offensive IQ**	**Pass. Ability**	**Ant. Ability**	**Defensive IQ**
Assistant Coach 1	Overall IQ	0.69*				
	Offensive IQ		0.78*			
	Pass. Ability			0.61		
	Ant. Ability				−0.50	
	Defensive IQ					0.13
Assistant Coach 2	Overall IQ	−0.01				
	Offensive IQ		0.40			
	Pass. Ability			0.66*		
	Ant. Ability				0.09	
	Defensive IQ					−0.01

* Significant at 5% level

Table 5 Correlation Between Women's Team Assistant Coaches' Perceptions of Player Attributes

		Assistant Coach 1				
		Overall IQ	**Offensive IQ**	**Pass. Ability**	**Ant. Ability**	**Defensive IQ**
Assistant Coach 2	Overall IQ	0.06				
	Offensive IQ		−0.02			
	Pass. Ability			0.36		
	Ant. Ability				0.06	
	Defensive IQ					0.56

* Significant at 5% level

Table 6 presents the correlation between players' real performance statistics and coaches' perceptions. uPER was significantly, positively correlated to Passing Ability ($r = 0.77$) and Anticipation Ability ($r = 0.73$). In comparison to the coaches of the men's team, Total Minutes was not significantly correlated to any category, nor were Points, Offensive Rebounds, Turnovers, Defensive Rebounds, and Fouls. Assists were significantly, positively correlated to Passing Ability for the first assistant coach ($r = 0.67$) and Offensive IQ for the second assistant coach ($r = 0.64$). Interestingly, blocks were negatively correlated with Overall IQ for both the head coach ($r = -0.40$) and first assistant coach ($r = -0.60$). Steals were also negatively correlated to Anticipation Ability for the head coach ($r = -0.60$) but not for the assistant coaches.

Table 6 Correlation of Women's Team Coaches VAR Scores Against Season Statistics

Head Coach					
Variable	**Overall IQ**	**Offensive IQ**	**Pass. Ability**	**Ant. Ability**	**Defensive IQ**
UPER	0.50	0.46	0.77*	0.73*	0.57
Total minutes	0.08	0.17	0.09	0.02	0.00
Points/30min	−0.50	−0.30	−0.50	−0.50	−0.50
Offensive Rebounds/30min	0.00	0.06	0.15	0.03	0.00
Assists/30min	0.39	0.26	0.19	0.01	0.00
Turnovers/30min	−0.10	−0.10	−0.10	−0.20	−0.30
Defensive Rebounds/30min	−0.20	−0.20	0.00	−0.10	−0.40
Fouls/30min	0.26	0.26	0.29	0.42	0.42
Blocks/30min	−0.40	−0.40	0.00	0.01	−0.20
Steals/30min	−0.30	−0.30	−0.50	−0.60*	−0.40
Assistant Coach 1					
Variable	**Overall IQ**	**Offensive IQ**	**Pass. Ability**	**Ant. Ability**	**Defensive IQ**
UPER	0.23	0.44	0.16	−0.10	0.29
Total minutes	0.07	0.04	0.12	0.00	0.00
Points/30min	−0.30	−0.10	−0.30	0.20	−0.60
Offensive Rebounds/30min	0.17	0.02	0.00	0.12	−0.20
Assists/30min	0.21	0.01	0.67*	−0.50	0.19
Turnovers/30min	−0.20	−0.30	0.38	−0.10	−0.10
Defensive Rebounds/30min	−0.10	−0.40	0.08	0.31	0.08
Fouls/30min	0.36	0.51	−0.30	0.00	0.13
Blocks/30min	−0.60*	−0.20	−0.20	0.51	0.18
Steals/30min	0.00	−0.30	0.05	0.01	−0.10
Assistant Coach 2					
Variable	**Overall IQ**	**Offensive IQ**	**Pass. Ability**	**Ant. Ability**	**Defensive IQ**
UPER	0.22	0.00	0.38	0.00	0.23
Total minutes	0.08	0.37	−0.10	0.07	0.00
Points/30min	−0.10	−0.30	−0.40	0.20	0.00
Offensive Rebounds/30min	0.14	0.00	−0.10	0.00	0.15
Assists/30min	0.06	0.64*	0.02	0.00	−0.20
Turnovers/30min	0.18	0.09	0.26	0.41	0.12
Defensive Rebounds/30min	0.32	0.14	−0.10	0.13	0.27
Fouls/30min	0.01	0.00	0.29	0.00	0.05
Blocks/30min	0.08	−0.40	0.00	0.29	0.33
Steals/30min	0.11	0.28	−0.40	0.02	0.00

* Significant at 5% level

DISCUSSION

The primary objective of this study was to determine whether head and assistant coaches' perceptions of their players correlated to their players' basketball performance. We hypothesized that perceptions of head coaches would be better predictors of basketball performance compared to assistant coaches. A secondary aim of the study was to determine the congruency between head and assistant coaches' perceptions of basketball performance. We hypothesized that the head coach and assistant coaches would have similar perceptions.

Perception versus actual performances

When considering our first hypothesis, results were mixed when considering the abilities perceived of players by the coaches and what transpired during the season. In addition, there was little congruence between the coaches of both men's team and women's teams. For example, while fouls were consistently negatively correlated to performance categories on the men's team (i.e., less fouls equated to a higher Overall IQ), they were positively correlated on the women's team. Other correlations appear counterintuitive; negative correlations between Defensive IQ and Blocks and Defensive Rebounds would indicate that perhaps coaches rely on perceptions more than they should.

These findings are difficult to explain beyond the obvious finding that coaches struggled to identify the characteristics of their players that translated into performances across the season. Yet, this is also a telling finding, and highlights the value of analytics over the opinions and impressions of a coach. Given that individuals typically perceive themselves more positively than their peers (Oliver & Robins, 1994), it is likely that coaches value specific traits in their players more than others. For example, players on the men's team might expect to get more playing time if they are perceived to have good Passing Ability and a high Offensive IQ. On the women's team, higher scores on the uPER might gain the attention of the coaches.

Although we could not find any empirical writing on this topic, we suggest that a coach's previous coaching and playing experiences may have a role in this situation. For example, a head coach whose previous coaching experiences focused on defense may be more inclined to look for similar traits in their own athletes. Previous playing experiences may also be a factor. Most coaches have playing experience within the sport they coach (Ewing, 2019); therefore, they may be more inclined to look more favorably on a player who plays their position or possesses the same physical or psychological characteristics.

Head coaches versus assistant coaches

If a single perspective may be an inadequate representation of reality (Vazire et al., 2008), it benefits coaches to have assistants who can provide alternate suggestions and ideas. Assistant coaches in basketball can have many differing roles, including assisting with team selection or evaluating team performance (Young, 2020). Therefore, it is imperative that assistant coaches can identify attributes necessary for success just as much as head coaches.

In the present study, there was congruence between the men's team head coach and the assistant coaches on their players' attributes. Only Offensive IQ was not significantly correlated suggesting coaches evaluated their players similarly. The women's team coaches were much less in agreement. There were significant correlations between the head coach and first assistant coach Overall IQ and Offensive IQ and between the head coach and second assistant coach for Passing Ability. Correlations for Anticipation Ability and Defensive IQ were very low, suggesting how the head coach perceived these attributes was very different to the assistant coaches. Furthermore, correlations were low between the two assistant coaches.

Is it better to have strong agreement between coaches on player attributes or not? Congruence can lead to unity, with coaches evaluating players' attributes similarly. Yet, there may be value in having different perspectives. A coach that works exclusively with assistants who sees things "their way" may miss seeing new opportunities or ideas, and head coaches have reported hiring assistants with different perspectives and coaching styles (Rathwell et al., 2014). Therefore, while results from the present study suggest a lack of congruence between perceptions, this may in fact be helpful, as an assistant coach might moderate or balance the differing perspectives of a head coach or another assistant coach.

Application, limitations, and future research

The findings of the present study represent what a research never hopes to experience; data that makes little logical sense. Yet, nonsensical data can lead to conclusions, and we posit that based on our findings, coaches at all levels will struggle to identify player skillsets that will be revealed throughout a season. Therefore, coaches should be cautious about making position or playing time decisions too soon.

Further, these findings reaffirm that talent identification is difficult and coach perceptions are likely to exhibit biases, whether explicit or not. Wiseman and colleagues (2014) investigated whether hockey coaches and scouts could similarly rank player skills and found little agreement. Therefore, coaches and scouts required to recruit to their programs need to consider their own biases in their evaluations, and recognize that their evaluation may not translate into expected performances.

These findings lend further credence to the use of analytics in sports. Sarlis and Tjortjis (2020) recently suggested that data science and sport analytics are becoming increasingly common in basketball, lending support to decisions such as strengths and weaknesses in the game, evaluation of opponents, how to optimize performance indicators, team and player forecasting, team composition, and minimizing unpredictability. However, there must be balance. Were computers and mathematicians to serve as decision makers, many nuances that occur during sports will be missed. These are the nuances that might cause a poor performer to make the winning shot when it counts, for example. In their systematic review and meta-analysis, Roberts et al. (2019) suggested that coaches identify talent through their tacit knowledge and instinct, and struggle to articulate how they identify talent. Therefore, perhaps a combination of data and coach knowledge and feeling might provide the best solution for team selection and performance.

There are limitations to this study, which also provide avenues for future research. For example, this sample was limited to two collegiate basketball teams, and results

may differ at other levels and sports. Further, the demographics of the coaches, including their playing and coaching experiences, will likely affect perceptions of their athletes. Therefore, investigating perceptions of coaches of different levels and experience may yield different results. Third, coach perceptions were acquired at the beginning of the season, and their players may have improved throughout the season thereby confounding results. Attaining coach perceptions throughout the season would help to alleviate this limitation.

CONCLUSION

To summarize, it is apparent that coaches' perceptions of their athletes have little consistent correlation to their performances. Yet, their perceptions of their players did appear have an impact on the amount of playing time the players received. Findings suggest that while coach perceptions and talent identification have their place, the use of data analytics in sports may provide additional support when making coaching decisions such as playing time. Therefore, coaches should recognize their own limitations at identifying player talent and balance these "feelings" with statistical evidence.

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The effectiveness of natural supplements on prevention and treatment of delayed onset muscle soreness and markers of muscle damage: a review of literature

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ABSTRACT

Objective. Unaccustomed or high-intensity eccentric exercise often leads to delayed onset muscle soreness (DOMS) that presents as pain, soreness, or swelling. Nonsteroidal anti-inflammatory medications (NSAIDs) are often used to treat DOMS. Due to the potential adverse effects of NSAIDs, commerically available supplements have been suggested as a potential alternative treatment of DOMS. The purpose of this review is to examine the effects of commerically available supplements on DOMS and markers of muscle damage and inflammation.

Method. Existing publications were examined and summarized regarding the effects of supplements such as curcumin, green tea extract, ginseng, ginger, branch chain amino acids, anatabine, pomegranate juice, and protease on DOMS and markers of both muscle damage and inflammation following eccentric exercise.

Results. Consuming branched chain amino acids (BCAA), pomegranate, and curcumin appear to have the greatest effect in preventing and treating DOMS. Anatabine and ginseng do not appear to decrease markers of muscle damage, inflammation, or DOMS.

Conclusion. Consuming supplements before or after exercise with anti-inflammatory and analgesia properties may be just as effective as NSAIDs in treating and preventing DOMS. Further studies should be conducted to determine the long-term effects of commerically available supplements and the safest dosage that can be consumed for maximal benefits.

Keywords

delayed onset muscle soreness; supplements; markers of muscle damage; eccentric exercise

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INTRODUCTION

Delayed onset muscle soreness (DOMS) is an overuse injury that occurs after unaccustomed or high-intensity eccentric exercise (Cheung, Hume, & Maxwell, 2003), and can occur in novice and elite athletes alike. In individuals who are just beginning to exercise, DOMS can result in decreased motivation. The eccentric actions of plyometric exercise, squatting, jumping, downhill running, and the lowering phase of resistance training are all known to result in DOMS (Connolly, Sayers, & McHugh, 2003). DOMS presents itself as pain, muscle soreness, swelling, and stiffness 8 to 24 hours post-exercise and peaks 24–48 hr following an unaccustomed bout of eccentric exercise and resolves within 10 days following exercise (Manimmanakorn et al., 2016; Mchugh, Connolly, Eston, & Gleim, 1999; Meamarbashi, 2017).

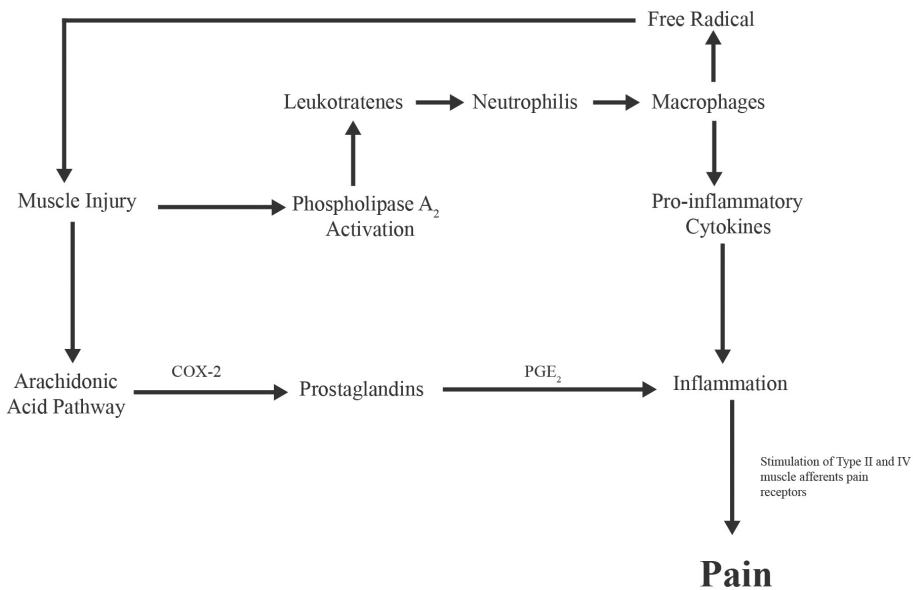

Figure 1 Schematic showing the possible sequence of injury leading to DOMS. COX-2, cycloxygenase; PGE_2; prostaglandin E_2

The underlying cause of DOMS is not fully understood. Most researchers agree that DOMS is caused by muscle damage (sarcomere disruption) and inflammation (Amalraj, Divya, & Gopi, 2020; Hoseinzadeh, Daryanoosh, Baghdasar, & Alizadeh, 2015) (Figure 1). During eccentric exercise, the sarcomeres become overstretched and fail to return to their resting length (Brooks, Fahey, & Baldwin, 2005). The overstretched sarcomeres allow calcium to accumulate in the injured portion of the muscle activating proteases and phospholipase (Cheung, Hume, & Maxwell, 2003; MacIntosh, Gardiner, & McComas, 2006). The activation of proteases and phospholipase lead to the production of both prostaglandins and leukotrienes (MacIntosh, Gardiner, & McComas, 2006). Neutrophils invade the injured area and increase vascular permeability, allowing fluids and intercellular components to enter the cells (MacIntosh,

Gardiner, & McComas, 2006). The fluid and intercellular components attract marcophages to invade the injuried area producing free radicals, proinflammatory cytokins and tumor nercosis factor-alpha (TNF-α) which further enhance muscle injury and stimulate type II and IV muscle afferent pain receptors, resulting in DOMS (Connolly, Sayers, & McHugh, 2003; MacIntosh, Gardiner, & McComas, 2006). Another pathway which is theorized to result in DOMS is the arachidonic acid pathway. Following muscle injury, arachidonic acid is released from the damaged cellular membranes (Maroon, Bost, Borden, Lorenz, & Ross, 2006). Archidonic acid is quickly transfomed into prostaglandins (PGE_2) and thromboxanes through the enxyme cyclooxygenase (COX-1 or COX-2) (Maroon, Bost, Borden, Lorenz, & Ross, 2006). COX-1 is a constitutive enzyme that protects the gastrointestinal lining and aids in platelet aggregation (Maroon, Bost, Borden, Lorenz, & Ross, 2006). In comparison, COX-2 is activated during muscle damage and aids in producing inflammation and stimulating type II and IV pain receptors (Maroon, Bost, Borden, Lorenz, & Ross, 2006).

Since the cause of DOMS is unknown, there is also a lack of knowledge for preventing DOMS. This lack of knowledge has led to multiple potential treatments, with mixed results (Cheung, Hume, & Maxwell, 2003). Over the years, treatments such as stretching, massage, nonsteroidal anti-inflammatory medications (NSAIDs), ultraound, hyperabaric oxygen, and exercise have all been examined as potential solutions to DOMS (Cheung, Hume, & Maxwell, 2003). Recently, athletes have increasingly sought natural remedies to treat pain and inflammation instead of NSAIDs, due to their potentially adverse effects within the gastrointestinal (stomach ulcers) and cardiovascular systems (blood clots leading to heart attacks and strokes). Many commerically available supplements are thought to have similar anti-inflammatory properties as NSAIDs, but without the adverse side effects. Some researchers believe that natural supplements may be an effective alternative to NSAIDs to control inflammation and oxidative stress induced by DOMS (Nakhostin-Roohi, Moradlou, Hamidabad, & Ghanivand, 2016). Therefore, the purpose of this review is to examine the effects of commerically available supplements on DOMS and markers of muscle damage and inflammation. The supplements examined include: anatabine, branched chain amino acids. curcumin, ginger, ginseng, green tea extract, pomegranate juice, and protease.

Anatabine

Anatabine is a minor tobacco alkaloid with a comparable chemical structure to nicotine (Jenkins et al., 2013). Anatabine is a member of the Solanaceae (nightshade) family and found in green tomatoes, peppers, and eggplants (Paris et al., 2013). Anatabine is thought to have anti-inflammatory properties; however, little research has been done in regard to anatabine's potential to decrease inflammation. The exact mechanism in which anatabine influences inflammation is unknown. Researchers speculate that anatabine's anti-inflammatory effect involves altering the signal transducer and activator of transcription 3 (STAT3) and nuclear factor Kappa-B (NF-kB) pathways, which play a major role in pro-inflammatory cytokine production and activating inflammatory cells (Paris et al., 2013).

The most compelling research to support the claim that anatabine has anti-inflammatory properties was conducted with 32-week old mice. Paris el al. (2013) discovered that anatabine reduced the production of pro-inflammatory cytokines IL-6,

IL-1, and TNF-α. The researchers also examined the anti-inflammatory activity of anatabine in vitro and found that anatabine prevented IL-1 production and STAT3 and NF-kB phosphorylation induced by lipopolysaccharide (LPS) or TNF-α (Paris et al., 2013). These results supported the claim that anatabine decreases inflammation by alternating both the STAT3 and NF-kB pathways. Jenkins et al. conducted two studies in 2013 and 2014 examining the effects of 6–12 mg of anatabine prior to and subsequent to unilateral eccentric elbow flexion. The results of both of these studies revealed that anatabine did not have any effect on DOMS or markers of muscle damage (CK, TNF-α, C-reactive protein (CRP), or myoglobin (MB)). The researchers concluded that the effectiveness of anatabine to block pro-inflammatory cytokines and decrease inflammation in humans after exercise was inconclusive (Jenkins et al., 2014) (Table 1).

Branched chain amino acids

Branched chain amino acids (BCAA) consist of leucine, isoleucine, and valine, which are three of the nine amino acids shown to be vital for protein synthesis and tissue repair (Leahy & Pintauro, 2013). Unlike other essential acids that are catabolized in the liver, BCAA are primarily catabolized in skeletal muscle (Harper, Miller, & Block, 1984). During exercise, the working skeletal muscles oxidize a greater proportion of BCAAs than any other amino acids (Shimomura, Yamamoto, & Bajotto, 2006). Therefore, researchers speculate that BCAA may prevent muscle damage by promoting skeletal muscle protein synthesis and suppressing protein degradation, in addition to aiding in reactive oxygen species (ROS) scavenging (Kadowaki & Kanazawa, 2003; Valerio, D'Antona, & Nisoli, 2011).

Numerous studies have examined the effects of BCAA on DOMS and markers of muscle damage. Most agree that BCAA have the potential to decrease muscle damage and DOMS following eccentric exercise. Greer and colleagues (2007) conducted a study examining the effects of 5.0 g of BCAA five min prior and one hr after cycling for 90 min on a cycle ergometer at 55% VO2max. The consumption of BCAA before and after an exhaustive bout of exercise decreased DOMS (24 hr post exercise) and lessened the increase in both creatine kinase (CK) and lactate dehydrogenase (LDH). Also, leg flexion torque was increased 48 hr post exercise with no effect on leg extension torque. Another group of investigators found that long distance runners who consumed a 2,500 ml drink containing 0.8% BCAA during a three day intensive training program experienced a decrease in DOMS, fatigue, CK, and lactate dehydrogenase (LDH) (Matsumoto et al., 2009). Others also found that BCAA consumption decreased DOMS after exercise (Asjodi, Khotbesara, Gargari, & Izadi, 2018; Howatson et al., 2012; Leahy & Pintauro, 2013; Nosaka, Sacco, & Mawatari, 2006; Shimomura et al., 2010). Shimomura et al. (2010) examined the effects of consuming 100 mg/kg BCAA 15 min after completing 140 squats. Although DOMS declined, consuming BCAA 15 min after performing exercise did not influence CK. In comparison, Howatson et al. (2012) found plasma CK levels were significantly lower when national rugby and football players consumed 20 mg of BCAA for 12 days (seven days prior and five days after 100 drop-jumps from a height of 0.6 m). Asjodi, Khotbesara, Gargari, and Izadi (2018) discovered that 10 mg/kg of BCAA increased CK levels 72 hr after a squat exercise (six sets at 75% 1RM) while significantly decreasing LDH up to 48 hr post

exercise. In summary, there is substantial evidence to suggest that BCAA may be effective in preventing muscle damage, thereby decreasing DOMS and fatigue following exercise. The exact amount of BCAA that is recommended for maximal benefit has not been established (Table 2).

Curcumin

Curcumin has been used for centuries in both traditional Chinese and Indian medicine to reduce pain and inflammation (Nicol, Rowlands, Fazakerly, & Kellett, 2015; Tanabe et al., 2019). Curcumin (diferuloylmethane) is extracted from the root of the curcumin plant (turmeric root) and is a natural polyphenolic substance with high anti-inflammatory and anti-oxidant properties (Delecroix, Abaidia, Leduc, Dawson, & Dupont, 2017; Nicol, Rowlands, Fazakerly, & Kellett, 2015; Singh & Aggarwal, 1995). Curcumin is believed to have similar anti-inflammatory properties as NSAIDs such as ibuprofen and Celebrex, but without the major cardiovascular and gastrointestinal side effects (Nakhostin-Roohi, Moradlou, Hamidabad, & Ghanivand, 2016). How curcumin influences inflammation is not agreed upon. However, it is believed that curcumin directly influences the activity of NF-kB, COX-2 or activator protein-1 (AP-1), which regulates the inflammation cascade (Davis et al., 2007). More specifically, curcumin may target NF-kB decreasing AP-1 binding to DNA decreasing the production COX-2, resulting in a blunted inflammation response to muscle injury following eccentric exercise (Singh & Aggarwal, 1995; Thaloor, Miller, Gephart, Mitchell, & Pavlath, 1999). The idea that curcumin inhibits NF-kB instead of COX-2 is why many researchers believe the supplement has a decreased risk of potential adverse side effects that NSAIDs possess (Davis et al., 2007).

Researchers have found conflicting results on the effects of curcumin and DOMS. For instance, Nicol, Rowlands, Fazakerly and Kellett (2015) examined the effects of curcumin on DOMS, sport performance, and markers of muscle damage and inflammation. They discovered that when moderately trained men consumed 2.5 g of curcumin twice a day for five days (two days prior and three days post exercise), curcumin decreased DOMS and increased jump height 24 hr and 48 hr after exercise. In addition, they found that curcumin blunted the increase of creatine kinase (CK), and interleukin-6 (IL-6). Likewise, Nakhostin-Roohi, Moradlou, Hamidabad and Ghanivand (2016) discovered that 150 mg of curcumin consumed immediately after eccentric exercise also decreased DOMS and markers of muscle damage (CK, alanine aminotransferase (ALT), and aspartate aminotransferase (AST)). In comparison, other researchers have shown that regardless of the dosage, curcumin did not have a significant effect on DOMS (Delecroix, Abaidia, Leduc, Dawson, & Dupont, 2017; Jager, Purpuna, & Kerksick, 2019; McFarlin et al., 2016; Tanabe et al., 2015).

While the effects of curcumin on DOMS are unclear, most researchers have shown that curcumin does decrease some markers of muscle damage (AST, ALT, CK) and inflammation (IL-6, interleukin-8 (IL-8) and TNF-α. McFarlin et al. (2016) examined the effects of 400 mg of curcumin daily (two days prior to and four days after exercise) and found that after eccentric leg press of 110% one repetition max (1-RM), curcumin significantly decreased CK, IL-6, IL-8 and TNF-α. However, there was no significant difference between the curcumin and placebo groups in regard to DOMS and activities of daily living soreness. Others authors (Nakhostin-Roohi, Moradlou,

Hamidabad, & Ghanivand, 2016; Nicol, Rowlands, Fazakerly, & Kellett, 2015; Tanabe et al., 2015; Tanabe et al., 2019) found similar results regarding the effects of curcumin on markers of muscle damage and inflammation. In comparison, Amalraj, Divya, and Gopi (2020) found that when 500 mg of curcumin was consumed for three days after a 45 min downhill (−10% grade) run, CK was not significantly different from the placebo. Delecroix et al. (2017) also found that 6 g of curcumin combined with 60 mg of peperline daily (two days prior and two days after exercise) did not result in a difference in CK from placebo.

Shortcomings of curcumin include its low bioavailability, poor solubility, and rapid elimination (Amalraj, Divya, & Gopi, 2020; Tanabe et al., 2019). Therefore, ingesting curcumin only before exercise has shown little or no effect on muscle damage (Tanabe et al., 2019). Tanabe et al. conducted two studies in 2015 and 2019 on the effects of curcumin (180 mg) before and after exercise. In both of the studies, DOMS was decreased when curcumin was consumed after exercise instead of before. The researchers also found that reduced CK lasted up to seven days after maximal elbow flexion only when curcumin was consumed following exercise (Tanabe et al., 2019). To gain maximal benefits from curcumin, researchers suggest it may be necessary to ingest curcumin continuously after exercise to keep curcumin concentrations in the blood elevated. (Tanabe et al., 2019). Overall, the general census in the literature is that curcumin can attenuate some, but not all, aspects of muscle damage and that more research should be done to determine the ideal dosage and consumption duration (Table 3).

Ginger

Ginger (zingiber officinale) is used in traditional Chinese medicine to treat arthritis, sprains, muscle aches, pain, and diabetes (Hoseinzadeh, Daryanoosh, Baghdasar, & Alizadeh, 2015; Mashhadi et al., 2013). Ginger and its constituents are shown to have both analgesic and anti-inflammatory properties (Hoseinzadeh, Daryanoosh, Baghdasar, & Alizadeh, 2015). The mechanism that is responsible for the analgesic and anti-inflammatory properties of ginger is through inhibiting COX-1 and COX-2, decreasing pro-inflammatory cytokines (TNF-α and IL-6) and blocking leukotriene synthesis (Ali, Blunden, Tanira, & Nemmar, 2008; Black & O'Connor, 2010; Hoseinzadeh, Daryanoosh, Baghdasar, & Alizadeh, 2015). Many studies have been conducted in an attempt to confirm the claimed benefits of ginger. Overall, the results of the reseaerch have been ambiguous. Mashhadi et al. (2013) had martial arts athletes consume 3 g of ginger daily six weeks before a sport-specific resistance training session during the competitive season. They found that DOMS was significantly lower when ginger was consumed before exercise, however ginger did not cause a significant decrease in IL-6. The authors suggested that 3 g may not have been large enough to have an influence on the pro-inflammatory cytokines. In comparison, Hoseinzadeh, Daryanoosh, Baghdasar, and Alizadeh (2015) compared the effects of 2 g of ginger extract in two conditions (one hr before a 20-min step test and immediately after exercise) in untrained adults. Muscle soreness was significantly lower only when ginger was consumed prior to exercise. Plasma IL-6 levels were significantly lower in both conditions. A possibility for inconsistent results between the two studies mentioned in regard to IL-6 could lie within the training status of the participants. Mashhadi and colleagues (2013) recruited martial art athletes for their study while (Hoseinzadeh,

Daryanoosh, Baghdasar, & Alizadeh (2015) recruited untrained women. Plasma IL-6 is released during muscle contractions and is shown to be lower after long-term training because of the chronic muscle contractions (Nicklas et al., 2008). Therefore, it seems likely that trained individuals would need a higher dose of ginger to see any significant pro-inflammatory cytokines reductions. Manimmanakorn et al. (2016) examined the effects of Plai (*zingiber cassumunar* Roxb) on markers of muscle damage and DOMS. Plai is within the ginger family and contains powerful phytochemicals (Manimmanakorn et al., 2016). The participants applied either 7% or 14% Plai cream on their quadriceps for seven days post eccentric knee extension exercise. They found no effect of Plai cream on CK levels but DOMS was significantly lower after the application of the 14% Plai cream, but not after the 7% cream. Additionally, applying 14% Plai cream to the quadriceps preserved quadricep strength while applying the 7% did not decrease strength loss. While the aforementioned studies confirmed that ginger can reduce DOMS, other studies have shown the opposite. Black and O'Connor (2010) determined that 2 g of ginger for two days following unilateral eccentric elbow flexion exercise did not have an effect on DOMS, range of motion (ROM), or arm volume. Others (Matsummura, Zavorsky, & Smoliga, 2015; Wilson, Fitzgerald, Rhodes, Lundstorm, & Ingraham, 2015) agreed that ginger (2.2 g and 4 g respectively) had no effect on DOMS. Due to the conflicting results, further research needs to be conducted to verify the potential benefits of ginger after exercise (Table 4).

Ginseng

Ginseng (genus panax) is another supplement that has been used for thousands of years in traditional Chinese medicine to manage stress, relieve fatigue, and reduce pain and swelling (Caldwell et al., 2018; Pumpa, Fallon, Bensoussan, & Papalia, 2013). The active ingredient in ginseng, saponins (ginsenosides), has shown the potential to block calcium influx into smooth muscle by activating Na^+–K^+ ATPase, decrease intercellular calcium ion levels and heart rate (Chen, Chung, Li, Lin, & Tzan, 2009). The influx of calcium ions into the working skeletal muscles is reported as a potential explanation for DOMS following an exhaustive bout of exercise (Pumpa, Fallon, Bensoussan, & Papalia, 2013). If ginseng can potentially block excessive calcium influx into the working skeletal muscle, it may prevent or blunt DOMS following exercise (Pumpa, Fallon, Bensoussan, & Papalia, 2013). Again, the mechanism in which ginseng acts upon is unclear.

The literature to support the claimed benefits of ginseng (reduction of pain, inflammation and fatigue) is sparse. Only a few studies have been conducted to examine the effects of ginseng on sports performance, soreness, or inflammation after exercise. Pumpa, Fallon, Bensoussan, and Papalia (2013) examined the effects of 400 mg of ginseng after a downhill run (−10% grade) at 80% HR_{max}. The authors found that DOMS was significantly lower 96 hr post exercise in participants after consuming ginseng. However, ginseng did not influence markers of muscle damage such as CK, CRP, or MB. It is interesting to note that in this particular study, both IL-6 and TNF-α were significantly higher after the consumption of ginseng compared to the control group. To explain these results, the authors suggested that ginseng may intensify the release or delay the clearance of TNF-α and impact the timing or expression of IL-6 following exercise (Pumpa, Fallon, Bensoussan, & Papalia, 2013). Hsu, Ho, Lin, Su, and Hsu

(2005) studied the effects of 400 mg of American ginseng on CK four weeks prior to running at 80% VO2max until volitional fatigue. The authors found that American ginseng significantly reduced CK immediately and up to 120 min following exercise. Lastly, Caldwell et al. (2018) compared the effects of consuming a high dose (960 mg) and low dose (160 mg) Korean ginseng, GINST15 (modified to have an increased bioavailability, 14 days prior to resistance training on DOMS and sport performance (reaction time and jump power). Consuming GINST15 decreased DOMS significantly in both groups. However, GINST15 did not improve reaction time nor jump power. As the results from these studies are mixed, the authors recommend that further research be conducted to identify the specific mechanism ginseng acts upon to decrease inflammation, soreness and fatigue, as well as the appropriate dosage required to achieve the aforementioned benefits (Table 5).

Green tea extract

Green tea extract is obtained from *camellia sinensis* and is rich in polyphenols such as epigallocatechin gallate, epicatechin, epigallocatechin, and epicatechin (da Silva, Machado, Souza, Mello-Carpes, & Carpes, 2018). The properties of green tea extract make it a powerful anti-oxidant that gather free radicals such as superoxide hydroxyl (SOD) and hydrogen peroxide (H_2O_2), and inhibits pro-oxidant enzymes (da Silva, Machado, Souza, Mello-Carpes, & Carpes, 2018). The exact redox mechanism leading to exercise induced oxidative stress remains vague (He et al., 2016). Some researchers speculate that under stressful conditions such as eccentric exercise, the stimulation of xanthine oxidase (XO) contributes to the enhancement of reactive oxygen species (ROS) greater than the capacity of the anti-oxidant system to reduce ROS activity, resulting in oxidative stress and muscle cell damage (He et al., 2016). The damage to the muscle cells caused by oxidative stress decreases athletic performance and increases muscle soreness (Jowko et al., 2012). Increasing the anti-oxidant concentration by consuming green tea extract may offset fatigue and the accumulation of free radical production for a faster exercise recovery (Kerksick, Kreider, & Willoughby, 2010). The anti-oxidant properties of green tea extract are believed to prevent ROS formation, thereby decreasing fatigue and preserving sport performance by inhibiting XO (Gomez-Cabrera, Domenech, & Vina, 2008; Panza et al., 2008). There have been several studies examining the effects of green tea extract on measurements of oxidative stress. The results from these studies are conflicting. Furthermore, the exact dosage and duration that green tea needs to be consumed to combat oxidative stress and improve DOMS is unknown at this time. For instance, da Silva, Machado, Souza, Mello-Carpes, & Carpes (2018) examined the effects of 500 mg green tea extract over the course of 15 days post eccentric exercise. They found green tea extract did not improve markers of muscle damage (CK, lactate dehydrogenase (LDH)) or decrease oxidative stress (ROS, or ferric reducing antioxidant power (FRAP)). These results were in agreement with a study done by Jowko et al. (2012) in which the authors evaluated the effects of 640 mg of green tea extract 1.5 hr before a muscular endurance test. The researchers found that 640 mg of green tea extract prior to exercise did not have an effect on markers of muscle damage (CK), oxidative stress (SOD, uric acid (UA) or total anti-oxidant capacity (TAC)). Other authors (Jowko, Dlugolecka, Makaruk, & Cieslinski, 2015; Kerksick, Kreider, & Willoughby, 2010) also found that green tea

extract had no significant effect on markers of muscle damage and oxidative stress. In contrast, Panza et al. (2008) had 14 healthy adults consume 600 ml of green tea daily, seven days before a bout of exhaustive bench press exercise. They found that FRAP was significantly higher after 14 days of consuming 600 ml of green tea and XO was significantly decreased. The authors also discovered that CK and AST were significantly lower after exercise. The authors concluded that consuming at least 600 ml of green tea may offer protection against oxidative stress after exercise. Due to the reduction in markers of muscle damage, the authors also suggested that the oxidative mechanism may play a role in the development of muscle damage following exercise. Herrlinger, Chirouzes, and Ceddia (2015) confirmed these results when they conducted a study examining the effects of 1,000 mg or 2,000 mg of green tea extract daily for four days following a 40 min downhill run (−10% grade) at 65% VO2max. Both doses of green tea extract significantly reduced CK and LDH and enhanced FRAP.

To date, there have been three studies regarding the effects of green tea extract on DOMS. Kerksick, Kreider, and Willoughby (2010) found after 14 days of 1800 mg of green tea extract following eccentric unilateral knee extension, DOMS was significantly decreased at 24 hr post exercise, but markers of inflammation were not influenced by green tea extract. Similarly, Herrlinger, Chirouzes, and Ceddia (2015) also found that green tea (2,000 mg) improved muscle soreness at both 48 hr and 96 hr after exercise. However, da Silva and colleagues (2018) found that muscle damage was minimized without any detectable significant changes in DOMS following 15 days of 500 mg of green tea after performing calf raises to voluntary fatigue. Green tea extract may offer some protection against oxidative stress and reduce muscle damage and DOMS. Future research needs to determine the exact consumption dosage and duration required for green tea to have maximal benefits against oxidative stress and muscle soreness (Table 6).

Pomegranate juice

Pomegranate juice contains high levels of polyphenols and offers many health benefits and can aid in preventing and treating conditions such hypertension and dyslipidemia (Ammar et al., 2016). In addition, some believe that pomegranate juice has properties that can decrease both inflammation and oxidative stress (Ammar et al., 2016). Pomegranate extract (liquid or dry form) has recently become a popular alternative source for obtaining the polyphenols found in pomegranate juice (Ammar et al., 2018). One of the benefits of pomegranate juice or extract over other polyphenols such as green tea is the high bioavailability with an anti-oxidant activity three times higher than green tea, making it more effective in destroying free radicals, inhibiting cellular oxidative stress, and decreasing lipid peroxidation (Seeram et al., 2008). Pomegranate juice is thought to act similarly to green tea in that it inhibits cellular transcription factors NF-kB, TNF-α, and COX-2, thereby preventing inflammation and pain (Adams et al., 2006; Afaq et al., 2005).

Although researchers have noted a beneficial effect of pomegranate juice, few have examined the potential effects of pomegranate juice after exercise. Lamb et al. (2019) examined the effects of a daily consumption of 500 ml pomegranate juice four days prior and five days after unilateral eccentric elbow flexion. The authors found that nine days of pomegranate juice did not have an effect on elbow flexion strength, DOMS,

ROM, or plasma CK levels. In comparison, Trombold, Barnes, Critchley, and Coyle (2010) investigated the effects of 100 ml of ellagitanni (pomegranate extract) four days prior and five days post unilateral eccentric elbow flexion. Nine days of ellagitanni consumption significantly decreased DOMS 2 hr after exercise and increased elbow flexor strength at 24 and 48 hr following exercise. However, ellagitanni was not successful at influencing markers of muscle damage (CK, CRP) or pro-inflammatory cytokines (IL-6). Trombold conducted a second study (2011) and found that 500 ml of pomegranate juice for 15 days (seven days prior and eight days after exercise) decreased DOMS in elbow flexors and improved elbow flexion strength up to seven days post unilateral maximal eccentric elbow flexion exercise.

In a study conducted by Amar and associates (2016), Olympic weight lighters consumed 500 ml of pomegranate juice prior to training and another 450 ml for two days following training. Pomegranate juice decreased knee extensor DOMS, rate of perceived exertion (RPE) and markers of muscle damage (CRP, CK, LDH and AST). In regard to elbow flexor DOMS, pomegranate juice had no effect. Based on the few studies conducted, it appears that pomegranate juice may be an effective treatment for muscle soreness and fatigue following exercise. However, more research needs to be completed to verify the effectiveness of pomegranate juice for recovery after exercise (Table 7).

Protease

Protease consists of a group of four biologically active enzymes (seline, cysteine, aspartic acid, and metalloproteases) that initiate protein catabolism through the hydrolysis of peptide bonds that link amino acids together in a polypeptide chain (Buford et al., 2009). Protease is believed to decrease inflammation and attenuate pain (Miller, Bailey, Barnes, Derr, & Hall, 2004). How protease decreases inflammation remains unknown. It is hypothesized that protease reduces inflammation by blocking COX-2 stimulation to decrease edema and pain (Buford et al., 2009; Miller, Bailey, Barnes, Derr, & Hall, 2004). A few studies have been conducted on the effects of protease on muscle damage and inflammation after exercise. Miller, Bailey, Barnes, Derr, and Hall (2004) studied the effects of protease on performance and DOMS after a 30 min downhill run (−10% grade). They discovered after four days of protease supplementation, DOMS was decreased 24 to 72 hr post exercise. In addition, knee flexion power and torque were maintained after exercise with no change in agility run time, or knee extension torque. Shing and colleagues (2016) studied bromelain, a mixture of proteases obtained from pineapples, and its effect on highly trained road cyclists. The cyclists completed a cycle of 10 stages over the span of six days while consuming 1000 mg of bromelain daily. Fatigue was decreased on day four only and the supplement did not influence CK, MB, or LDH. Beck et al. (2007) found similar results when 29 recreationally active men consumed a protease supplement that contained both 325 mg of protease 6.0 and 340 mg protease 4.5 four days after completing damaging eccentric forearm flexion exercise. While the protease supplement increased forearm flexion strength, it had no effect on DOMS, joint angle, or arm circumference. In addition, plasma CK and MB levels were not blunted after supplementation. Budfold et al. (2009) also found that 24 days of 5.828 mg of protease had no effect on DOMS or some markers of muscle damage and inflammation (CK, SOD, IL-8, IL-10, IL-1, and TNF-α).

Intriguingly, protease did decrease three markers of inflammation (IL-6, IL-12 and COX-2) and improved quadriceps flexion strength. The authors concluded that while not all pro-inflammatory cytokines were decreased by protease, the decrease in IL-6 and IL-12, as well as COX-2, supported the concept that protease has the ability to decrease muscle inflammation and improve muscle function following exercise. Based on available evidence, it appears that protease may decrease inflammation and improve performance after a damaging bout of exercise. To gain a better insight in the potential post exercise benefits of protease, again, more research should be conducted (Table 8).

DISCUSSION

Finding ways to prevent and treat the negative effects of DOMS can maximize training performance in athletes, prevent injury, and help exercise novices maintain motivation (Nicol, Rowlands, Fazakerly, & Kellett, 2015). The series of events that cause DOMS is unclear. However, researchers have come to the conclusion that both mechanical injury to the sarcomere and the inflammation cascade are key players in the development in DOMS (Cheung, Hume, & Maxwell, 2003). Without knowing the exact cause of DOMS, finding the ideal treatment ramains difficult. Therefore, many proposed treatments for DOMS exsist (NSAIDs, massage, ultraound, hyperabaric oxygen, and exercise) and their effects on DOMS has produced mixed results (Cheung, Hume, & Maxwell, 2003). NSAIDs are often used as the first line of defense in the treatment of inflammation and soreness following exercise. However, other than their potential adverse effects, NSAIDs may supress muscle protein synthesis (Mackey, 2013), thereby slowing the healing processes (Paulsen et al., 2010) following an injury, making them less than ideal. Many commerically available supplements have similar anti-inflammatory properties as NSAIDs without the possible adverse effects and remain safer alternativse for treating pain and inflammation. While they may be safer alternatives, as shown throuhgout this review, the exact mechanism in which these supplements target and the safest maximal dosages remain unknown.

It appears that many of the supplements reviewed may decrease DOMS following eccentric exercise, as well as decrease markers of muscle damage and inflammation. BCAA, pomegranate juice/extract and curcumin appear to have the greatest effect on DOMS. In comparision, anatabine and ginseng do not appear to have a significant effect on inflammation or DOMS following exercise. However, due to a lack of consistent study design and dosing for each supplement, it is diffuclt to draw a final conclusion on the effectiveness of these supplements on DOMS. Future research should examine the effects of consuming natural supplements on relieving the symptoms of DOMS on clinical populations such as those with diabetes and peripheral artery disease. In addition, for all populations, the safety of consuming natural supplements needs to be examined regarding adverse side effects, long-tem effects, as well as the optimal dosage.

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Table 1 Effects of Anatabine on Performance, Soreness, and Markers of Inflammation and Muscle Damage

Authors	Subjects	Dosage	Duration	Design	Exercise Protocol	Performance	Fatigue/Soreness/ ROM	Markers of Inflammation / Muscle Damage
Jenkins et al. (2013)	18 healthy men	1d–2d: 6 mg 3d–4d: 9 mg 5d–10d: 12 mg	10d	Double-blinded, PLAC controlled, crossover design (2wk–4wk washout)	Unilateral elbow flexion (6 × 10)	↔ flexion strength	↔ HJA ↔ DOMS ↔ AC	↔ CK
Jenkins et al. (2014)	17 healthy men	1d–2d: 6 mg 3d–4d: 9 mg 5d–10d: 12 mg	10d	Double-blinded, PLAC controlled, crossover design (2wk–4wk washout)	Unilateral eccentric elbow flexion (6 × 10)	N/A	N/A	CK ↔ LDH ↔TNF-α ↔ MB ↔ CRP

↑ significantly higher than placebo; ↓ significantly lower than placebo; ↔ no significant difference from placebo; ex, exercise; MB, myoglobin; PLAC, placebo; DOMS, delayed onset muscle soreness; CK, creatine kinase; LDH, lactate dehydrogenase; TNF-α, Tumor necrosis factor-alpha; CRP, C-reactive protein; AC, arm circumference; HJA, hanging joint angle.

Table 2 Effects of Branched Chain Amino Acids on Performance, Soreness, and Markers of Inflammation and Muscle Damage

Authors	Subjects	Dosage	Duration	Design	Exercise Protocol	Performance	Fatigue/Soreness/ROM	Markers of Inflammation / Muscle Damage
Shimomura et al.	12 untrained females	100 mg/kg body weight	15 min prior to ex	Randomized, double-blind, PLAC controlled crossover design (11wk washout)	Squat exercise (7×20)	↑ knee extension torque	↓ DOMS	↔ MB ↔ CK
Asjodi et al.	50 untrained men	10 mg/kg body weight 2×	30 min prior to ex and 0h	Randomized, PLAC controlled design	Squat exercise 6 sets at 75% 1-RM until fatigue	N/A	↓ DOMS 48hr post ex ↑ ROM 24hr–72hr post ex	↑ CK 72hr post ex ↓ LDH 24hr-48hr post ex
Greer et al.	9 untrained men	2.5 g 2×	5 min prior and 60 min post ex	PLAC controlled crossover design (8wk washout for each trial)	Three 90 min cycling bouts at 55% VO_{2max}	↑ leg flexion torque 48hr post ex ↔ leg extension torque	↓ DOMS 24hr post ex	↓ CK 4hr–48hrr post ex ↓ LDH 4hr post ex
Leahy et al.	20 healthy adults	1.22 mg	4d post ex	Randomized, PLAC controlled, double-blind crossover design (3wk washout)	Squat exercise (3×12)	N/A	↓ DOMS females 24hr post ex	N/A
Matsumoto et al.	12 long distance runners	0.8% BCAA drink; 2,500 ml/day	3d of training	Randomized, PLAC controlled, double-blind, crossover design (3wk washout)	Intensive training period 2 sets of 3d	N/A	↓ DOMS ↓ Fatigue	↓ CK ↔ MB ↓ LDH
Nosaka et al.	38 untrained men	Exp.1: 3.6 g 2× Exp. 2: 3.6 g 3× daily	Exp. 1: 30 min prior and 0h Exp. 2: 30 min prior, 0h, and 4d after ex	Randomized, PLAC controlled, double-blind crossover design (3-4wk washout)	Isometric arm curl at 90% 1-RM for 30min	↔ Exp. 1 and Exp. 2 max forearm strength	↔ Exp. 1; ↓ Exp 2 (1d–3d post ex): DOMS ↔ ROM ↔ Exp. 1; ↓ Exp. 2 (72hrs–96hrs) AC	↔ Exp. 1; ↓ Exp. 2 (3–4d post ex): CK ↔ Exp. 1; ↓ Exp. 2 (3–4d post ex): MB ↔ Exp. 1; ↓ Exp. 2 (3–4d post ex) ALD
Howatson et al.	12 national rugby and football players	10 g 2× daily	12d (7d prior to ex, 5d after ex)	Randomized, PLAC controlled, double-blind design	Drop jumps from 0.6m with immediate vertical jump with max force (5×20)	↔ JH ↑ dominant knee extensors force 24h post ex	↔ TC ↔ CC ↓ DOMS 24–48h post ex	↓ CK 24hr post ex

↑ significantly higher than placebo; ↓ significantly lower than placebo; ↔ no significant difference from placebo; 0hr, immediately after exercise, DOMS, delayed onset muscle soreness; PLAC; placebo; CK, creatine kinase, AC, arm circumference; TC, thigh circumference; CC, calf circumference; MB, myoglobin; BCAA, branched chain amino acids; ROM range of motion; LDH, lactate dehydrogenase; JH, jump height.

Table 3 Effects of Curcumin on Performance, Soreness, and Markers of Inflammation and Muscle Damage

Authors	Subjects	Dosage	Duration	Design	Exercise Protocol	Performance	Fatigue, Soreness and Range of Motion	Markers of Inflammation / Muscle Damage
Nicol et al.	19 moderately trained men	2.5 g 2× daily	5 d (2 d prior, 3 d after ex.)	Double-blind, randomized, PLAC controlled crossover design (14d washout)	Unilateral eccentric leg press (7 × 10)	↑ JH 24hr and 48hr post ex	↓ DOMS 24hr and 48hr post ex	↓ CK 24 hr and ↓ 1L-6 24hr post ex.
Nakhostin-Roohi et al.	10 healthy males	150 mg	Immediately after ex	Double-blind, randomized PLAC controlled crossover design (14d washout)	Eccentric squat machine 50% 1-RM (7 × 20)	N/A	↓ DOMS 48 hr post ex	↓ AST 24hr post ex ↓ CK 48hr and 72rh post ex
McFarlin et al.	20 healthy adults	400 mg	6d (2d prior, 4d after ex)	Randomized-controlled design	Eccentric leg press 110% 1-RM (6 × 10)	N/A	↔ DOMS ↔ ALDS	↓ TNF-α 1d, and 4d post ex ↓ CK 1d-4d post ex ↓ IL-8 1d-2d post ex. ↔ 1L-6 ↔ 1L-10
Jager et al.	63 active adults	Low dose: 250 mg High dose: 1,000 mg	8wks prior to ex	Double-blind, randomized, PLAC controlled, parallel design	Downhill running (−15% grade) for 45 mins	↔ High; ↓ Low: isokinetic peak flexion torque ↔ High; ↓ low: isokinetic peak extension torque	↔ DOM	N/A
Tanabe et al. (2015)	14 untrained men	150 mg	1hr prior to ex 12hr after ex	Single-blinded, randomized, crossover design (4wk washout)	50 max eccentric elbow flexion	↑ MVC torque of elbow flexor 0h and 48hr–96hr post ex	↔ ROM ↔ DOMS ↔ RC	↓ CK ↔ IL-6 ↔ TNF-α
Tanabe et al. (2018)	20 healthy men	180 mg	Exp. 1: 7d prior to ex Exp. 2: 7d after ex	Double-blind crossover, parallel design (4wk wash out)	30 max eccentric elbow flexion	↑ Exp. 2; ↔ Exp. 1: MVC torque of elbow flexor	↓ Exp. 2 (3d–6d post ex); ↔ Exp. 1: DOMS ↑ Exp.2 (3d–7d post ex); ↔ Exp. 1: ROM	↓ Exp. 2 (5d–7d post ex); ↔ Exp. 1: CK ↓ Exp. 1 (12hrs post ex); ↔ Exp. 2: IL-8 ↔ TNF-α
Tanabe et al. (2019)	24 healthy men	180 mg	PRE: 7d prior POST: 4d after ex	Randomized, single-blinded, parallel design	30 max eccentric elbow flexions	↔ torque of elbow flexor	↔ PRE; ↓ (3d post ex) POST: DOMS ↔ PRE; POST ↑ (3d–4d post ex): ROM	↔ CK

Authors	Subjects	Dosage	Duration	Design	Exercise Protocol	Performance	Fatigue, Soreness and Range of Motion	Markers of Inflammation / Muscle Damage
Delecroix et al.	10 elite rugby players	2g 2× daily curcumin 20 mg 3× daily piperine	4d (2d prior, 2d after ex)	Randomized, balanced crossover design (15d washout)	25 unilateral jumps on −8% downhill slope	↔ CMJH ↔ concentric peak torque isometric peak torque	↔ DOMS	↔ CK
Amalraj et al.	33 healthy adults	500 mg	3d post ex	Randomized, PLAC controlled, double-blind design	Downhill running (−10% grade), 6 km/h increasing by 1 km/h each min until max maintainable effort – for 45mins	↑ VO_{2max}	↓ DOMS	↔ CK
Drobnic et al.	20 moderately trained men	200 mg	4d (2d prior and 2d after ex)	Randomized, PLAC controlled, single blinded design	Downhill running (−10% grade) for 45 minutes	N/A	↓ DOMS	↓ IL-8 ↔ CK

↑ significantly higher than placebo; ↓ significantly lower than placebo; ↔ no significant difference from placebo; ex, exercise; CK, creatine kinase; ALT, alanine aminotransferase; AST, aspartate aminotransferase; ALDS, activities of daily living soreness; PLAC, placebo; ROM, range of motion; IL-6, Interleukin-6; IL-8, Interleukin-8; IL-10, Interleukin-10; TNF-α, Tumor necrosis factor-alpha; MVC, maximal voluntary contraction; VO_{2max}, maximal oxygen consumption; AC, arm circumference; CMJH, counter movement jump height; 0hr, immediately after exercise.

Table 4 Effect of Ginger Supplement on Performance, Soreness, and Markers of Inflammation and Muscle Damage

Authors	Subjects	Dosage	Duration	Design	Exercise Protocol	Performance	Fatigue/Soreness/ROM	Markers of Inflammation / Muscle Damage
Black et al.	27 healthy adults	2 g	2d post ex	Double-blind, crossover design	Unilateral elbow flexion (6 × 8) 120% 1-RM	N/A	↔ AV ↔ VASP ↔ ROM	N/A
Manimmanakorn et al.	75 untrained adults	7% Plai cream 14% Plai cream	7d post ex	Randomized, PLAC controlled design	Dominant max knee extension (4 × 25)	↑ 14%; ↔ 7% quadricep strength ↔ JH (7% and 14%)	↓ 14%; ↔ 7%: DOMS ↔ TC	↔ CK
Wilson et al.	20 marathon trained men	2.2 g	3d prior, day of ex, and 24hr after ex	Randomized, double-blind, PLAC controlled design	20–22 mi training run	↔ JH ↔ Peak Force ↔ RFD	↔ DOMS ↓ RPE 24hr post ex	N/A
Matsumura et al.	20 untrained adults	4 g	5d prior to ex	Randomized, double-blind, PLAC controlled design	Non-dominant elbow flexion (4 × 10 or to failure) at 80% and 100% of 1-RM	↑ elbow flexion strength 24h post ex	↔ DOMS ↑ ROM 24hr post ex ↔ AC	↔ CK ↔ LDH
Mashhadi et al.	49 martial artists	3 g	6wk	Randomized, double-blind, PLAC controlled design	Specific resistance exercise for the competitive season	N/A	DOMS	IL-6
Hoseinzadeh et al.	36 untrained women	60 mg	GIBE:1hr prior ex GIAE: 0hr post ex	Randomized, double blind, PLAC controlled design	20 min step test with 46 cm step with a rate of 15 steps per min	↔ isometric thigh strength	↔ ROM ↓ GIBE; ↔ GIAE: DOMS ↔ TC	↓ IL-6 (1hr both groups an 1hr post ex and 48hr in GIBE group ↔ CK

↑ significantly higher than placebo; ↓ significantly lower than placebo; ↔ no significant difference from placebo; 1-RM, one repetition max; ex, exercise; DOMS, delayed onset muscle soreness; ROM, range of motion; AV, arm volume; PLAC, placebo; RFD, rate of force development; RPE, rating of perceived exertion; LDH, lactate dehydrogenase; 1L-6, Interleukin-6; 0hr, immediately following exercise; GIAE, ginger immediately after exercise; GIBE, ginger immediately before exercise; CK, creatine kinase; AC, arm circumference; TC, thigh circumference; VASP; visual analog scale pain; JH, jump height.

Table 5 Effects of Green Tea on Performance, Soreness, Markers of Inflammation, Muscle Damage and Oxidative Stress

Authors	Subjects	Dosage	Duration	Design	Exercise Protocol	Performance	Fatigue/ Soreness/ROM	Markers of Inflammation / Muscle Damage	Oxidative Stress
da Silva et al.	20 non-trained men	500 mg	15d post ex	Randomized triple blind PLAC controlled design	calf raises until voluntary fatigue	N/A	↔ DOMS	↓ CK 0h, 48h post ex ↔ LDH	↔ ROS ↔ FRAP
Jowko et al. (2012)	16 soccer players	640 mg	1.5 hrs. prior to ex	Randomized, double-blind design	Bench press and back squat (3 sets to exhaustion) at 60% 1-RM	N/A	N/A	↔ CK	↔ SOD ↔ UA ↔ TAS
Jowko et al. (2015)	16 sprinters	250 mg 2× daily	4wk prior ex	Double-blind, randomized, PLAC controlled crossover design (4wk washout)	RST 4 × 15 with 1-min rest intervals	↔ RST	N/A	↔ CK	↓ SOD ↑ TAC (rest) ↓ MDA ↔ AL ↔ UA ↔ GPx
Herrlinger et al.	37 active men	Low: 250 mg 4× daily High: 500 mg 4× daily	13wk after ex	Randomized, double-blind, PLAC controlled design	Downhill run (−10% grade) for 40mins at 65% VO_{2max}	↑ High; ↔ Low: peak torque	↑ High; ↔ Low: DOMS	↓ CK ↔ IL-6 ↔ IL-10 ↔ TNF-α	↑ FRAP
Kerksick et al.	30 active men	1800 mg NAC 1800 mg EGCG	14d after ex	Double-blind parallel design	Unilateral knee extensions (10X10)	↔ peak isometric torque	↓ DOMS	↔ CK ↔ LDH ↔ TNF-α	↔ SOD
Panza et al.	14 healthy adults	200 mL 3× daily	7d prior to ex	PLAC controlled crossover design	Bench press 4 sets of 10, 8, 6, 4 reps at 75%, 80%, 85%, and 90% 1-RM	N/A	N/A	↓ CK ↓ AST	↑ FRAP ↓ UA ↓ XO

↑ significantly higher than placebo; ↓ significantly lower than placebo; ↔ no significant difference from placebo; PLAC, placebo; ex, exercise; DOMS, delayed onset muscle soreness; CK, creatine kinase; LDH, lactate dehydrogenase; 0hr, immediately following exercise; RST, repeated sprint test; ROS, reactive oxygen species; SOD, superoxide dismutase; TAC, total antioxidant capacity; MDA, malondialdehyde; UA, uric acid; AL, albumin; GPx, glutathione peroxidase; FRAP, ferric-reducing ability of plasma; AST, aspartate aminotransferase; XO, xanthine oxidase; NAC, N-acetyl-cysteine; EGCG, epigallocatechin gallate.

Table 6 Effects of Ginseng on Performance, Soreness, and Markers of Inflammation and Muscle Damage

Authors	Subjects	Dosage	Duration	Design	Exercise Protocol	Performance	Fatigue/Soreness/ROM	Markers of Inflammation / Muscle Damage
Hsu et al.	13 active men	400 mg 4× daily	4wk prior to ex	Randomized, double-blind, PLAC controlled, crossover design (4wk washout)	Running test at 80% VO_{2max} until volitional fatigue	N/A	N/A	↓ CK 0h, 30 min, 60 min, and 120 min post ex
Pumpa et al.	20 trained men	100 mg 4× daily	1hr prior, 0hr, 24–48hr post ex: every 4hrs. (waking) 48–27hr post ex: every 2hrs (waking)	Randomized, double-blind, PLAC controlled design	Downhill run (-10% grade) at 80% HR_{max}, (5 bouts of 8mins)	↑ JH: 0hr	↓ DOMS 96hr post ex	↔ IL-1 ↑ IL-6 24hr post ex ↑ TNF-α 24hr post ex ↔ CK ↔ CRP ↔ MB
Caldwell et al.	19 active adults	High: 160 mg 6× daily Low: 160 mg daily	14d prior to ex	Randomized, double-blind, PLAC controlled cross over design (7d washout)	Leg press at 70% 1-RM (5 × 12)	↔ High and Low RT ↔ High and Low BJH	↓ High and Low DOMS ↓ High; ↔ Low RPE	N/A

↑ significantly higher than placebo; ↓ significantly lower than placebo; ↔ no significant difference from placebo; ex, exercise PLAC, placebo; IL-1 Interleukin-1; TNF-α, Tumor necrosis factor-alpha; IL-6, Interleukin-6; 0hr, immediately after exercise; DOMS, delayed onset muscle soreness; MB, myoglobin; CK, creatine kinase; CRP, C-reactive protein; 1-RM, one repetition max; RT, reaction time; BJH, ballistic jump height; RPE, rating of perceived exertion; JH, jump height.

Table 7 Effect of Pomegranate Juice on Performance, Soreness, and Markers of Inflammation and Muscle Damage

Authors	Subjects	Dosage	Duration	Design	Exercise Protocol	Performance	Fatigue/Soreness/ ROM	Markers of Inflammation / Muscle Damage
Lamb et al.	36 non-resistance trained men	250ml 2× daily	9d (4d prior and 5d post ex)	Randomized, double-blind, PLAC controlled parallel design	Unilateral elbow flexion (5 × 10)	↔ elbow flexion strength	↔ ROM ↔ DOMS	↔ CK
Ammar et al.	9 elite male weightlifters	150ml 3× daily + 500ml 1hr prior ex	1hr prior ex 2d post ex	Non-randomized, PLAC controlled, crossover design (48hr washout)	3 Olympic weight lifting ex (snatch, clean, and jerk squat) 5 set each 2 at 85% 1-RM 4 at 90% 1-RM	↑ total and maximal load lift	↓ RPE ↓ knee extensors; ↔ elbow flexors DOMS	↓ CRP 3min post ex ↓ CK 3min and 48hr post ex ↓ LDH 3min and 48hr post ex ↓ AST 3min and 48hr post ex
Trombold et al. (2010)	16 recreationally trained men	500 ml 2× daily at 12hr interval	9d (4d prior and 5d post ex	Randomized, double-blind, PLAC controlled crossover design (14d washout)	Unilateral max elbow flexion (2 × 20)	↑ elbow flexion strength at 48hr and 72hr post ex	↓ DOMS 2hr post ex	↔ CK ↔ IL-6 ↔ CRP
Trombold et al. (2011)	17 physically resistance trained men	250 ml 2× daily at 12hr intervals	15d (7d prior to ex. 8d after ex)	Randomized double-blind, counterbalanced, PLAC controlled crossover design (14d washout)	Unilateral max elbow flexion (3 × 20) Unilateral max knee extensions (6 × 10) at 110% 1-RM	↑ elbow flexion strength 2h-168hr post ex knee extension strength	↓ elbow flexors; ↔ knee extensors: DOMS	N/A

↑ significantly higher than placebo; ↓ significantly lower than placebo; ↔ no significant difference from placebo; ex, exercise; PLAC, placebo; 1-RM, one repetition max; CRP, c-reactive protein; DOMS, delayed onset muscle soreness; RPE, rating of perceived exertion; LDH, lactate dehydrogenase; CK, creatine kinase; AST, aspartate aminotransferase, 1L-6, Interleukin-6.

Table 8 Effects of Protease Supplement on Performance, Soreness, and Markers of Inflammation and Muscle Damage

Authors	Subjects	Dosage	Duration	Design	Exercise Protocol	Performance	Fatigue/ Soreness/ROM	Markers of Inflammation / Muscle Damage
Shing et al.	15 highly trained road cyclist men	500 mg 2× daily	6d	Randomized, double-blind, PLAC controlled design	Cycle race of 10 stages for 6d with average of 96.7 km·day	N/A	↓ Fatigue 4d stage 7	↔ CK ↔ MB ↔ LDH
Buford et al.	29 recreationally active men	5.828 g	24d (21d prior and 3d after ex)	Randomized, double-blind, PLAC controlled design	Downhill run (−17%) grade for 45 min at 60% VO_{2max}	↑ quadriceps flexion strength ↔ quadriceps extension strength	DOMS	↔ CK ↔ SOD ↓ IL-6 ↔ IL-8 ↔ 1L-10 ↔ IL-12 12hr post ex ↔ IL- ↔ TNF-α ↓ COX-2
Beck et al.	20 untrained men	324 mg Protease 6.0 340 mg Protease 4.5	4d after ex	Randomized, double-blind, PLAC controlled, crossover design (2wk washout)	Unilateral max forearm flexion (6X10)	↑ FFS	↔ AC ↔ JA ↔ DOMS	↔ CK ↔ MB
Miller et al.	20 healthy men	325 mg pancreatic enzymes 75 mg trypsin 50 mg papain 50 mg bromelain 10 mg amylase 10 mg lysozyme 2 mg chymotrypisn	4d (1d prior and 3d after ex)	Randomized, double-blind, PLAC controlled design	Downhill run (−10% grade) for 30min at 80% HR_{max}	↔ agility run time ↑ knee flexion power 24hr-48hr post ex ↔ knee extension power ↑ knee flexion torque 24hr-48hr post ex ↑ knee extension torque 48hr post ex	↓ DOMS anterior thigh 24h–48h post ex ↓ DOMS posterior thigh 24h–72h post ex	N/A

↑ significantly higher than placebo; ↓ significantly lower than placebo; ↔ no significant difference from placebo; ex, exercise; MB, myoglobin; CK, creatine kinase; LDH, lactate dehydrogenase; PLAC, placebo; VO_2max, maximal oxygen consumption; DOMS, delayed onset muscle soreness; SOD, superoxide dismutase; 1L-6, Interleukin-6; IL-8, Interleukin-8; TNF-α, tumor necrosis factor-alpha; IL-12, Interleukin-12; IL-10, Interleukin-10; IL-, Interleukin 1- COX-2, cyclooxygenase 2; HR_{max}, maximal heart rate; AC, arm circumference; JA, joint angle.

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Effects of physical exercise on cognitively impaired older adults: a systematic review

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ABSTRACT

Background. The main aim of this study was to estimate the effect of physical activities (PA) on cognitive functions (CF) in cognitively impaired older adults divided according to the impairment severity.

Methods. We searched Web of Science, Scopus, and PubMed for randomized controlled trials (RCT). We focused on the effect of exercise on CF in intervention groups and control groups separately in people with cognitive impairment across three levels - borderline intact, mild, and moderate cognitive impairment separately.

Results. Data from 40 studies involving 1,780 participants from intervention groups and 1,508 participants from control groups were analyzed. 37.0% of intervention groups presented a statistically significant beneficial effect of PA on CF, while 5% presented a statistically significant harmful effect of PA on CF. 40.0% of the control groups showed a significant decrease in CF. 54.3% interventions had a statistically significant beneficial effect (Hedges' $g > 0$). However, there was a great variability between the studies in terms of exercise program description and cognitive impairment of the subjects.

Conclusions. Physical exercise was associated with cognitive function improvement in older people with cognitive impairment. The positive effect is stronger in people with a mild level of cognitive impairment.

KEYWORDS

physical activity; dementia; ageing; aerobic exercise; resistance exercise; cognitive function

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BACKGROUND

The number of older adults with dementia is on the rise due to ageing of the global population. Current estimates suggest that more than 131.5 million people will be affected by dementia by the year 2050 (Sha et al., 2016). Dementia is generally characterized by a progressive decline in cognitive and physical function, often leading to a loss of independence, and institutionalization in some cases (Winblad et al., 2016). Thus, dementia impacts not only the daily lives of individuals diagnosed with the condition but also their families and broader society. During the past two decades, epidemiological research has highlighted the link between modifiable lifestyle factors and cognitive functions. For example, current evidence has demonstrated that a physically active lifestyle may help to delay the onset of cognitive decline and to slow down disease progression (Rolland et al., 2008). Also, physically active individuals have been shown to have a smaller risk of developing dementia or mild cognitive impairment than those who do not take part in any regular physical activity (Rockwood & Middleton, 2007). Moreover, results from several prospective studies have shown that exercise and physical fitness seem to have a positive effect on brain health (Blondell et al., 2014; Stephen et al., 2017). In particular, it has been demonstrated that regular physical activity in mid-life is associated with a lower risk of dementia in later life (Chen et al., 2016), as well as that one of the most effective protections against neurodegenerative or vascular dementia is to be sufficiently physically active from mid-life (Rolland et al., 2008). In addition, it is now well known that exercise interventions increase the functional performance and activities of daily living in patients with cognitive impairment (Garuffi et al., 2013; Hauer et al., 2012; Pitkala et al., 2013; Schwenk et al., 2014; Steinberg et al., 2009). Partial confirmation of a general positive effect of physical exercise was seen as well as stratified effect according to the type of exercise undertaken on executive function, memory (Gates et al., 2013), and global cognition (Groot et al., 2016; Song et al., 2018; Wang et al., 2014) in individuals with mild cognitive impairment. However, there are other important variables that may influence results; for example the effects of exercise on cognitive function in people in relation to the level of cognitive impairment, frequency of sessions or duration of interventions. It is necessary to focus attention on these variables to better understand this complex issue.

Therefore, the main aim of this study was to investigate which type of exercise interventions work effectively in the prevention of cognitive decline in older adults stratified according to the level of cognitive impairment. Additionally, we aimed to investigate the association between other factors, e.g. whether there is a difference between passive and active controls. We hypothesized that there is a difference between exercise programs (mainly from the duration point of view) and that the effect might vary across different levels of cognitive impairment. We also hypothesized that different activity programs in control groups might influence the results. For example, a social program without physical activities may be beneficial for older adults with cognitive impairment. We also assumed that social or education activities in control groups might be more helpful against the cognitive decline rather than inactivity in passive control groups.

METHODS

This review assessed the effects of physical exercise programs on people with cognitive impairment. It is reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (Moher et al., 2019). A compiled PRISMA checklist is included in Table 1.

Table 1 Checklist of items to include when reporting a systematic review or meta-analysis

Section/topic	#	Checklist item	Reported on page #
		TITLE	
Title	1	Identify the report as a systematic review, meta-analysis, or both.	51
ABSTRACT			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	51
		INTRODUCTION	
Rationale	3	Describe the rationale for the review in the context of what is already known.	52
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	52
		METHODS	
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	–
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	55
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	56, Table 2
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	Table 2
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	58, Figure 1
Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	56
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	–

Section/topic	#	Checklist item	Reported on page #
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	59 Table 4
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	57–58
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I^2) for each meta-analysis.	57–58
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	–
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	–
		RESULTS	
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	57–60, Figure 1
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	Tables 3, 4, 5
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).	–
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.	Tables 6, 7, 8
Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency.	–
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	–
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	–
		DISCUSSION	
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).	70–71
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	71
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	71
		FUNDING	
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	72

The PICO (population, intervention, comparisons, and outcomes) framework was used for framing the inclusion criteria (see below) (Higgins et al., 2019).
- Participants: people >50 years of age with a cognitive impairment
- Intervention: physical exercise interventions
- Comparisons: active or passive controls with no additional physical activities
- Outcomes: cognitive function

Inclusion criteria for this study

Based on the above-mentioned PICO framework, the following inclusion criteria were applied:
- only data from randomized controlled trials (RCT)
- the participants had to be diagnosed with any stage of cognitive impairment by one of the standardized tools
- written in the English language

Exercise intervention

We considered only exercise programs that require increased energy output such as aerobic, resistance exercise, walking, dancing, various types of combat activities or sports games. The intervention programs involving a combination of physical exercise and cognitive training were not included. In addition to the program itself, we focused on the duration of exercise program and exercise frequency. Regarding exercise program duration and frequency of exercise per week, we used the same classification as Forbes et al (2015) in the Cochrane systematic review – "up to three times per week" or "more than three times per week" and "up to 12 weeks" or "more than 12 weeks" (Forbes et al., 2015).

According to activities that were prescribed, we have also divided control groups into two categories – active and passive control groups. All control groups where extra activities that could have potentially been beneficial for cognitive functions (for example, attention-control educational programs, social visits, or recreational activities such as card playing or home craftwork), were categorized as "active control groups". Control groups asked to maintain their usual activities were categorized as "passive control groups".

Cognitive function

The following global cognitive function tests were considered appropriate:
- Mini-Mental State Examination (MMSE) (Folstein et al., 1983)
- Rapid Evaluation of Cognitive Function (ERFC) (Gil et al., 1986)
- Alzheimer's Disease Assessment Scale-Cognitive Subscale (ADAS-Cog) (Mohs et al., 1997)
- Montreal Cognitive Assessment (MoCA) (Nasreddine et al., 2005)
- Cambridge Cognitive Examination (CAMCOG) (Roth et al., 1998)

Search strategy

The analysis was conducted by identifying relevant papers referenced in the Web of Science, Scopus, and PubMed. Search terms used in all databases are presented in Table 2.

Table 2 Search results in electronic databases

DATABASE	KEY	NUMBER
Web of Science	TOPIC: (training) OR TOPIC: (exercise) OR TOPIC: (physical) OR TOPIC: (activit*) AND TOPIC: ("Mini-Mental State Examination") OR TOPIC: (MMSE) OR TOPIC: ("Cambridge Cognitive Examination") OR TOPIC: (CAMCOG) OR TOPIC: ("Montreal Cognitive Assessment") OR TOPIC: (MoCA) OR TOPIC: ("Alzheimer's Disease Assessment Scale-Cognitive Subscale") OR TOPIC: (ADAS-Cog) OR TOPIC: ("Rapid Evaluation of Cognitive Functions test") OR TOPIC: (ERFC) AND TITLE: (dementia) OR TITLE: (Alzheimer*) OR TITLE: (cognitive) OR TITLE: (MCI) AND TITLE: (randomized) OR TITLE: (randomised) OR TITLE: (trial) OR TITLE: (intervention)	425
Scopus	((TITLE (training) OR TITLE (exercise) OR TITLE (physical) OR TITLE (activit*))) AND ((TITLE-ABS-KEY ("Mini-Mental State Examination") OR TITLE-ABS-KEY (mmse) OR TITLE-ABS-KEY ("Cambridge Cognitive Examination") OR TITLE-ABS-KEY (camcog) OR TITLE-ABS-KEY ("Montreal Cognitive Assessment") OR TITLE-ABS-KEY (moca) OR TITLE-ABS-KEY ("Alzheimer's Disease Assessment Scale-Cognitive Subscale") OR TITLE-ABS-KEY ("Rapid Evaluation of Cognitive Functions test") OR TITLE-ABS-KEY (erfc))) AND ((TITLE (dementia) OR TITLE (alzheimer*) OR TITLE (cognitive) OR TITLE (mci))) AND ((TITLE-ABS-KEY (randomized) OR TITLE-ABS-KEY (randomised) OR TITLE-ABS-KEY (trial) OR TITLE-ABS-KEY (intervention))) AND NOT ((TITLE-ABS-KEY (review) OR TITLE-ABS-KEY (meta-analysis) OR TITLE-ABS-KEY (protocol)))	460
PubMed	Search (((((((training[Title/Abstract]) OR exercise[Title/Abstract]) OR physical[Title/Abstract]) OR activit*[Title/Abstract])) AND ((((((((("Mini-Mental State Examination") OR MMSE) OR "Cambridge Cognitive Examination") OR CAMCOG) OR "Montreal Cognitive Assessment") OR MoCA) OR "Alzheimer's Disease Assessment Scale-Cognitive Subscale") OR ADAS-Cog) OR "Rapid Evaluation of Cognitive Functions test") OR ERFC)) AND ((((dementia[Title]) OR Alzheimer*[Title]) OR cognitive[Title]) OR MCI[Title])) AND ((((randomized[Title/Abstract]) OR randomised[Title/Abstract]) OR trial[Title/Abstract]) OR intervention[Title/Abstract])) NOT (((review[Title/Abstract]) OR meta-analysis[Title/Abstract]) OR protocol[Title/Abstract])	830

Data extraction and quality assessment

All potential papers were first downloaded into EndNote. Then, our three reviewing authors (LS, AT, and MS) deleted all the duplicates and scanned the titles and abstracts of the papers in order to identify studies that had the potential to meet the eligibility criteria. Full texts were subsequently assessed for eligibility by reviewers KD, MS and IH who extracted the data. Any disagreements among reviewers were resolved through discussions.

We used the Physiotherapy Evidence Database (PEDro) scale to assess the methodological quality of the included studies (Maher et al., 2003).

Data collection

We collected the following data for both exercise groups and control groups separately: the post/pre-intervention mean of the cognitive function test with a 95% confidence interval (CI) and/or standard deviation (SD), if they were not described, we collected means of the cognitive function tests from baselines and after intervention. Additionally, we collected information about the type of exercise and control group activities, age of participants, female ratio, exercise program duration, and frequency of exercise.

Cognitive impairment classification

We divided the participants according to the level of their cognitive impairment into three categories – borderline intact, mild, and moderate cognitive impairment. In the classification, we used the mean of the baseline cognitive function test using the standard classification of each diagnostic tool from which it was calculated.

Data analysis

To see the effect of physical activity on cognitive function of participants, we calculated Hedges' g (Hedges, 1981) for intervention groups and control groups separately as well as for both groups together as follows:

$$Hedges'\ g = \frac{M_{IG} - M_{CG}}{SD_{pooled}} \times \left(\frac{N-3}{N-2.25}\right) \times \sqrt{\frac{N-2}{N}}$$

where $M_{IG} - M_{CG}$ is the difference in mean changes in intervention and control groups and SD_{pooled} is the pooled and weighted standard deviation. Hedges' g is interpreted as:

- Small Effect = 0.2
- Medium Effect = 0.5
- Large Effect = 0.8

Negative values represented a harmful effect (i.e. decrease of cognitive functions) of intervention. To test statistical significance we calculated 95% Confidence Interval (CI) for each study as follows:

$$95\ \%\ CI = g \pm SE \times 1.96$$

where SE is standard error calculated as:

$$SE = \sqrt{\frac{n_1 + n_2}{n_1 \times n_2} + \frac{g^2}{2(n_1 + n_2)}}$$

If the post-pre intervention mean and SD were not available in the paper, we calculated the post-pre intervention mean as the post-intervention mean minus the pre-intervention mean and SD was estimated as:

$$SD_{dif} = \sqrt{SD_{pre}^2 + SD_{post}^2 - (2 \times Corr \times SD_{pre} \times SD_{post})}$$

We used Corr = 0.8 based on the assumption of a relatively high correlation between pre and post-measurements.

The statistics were calculated using Microsoft Excel.

RESULTS

We included 40 RCT in the final analysis out of the 1,258 publications resulting from the database search. These were controlled trials on physical activity and its effect on cognitive functions in people with cognitive impairment. Figure 1 shows the PRISMA flow diagram.

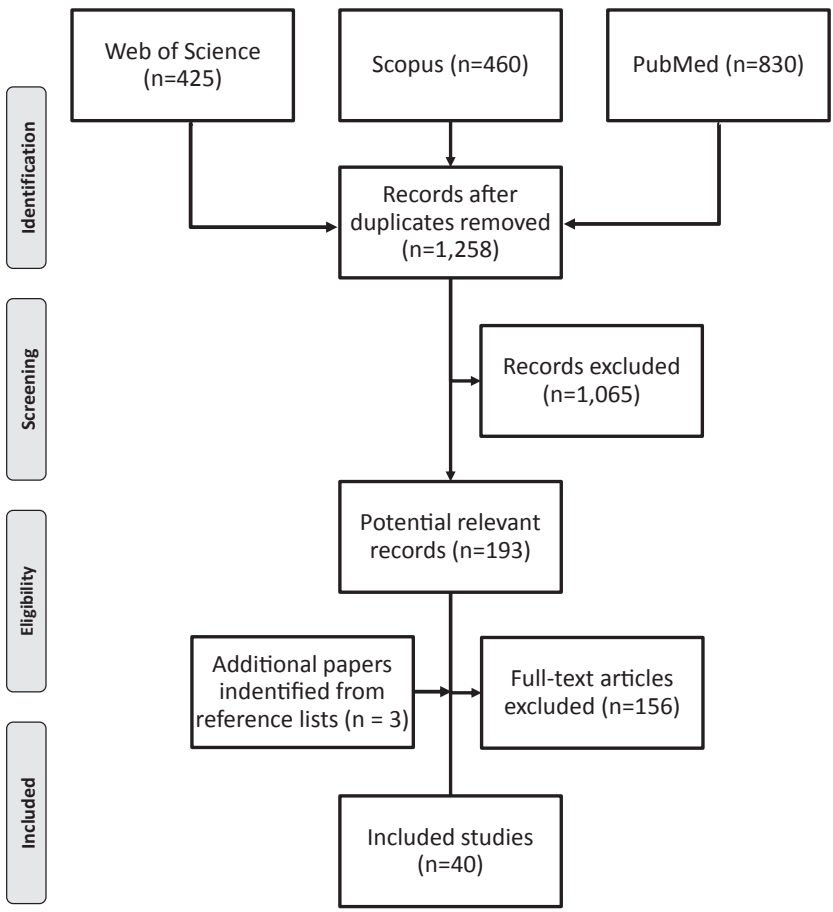

Figure 1 Flowchart illustrating the different phases of the search and study selection

Across the studies, we extracted data from 3,288 participants, the average age was 77.1 years and the average female ratio was 69.1%. The shortest duration of the exercise program was 6 weeks, and the longest was 60 weeks. As the main outcome, the following were used: 31× MMSE (Folstein et al., 1983), 5× MoCA (Nasreddine et al., 2005), 1× ERFC (Gil et al., 1986), and 3× ADAS-Cog (Mohs et al., 1997). The majority of participants lived in their own homes (21 studies). 19 studies came from Europe, 14 from Asia, 4 from South America, 2 from North America and 1 from Australia. The basic data on studies included in the analyses are presented in Table 3. All of the included studies were considered to have a good methodological quality, scoring between 7 and 9 points according to the PEDro. The methodological quality of the included studies according to the PEDro scale is presented in Table 4.

Table 3 The basic data on studies included in the analyses

Study	Year	Country	Duration (weeks)	Settings	N	Mean Age	Females (%)	Main Outcome
Arcoverde	2014	Brazil	16	H	20	78.5	60	MMSE
Arrieta	2020	Spain	36	N	88	84.8	71	MoCA
Bademli	2018	Turkey	20	N	60	72.2	60	MMSE
Bossers	2015	Netherlands	9	N	109	85.5	78	MMSE
Cancela	2016	Spain	60	H	114	80.6	43	MMSE
de Souto Barreto	2017	France	24	N	91	88.3	93	MMSE
Dorner	2007	Austria	10	LTC	30	86.8	77	MMSE
Enette	2020	France	9	Hos	52	77.0	65	MMSE
Fiatarone	2014	Australia	26	H	49	–	–	ADAS-Cog
Harris	2017	Canada	12	LTC	16	83.3	63	MMSE
Henskens	2018	Netherlands	26	N	44	85.1	77	MMSE
Holthoff	2015	Germany	12	H	30	72.4	53	MMSE
Hong	2018	South Korea	12	H	22	77.2	73	MoCA
Cheng	2014	Hong Kong	12	N	74	81.8	64	MMSE
Christofoletti	2008	Brazil	26	N	37	72.9	71	MMSE
Kemoun	2010	France	15	N	31	81.8	73	ERFC
Kwak	2008	South Korea	12	H	30	79.7	100	MMSE
Lam	2015	Hong Kong	52	H	278	75.5	77	MMSE
Lamb	2018	UK	26	Hos	443	77.0	55	ADAS-Cog
Langoni	2018	Brazil	24	H	52	72.6	77	MMSE
Lautenschlager	2008	Australia	24	H	170	68.7	50	ADAS-Cog
Miu	2008	Hong Kong	12	H	85	75.0	53	MMSE
Mollinedo Cardalda	2019	Spain	12	N	77	85.4	70	MMSE
Muscari	2009	Italy	52	H	120	69.6	50	MMSE

Study	Year	Country	Duration (weeks)	Settings	N	Mean Age	Females (%)	Main Outcome
Nascimento	2015	Brazil	26	H	45	66.7	80	MoCA
Qi	2019	China	12	H	32	70.6	69	MMSE
Sanders	2020	Netherlands	24	H	69	81.7	54	MMSE
Siu	2018	China	16	H	160	77.7	75	MMSE
Song	2019	China	16	H	120	75.8	75	MoCA
Sun	2015	China	26	H	138	68.3	81	MMSE
Tao	2019	China	24	H	57	65.5	68	MoCA
Toots	2017	Sweden	16	N	166	84.4	75	MMSE
Van de Winckel	2004	Belgium	6	Hos	25	81.3	100	MMSE
Varela	2012	Spain	12	N	48	76.2	56	MMSE
Venturelli	2011	Italy	26	N	24	83.0	83	MMSE
Vreugdenhil	2012	Australia	16	H	40	73.5	45	MMSE
Wei	2014	China	26	N	60	66.7	30	MMSE
Williamson	2009	US	52	H	102	76.8	72	MMSE
Yang	2015	China	12	Hos	50	72.6	60	MMSE
Yoon	2017	South Korea	12	H	30	75.0	100	MMSE

Note: MMSE – Mini-Mental State Examination; ERFC – Rapid Evaluation of Cognitive Function; ADAS-Cog – Alzheimer Disease Assessment Scale-Cognitive Subscale; MoCA – Montreal Cognitive Assessment; H – home; N – nursing home; Hos – hospital; LTC – long-term care facility.

Many types of exercise such walking, cycling, exercising with pneumatic resistance machines or therabands were used in the studies. Altogether 62.5% of control groups were enrolled in some additional activities such as education, one-to-one conversation, handicrafts, drinking tea with the nursing staff, watching videos or recreational activities. The other participants in the control groups were instructed to maintain their normal physical activities, or they were given standard care in nursing homes. The shortest session was only 15 minutes and the longest was 75 minutes, 60 minutes was the most usual (19×). The frequency of exercise program started at 2 sessions a week, and 3 sessions a week was the most frequent (21×). Four intervention programs required participants to exercise daily. Descriptions of intervention and control groups included in the review are presented in Table 5.

When we divided interventions according to cognitive impairment severity, duration of program, frequency of program, type of exercise, and activities in control groups we created 27 different categories. In general, 37.0% of intervention groups presented a statistically significant beneficial effect of physical activity, while only two presented a statistically significant harmful effect on cognitive functions. Nevertheless, 40.0% of control groups showed a significant decrease in cognitive functions and no group showed an increase. 54.3% of interventions had a statistically significant beneficial effect (Hedges' g significantly > 0). No intervention demonstrated a statistically significant harmful effect (Hedges' g significantly < 0). A statistically significant bene-

Table 4 PEDro scores of the included studies

Study	Eligibility criteria	Randomization	Concealed allocation	Similar group baselines	Blinding of all subjects	Blinding of all therapists	Blinding of all assessors	Drop out < 15%	Intention-to-treat method	Statistical between-group comparison	Point measures and measures of variability	Score
Arcoverde	1	1	1	1	1	0	0	1	1	1	1	9
Arrieta	1	1	1	1	0	0	0	0	1	1	1	7
Bademli	1	1	1	1	0	0	0	1	1	1	1	8
Bossers	1	1	1	1	0	0	0	1	1	1	1	8
Cancela	1	1	1	1	0	0	1	0	1	1	1	8
de Souto Barreto	1	1	1	1	0	0	0	0	1	1	1	7
Dorner	1	1	1	1	1	0	0	1	1	1	1	9
Enette	1	1	1	1	0	0	0	0	1	1	1	7
Fiatarone	1	1	1	1	1	0	0	1	1	1	1	9
Harris	1	1	1	1	0	0	0	1	1	1	1	8
Henskens	1	1	1	1	0	0	1	0	1	1	1	8
Holthoff	1	1	1	1	0	0	0	1	1	1	1	8
Hong	1	1	1	1	0	0	0	0	1	1	1	7
Cheng	1	1	1	1	1	0	0	1	1	1	1	9
Christofoletti	1	1	1	1	0	0	1	1	1	1	1	9
Kemoun	1	1	1	1	0	0	0	0	1	1	1	7
Kwak	1	1	1	1	0	0	0	1	1	1	1	8
Lam	1	1	1	1	0	0	0	1	1	1	1	8
Lamb	1	1	1	0	0	0	0	1	1	1	1	7
Langoni	1	1	1	1	1	0	0	1	1	1	1	9

Study	Eligibility criteria	Randomization	Concealed allocation	Similar group baselines	Blinding of all subjects	Blinding of all therapists	Blinding of all assessors	Drop out < 15%	Intention-to-treat method	Statistical between-group comparison	Point measures and measures of variability	Score
Lautenschlager	1	1	1	1	1	0	0	1	1	1	1	9
Miu	1	1	1	0	0	0	0	1	1	1	1	7
Mollinedo Cardalda	1	1	1	1	0	0	0	0	1	1	1	7
Muscari	1	1	1	1	0	0	0	1	1	1	1	8
Nascimento	1	1	1	1	1	0	0	1	1	1	1	9
Qi	1	1	1	1	0	0	0	0	1	1	1	7
Sanders	1	1	1	1	0	0	0	1	1	1	1	8
Siu	1	1	1	1	1	0	0	1	1	1	1	9
Song	1	1	1	1	0	0	0	0	1	1	1	7
Sun	1	1	1	1	1	0	0	1	1	1	1	9
Tao	1	1	1	1	1	0	0	1	1	1	1	9
Toots	1	1	1	1	1	0	0	1	1	1	1	9
Van de Winckel	1	1	1	0	0	0	0	1	1	1	1	7
Varela	1	1	1	1	0	0	0	0	1	1	1	7
Venturelli	1	1	1	1	0	0	0	0	1	1	1	7
Vreugdenhil	1	1	1	1	0	0	1	1	1	1	1	9
Wei	1	1	1	1	0	0	0	0	1	1	1	7
Williamson	1	1	1	1	0	0	1	1	1	1	1	9
Yang	1	1	1	1	0	0	0	1	1	1	1	8
Yoon	1	1	1	1	1	0	0	1	1	1	1	9

Table 5 Detailed description of intervention and control groups included in the review

Intervention groups		
Study	**Main parts of interventions**	**Frequency (weekly)**
Arcoverde	30 min treadmill walking at 60% of VO_2max	2
Arrieta	25 min strength training – arm curl, chair stand, leg flexion and abduction	2
Bademl	40 min aerobics exercise 4× a week and 40 min walking 3× a week	7
Bossers	30 min walking	4
Bossers	30 min of strength sessions or walking sessions	4
Cancela	15 min cycling ergometer	7
de Souto Barreto	10–15 min of muscle strengthening (e.g., weight lifting), 20 minutes of aerobic exercise (mostly walking)	2
Dorner	25 min of strength training, 10 minutes of balance training	3
Enette	30 min of continuous aerobic training	2
Enette	30 min of interval aerobic training	2
Fiatarone	75 min on pneumatic resistance machines	3
Harris	15–30 min walking	3
Henskens	30–45 min combined strength and walking	3
Holthoff	30 min home-based motor-assisted or active resistive training of the legs	3
Hong	60 min exercise with an elastic band at 15-repetition maximum (65% of 1RM)	2
Cheng	60 min Tai Chi 12-form yang-style	3
Christofoletti	60 min kinesiotherapeutic exercises	3
Kemoun	60 min articular mobilization, muscle stimulation, and walking	3
Kwak	30–60 min chair exercises max. 60% VO_2 max	2–3
Lam	60 min stretching and toning exercise, one mind body exercise (e.g. Tai Chi) and one aerobic exercise session (e.g. static bicycle riding)	3

Lamb	70 min aerobic and strengthening exercise program of moderate to high intensity	2
Langoni	60 min exercise with elastic bands, balls, ankle weights, own body weight, and dumbbells	2
Lautenschlager	50 min walking, light strength training exercise, circuit gym exercise	3
Miu	60 min aerobic exercise training with treadmill, bicycle, arm ergometry and flexibility exercises	2
Mollinedo Cardalda	60 min strength training with therabands	2
Mollinedo Cardalda	60 min multi-calisthenics performed mostly in the seated position	2
Muscari	60 min cycle ergometer, treadmill and free-body activity at intensity 70% of maximal heart rate	3
Nascimento	60 min program aimed to stimulate aerobic metabolism	3
Qi	35 min dance with a target heart rate	3
Sanders	30 min walking and lower limb strength training program with 12 weeks low- and 12 weeks high-intensity training	3
Siu	60 min Tai Chi 24 yang-style simple form	2
Song	60 min aerobic stepping exercise program	3
Sun	60 min Tai Chi 24 yang-style simple form	2
Tao	60 min Baduanjin training	3
Tao	60 min brisk walking	3
Toots	40 min high-intensity functional exercises performed in weight bearing positions	5
Van de Winckel	30 min music-based dance therapy	7
Varela	30 min exercise on 60% of participant's heart rate reserve	3
Varela	30 min exercise on 40% of participant's heart rate reserve	3
Venturelli	30 min walking	4
Vreugdenhil	30 min upper and lower body strength and balance training in addition to at least 30 minutes of brisk walking	7
Wei	30 min handball training	5
Williamson	60 min combination of aerobic, strength, balance, and flexibility exercises	3

Yang	40 min cycling training at 70% of maximal intensity	3
Yoon	60 min elastic band training (tension: very low)	2
Yoon	60 min elastic band training (tension: high)	2

Control groups

Study	Activities	Frequency (weekly)
Arcoverde	–	–
Arrieta	Activities will be low intensity: memory workshops, reading, singing, etc.	–
Bademli	–	–
Bossers	Four social visits each week	–
Cancela	Recreational activities - card-playing, reading, craftwork	–
de Souto Barreto	Social activity 60 min	2
Dorner	–	–
Enette	Interactive information sessions around multiple-choice questionnaires	1
Fiatarone	Watching 5 short National Geographic videos + tests and stretching and seated calisthenics	–
Harris	30–45 minute social visits from a student volunteer	1
Henskens	Drink tea with the nursing staff	3
Holthoff	–	–
Hong	–	–
Cheng	60 min simple handicrafts	3
Christofoletti	–	–
Kemoun	Manual and intellectual activities organized by the nursing home (pottery, painting, soft gymnastics, outings, etc.)	–
Kwak	–	–
Lam	At least three one-hour social activity sessions per week	–

Lamb	–	–
Langoni	–	–
Lautenschlager	Educational material about memory loss, stress management, healthful diet, alcohol consumption, and smoking	–
Miu	–	–
Mollinedo Cardalda	60 min crafts, reading comprehension and cognitive stimulation activities	2
Muscari	Educational materials about suggestions to improve lifestyle, including individualized self-administered programs to increase physical activity	–
Nascimento	–	–
Qi	–	–
Sanders	Flexibility exercises and recreational activities	–
Siu	–	–
Song	Health education program included eight bi-weekly educational classes (45 min/each session)	–
Sun	Playing cards or singing at the activity center	–
Tao	Health education every 8 weeks for 30 min per session	–
Toots	Participants conversed, sang, listened to music or readings, and/or looked at pictures and objects	–
Van de Winckel	One-to-one conversation	–
Varela	Recreational activities – playing cards, reading newspapers, handicrafts	–
Venturelli	Organized activities like bingo, patchwork sewing, and music therapy	–
Vreugdenhil	–	–
Wei	–	–
Williamson	Health education – a session per week included health topics relevant to older adults such as nutrition, medications, foot care, and recommended preventive services at different ages	–
Yang	Health education	–
Yoon	Static and dynamic stretching once a week for 60 min	–

Table 6 Effect of physical exercise on cognitively impaired older adults – borderline intact

	Exercise program		Intervention groups		Control groups		Effect size		
	Duration (weeks)	Frequency (weekly)	Physical activity	Statistically significant effect	Control	Statistically significant effect	Hedges' g	95% CI lower	95% CI upper
Hong, 2018	≤ 12	≤ 3	Resistance	No	Passive	No	0.23	–0.61	1.07
Qi, 2019	≤ 12	≤ 3	Dance	**Beneficial**	Passive	No	0.41	–0.29	1.11
Kemoun, 2010	> 12	≤ 3	Aerobic	**Beneficial**	Active	**Harmful**	**1.80**	**0.96**	**2.63**
Lam, 2015	> 12	≤ 3	Aerobic	No	Active	No	0.20	–0.03	0.44
Muscari, 2009	> 12	≤ 3	Aerobic	No	Active	**Harmful**	**0.43**	**0.06**	**0.79**
Song, 2019	> 12	≤ 3	Aerobic	No	Active	No	**1.87**	**1.44**	**2.30**
Tao, 2019	> 12	≤ 3	Aerobic	No	Active	No	–0.11	–0.76	0.53
Fiatarone, 2014	> 12	≤ 3	Resistance	No	Active	No	**0.83**	**0.25**	**1.42**
Lautenschlager, 2008	> 12	≤ 3	Combined	No	Active	**Harmful**	0.28	–0.02	0.58
Williamson, 2009	> 12	≤ 3	Combined	No	Active	No	–0.17	–0.56	0.22
Sun, 2015	> 12	≤ 3	Tai Chi	**Beneficial**	Active	No	**0.84**	**0.49**	**1.19**
Tao, 2019	> 12	≤ 3	Tai Chi	No	Active	No	0.52	–0.11	1.15
Nascimento, 2015	> 12	≤ 3	Aerobic	**Beneficial**	Passive	No	**0.70**	**0.10**	**1.30**
Siu, 2018	> 12	≤ 3	Tai Chi	No	Passive	No	**0.52**	**0.20**	**0.83**
Wei, 2014	> 12	> 3	Other	**Beneficial**	Passive	No	**1.37**	**0.81**	**1.93**

Table 7 Effect of physical exercise on cognitively impaired older adults – mild cognitive impairment

	Exercise program		Intervention groups		Control groups		Effect size		
	Duration (weeks)	Frequency (weekly)	Physical activity	Statistically significant effect	Control	Statistically significant effect	Hedges' g	95% CI lower	95% CI upper
Enette, 2020	≤ 12	≤ 3	Aerobic	No	Active	No	**2.23**	**1.38**	**3.08**
Enette, 2020	≤ 12	≤ 3	Aerobic	No	–	–	0.57	–0.08	1.22
Mollinedo Cardalda, 2019	≤ 12	≤ 3	Aerobic	No	Active	**Harmful**	0.41	–0.15	0.96
Yang, 2015	≤ 12	≤ 3	Aerobic	**Beneficial**	Active	**Harmful**	**1.03**	**0.44**	**1.62**
Yoon, 2017	≤ 12	≤ 3	Resistance	**Beneficial**	Active	**Harmful**	**3.66**	**2.23**	**5.09**
Yoon, 2017	≤ 12	≤ 3	Resistance	**Beneficial**	–	–	**1.89**	**0.71**	**3.08**
Cheng, 2014	≤ 12	≤ 3	Tai Chi	No	Active	No	**0.53**	**0.06**	**0.99**
Miu, 2008	≤ 12	≤ 3	Aerobic	**Harmful**	Passive	**Harmful**	–0.42	–0.85	0.02
Dorner, 2007	≤ 12	≤ 3	Resistance	**Beneficial**	Passive	No	**0.92**	**0.17**	**1.68**
Holthoff, 2015	≤ 12	≤ 3	Resistance	No	Passive	No	0.45	–0.27	1.18
Mollinedo Cardalda, 2019	≤ 12	≤ 3	Resistance	No	–	–	**0.94**	**0.38**	**1.51**
Varela, 2012	≤ 12	> 3	Aerobic	**Beneficial**	Active	**Harmful**	**1.58**	**0.78**	**2.37**
Varela, 2012	≤ 12	> 3	Aerobic	**Beneficial**	–	–	**1.47**	**0.68**	**2.27**
Arrieta, 2020	> 12	≤ 3	Resistance	No	Active	**Harmful**	**0.65**	**0.22**	**1.08**
Sanders, 2020	> 12	≤ 3	Combined	No	Active	No	–0.09	–0.57	0.38
Arcoverde, 2014	> 12	≤ 3	Aerobic	BENEFICIAL	Passive	**Harmful**	0.46	–0.43	1.35
Bademli, 2018	> 12	≤ 3	Aerobic	BENEFICIAL	Passive	**Harmful**	**3.93**	**3.07**	**4.80**
Langoni, 2018	> 12	≤ 3	Resistance	BENEFICIAL	Passive	**Harmful**	**2.96**	**2.17**	**3.74**
Lamb, 2018	> 12	≤ 3	Combined	No	Passive	No	–0.14	–0.34	0.06
Vreugdenhil, 2012	> 12	> 3	Resistance	**Beneficial**	Passive	**Harmful**	0.55	–0.08	1.18

Table 8 Effect of physical exercise on cognitively impaired older adults – moderate cognitive impairment

	Exercise program		Intervention groups		Control groups		Effect size		
	Duration (weeks)	Frequency (weekly)	Physical activity	Statistically significant effect	Control	Statistically significant effect	Hedges' g	95% CI lower	95% CI upper
Harris, 2017	≤ 12	≤ 3	Aerobic	No	Active	No	–0.31	–1.30	0.67
Bossers, 2015	≤ 12	> 3	Aerobic	No	Active	No	0.33	–0.14	0.79
Bossers, 2015	≤ 12	> 3	Combined	No	–	–	**0.77**	**0.29**	**1.24**
Van de Winckel, 2004	≤ 12	> 3	Dance	No	Active	No	0.79	–0.04	1.62
de Souto Barreto, 2017	> 12	≤ 3	Combined	No	Active	No	–0.15	–0.56	0.26
Henskens, 2018	> 12	≤ 3	Combined	No	Active	No	0.08	–0.51	0.67
Christofoletti, 2008	> 12	≤ 3	Other	**Beneficial**	Passive	No	**1.79**	**1.03**	**2.56**
Kwak, 2008	> 12	≤ 3	Aerobic	**Beneficial**	Passive	No	**1.41**	**0.61**	**2.20**
Cancela, 2016	> 12	> 3	Aerobic	No	Active	**Harmful**	**0.68**	**0.30**	**1.06**
Venturelli, 2011	> 12	> 3	Aerobic	No	Active	**Harmful**	**3.95**	**2.58**	**5.33**
Toots, 2017	> 12	> 3	Resistance	**Harmful**	Active	**Harmful**	–0.08	–0.39	0.22

ficial effect was found in: 52.7% of interventions with frequency ≤ 3 sessions weekly, 60% of interventions with frequency > 3 sessions weekly, 61.1% of aerobic exercise, 63.3% of resistance exercise, 35.3% of other exercise interventions, 50% of bordeline intact participants, 60% of participants with mild cognitive impairment, and 45.5% of participants with moderate cognitive impairment. The highest effect was found in Bademli (Bademli et al., 2018) in participants with mild cognitive impairment where the duration was > 12 with frequency ≤ 3 of aerobic exercise against a passive control Hedges' g = 3.82 (95% CI 2.97–4.67). On the other hand, an almost statistically significant harmful effect was found in the Miu study (Miu et al., 2008) with a similar design where the only difference was in the duration that was ≤ 12 weeks Hedges' g = –0.41 (95% CI –0.84–0.03). The effect of physical exercise on cognitively impaired older adults according to impairment severity is presented in Tables 6, 7 and 8.

DISCUSSION

It is well-established that cognitive functions decline gradually over time as part of the natural ageing process (Harada et al., 2013). The findings of this systematic review partly indicate that physical exercise may have the power to mitigate the cognitive decline process even in people with cognitive impairment. The similar findings were found in previous reviews where physical exercise had a positive effect on executive function (Gates et al., 2013; Song et al., 2018), and on global cognition (Groot et al., 2016; Wang et al., 2014; Ohman, 2014) in individuals with mild cognitive impairment. However, the new knowledge from this study is that the positive effect is stronger in people with a mild level of cognitive impairment and, above all, it points to a very strong negative effect of physical inactivity on cognitive function in the control groups.

However, it was practically impossible to merge the studies together into one analysis because so many different approaches were used regarding physical exercise activities, control group activities as well as the frequency of exercise program. Studies included in this review varied in terms of duration of exercise programs. In twenty-seven studies, the duration of interventions was less than half a year, and in another nineteen, the duration of the interventions was for more than or equal to half a year. According to our analysis, it seems that the duration of the exercise program was associated with cognitive decline, which may be caused by the natural cognitive decline during ageing. Surprisingly, the frequency of exercise per week did not play any significant role in global cognition.

It has been well described that the positive effect of aerobic exercise on brain health lies in the mechanisms behind aerobic exercise such as neovascularization, synaptogenesis and angiogenesis, hippocampal high-affinity choline uptake and upregulation of muscarinic receptor density, increasing of mitochondrial volume in Purkinje cells, inhibition of the apoptotic biochemical cascades, identified primarily through animal research (Black et al., 1990; Fordyceet al., 1991; Isaacs et al., 1992; Um et al., 2008).

Moreover, a higher number of female participants in intervention groups experienced a positive effect on global cognitive function. This result could be explained by both different cognitive responses to exercise between men and women as well as by the different ratios in elderly females suffering dementia. As described by Baker et al. (2010), aerobic exercise improved performance on multiple tests of executive

function, increased glucose disposal during the metabolic clamp, and reduced fasting plasma levels of insulin, cortisol, and brain-derived neurotrophic factor in women but not in men (Baker et al., 2010). They also found that peak oxygen consumption was associated with improved executive function in women. It turns out that gender differences in cognitive functions can be related to the metabolic effects of physical activity. However, there are several other reasons why gender may influence trial results. For instance, women have a higher lifetime risk of dementia (Chene et al., 2015), greater vulnerability to certain risk factors such as gender-specific chromosomes, APOE ε4, gender differences in hormone levels etc. (Snyder et al., 2016), and they demonstrate higher differential associations between biomarkers and cognitive impairment than men (Koran et al., 2017). Moreover, there was a higher percentage of female participants in the intervention studies (32 of 36 intervention groups had a majority of female participants). One reason for this fact could be higher life expectancy in females (Samaras et al., 2018) although the gender age gap has been narrowing in Europe recently (Kolip & Lange, 2018). Another explanation could be greater adherence to health-related exercise programs in older women (Aartolahti et al., 2015). Thus, it would be of interest to explain which of the above-mentioned proposed factors is responsible for gender differences.

It should be noted that one of the biggest limitations of this study was considerable heterogeneity in all the analyses which hampered the meta-analysis. In fact, heterogeneity is a common problem of meta-analyses on this topic (Gates et al., 2013; Ohman et al., 2014). Moreover, it was almost impossible to create a category with similar cognitive impairment because it varied considerably among the studies so the classification has some limitations, because if the variability was high then we could not be sure that all the participants were allocated correctly. The same is true for exercise interventions because the interventions included many different activities with different durations and intensities.

CONCLUSION

Despite the numerous limitations mentioned above, this study has shown that physical exercise may have the power to influence cognitive functions in people with cognitive impairment especially in people with a mild level of cognitive impairment. Such findings could have practical implications for recommending physical activity as a non-pharmacologic treatment to combat the progression of cognitive decline in patients with dementia. Future research based on longitudinal epidemiological studies is needed to confirm such findings further.

List of abbreviations

ADAS-Cog	Alzheimer Disease Assessment Scale–Cognitive Subscale
B	Standardized Coefficient Beta
CAMCOG	Cambridge Cognitive Examination
CI	Confidence Interval
ERFC	Rapid Evaluation of Cognitive Function
MMSE	Mini Mental State Examination
MoCA	Montreal Cognitive Assessment

PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PEDro	Physiotherapy Evidence Database
RCT	Randomized Control Trials
SE	Standard Error
SMD	Standardized Mean Difference
VO_{2max}	the maximum amount of oxygen the body can utilize during a specified period of usually intense exercise
WA	Weighted Averages

DECLARATIONS

Ethics approval and consent to participate
N/A

Consent for publication
N/A

Availability of supporting data and material
The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests
This manuscript has not been previously submitted or published and is not under consideration in any other peer-reviewed media. To the best of our knowledge, no conflict of interest, financial or other, exists.

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Authors' contribution
LS, AB, and MS have screened the literature and selected papers for inclusion in the review. LS, MS, KD, and IH have contributed to data extraction. All authors read and approved the final manuscript.

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Trends in the Brain-Computer Interface

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ABSTRACT

The goal of every human being on our planet is to improve the living conditions not only of his life, but also of all humanity. Digitization, dynamic development of technological equipment, unique software solutions and the transfer of human capabilities into the form of data enable the gradual achievement of this goal. The human brain is the source of all activities (physical, mental, decision-making, etc.) that a person performs. Therefore, the main goal of research is its functioning and the possibility to at least partially replace this functioning by external devices connected to a computer. The Brain-Computer Interface (BCI) is a term which represents a tool for performing external activities through sensed signals from the brain. This document describes various techniques that can be used to collect the neural signals. The measurement can be invasive or non-invasive. Electroencephalography (EEG) is the most studied non-invasive method and is therefore described in more detail in the presented paper. Once the signals from the brain are scanned, they need to be analysed in order to interpret them as computer commands. The presented methods of EEG signal analysis have advantages and disadvantages, either temporal or spatial. The use of the inverse EEG problem can be considered as a new trend to solve non-invasive high-resolution BCI.

KEYWORDS

brain-computer interface; electroencephalography (EEG); inverse EEG problem; neuro imaging; medicine, brain activity imaging

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INTRODUCTION

The concept of human-machine interface, which encompasses all the means and techniques used by man to communicate with a machine, is ubiquitous in today's world. While the computer keyboard and mouse are now used almost daily by part of the population, many studies are still seeking to improve their ergonomics. This improvement can go through the use of new interfaces such as voice, vision or even the positioning of the user in the case of virtual reality. However, we must also be able to respond to cases where all of these interfaces cannot be used. It is therefore interesting to provide other means of communication for users who cannot generate the muscular movements necessary for human-machine interfaces. This is the challenge facing the Brain-Computer Interface (BCI) domain.

BCI, also known as the direct neural interface, is a means of communication that uses brain activity. It is important to note that this is done completely independently of the usual brain peripherals – the peripheral nerves and muscles. The aim of the BCI is therefore to provide the brain with another communication intermediary, under user control, and not to "listen" to its brain activity without its knowledge. There are several areas of application. The first one that comes to mind is necessarily the medical field, where BCI can allow people with disabilities to control a chair, prosthesis or even a hospital bed. But this technology is not necessarily intended for people with disabilities. Indeed, several applications can be envisaged, notably in entertainment, authentication or even neuro-marketing. The BCI world therefore seems to have, from an application point of view, the potential to interest the general public. However, its use is currently far from being widespread in everyone's daily life.

The idea of being able to control a device with the signals generated by brain activity was born in 1929, following Berger's work on the EEG (He, 2013). The notion of BCI appeared in the 1970s with the work of Vidal (1973). This research was carried out under a contract with the Defense Advanced Research Projects Agency (DARPA), which was also involved in the development of early versions of the Internet. These works have shown that it is possible to use signals from brain activity to transmit the will of the user effectively and have initiated decades of research.

The BCI works in the following way. One system acquires and processes brain signals, then another translates and classifies them to transform them into commands. To make it simpler, the subject thinks of what he/she wishes to do, and this information will be transmitted to the computer which will translate it and execute the command (for example: Movement of the person's prosthesis replacing a part of the body which had been amputated to this person.). A real innovation in this digital age.

The one who "dictates" this action is the human brain. Therefore, the brain-machine interface must record brain activity by simply using electrodes installed on the skull, cortex, or even in the brain. Thus, BCI can pick up electrical signals transmitted by neurons. Here's how its two methods of recording electrical signals work. One using invasive acquisition methods and the other one using non-invasive methods.

Invasive BCI requires neurosurgical surgery. The principle consists in fact by placing electrodes directly on the gray matter to have the least noisy signal possible. This method has the particularity of allowing BCI in the brain sense in the direction from brain to machine but also from machine to brain. Indeed, the electrodes can be used

to, for example, transmit signals from a camera to the visual cortex, in order to bring artificial vision to blind people. Concerning the direction brain to machine, the use of an invasive acquisition method allows high spatio-temporal resolution to be achieved, allowing faster and more precise response. On the other hand, there are certain problems to be considered. Besides the fact that each application requires a specific placement of electrodes, it is difficult to guarantee the stability of the signal over operating periods at the level of months or years.

Non-invasive methods are mainly distinguished from invasive methods by the fact that they involve much less risk for the user. In fact, they use brain imaging, which does not require surgery. This makes it possible to envisage a single system for measuring brain activity for any application since all of the brain activity can be taken into account. They are also less restrictive for the user. Nevertheless, they suffer from a lack of spatial resolution since the signal is noisy by the passage through the cranium. Several means of measurement can be used, such as Magnetic Resonance Imaging (MRI), Functional Magnetic Resonance Imaging (fMRI), Magnetoencephalography (MEG) or also Electroencephalography (EEG).

The measurement methods like MRI, fMRI and MEG are based on the measurement of magnetic fields, which requires large and expensive equipment. Indeed, MRI machines weigh several tens of tonnes and cost more than 850,000 euros (Sarracanie, LaPierre, Salameh, Waddington, Witzel, & Rosen, 2015). This is mainly due to the fact that they need a strong magnet in order to generate a stable magnetic field. Any attempt of miniaturization, however, involves decreasing the power of the device's magnet, which decreases the spatial resolution of the measurement. Regarding the MEG, the measuring device required is also relatively large. In addition, since the magnetic fields measured are very weak (of the order of femtoTesla in the case of MEG), magnetic shielding may be necessary around the measuring device in order to avoid the risks of interference with the outside world. These methods based on the measurement of magnetic fields are therefore too cumbersome, and miniaturization is not possible immediately. Therefore, they do not meet the comfort criteria of the BCI user. These arguments partly explain why EEG is the most studied measurement method for BCI. Indeed, this method, using a helmet on which electrodes are placed, is very simple to wear for the user, in addition to having a very good temporal resolution in comparison with the other non-invasive methods. The latter method therefore seems to be the most suitable for bringing BCI into everyday life, also because the price of EEG helmets varies according to the number of electrodes. This can range from 90 euros for a helmet with a single electrode up to more than 20,000 euros for a helmet with 256 electrodes, which is the highest measurement capacity currently (Farnsworth, 2017).

Interface brain machine by electroencephalography (EEG)

The principle of the EEG as well as its current use in the framework of the BCI rests on the activity of the brain when it generates electro-chemical exchanges at the level of the neurons. These exchanges create electromagnetic fields which can therefore be considered as images of brain activity. The principle of the BCI is to measure these signals in order to deduce there from a willingness of the patient to transmit to a machine. This field is currently in expansion.

The potentials measured by EEG are the images of postsynaptic excitatory or inhibitory potentials of neurons. These potentials occur respectively at the entrance of a flow of positive and negative ions in the cell. These neuron-wide events generate a very small potential which does not significantly contribute to the potential measured on the scalp. As a result, the potentials recorded by EEG represent the sum of the potentials generated by thousands or even millions of neurons at the same time. The amplitude of the signals measured on the scalp by EEG, which can reach 300 μV, is therefore a direct image of the number of synchronous neurons at a given time. An EEG measurement makes it possible to visualize different electromagnetic oscillations, which are called cerebral rhythms. Each rhythm has its own frequency band and corresponds to a specific brain function. The most interesting EEG waves are as follows (Schomer & Lopes Da Silva, 2012):

- The delta wave, 0.4 to 4 Hz, which characterizes deep sleep.
- The theta wave, 4 at 8 Hz, which characterizes drowsiness.
- The alpha wave, 8 at 13 Hz, which characterizes a calm state of consciousness, contains the MU sub-wave, between 10 and 12 Hz, which dampens the movement of limb contralateral.
- The beta wave, 13 at 30 Hz, which characterizes a period of concentration.

The study of these waves in specific situations can make it possible to deduce possible orders for a BCI.

EEG signal analysis methods

Potential linked to the event

These are brain responses appearing at fixed time moments after an external event, such as a sensory stimulus, or an internal event, such as thinking of a specific action. There are thus 2 types of potential:

- Exogenous potential is the consequence of an external event. This potential is a physiological response to the stimulus and therefore does not depend on any context.
- Endogenous potential is the consequence of an internal event. This potential can also be context-dependent. For example, if a user tries to locate the letter D in a word, he/she will generate a potential if this letter is presented to him, but nothing is measurable with this same letter if the user searches for the letter T.

The use of these potentials linked to the event is therefore a relatively simple method to set up BCIs. The nature of the potential determines the importance of the training phase when setting up a BCI. If an exogenous potential is used, almost no training is required, the response being physiological. Conversely, if an endogenous potential is implemented, a training phase via a return of the BCI is necessary.

Visually evoked potentials of steady state

These potentials use a visual stimulus, most often a flashing graphic element. This method is based on the fact when, during the EEG measurements, a peak in amplitude is observed at the same frequency as that of a blinking element in the center of the visual field. The responses are more easily observable for stimulation frequencies between 5 and 27 Hz. It is therefore possible to present different stimuli to the user

on the same screen. When the user directs his/her gaze on a stimulus, a characteristic EEG signal is then measured and detected to trigger the desired command.

However, this method has its limits. Having to present visual stimuli for each command limits the possibilities for the same screen size. In addition, the need to have to set flashing elements can trigger epileptic seizures and certain stimulation frequencies can cause fatigue as it requires a lot of concentration. This method therefore remains too restrictive and limited in the perspective of a general public BCI.

Desynchronizations and synchronizations linked to the event

This method is another special case of potentials linked to the event. This corresponds to 2 visible phenomena in the power spectrum of cerebral rhythms which can be triggered by internal or external events. Event Related Desynchronization (ERD) is a decrease in the power of the EEG in a given frequency band, all in relation to a particular event. The most well-known ERD is that caused by the opening of the eyes and which is visible in the frequency band of the alpha wave. These desynchronizations are indeed very widespread in the alpha band, especially during tasks involving memory or anything related to perception (He, 2013).

Conversely, Event Linked Synchronization (ELS) is an increase in the power of the EEG in a given frequency band. While the overall response of EEG signals to the same event is the same for each user, the precise characteristics may vary, such as the extent of desynchronizations and the frequencies where they are most visible or when they start. BCIs based on the ERD method therefore need a learning phase in order to memorize the user's brain response to the event studied. Then, the EEG signals are analyzed during the use of the BCI in order to find this response and thus determine a command to send.

The main advantage of the ERD and ELS method is that it uses internal events. Thus a BCI using this method does not require additional elements to generate the stimuli. However, the difficulty of increasing the number of detectable commands currently limits the resolution of the systems offered.

The EEG is a non-invasive measurement method that stands out in the field of BCI. Indeed, its reduced cost compared to other measurement means, as well as its small footprint, make it a method of choice for developing BCI at lower cost. The majority of the systems proposed are based on the analysis of evoked potentials, which correspond to modifications of the cerebral rhythms following exposure to external or internal events. However, these systems suffer from the lack of spatial resolution of the measurement by EEG, which implies either a reduced number of commands carried out by BCI, or an extended command detection time, which removes the possibility of applications in real time and therefore limits the current perspectives of the field of BCI.

The spatial resolution of EEG can be improved by solving the EEG inverse problem, which allows to determine the distribution of electrical sources in the brain from EEG. Currently, the main difficulty is the time needed (several hours) to compute the matrix which is used to solve the EEG inverse problem. The solution to provide a hardware acceleration of the matrix computation can be done by dedicated electronic architecture. First results show that the proposed architecture divides the calculation time by a factor of 60 on a programmable circuit. This acceleration opens up new perspectives for EEG BCI.

The inverse EEG problem – a new trend towards solving non-invasive high-resolution BCI

The electrical activity of the brain is a spatio-temporal process, which is indeed distributed in the 3 dimensions of the brain and evolves over time. The resolution of the 2 domains is therefore essential to analyze the precision of the cerebral imaging method used. If the strong point of the EEG is its temporal resolution, of the order of a millisecond, the spatial resolution is meanwhile much more limited for two reasons. The first of these reasons is the limitation of spatial sampling. In fact, the classic international system 10–20 places electrodes on a helmet with an average gap of 6 cm between 2 of them (Nunez, Silberstein, Cadusch, Wijesinghe, & Westdorp, Srinivasan, 1994). Recent developments in EEG systems have made it possible to offer better resolution systems with 64 to 256 electrodes. For example, with 124 electrodes, the distance between the 2 measurement points is reduced to 2.5 cm (Gevins, A., Le, J., Martin, N. K., Brickett, P., Desmond, J., & Reutter B., 1994). The second reason for the lack of spatial resolution comes from the different conduction effects. To reach the electrodes of the EEG helmet, the electrical potentials generated by the neurons must cross, among other things, the nervous tissue, the cerebrospinal fluid, the skull and the scalp. This path implies that the signal arriving at the electrodes is attenuated, distorted and noisy (Nunez, Srinivasan, 2009). We must therefore seek to correct these faults with dedicated techniques in order to improve the spatial resolution of the EEG. This is where distinct but closely related problems come into play – the direct problem and the inverse problem of the EEG. In fact, their resolutions are required in order to establish a high resolution map of the brain's electrical activity from an EEG measurement.

From the knowledge of the distribution of electrical sources in the brain and models of the conduction properties of the head, the direct problem of the EEG aims to determine the electric field generated by these sources. The solution can take the form of electrical potentials, such as the potentials on the surface of the cerebral cortex or the scalp. This solution can also be represented by other metrics such as for example a current density distribution. The direct problem is well defined and has a unique solution, defined by Maxwell's equations (Malmivuo, Plonsey, 1995). Solving this direct EEG problem helps to establish the relationship between electrical sources in the brain and what is actually measured by the electrodes. This relationship can then be represented in the form of a transfer matrix whose coefficients are dependent on the geometry and the conduction characteristics of the head of the subject studied.

On the other hand, the inverse problem of the EEG is interested in determining the location and importance of the active electrical sources in the brain from the potentials measured by the EEG headset and the conduction characteristics of the head of subject. This duality between direct problem and inverse problem is illustrated in Figure 3. Unlike the direct problem, the inverse problem does not admit of a single solution. Indeed, Helmholtz proved in 1853 that an infinity of configurations of sources in a volume can generate a given set of potentials measured at its surface (Hermann von Helmholtz, Wikipedia, 2020). Other constraints must therefore be added in order to obtain a single solution.

These constraints can be anatomical, physiological, spatio-temporal or even functional and come from community knowledge about how the brain works. When solving the inverse problem of EEG, several source models can be considered. The isolated

sources model is concerned with determining the electrical activity of the brain at the neuron scale, while the distributed sources model considers groupings of sources located in the 3 dimensions of the brain. The choice of source model depends on the intended application, although the primary objective of solving the opposite EEG problem remains the same – finding a representation of electrical sources in the brain that explains the potentials measured by the EEG helmet. Neuroimaging based on the inverse problem therefore makes it possible to establish a high-resolution mapping of the brain in a non-invasive and inexpensive manner.

Neuroimaging by solving the inverse EEG problem is an interesting way to offer non-invasive high resolution BCI in the long term. This method is already used in scientific disciplines which do not have significant time constraints. Therefore, in the case of an epilepsy study, the calculations are made after the measurement session. In order to apply new trends in the field of BCIs, it is therefore necessary to choose a method in which data processing can be carried out simultaneously with the measurement of EEG signals.

Interface brain machine by other non-invasive methods

Functional Near-Infrared Spectroscopy (fNIRS)

Functional Near-Infrared Spectroscopy or Optical Topography, as it is called in Japan exclusively, is the use of near-infrared spectroscopy (NIRS) for functional neuroimaging. Using fNIRS, cerebral hemodynamic responses are measured by near-infrared light, which go in line with cerebral activation or deactivation. In particular, this technology is capable of visualizing changes both in oxy- and deoxyhaemoglobin concentration. fNIRS is based on the absorption of near infrared light by haemoglobin. The light moves, or propagates, through the head and lends information about blood volume, flow and oxygenation. This technique is safe, non-invasive, and can be used with other imaging modalities.

fNIRS is a non-invasive imaging method involving the quantification of chromophore concentration resolved from the measurement of near infrared (NIR) light attenuation or temporal or phasic changes. fNIRS spectrum light takes advantage of the optical window in which:

- skin, tissue, and bone are mostly transparent to NIR light (700–900 nm spectral interval),
- haemoglobin and deoxygenated-haemoglobin are strong absorbers of light. These are the principals adapted from pulse oximeters.

There are six different ways for infrared light to interact with the brain tissue: direct transmission, diffuse transmission, specular reflection, diffuse reflection, scattering, and absorption. fNIRS focuses on absorption: differences in the absorption spectra of deoxy-haemoglobin and oxy-haemoglobin allow the measurement of relative changes in haemoglobin concentration through the use of light attenuation at multiple wavelengths. Two or more wavelengths are selected, with one wave length above and one below the isosbestic point of 810 nm, at which deoxy-haemoglobin and oxy-haemoglobin have identical absorption coefficients. Typically, the light emitter and detector are placed ipsilaterally (each emitter/detector pair on the same side) on the subject's skull so recorded measurements are due to back-scattered (reflected) light following

elliptical pathways. fNIRS is the method the most sensitive to scalp and skull, so in order to have an increased sensitivity to the superficial cortex, there needs to be a larger source-detector ratio (Functional near-infrared spectroscopy, Wikipedia, 2020).

fNIRS technology is dependent on the level of oxygen in the blood. Due to light limits, fNIRS cannot be used for cortical measurements activities in the brain below 4 cm. Also, the time resolution of fNIRS is relatively lower than electrical or magnetic signals.

Functional Magnetic Resonance Imaging (fMRI)

Functional Magnetic Resonance Imaging (fMRI) measures brain activity by detecting changes associated with blood flow. This technique relies on the fact that cerebral blood flow and neuronal activation are coupled. When an area of the brain is in use, blood flow to that region also increases. The primary form of fMRI uses the blood-oxygen-level dependent contrast. This is a type of specialized brain scan used to map neural activity in the brain or spinal cord of humans by imaging the change in blood flow (hemodynamic response) related to energy use by brain cells. fMRI has come to dominate brain mapping research, because it does not require people to undergo injections or surgery, to ingest substances, or to be exposed to ionizing radiation. This measure is frequently corrupted by noise from various sources, hence, statistical procedures are used to extract the underlying signal. The resulting brain activation can be graphically represented by color-coding the strength of activation across the brain or the specific region studied (Functional magnetic resonance imaging, Wikipedia, 2020).

fMRI has higher spatial resolution and collects information from the brain from deeper areas than fNIRS. However, the same disadvantage of fMRI as of fNIRS is the low time resolution slowed down due to blood flow. The most significant disadvantage of fMRI is the need for an expensive and heavy magnetic field scanner. Required scanners are non-relocatable or require a lot of effort to relocate.

The fMRI method as well as the fNIRS method show the required high spatial resolution. The main disadvantage is the time delay caused by the fact that the flow of oxygenated blood connects to the nerve cells after a few seconds. Another disadvantage is that fMRI is laboratory bound and fNIRS only reaches approximately 3 cm deep into the brain (Kübler, 2019).

Positron emission tomography (PET)

Positron emission tomography (PET) is an imaging technique that uses radioactive substances to visualize and measure metabolic processes in the brain and the human body. PET is mainly used in the area of medical imaging for detecting or measuring changes in physiological activities like metabolism, blood flow, regional chemical composition, and absorption, and therefore, it is also called a functional imaging technique. The PET method uses radioactive materials for imaging. A tracer is injected into the body, which gets trapped within the tissues of interest. The unstable nucleus of radio-ligand emit positrons, which combine with neighbouring electrons to produce gamma rays in the opposite direction at 180 degrees to each other. These gamma rays are detected by the ring of detector placed within the donut-shaped body of the scanner. The energy and location of these gamma rays are recorded and used

by a computer program to reconstruct three-dimensional (3D) images of tracer concentration within the body.

In modern PET computed tomography scanners, PET images are often reconstructed with the aid of a computed tomography X-ray scan performed on the patient during the same session, in the same machine. PET imaging is best performed using a dedicated PET scanner. It is also possible to acquire PET images using a conventional dual-head gamma camera fitted with a coincidence detector. The quality of gamma-camera PET imaging is lower, and the scans take longer to acquire. However, this method allows a low-cost on-site solution to institutions with low PET scanning demand.

Alternative methods of medical imaging include single-photon emission computed tomography (SPECT). SPECT is an imaging technique similar to PET that uses radio ligands to detect molecules in the body. SPECT is less expensive but provides inferior image quality than PET.

Magnetoencephalography (MEG)

Magnetoencephalography (MEG) is a functional neuroimaging technique for mapping brain activity by recording magnetic fields produced by electrical currents occurring naturally in the brain, using very sensitive magnetometers. Arrays of SQUIDs (superconducting quantum unit interference devices) are currently the most common magnetometer, while the SERF (spin exchange relaxation-free) magnetometer is being investigated for future machines. Applications of MEG include basic research into perceptual and cognitive brain processes, localizing regions affected by pathology before surgical removal, determining the function of various parts of the brain, and neurofeedback. This can be applied in a clinical setting to find locations of abnormalities as well as in an experimental setting to simply measure brain activity.

In research, MEG's primary use is the measurement of time courses of activity. MEG can resolve events with a precision of 10 milliseconds or faster, while functional MRI (fMRI), which depends on changes in blood flow, can at best resolve events with a precision of several hundred of milliseconds. MEG also accurately pinpoints sources in primary auditory, somatosensory, and motor areas. For creating functional maps of human cortex during more complex cognitive tasks, MEG is most often combined with fMRI, as the methods complement each other. Neuronal (MEG) and hemodynamic (fMRI) data do not necessarily agree, in spite of the tight relationship between local field potentials and blood oxygenation level-dependent (BOLD) signals. MEG and BOLD signals may originate from the same source (though the BOLD signals are filtered through the hemodynamic response).

MEG is also being used to better localize responses in the brain. The openness of the MEG setup allows external auditory and visual stimuli to be easily introduced. Some movement by the subject is also possible as long as it does not jar the subject's head. The responses in the brain before, during, and after the introduction of such stimuli/movement can then be mapped with greater spatial resolution than was previously possible with EEG. Psychologists are also taking advantage of MEG neuroimaging to better understand relationships between brain function and behaviour. For example, a number of studies have been done comparing the MEG responses of patients with psychological troubles to control patients. There has been great success

isolating unique responses in patients with schizophrenia, such as auditory gating deficits to human voices (Cui, Cunnington, Beisteiner, Deecke, 2012). MEG is also being used to correlate standard psychological responses, such as the emotional dependence of language comprehension (Magnetoencephalography, Wikipedia, 2020).

Electrooculography (EOG)

In 1989 report was given on control of a mobile robot by eye movement using Electrooculography (EOG) signals. A mobile robot was driven from a start to a goal point using five EOG commands, interpreted as forward, backward, left, right, and stop. The EOG as a challenge of controlling external objects was presented by Vidal (1973).

Forecast

A new study from Juniper Research[1] predict good news for Brain-Computer Interfaces (BCI) and has found that global hardware sales revenue from BCI will reach $19 billion per annum by 2027, up from an estimated $2.4 billion in 2018. BCIs bridge the gap between technology and the brain, interpreting brain signals for the purpose of interpretation or control. Research is continuing to improve the quality of BCIs so that they can be ready to use for the general public in a few years.

The research found that the greatest impact of BCIs will be when used for concentration monitoring, where EEG (Electroencephalogram) technology can be leveraged to monitor fatigue. This is crucial for industrial businesses, which strive to improve safety and productivity. Juniper predicted that heavy industry will use EEG to replace more expensive existing monitoring systems. Research author Nick Maynard explained: "EEG is more accurate than current wrist-based optical sensors for concentration monitoring, so adoption where concentration is crucial in high-risk environments is anticipated to be a big driver in the market."

The research found that while shipments of BCI devices for consumer uses such as guided meditation account for a very low proportion of device shipments presently, of under 1% in 2018, the proportion will climb to over 6% of a much larger market in 2027. Juniper predicted that technology advancement in tandem with consumer virtual/mixed-reality uptake would facilitate new interface paradigms when integrated. This higher proportion will be aided by the lower average sales price of these devices, just $270 in 2027, compared to $11,570 in the medical area.

CONCLUSION

A Brain-Computer Interface (BCI) is a connection system between the brain and a computer. It therefore offers the user the possibility of performing tasks without the intermediary of the peripheral nerves. Therefore, it is mainly intended for medicine for the treatment of people with disabilities. There are many examples - a subject with a prosthesis can control the movements of the latter with his thought, like a person who has never lost his limbs. Likewise, BCI makes it possible to speak and write through computers using neurons.

[1] Juniper Research is an analyst house that focuses on digital technology markets, providing reports, consulting, technology, trends and forecasting. Available: https://www.juniperresearch.com.

It's not just the suffering who can benefit from BCI. Indeed, they are also useful for the general public. Gamers can for example get a unique gaming experience using these systems. What could be better than having a brain controller? In short, BCIs seem to embody the future of virtual reality and mixed reality. You just have to wait until the project is completed and it is fully functional.

The BCI is somewhat of a miracle product of computing and science. However, it also requires effort on the part of the person who uses it and who wishes to use it more easily. Indeed, it takes adaptation time and exercises to refine the control of the system which operates in a closed loop. This means that when you first use it, the subject will not immediately master everything. He/she will have to observe the results of his brain commands and apprehend the beast until the manipulation becomes automatic. A bit like a baby who discovers the world, the person will gradually tame his/her different capacities.

However, studies have shown that 30% of the world's population is currently unable to control BCIs. This is pushing researchers to work on improving the system so that the devices can finally hit the market. BCI can open many doors. You just have to wait until everything is developed to take advantage of it. By waiting, we can already save because the price of a consumer device would be estimated at around 300 euros (Megabyte, 2020).

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Athletes vs. bloggers: influence on purchase preferences of the Generation Z

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ABSTRACT
The paper deals with the comparison of the impact of the use of athletes and bloggers in marketing communication on purchasing preferences of individuals which belong to the so-called Generation Z. There are two interdependent methods used for the research. The first of these methods is a questionnaire survey, which includes 508 respondents. 32 respondents separated in two groups attended the second method, which is a focus group. The research results show that athletes influence the behavioral intentions of members of the Generation Z more than bloggers in every researched sphere. The main difference in effectivity is clear from the comparison between both groups by respondents.

KEYWORDS
marketing communication; shopping behaviour; reference group; Generation Z; sports celebrity; influencer

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INTRODUCTION AND THEORETICAL BACKGROUND

Knowing the customer is one of the cornerstones of an organisation's success. Nowadays, it is essential for firms to know what target groups to aim at, and what their characteristics and shopping preferences are. To a certain degree, knowing the customer allows brands to work on influencing the shopping preferences of the customer. One way to do that is to enter into cooperation with a famous person capable of attracting the attention of the customer and exerting a tactical influence over the customer's decision-making. An interesting group that firms often cooperate with is sports celebrities. Nowadays, they no longer promote sports goods only; they also appear in advertisements for companies producing, for instance, cars, clothes, electronics or cosmetics.

Numerous studies have been carried out on the influence sports celebrities exert over the shopping preferences of various age groups in the last years – especially the young, promising generation (Sassenberg, 2015; Sassenberg et al., 2018; Düsenberg, de Almeida, de Amorim, 2016; Hameed, Madhavan, 2017; Liu et al., 2016; Dugalić, Lazarević, 2017). Some studies carried out by international authors are also worth mentioning: Bush, Martin, Bush (2004), Dix, Phau, Pougnet (2010), Shuart (2007), Koernig, Boyd (2009), Simmers, Damron-Martinez, Haytko (2009), Baig, Siddiqui (2012).

Nevertheless, a direct comparison with a different referential group could offer an interesting perspective on the influence of sports celebrities on shopping preferences. That is the reason why this research compares the influence of sports celebrities and bloggers – two significant referential groups of the adolescent generation.

Casaló, Flavián, Ibáñez-Sánchez (2018) claim that influencers, e.g. among bloggers, can be considered opinion-leaders. The study conducted by Uzunoglu, Kip (2014) uses the term "digital opinion-leader". It is social networks that transform the perception of opinion-leaders able to exert a faster, space- and time-unlimited influence over others, says Jungnickel (2018). The content is not only created by media houses, but also by firms, organisations and even individuals who strive to inform the public and participate in forming the public's attitudes.

Celebrity Endorsement

Celebrity Endorsement is defined as a kind of an advertisement campaign featuring a famous person using their fame to promote a product or a service (Lee, 2016). Dacko (2008) claims that the term "Celebrity Endorsement" has now become more wide-spread than the formerly superior term "Celebrity Marketing". At the moment, it is a term covering all activities performed by celebrities in marketing communications.

Khatri (2006) says that within Celebrity Endorsement, famous people make use of their name and fame in order to promote a product and a service in an area that does or does not fall within the field of their expertise. Smith (2008) also mentions the possibility of making use of a celebrity to improve the company's image: "*Marketing support appears at the moment when a well-known celebrity and/or an athlete makes use of their fame in order to help a company sell its products. They can also make use of their name to improve the image of the company, its products or brand.*" In today's colourful

marketing, the brand's and the company's image is one of the important aspects for catching the attention of the young generation consumers, says Voracek (2015).

Based on the focus of a given research, the theoretical background of Celebrity Endorsement relates in particular to sports celebrities that are popular among the public, that the public often associates with, that the members of the public often support as their fans and identify with them in certain aspects (Kahle, Riley, 2004). Athletes, unlike other celebrities, do not only depend on their media representation, but also on their sports results (Stevens, Lathrop, Bradish, 2003). Athletes deserve to be admired in particular thanks to their athletic skills and the success achieved (Liu et al., 2016; Dugalić, Lazarević, 2017). Publicly-known celebrities attract media coverage which presents them to the wide public (SSassenberg et al., 2018).

Influencer Marketing

A similar form of marketing communication is a cooperation with influencers able to reach hundreds of thousands of individuals on social networks (Dhanesh, Duthler, 2019; Kapitan, Silvera, 2016). Just as the development of modern technologies, the internet and the access thereto is accelerating, so is marketing – especially its digital part (Silva et al., 2020). Over the past years, the on-line environment has been offering interesting trends in reaching out to the customer, either through PPC ads, SEO, social networks and/or Influencer Marketing (Caslavova, Voracek, 2019).

Influencer Marketing means: "*the art and science of influential people participating in the on-line environment who can share information about a brand with their audience by means of sponsored content*" (Sammis, Lincoln, Pomponi, 2016, p. 7). It is an entire strategy based on the use of an influencer and their influence over their followers with the aim of promotion and an increase in sales (Baker, 2017). Similarly to Celebrity Endorsement, Influencer Marketing is based on the fame of a given person and their influence over their fans (Kapitan, Silvera, 2016). The Forbes magazine has even labelled influencers as the modern celebrity endorsement and regards their work as building one's own brand (Weinswig, 2016; Voracek, 2019). Influencer Marketing is essentially specific in that it is about the relationship between the influencer and the follower based on their similar interests, opinions and trust (Torres, Augusto, Matos, 2019). Novotny (2017, p. 41) specifically pinpoints trust in the relationship, as Influencer Marketing: "*represents a unique and honest relationship between consumers, brands and influencers*". Thanks to the trust between the influencer and the consumer, Influencer Marketing is a unique and modern tool to reach goals such as brand building, increasing the awareness about a product or gaining new followers on social networks (Torres, Augusto, Matos, 2019). Consumers trust recommendations made by their family and friends (Chuang, Cheng, Hsu, 2012). Sammis, Lincoln, Pomponi (2016) claim that thanks to the influencer's personal attitude, followers view influencers as friends.

Social networks have brought the word-of-mouth practise back to life and thanks to on-line influencers; it can be used on an enormous scale (Scott, 2015; Waller, 2016). In order for the brands to target their potential consumers well, they must first target opinion-leaders well (Kapitan, Silvera, 2016). It is them who become the intermediaries between the brand and the consumer and them who share their experiences and opinions (Cramer, 2017). Prikrylova, Jahodova (2010) also perceive Influencer

Marketing as identifying and influencing opinion-leaders with the ability to influence the opinions of others. It is the adolescents in particular who describe their favourite youtubers as being similar to themselves, sharing the same interests, being honest and giving good advice (Torres, Augusto, Matos, 2019).

Abidin (2016) says influencers are "micro-celebrities" who gain their followers on blogs and social networks, and create content with the help of textual and visual story-telling featuring personal stories. The term "influencer" used to be primarily used for bloggers or vloggers (De Veirman, Hudders, Nelson, 2019). At the moment, influencers are active on various platforms such as Facebook, Youtube, Instagram, TikTok and Twitter (De Veirman, Hudders, Nelson, 2019). They either use one of the platforms or combine more of them (De Veirman, Hudders, Nelson, 2019). In his article, Pophal (2016) highlights the vast applicability of the term "influencer" – it is not only famous bloggers and celebrities who can be one. Anyone adding content to social media and influencing followers, be it only a small circle, can be an influencer (De Veirman, Hudders, Nelson, 2019; Pophal, 2016; Abidin, 2016). For the purpose of this research, the term "blogger" is synonymous to the term "influencer", the primary activity of whom is to create content on social media and/or blogs.

There are various categories of influencers based on their interests, for instance: lifestyle, fashion, travelling, fitness and sport, beauty, art, games, education and many more (Levine, 2017). To strike up cooperation with a mega-influencer means not only securing an advertisement for the company, but also gaining a certain prestige and potential to significantly increase sales (Davis, 2019).

The consumers themselves choose what, where, and when they want to follow (Debroff, 2016). Voluntary following and seeking information provided by influencers is a strong part of Influencer Marketing (Lou, Yuan, 2019). This is also why Influencer Marketing is the fastest growing tool for gaining new customers in the on-line environment (Odell, Wiley, Talamantez, 2016). It can lead to consumer participation up to 16 times higher than with the traditional forms of paid media (Odell, Wiley, Talamantez, 2016).

If the potential of Influencer Marketing is well-harnessed, it can function as a cost-effective marketing type that can be a source of creative content with the possibility to reach specific target groups in a natural way (Waller, 2016).

For the purposes of this research, anyone with an influence exerted over other individuals and with an active presence on social media can be an influencer.

Generation Z

Similarly to the case of other generations, the experts, too, do not exactly agree on the birth years of individuals belonging to Generation Z. For McCrindle (2014), Generation Z comprises young people born between the years 1995–2009. Fry, Parker (2018) expand Generation Z by including individuals born between 1997 and 2012, that is people aged 8 to 23 in 2020. Nevertheless, they (Fry, Parker, 2018) immediately add that the 16-year-long range may change in the future, depending on the changes within the generation and its crystallisation. There is something more important than an exact definition of birth years – values, social behaviour and attitudes characteristic for Generation Z, which shall serve as a basis for further stabilisation of the time range (McCrindle, 2014; Fry, Parker, 2018; Seemiller, Grace, 2016).

One of the most significant factors influencing Generation Z is, no doubt, modern technology and access thereto (Seemiller, Grace, 2016). Post-Millennials, a name also used for Generation Z, were born into a digitalised world offering them more open access to various modern technologies from a very young age (Seemiller, Grace, 2016). It is the first generation that has not experienced the times without mobile devices or the internet (Bergh, Behrer, De Maeseneire, 2016). Modern technology is a common part of their every-day life (Bergh, Behrer, De Maeseneire, 2016). The way they perceive modern technology, the presence of which they take for granted, has earned them the name "digital natives" (Koulopoulos, Keldsen, 2016). According to Stillman, Stillman (2017), another specific aspect regarding modern technologies is the fact that the young generation perceives even physical aspects – e.g. places and people – in a digital sense.

Some literary sources offer the name "iGen" for the generation examined, with the name comprising, on the one hand, the pronoun "I", reflecting the self-centeredness of the individuals, and, on the other hand, referring to the internet and to the Apple smart phone owned by as many as two out of every three American teenagers (Rosen, 2010; Twenge, 2017).

Generation Z members tend to have older parents, which means better financial and property stability for them. In this case, the parents often belong to the X or Y Generations and raise their offspring to be individualistic; they support them and remind them to have a realistic view of the world and to find their own ways (Sladek, Grabinger, 2018). Even though Generation Z is still only coming of age, the research of Sladek, Grabinger (2018) shows that, for now, they are well financially-educated. The majority of young people find the time to search for reviews on products and consequently to search the internet to find the best and the most cost-effective option (Sladek, Grabinger, 2018). The young people can search for reviews on websites designated for this purpose, on on-line store websites, but also on social media where they can be exposed to the influence of their friends and their favourite influencers (Sladek, Grabinger, 2018).

RESEARCH OBJECTIVE

The main research objective is, with the use of a marketing research, to compare the levels of influence of athletes and bloggers exerted over the shopping preferences of the members of the so-called Generation Z.

METHODOLOGY

The research makes use of both quantitative and qualitative methods. The quantitative part is designed to bring results with measurable data. The quantitative data shall also serve to generalise the results of the research. The second part of the research supplements the data by a qualitative perspective intended to discover the causes of the present state. The research connects both types of the research for the purpose of an overall assessment of the issue examined.

A questionnaire survey has been chosen for the purpose of the quantitative method of the research. The basic tool thereof is a questionnaire containing a statement with

the respondents rating the level of agreement thereon by using a 5-point Likert scale (1 – strongly disagree, 5 – strongly agree). Furthermore, the questionnaire contains three open questions regarding cooperation with bloggers and athletes.

The construction of the whole questionnaire divides the items of the issue examined into 5 dimensions. Specifically, it relates to the purchase intention, to the positive word-of-mouth, or else a positive verbal communication, to the brand loyalty (Bush, Martin, Bush, 2004), to the harmony and trustworthiness, and finally to the area of comparison, where the respondents have three statements where they choose the side of the athlete or the influencer. The individual items of the questionnaire are provided in Appendix 1.

The questionnaire has been made in two modifications, one is focused on statements and questions regarding sports celebrities, the other is focused on bloggers. The individual questions and statements are the same, only the subject of the focus thereof is either an athlete or an influencer.

508 respondents took part in the questionnaire survey. For the purpose of ease of reference, in regard to the two modifications of the questionnaire, Table 1 has been created to display the number of respondents in view of the modification of the questionnaire and of the gender. The first version of the questionnaire is focused on questions and statements regarding the influence of athletes (in the Table and hereinafter referred to as the "ATHLETE"); the second version, on the other hand, is focused on the influence of bloggers (in the Table and hereinafter referred to as the "BLOGGER").

Table 1 Respondent Structure

	ATHLETE		BLOGGER	
Variants	**Absolute size**	**Relative size (%)**	**Absolute size**	**Relative size (%)**
Male	147	57.87	152	59.84
Female	107	42.13	102	40.16
Total	254	100	254	100

The number of respondents in both modifications of the questionnaire was 254; the total number was, therefore, 508 respondents. Men represented a bigger proportion of the respondents, nevertheless their number did not exceed 60%.

The second research method was a focus group. The order of the methods has been selected purposefully so that the discussion follows the questionnaire survey and the data collected therein. The first group comprised 18 respondents (15 women and 3 men); the second group comprised of 14 male respondents. The total number of participants of the focus group was 32 respondents – 15 women and 17 men.

RESULTS

Specific results of the influence of athletes and influencers on the shopping preferences are divided into chapters corresponding to the individual dimensions of the questionnaire.

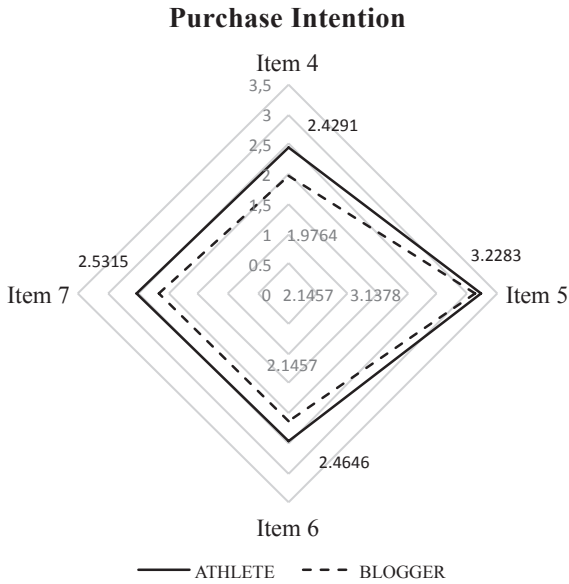

Figure 1 Mean values of the area of the Purchase Intention

Purchase Intention

The respondents agreed with the statements more when the subject was an athlete (see Figure 1). It can be stated that the respondents' purchase intention is higher if the brand and/or the product is connected to the name of an athlete rather than a blogger.

Unlike in the case of the questionnaire survey, the group discussion respondents (focus groups) were more open to purchasing products on the basis of recommendations made by bloggers. A few of the participants of both of the discussion groups admitted purchasing a product thanks to an advertisement seen presented by influencers. The Generation Z chapter states that the individual tends to think their purchase through and to make rational decisions, as is apparent from this contribution to the discussion: "*I do not simply buy something just because I saw it being praised on Instagram. I like to find out some information about the product beforehand, its pros and cons*" (a man, discussion group No. 1). The respondents share a similarly rational view of cooperation with athletes.

Positive Word-of-Mouth

With regard to the research sample of individuals, the whole area of positive verbal communication has proven higher effectiveness of using athletes within marketing communications (see Figure 2). The respondents lean more towards the effective-

ness of a product promoted by an athlete rather than a blogger. In a similar fashion, they also notice that the popularity of the celebrity is transferred onto the product. In a more varying degree, they take more pleasure in purchasing a product promoted by an athlete rather than a blogger. The results of the Word-of-Mouth dimension depict the fact that the respondents have a higher tendency to give more positive feedback on a cooperation of brands with athletes rather than bloggers which is most visible in Figure 2 at the mean values of the item No. 11.

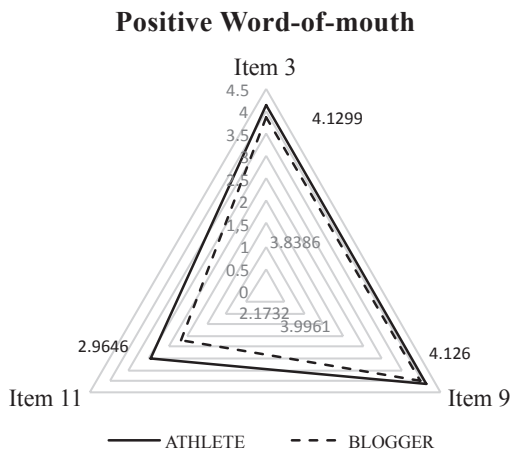

Figure 2 Mean values in the Positive Word-of-Mouth area

The comments in the discussion groups supported the results of measuring the item regarding the negative impact of the blogger's image on the product. The respondents also stated that they discuss some videos with friends and that they themselves, for instance, review products that are the subject of the videos. The participants are of the opinion that in the case of the athlete's influence, their sports results play an important role.

Brand Loyalty

The items within the Brand Loyalty dimension showed a significantly higher influence of neither the athletes nor the bloggers on the shopping preferences of the respondents. The athletes show a slightly higher influence on the shopping preferences of the individuals examined.

The area of Brand Loyalty is also connected to the ability to recall a brand using Celebrity Endorsement and/or Influencer Marketing. Based on the results of item No. 14, it can be assumed that the consumers in the age group examined tend more to recall a brand that is connected to an athlete rather than a blogger. On the other hand, however, the respondents mentioned more names of brands in connection to influencers, as depicted in Figures 3 and 4. The brands mentioned most often in both of the modifications belong among sports brands. The absolutely most often appearing brand was the sports brand Nike with 53 mentions in the ATHLETE modification and 9 in the BLOGGER modification. The second most often mentioned brand was the company

Adidas with 25 mentions in the ATHLETE modification and 12 in the BLOGGER modification. The majority of the brands come from abroad, which refers to their financial capacities and the possibility to enter into cooperation with famous faces.

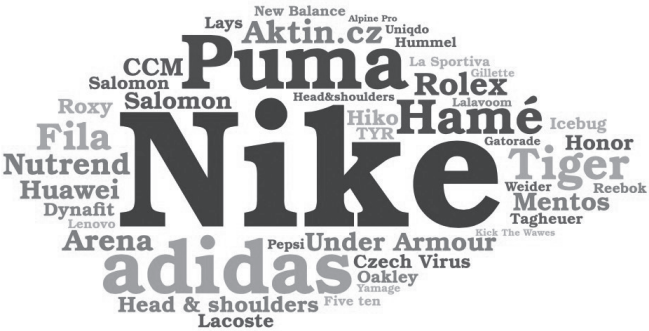

Figure 3 Answers to item No. 14 – ATHLETE

Figure 4 Answers to item No. 14 – BLOGGER

The focus group shows that in some cases the respondents do not tend to purchase a product of the brand promoted, but they start to notice it more. The discussion participants prefer long-term cooperation and negatively perceive one blogger promoting competing brands within a short-term period.

Harmony/Trustworthiness

The values of three items from the Trustworthiness dimension suggest an important interconnection of a celebrity and a product they promote (see Figure 5). Brands should thus focus on cooperating with celebrities who harmonize with the product, who will actually make use of it and promote it based on their personal experience with it. The name of the celebrity is similarly important as it can influence the consumer to alter their opinion. This area has given rise to the fact that the respondents show a slightly higher degree of trust to advertisements featuring athletes.

Generation Z individuals, who took part in the discussion groups, were sceptical towards the blogger-brand cooperation. They claim to not let themselves be influ-

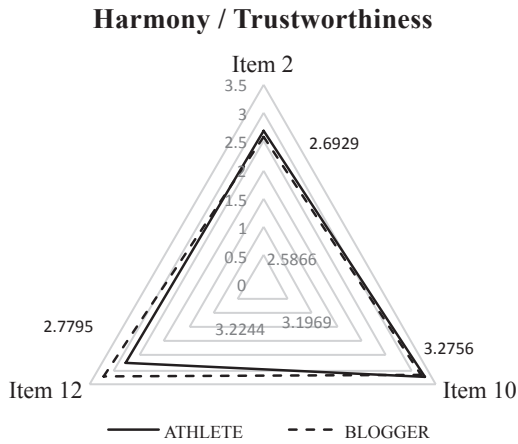

Figure 5 Mean values of the area Harmony/Trustworthiness

enced by Influencer Marketing and to be of the opinion that advertisements are aimed at younger people more. If the respondents cannot see the results of using the product, they do not trust it. They realise that the nature of the cooperation is a paid cooperation and they regard the products as such. On the other hand, the respondents think that athletes truly do use the products promoted and thus the respondents trust them more. This relates to the fact that the participants think that thletes should promote products they understand and that fall within the area of their interest.

Comparison

The complete Figure 6 of the mean values relating to the dimension of Comparison implies that the respondents trust athletes more, and more likely let themselves be persuaded by athletes. The lower the mean value, the more the respondents inclined to select the answer Athlete. Answers of a similar value in both modifications of the

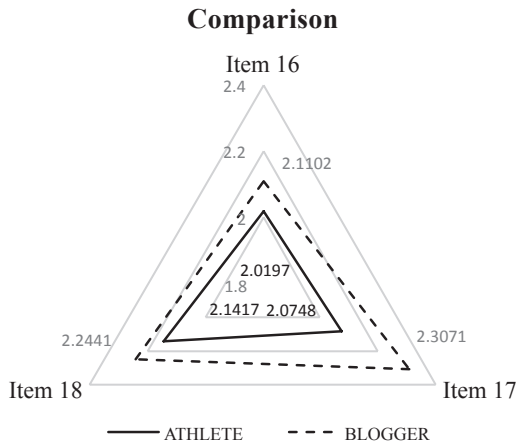

Figure 6 Mean values of the area of Comparison

questionnaire indicate that the respondents are truly more likely to be persuaded by athletes making the results thus reliable. The results of the measuring perhaps result from the fact that athletes mostly tend to promote sports brands and the consumers can be persuaded that the given products are actually used by the athlete during races and matches. Athletes also do not tend to change the brands they promote and continue to support the brand for more than one season. Bloggers, on the other hand, more often cooperate with various firms, which can mean less transparency for the respondents.

DISCUSSION

The respondents often have their favourite athletes and bloggers whom they follow on social networks. The focus group participants follow athletes because of the attractiveness of the sports environment, because of the attempt to become better at sports and because they are the athlete's fans. They follow bloggers to be inspired and entertained. For these reasons, it can be inferred that the respondents view athletes as heroes with sports achievements. Therefore, advice provided by athletes can be perceived as more important. Shuart (2007), Stevens, Lathrop, Bradish (2003) say that this perception of athletes underlines their position as heroes. Bloggers rather act as friends, encountering the same problems their followers do, as stated by Sammis, Lincoln, Pomponi (2016). An advantageous fact for bloggers is that the advice given by friends is very valuable for teenagers. Nevertheless, it is up to each athlete and blogger to make use of this disposition to strengthen the trust and their name overall. The results of the questionnaire survey imply that in marketing communications of firms, famous celebrities from the sports environment exert a more effective influence over the respondents than bloggers do. The comparison part of the questionnaire clearly shows a higher trustworthiness of athletes when presenting products. This trend has also been proven in the discussion groups. The respondents are of the opinion that the use of a product can be more likely verified by an athlete rather than an influencer.

The survey participants are more likely to buy a product on the basis of a recommendation made by an athlete rather than a blogger. However, this fact is dependent on specific cases of the athlete's way of use of the product. The majority of the respondents prefer athletes in advertisement campaigns focused on the sports sector, or else nutrition and other areas of the athlete's activity. This relates to the persuasiveness of the advertisement. Bloggers more often present products that they, at the first sight, do not use or which do not fall within the area of their interest – which decreases the persuasiveness of the campaign and the blogger's influence. This relates to the fact stated by Waller (2016), saying that the target group should be reached in the most natural – and persuasive – form possible. Even in the case of persuasiveness, the majority of respondents incline towards athletes.

Approximately one half of the respondents, pursuant to the questionnaire survey, are more likely to be influenced to purchase a product promoted by an athlete and/or an influencer. This corresponds to the fact of how many respondents have already purchased a product on the basis of an advertisement made by an athlete and/or an influencer. However, the respondents definitely see the effectiveness of using famous faces in advertising campaigns and think that they influence the consumer. In this regard,

the respondents themselves admit to being influenced, as presented in various studies on the previous Generation Y (Bush, Martin, Bush, 2004; Dix, Phau, Pougnet, 2010; Shuart, 2007; Koernig, Boyd, 2009; Simmers, Damron-Martinez, Haytko, 2009; Baig, Siddiqui, 2012; Voracek, Caslavova, 2019). These contradictory statements may imply that the respondents do not want to be in the role in which they can be influenced or controlled by others. Another fact can work in a similar fashion here in that the respondents do not always knowingly recollect the connection between the product purchased and its promotion by an athlete or a blogger. This is confirmed in a study conducted by Voracek, Caslavova (2019). Even though the overall answers do not give the impression of a straight-forward effectiveness in using famous celebrities in advertisements, the results imply a higher effectiveness and a greater influence of athletes. The results acquired can prove greater familiarity with brands in the area of Celebrity Endorsement and that athletes are used more than bloggers. Influencer Marketing is a rather young marketing channel which is developing at a dynamic pace and firms do not yet have much experience with it. Nonetheless, there has been some evident dynamic development (Caslavova, Voracek, 2019; Weinswig, 2016; Voracek, 2019; Dhanesh, Duthler, 2019; Kapitan, Silvera, 2016; Silva et al., 2020; Baker, 2017; etc.).

The bloggers themselves are still learning how to approach the advertising cooperation and it often takes place in the absence of an intermediary who would provide advice to both parties. This especially concerns the micro-influencers, as described by Abidin (2016), as well as Jungnickel (2018). In this case, athletes make use of their managers who have been pursuing the issue examined for a long time and can thus provide suitable recommendations.

It can be stated that the cooperation between brands and famous celebrities provides for a higher awareness of the brand. The respondents remember it better and, when selecting a product, they are likely to include it among the items they consider. To help spread the name of a brand, it is suitable to enter into a cooperation with a face that the target group knows well. It is the fame and image of a brand that Voracek (2015) regards as very important.

The research shows interesting findings which open the doors for further studies of the issue of using athletes and bloggers in marketing communications of firms.

This area would benefit from a discovery of individual areas in which athletes influence the consumer and vice versa. Further research questions could also be concerned with the athletes themselves, e.g. what aspects the respondents view as giving rise to the trustworthiness of the athlete. Various communication channels could be yet another point of interest. Generation Z makes use of the most various communication channels and some can be more attractive and influential than others.

CONCLUSION

Although Generation Z is still being formed, in a few years' time, it will belong among the strongest economic groups. The sample of 508 respondents took part in the questionnaire survey performed and 32 respondents took part in the group discussions within the research conducted. The data collected show the fact that the respondents take notice of commercial messages featuring athletes and bloggers and generally regard them as effective. They even see it as beneficial to have the option of getting

to know more about a product, to see the product in action and to see it compared with other alternatives. Despite a small proportion of respondents admitting to have bought some product on the basis of an athlete's or a blogger's recommendation, they do not think that they are fundamentally influenced by this kind of advertisement. The contradictory answers in some of the areas most certainly did not overshadow the comparison part of the research, which has presented interesting observations. When young people compare the two groups of famous celebrities, the answers quite clearly agree on athletes being more trustworthy. The trust relates to the persuasiveness that is yet again found more often with athletes rather than with bloggers. The majority of the respondents are more likely to purchase a product which is promoted by their favourite athlete. The results show a higher effectiveness in making use of athletes rather than bloggers in marketing communications.

In order to retain or to increase the effectiveness of athletes and bloggers in commercial messages, it is necessary to, in particular, take account of the harmony between the products and the celebrity. The respondents like to believe a promoter in case that it is obvious that the product is used by them and that they are content with it. It is the use of the product that is one of the factors that make the respondents tend to trust athletes more. By using a product, the celebrity also shows that they understand the product to a certain degree and that they use it for the purpose the product is intended for. This knowledge leads to the celebrity being perceived as someone who can recommend the product. The research is only peripherally concerned with the issue of making use of bloggers and athletes as celebrities promoting products. Despite this fact, the research has proven some statements mentioned in expert literature and, at the same time, it has offered a comparison of two different groups that Generation Z looks up to.

Athletes are more likely to exert influence over young people. However, it is both athletes and bloggers who can provide for a higher awareness of the brand, for the attractiveness of the brand and for increasing the interest in products. All results depend on the selection of a suitable celebrity and due participation in a specific advertising cooperation.

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APPENDIX 1

Measures of Constructs

1. The presence of an athlete/influencer (blogger, youtuber) in the advertisement helps me to recall and recognize the product.
2. Do you think that athletes/influencers really use the promoted product in real life?
3. Do you think that the cooperation of brands with athletes/influencers is effective?
4. I get influenced to buy a product that the athlete/influencer promotes.
5. Will you be influenced by athlete's/influencer's knowledge when you decide to buy (he/she promotes what he/she understands)?
6. Will the athlete's/influencer's popularity affect you when making your purchase?
7. Have you ever purchased a product based on an advertisement from an athlete/influencer?
8. If your favourite athlete/influencer promotes a product, will it affect you so much that you are willing to pay a higher price for that product?
9. Athletes/influencers can transfer their popularity to a product.
10. The credibility (I believe the product uses) of the athlete/influencer-product connection is important to me.
11. It makes me happy when I buy something that my favourite athlete/influencer promotes.
12. Negative publicity of an athlete/influencer can influence your purchasing decision.
13. Is it important for you that the athlete/influencer indicates advertise in his/her social media posts?
14. Can you recall a brand that a well-known athlete/influencer works with?
15. Write your favourite athletes/influencers that you follow on social networks (Instagram, Facebook, YouTube).
16. When presenting a product, I have more confidence in: Athlete 1 2 3 4 5 Influencer.

17. I would rather buy a product that promotes my favourite: Athlete 1 2 3 4 5 Influencer.
18. Advertising is more convincing to me from: Athlete 1 2 3 4 5 Influencer.

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The effect of a repeated intensive programme in patients with mid-stage Huntington's disease

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ABSTRACT

The purpose of the study was to evaluate the effect of a repeated 1-week intensive programme in patients with mid-stage Huntington's disease on stability and quality of life. 12 patients completed two 1-week programmes, separated by a one-year interval. Each programme consisted of a 120-minute intervention in the form of a fitness exercise, procedures targeting static and dynamic postural stability, procedures of respiratory physiotherapy and orofacial region therapy. The patient completed a total of 4 evaluations using the Sit to Stand Test, Timed up and Go Test and completed the quality of life SF-36 questionnaire. Statistically significant changes have been shown in the Sit-and-stand test in both years. Weaker but still significant changes were found in the TUG test only in the first year, while there was improvement in the second intervention year that was not statistically significant. Evaluation of the quality of life suggested a positive influence of physical activity in the dimensions: restriction caused by emotional problems, somatic pain and change of health. Our results suggest that a repeated, intensive one-week intervention can have a positive influence on postural stability and can contribute to the improvement of some quality of life dimensions in patients with mid-stage HD.

KEYWORDS

quality of life; Huntington's disease; TUG, SF-36, Sit-to-stand; intensive programme

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INTRODUCTION

Huntington's disease (HD) is an autosomal dominant neurodegenerative disorder characterized by a progressive course, usually including motor, cognitive and psychiatric disturbances (Walker, 2007; Munoz-Sanjuan, Bates, 2011). The patient's age at the start of the disease most commonly corresponds to the fourth life decade (Chaganti, McCusker, Loy, 2017), its duration is between 15–20 years. In connection with diagnostic testing the prevalence of HD has increased in recent years, and amounts to 2.71 per 100,000 inhabitants worldwide, being significantly lower in the Asian population (0.40 per 100,000), compared to a prevalence of 5.70 per 100,000 in Western Europe, North America and Australia (Pringsheim et al., 2012; Sheharyar, Strong, Quarrell, 2016).

Since 1996 we have witnessed a growing number of publications on HD, mostly in the fields of neurosciences and neurology, further in the fields of psychiatry, genetics and molecular biology (Barboza, Ghisi, 2018), other specialties being rehabilitation and physiotherapy (e.g. Quinn, Busse, 2017; Drew et al., 2019; Quinn et al., 2020; Busse, et al. 2008). The latter are concerned with finding methods that would influence and/or slow down the increase of HD symptoms. Even though physiotherapy is recommended as one of the treatment, methods in HD reliable studies investigating its efficacy are still missing (Zinzi et al., 2007). As Huntington's disease is limiting, progressive and probably responsible for a set of changes in behaviour, social competency and, last but not least, quality of life (Silva, Lindau, Giacheti, 2015) methods are also being looked for that could positively influence quality of life.

In our study we present a 1-week intense programme we have proposed and repeatedly implemented in a small group of patients with mid-stage Huntington's disease and subsequently evaluated regarding its influence on static and dynamic stability and quality of life. We were interested in whether even a short, but intense programme could contribute to slowing down the increase of some symptoms in HD.

MATERIALS AND METHODS

Subjects

We performed a descriptive intervention study including 12 patients (6 men and 6 women) with mid-stage Huntington's disease. Patients aged between 26–55 years old were included in the study based on recommendation by a physician and the inclusion criteria that included: voluntary participation in the study, aged above 18 years old, both sexes – males and women, disease stage – mid-stage, absence of severe psychiatric disorders, absence of severely damaged general cognitive functions, absence of orthopaedic or traumatology disturbances, and absence of acute diseases. All participants in the programme and their caretakers provided written consent to participate in the programme.

Intervention

Patients attended a 1-week intensive physiotherapy programme (6 days in 2019) and, after one year, participated in the same programme (in 2020), also lasting 6 days. In the period between the programmes, no other programmes were organized for the

patients, and all performed their common accustomed activities as before initiation of the first week of the intensive programme.

The weekly programme in both years consisted of the application of intensive physiotherapy methods, each day 60 minutes in the morning and 60 minutes in the afternoon hours. The physiotherapy programme was completed with music therapy lasting 60 minutes and occupational therapist interventions, lasting 30 minutes in the morning and 30 minutes in the afternoon hours.

The physiotherapy programme included simple and special procedures that were distributed as follows: fitness training 30 minutes in the morning and then 30 minutes of methods influencing static and dynamic postural stability, in the afternoon 15 minutes of respiratory physiotherapy methods, 15 minutes of therapy focussing on the orofacial region, and 30 minutes of postural therapy. The most commonly employed elements were based on the PNF concept (Adler, Beckers, Buck, 2008), the sensorimotor training (Janda et al., 2019), the Brügger concept (Pavlů, 2017) and the manual therapy concept (Lewit, 2009), but also common elements of fitness exercises and breathing therapy. Some of the methods were implemented in the form of individual physiotherapy and some in the form of exercises in small groups.

Outcome measures

To evaluate static and dynamic postural stability 2 simple tests have been selected that were performed in all subjects on the first and last days of the intensive programme. To evaluate the quality of life the SF-36 quality of life test was used, performed also on the first and last days of the programme.

1. Sit to stand test

The Sit to Stand test (Bohannon, 2011; Mong, Teo, Ng, 2010) is used to test dynamic postural stability and lower extremities strength of the patient. The test requires only the use a chair with a backrest, and a stopwatch to measure time. The test starts with the patient sitting on the chair with his back rested. Part of the test is measurement of the time in which the subject is able to stand up and sit back on the chair again. Our evaluation used a modified version with 3 repetitions.

2. Timed up and go test

Timed Up and Go (Nordin, Rosendahl, Lundin-Olsson, 2006) is a simple test used to evaluate mobility of the tested subject, but also the possibility of fall, a static and dynamic stability. As part of the test in which the time is measured the tested subject needs to get up from a chair, walk 3 m, turn around and return back to the sitting position on the chair.

3. SF-36

Patient perception of the quality of life was evaluated using the Czech version of the SF-36 questionnaire (Ware, Sherbourne, 1992; Sobotík, 1998) that consists of 36 questions, divided into and assessing 8 basic dimensions + 1 dimension, i.e. physical activity, restriction of physical activity, restriction caused by emotional problems, vitality, overall mental health, social activity, somatic pain, overall perception of health and change of health.

Statistical analysis

We used the paired one-sided Wilcoxon test to test the effect of the intervention in the form of the sit-to-stand test and timed-up-and-go test, to evaluate the standardized effect in both tests the Cohen's D for paired design was used. The analyses were performed using the R 3.5.3 environment (R Core Team, 2019) and with the aid of the lsr library (Navarro, 2015). Real significance was determined using the following bounds d = 0.2–0.49 (small effect), d = 0.5–0.79 (moderate effect), d ≥ 0.8 (large effect).

In the SF-36 quality of life questionnaire the TS score was calculated (Transformed Scales Score).

RESULTS

1. Sit to stand test

The intensive programme resulted in statistically significant improvement in the sit-to-stand test, both in the years 2019 and 2020 ($p = 0.013$ or $p = 0.006$, respectively) in which the programme was implemented, even when the Bonferroni correction for multiple comparisons was considered ($p = 0.026$ or $p = 0.012$, respectively). In 2019 and 2020 moderate ($D = 0.63$) or large ($D = 0.82$), respectively, standardized effects of the intervention were obtained. The median of improvement in the sit-and-stand test was 1.75 s in 2019 and 1.60 s in 2020 (Graph 1a, Graph 1b).

2. Timed up and go test

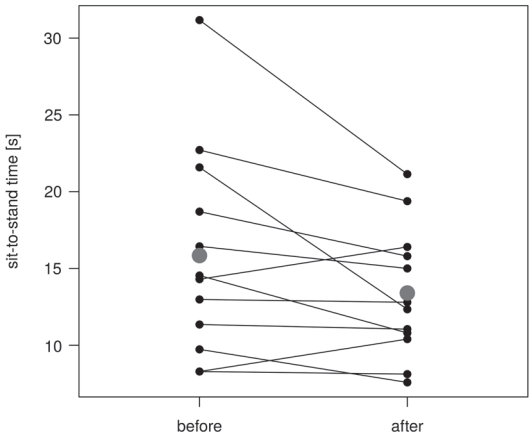
In the timed up and go test there was improvement in both years the programme was implemented. In 2019 the improvement was marginally significant ($p = 0.071$). Improvement in 2020 was significant ($p = 0.034$), or marginally significant when the correction for multiple comparisons was considered ($p = 0.068$). In 2019 the standardized effect was weak ($D = 0.19$) and in 2020 moderate ($D = 0.62$). The median of improvement in the up-and-go test was 0.75 s in 2019 and 0.37 s in 2020. The result from 2019 is a reflection of the fact that most patients experienced mild improvement, but two of them had relatively marked deterioration (Graph 2a, Graph 2b).

3. Quality of life – SF-36

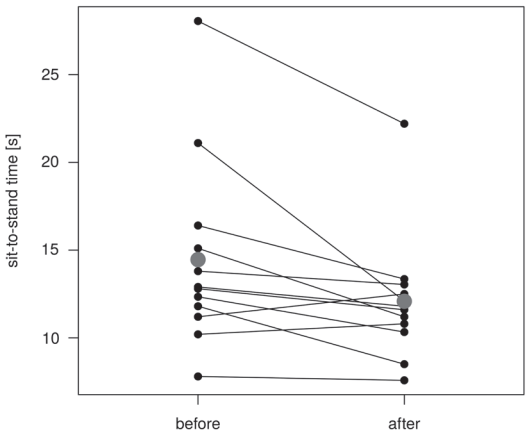
Quality of life evaluation using the SF-36 questionnaire logically demonstrated deteriorations in the dimensions that are related to disease progression, but in the case of three dimensions – Restriction caused by emotional problems, Somatic pain and Change of health – there was improvement in both weeks (repeatedly in both 2019 and 2020) of the administered intervention (Graph 3a, Graph 3b).

DISCUSSION

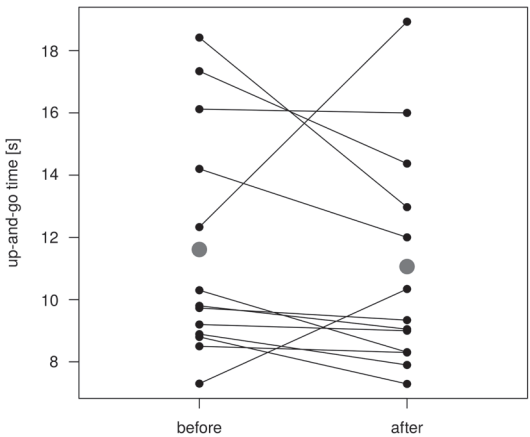
The objective of the presented study was to evaluate the effect of the repeated 1-week intensive programme in patients with mid-stage Huntington's disease. To achieve this objective we administered an intensive physiotherapy programme complemented with occupational therapy and music therapy, the effects of this one-week intensive physiotherapy intervention may have a positive influence on the evaluated static and dynamic postural and quality of life.



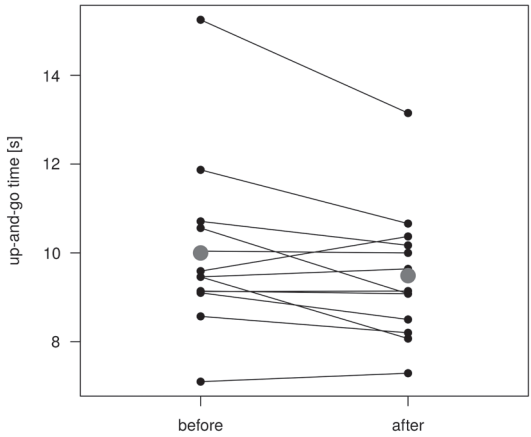
Graph 1a Timed Up and Go Test – comparison of results at the beginning and end of the intervention in 2019 for individual probands



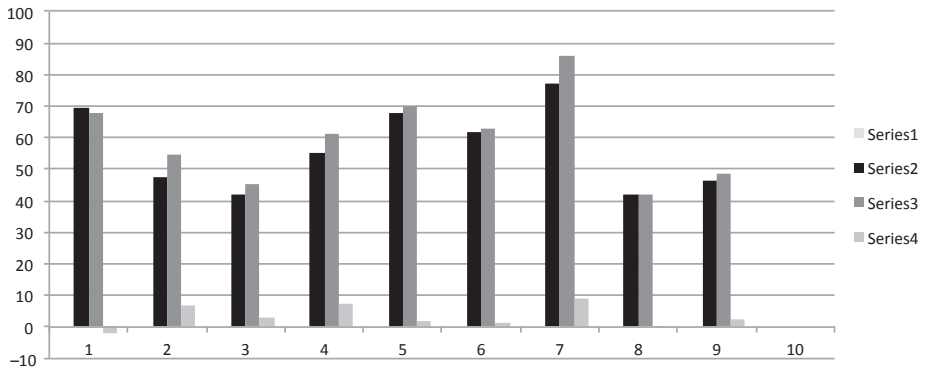
Graph 1b Timed Up and Go Test – comparison of results at the beginning and end of the intervention in 2020 for individual probands



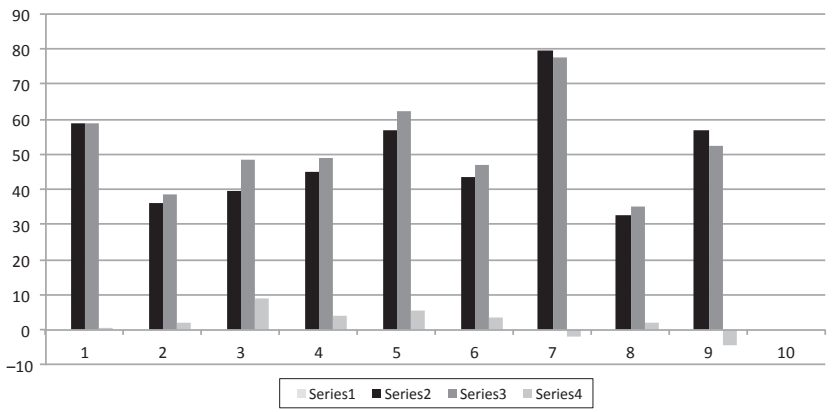
Graph 2a Sit – to Stand Test – comparison of results at the beginning and end of the intervention in 2019 for individual probands



Graph 2b Sit – to Stand Test – comparison of results at the beginning and end of the intervention in 2020 for individual probands



Graph 3a SF36 – comparison of results in 9 dimensions, at the beginning and end of the intervention in 2019 (N = 12)



Graph 3b SF36 – comparison of results in 9 dimensions, at the beginning and end of the intervention in 2020 (N = 12)

The intervention programme applied in the study was composed based on our previous experience (Novotná, Nováková, Pavlů, 2019; Novotná, Pavlů, 2019) where we succeeded in influencing some neurological symptoms in patients with mid-stage Huntington's disease, primarily with targeted therapy. The therapy influenced mobility and ability to walk, the ability to cope with ADL, including the rehearsal of swallowing with orofacial therapy.

The intervention procedures we used correspond to the recommended or already applied procedures in a number of other studies. Aerobic exercise performed separately or in combination with resistance training as recommended e.g. by Quinn et al. (Quinn et al., 2020) had the form of the fitness training in our study, as was the case of walk training. As an essential element to include, in agreement with a number of other authors (e.g. Fritz et al., 2017) are procedures of respiratory physiotherapy. In view of time limitations, however, our study did not evaluate respiratory parameters.

Several previous studies demonstrated or suggested positive effects of an intensive physiotherapy/rehabilitation programme (Piira et al., 2013). Specific programmes, however, were implemented over the course of very long periods of time – 1–2 years. Our study is unique in pointing to the possibility to obtain a positive effect on repeated occasions consisting in influencing the static and dynamic postural stability in a short time period – one week.

To evaluate stability we used only two Sit to stand test and TUG that we consider to be easily implemented and also appropriate in view of the common patient daily activities. Studies concerned with evaluation of the training effect on motor function often use, in addition to the tests we have used, the Berg Balance Scale (Mueller, Petersen, Jung, 2019), the Six Minute Walk Test (Piira et al., 2013) that are unequivocally suitable outcome measures, but their implementation requires more time. The tests we have chosen can be well accomplished in a situation when the entry measurement must be managed during the first day of initiation of the intervention as part of our programmes as well as a final measurement on the last day of the programme.

To evaluate quality of life we used the SF-36 questionnaire that appears to be suitable and is recommended also for patients with various stages of HD and exhibits convergent validity and reliability for patients and care takers (Aileen et al., 2004; Mestre et al., 2018). It was not the primary objective of our study to evaluate the quality of life of its participants as is the case in commonly available studies (e.g. Dorey et al., 2016). Instead we evaluated possible effects of an intensive intervention on maximizing functional mobility of patients, and thereby aim to support their quality of life. The results have shown that most of the dimensions evaluated in the quality of life questionnaire showed deterioration or no change, which can rather be expected in the setting of continuing disease progression, but nonetheless we have still repeatedly demonstrated improvement in the case of three evaluated dimensions that reflect the influence of movement activity in both 2019 and 2020.

Our work has some limitations. The study included a relatively small number of subjects and had no control group, similar to a number of other studies of patients with the diagnosis of M. Huntington (e.g. Dawes et al., 2015; Kloos et al., 2012). Clinical studies, however, often include patients with relatively small samples due to difficult access to study subjects / patients who would exhibit the same or a similar specific set of symptoms, which is also a problem in the case of HD. But in spite of the above we

regard the considerable homogeneity of our sample to be a strong aspect, and this can also be said about the fact that all patients included in the study attended both weekly intensive programmes and completed the study within 2 years. Our results should, however, be considered with some caution as the effect was evaluated based on the use of only two tests and a quality of life questionnaire. Future studies should thus attempt to continue our work in a larger sample and assess other aspects related to postural stability and quality of life.

CONCLUSIONS

Our results suggest that repeated one-week intensive physiotherapy intervention can positively influence both the static and dynamic postural stability in patients with mid-stage Huntington's disease and can also positively influence some quality of life dimensions. In view of the low number of patients, however, caution is necessary when interpreting the results.

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DPav, DPan and ION contributed to the initial development of research, its preparation and implementation, ION led the interventions and gathered the data, and JS contributed to statistical analysis. DP was the main author and is responsible for the overall study content.

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The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by Ethics Committee (EC of Charles University, FTVS, EK 264/2018). Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

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