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REVIEW ARTICLE

Sleep, nutrition, hydration and rest: The equal importance of external factors outside of training and practice for sports injury prevention

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ABSTRACT

Training and practice preparation have long received attention as the largest factors for injury prevention. While proper training and practice programs are a crucial component of injury prevention, they only represent a piece of a larger puzzle. External factors outside of training and practice such as sleep, nutrition, hydration, and rest are equally important for injury prevention due to athletes spending a majority of their day outside of their sport. These external factors have been shown to have powerful effects relating to injury epidemiology. They have also been shown to have major effects on the body's autonomic and hormonal regulation systems. Due to athletes spending a majority of their day outside of training and practice, it is necessary that equal importance be given to external factors outside of sport, especially in regards to sleep, nutrition, hydration, and rest for optimal injury prevention strategies.

Keywords: Sport medicine, Injury prevention, Nutrition, Sleep, Hydration, Rest.

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INTRODUCTION

Training and practice preparation have long been emphasized as key factors in sports injury prevention (Beato et al., 2021; Petushek et al., 2019; Lauersen et al., 2018). While a structured training program is important regarding injury prevention (Beato et al., 2021; Petushek et al., 2019; Lauersen et al., 2018), it is just part of a much larger puzzle. Athletes ultimately spend a majority of their day outside of training and practice, since this time may only be a few hours out of an athlete's entire day. Training and practice are critical for injury prevention; however, external factors outside of sport during the remaining majority of the day such as sleep (Huang & Ihm, 2021), nutrition (Turnagöl et al., 2021), hydration (Judge et al., 2021), and rest (Orlando et al., 2011) are just as equally important for injury prevention. This opinion article aims to emphasize that multiple external factors outside of sport (sleep, nutrition, hydration, and rest) are of equal importance in helping to prevent injuries.

SLEEP

Sleep is an essential part of homeostasis that aids with the body's metabolic, immunologic, and endocrine functions. Most experts recommend that adults should get at least eight hours of sleep per night (Van Dongen et al., 2003). However, many professional athletes experience poor sleep habits upon study (Leeder et al., 2012). This is measured as the time to fall asleep, as well as with subjective reports on sleep quality (Leeder et al., 2012). Poor sleep hygiene leads to fatigue and increases the likelihood of musculoskeletal injury (Luke et al., 2011).

Additionally, several studies have linked short-term sleep deprivation to poor immunologic function (Bollinger et al., 2010). Since sleep promotes recovery and preparation for high-intensity training and competition, it is essential to promote better sleep habits in athletes for prevention and recovery (Samuels, 2008). Traveling for games and competitions also makes athletes more susceptible to poor sleep quantity and quality. Travel disrupts sleep schedules and increases variability which predisposes athletes to be more fatigued and prone to injuries during training and competition (Peacock et al., 2018). To explore interventions and correct sleep disruptions, several studies have found napping to be an effective sleep extender (Faraut et al., 2011).

Sleep deprivation has been associated with increased basal cortisol levels (Nollet et al., 2020). This becomes crucial when considering adolescent pre-collegiate and collegiate athletes. In addition to the physical stress of high-intensity training and competition, the long-term health detriments of sleep deprivation in athletes undergoing development must be considered with equal importance.

Sleep recommendations

Due to the increased risk of sport-related injuries with sleep deprivation, it is imperative that athletes at all levels are cognizant of healthy sleeping habits. We recommend the incorporation of educational programs for athletes as a part of pre-season conditioning that focuses on the importance of adequate sleep quantity and quality.

During travel for away competitions, coaches and athletic staff must account for the sleeping challenges that come with travel when planning meals, curfew and wake-up calls. This is especially important if there is a time change. In addition, appropriate travel accommodations and times for napping prior to competition should be implemented to reduce the risk of injury. Athletes can benefit from sleep supplementation in the form of napping. Previous research has shown that a 30-minute post lunch nap after partial sleep loss (4 hours less than normal) significantly improved 20-m sprint performance and subjective alertness (Bird, 2013).

Additionally, increasing sleep by two hours for athletes, with a goal of up to nine total hours of sleep in elite athletes, should be prioritized to increase the overall well-being of athletes and optimize performance (Vitale et al, 2019). A study that was conducted on the Stanford University men's basketball team had 11 players obtain extra sleep with a goal of 10 hours per day for a 5-7 week period. Ultimately, the players were found to have enhanced basketball performance (Bird, 2013). The players who obtained extended sleep also reported improved alertness and mood, as well as less sleepiness and fatigue (Bird, 2013).

Sleep hygiene recommendations include maintaining a regular sleep schedule by minimizing bedtime and waketime variability, avoiding coffee, alcohol, and nicotine in the hours before bed, napping appropriately (limiting naps to 30 minutes and avoiding late-afternoon naps), maintaining proper hydration, avoiding high-intensity exercise right before bed, and utilizing nightshades and earplugs if needed (Vitale et al, 2019). Other sleep hygiene recommendations include minimizing blue light close to bedtime, reducing stress through meditation, and taking melatonin as a supplement (Vitale et al, 2019). Additionally, educational programs for athletes as a part of pre-season conditioning should focus on the importance of adequate sleep quantity and quality. These sleep hygiene recommendations are used to maximize well-rested sleep in athletes of all levels and have proven to enhance performance.

With today's technological advances, the use of smartphone applications for sleep tracking and schedules can help monitor the efficacy of these interventions. Although many of the current applications only offer limited features, athletic programs should establish an agreement to provide their athletes with discounted subscription plans. Integrating a majority of these sleep hygiene recommendations will help maximize vital body function and help athletes perform at their best.

Finally, as part of the annual sports physical, athletic teams should reserve time to evaluate the sleep habits of the athlete. Annual physicals and questionnaires provide opportunities to identify athletes in need of supplemental aid with their sleep schedules. Interventions geared towards education, continuous feedback by sleep tracking, and the incorporation of annual investigations can help athletes develop healthy long-term sleep habits while also providing opportunities to intercede when athletes might still be suffering.

NUTRITION

While there has been a shift to improving nutrition at the professional sports level and higher collegiate athletic levels, nutrition problems persist throughout all levels of sport. Proper nutrition is typically considered a balance of macronutrients and micronutrients (Holt, 1993; Purcell,2013); however, there can be variances to the typical numbers needed depending on the athlete. Many athletes at the collegiate level might face imbalances in regards to macronutrients (proteins, fats, carbohydrates) and micronutrients (vitamins and minerals) without proper guidance (Riviere et al., 2021; Lambert et al., 2022). Many of the larger collegiate and professional sports have emphasized nutrition and the associated proper recommendations from nutritionists for their athletes (Andrews et al., 2016). Meanwhile at the lower collegiate levels, nutrition knowledge amongst athletes may be inadequate, which could lead to decreased energy (Andrews et al., 2016) and an associated lower performance. While most sports at the professional level have recently started to emphasize nutrition, professional minor league baseball nutrition remains poor. Many athletes in minor league baseball may struggle financially (Pifer et al., 2020), and may have barriers regarding education, resources, and costs of food. The struggle to acquire proper nutrition could impact their performance, as many of these prospects are still working to develop efficiently. Many of these barriers exist at smaller collegiate institutions and at the amateur level as well. Interventions should consider these potential barriers.

Several studies have shown that nutritional programs may help to decrease sport injuries, as it helps with the energy, recovery, and growth of athletes (Turnagöl et al., 2021; Pyne & Verhagen, 2014) Proper nutrition guidance through a sports dietitian, or nutritionist, has the ability to increase recovery and athletic performance (Turnagöl et al., 2021; Pyne & Verhagen, 2014; Hull et al., 2017). Proper nutrition is, therefore, critical for improving physical fitness (Malsagova et al., 2021). Supplements such as creatine may also help with building lean muscle mass and improving performance (Hall et al., 2021). Nutrition is also essential in helping to maintain proper hormonal regulation (Dinu et al., 2020). Hormonal regulation is necessary for proper body system functions. Nutrition induced hormonal imbalances can be seen in eating disorders (Schorr & Miller, 2017).

Nutrition recommendations

Nutrition is a complex topic, and optimal nutrition recommendations are difficult to calculate. At the professional level and collegiate level, nutritionists should be involved in developing the proper dietary and supplementation plan for athletes. Larger collegiate and professional programs are using nutritionists to help with meal preparation; however, smaller colleges and some professional sports such as minor league baseball still struggle. Baseball organizations should emphasize nutrition to help aid in the development of their prospects, as this nutritional guidance would be an investment in injury prevention and performance. One previous recommendation in the literature is that lower level collegiate athletics should provide nutritional courses and education from professionals (Andrews et al., 2016). This can act to aid in the immediate nutritional consumption, as well as provide a long-term education on the topic that athletes can utilize throughout their lives. The amateur level sees similar barriers as the lower level collegiate athletics. Nutritional education should be improved within primary school systems to help better guide the building blocks for these athletes. Undergraduate or other online courses in nutrition could be a future way to help athletes improve their nutrition.

Technology is one important factor that could play a role in nutrition. With growing technologies and the development of many virtual platforms, technology may be a solution for nutrition education access. iPhone nutrition applications, such as calorie counters or virtual coaching, may also play a role in helping with following nutrition (Dunne et al., 2022; König et al., 2021). This is the most practical option for most athletes across lower level college sports and amateur sports. Nutrition may be the hardest intervention to plan for due to the potential cost barriers and education barriers that exist; however, online courses and, in turn, expansion of education on the topic may help athletes optimize their nutrition.

HYDRATION

Hydration is another critical factor in injury prevention due to its effects on recovery and hormones. Proper hydration can play a large role in assisting with athlete recovery from competition or training (Judge et al., 2021; Shirreffs & Sawka, 2011). Hypohydration could potentially lead to increased stress levels (Maughan & Meyer, 2013). Increased stress levels have been associated with increased cortisol release (Yaribeygi et al., 2017), and chronic states of high cortisol could lead to an increased risk of injury (Perna & McDowell, 1995). Hypohydration has many negative effects and can lead to an increased risk of injuries and decreased athletic performance (Sawka et al., 1995). Several studies have found high levels of hypohydration amongst athletes at multiple levels of sports (Chapelle et al., 2020; Volpe et al., 2009). Proper hydration levels are crucial for athletes engaging in training or competition to reduce injury effects and changes to their hormonal regulatory systems.

An additional consideration when assessing hydration at the collegiate level is the possible high levels of alcohol consumption (Volpe et al., 2009) High levels of alcohol consumption and binge drinking have been noted in college athletes (Nelson & Wechsler, 2001). Alcohol consumption has many negative effects on the human body (Standridge et al., 2004). It can lead to increased injury levels (O'Brien & Lyons, 2000) and potentially delay recovery from training or sport (Vella & Cameron-Smith, 2010). Alcohol causes dehydration due to its blocking effects on water resorption in the kidneys (Vella & Cameron-Smith, 2010). Due to the high levels of alcohol usage at the collegiate level, it is important that intervention is undertaken to reduce alcohol intake for better hydration levels and protection from injury.

Hydration recommendations

Hydration is necessary to help athletes recover and reduce injury. Hydration testing strategies should be implemented by coaches and athletes in order to evaluate proper hydration levels. There are many external factors that affect hydration such as weather/environment, type of exercise, and duration of exercise (Velval et al., 2019). Coaches should aim to optimize these factors in order to maintain hydration levels. The most practical way of tracking hydration levels involves body weight tracking and urine colour tracking (Velval et al., 2019). Coaches and athletes should be educated on these factors. Other interventions include weight charts, and posters that may serve as a reminder for athletes and coaches to emphasize hydration. The National Strength and Conditioning Association (NSCA) recommends that athletes should consume 20-24 ounces of fluids for every pound of body weight lost (Campbell et al., 2011). The American College of Sports Medicine (ACSM) and NSCA both recommend that athletes should consume drinks with electrolytes and carbohydrates during competition, due to the losses through sweat (Campbell et al., 2011; American College of Sports Medicine et al., 2007). The NSCA also recommends avoiding alcohol after the first few hours of competition due to its effects on recovery (Campbell et al., 2011). Coaches and athletes should be educated on these values and track these values for optimal recovery.

Due to alcohol having many negative effects on the body and predisposing the athlete to injuries (Nelson & Wechsler, 2001; O'Brien & Lyons, 2000), interventions should be undertaken to reduce alcohol intake. Counselling resources and education should be available to both athletes and coaches to reduce alcohol intake. These counselling resources could also be useful for athletes who struggle with alcohol use disorder. Awareness of the effects of alcohol on athletic recovery and injuries is necessary for all athletes, but collegiate athletes in particular due to the high rates of consumption.

REST

Rest is a critical component of recovery. There are still many overuse injuries that are occurring throughout all levels of sport (Franco et al., 2021; Roos et al., 2015), particularly in the collegiate setting (Roos et al., 2015). The youth level has seen increased attention due to excessive sports schedules, where they may be playing year round or without any time to rest (Luke et al., 2011). This can result in an increase in injuries in the youth population (Luke et al., 2011) and it can cause long-term complications to occur later in life.

One particular topic of interest regarding excessive training is overtraining syndrome. Overtraining syndrome is a common syndrome that athletes can face due to training too much without adequate rest (Luke et al., 2011). Overtraining syndrome can lead to disruptions of immune function, neurological function, and disruptions of the hypothalamic-pituitary-adrenal axis. Overtraining syndrome can result in fatigue, poor performance in athletes (Kreher, 2016) and can lead to increased levels of injuries (Gabbett, 2016). The balance between training and rest is necessary for ultimate athlete health and performance.

A second major challenge in rest is the current state of athletes' competition schedules. Youth athletics in particular has seen excessive schedules with little rest in recent years (Luke et al., 2011). Many travel league schedules pack in many competitions into a weekend, and some athletes may do this all year round. Youth athletes are particularly susceptible to overuse injuries and may see injuries due to overuse and overscheduling (Luke et al., 2011; Bean et al., 2014). Some youth athletes may specialize early in a particular sport, and never have any breaks from sport throughout the year. This does not allow time for rest and recovery (Jayanthi et al., 2013). While college athletes play a lot of games, the most critical time frame is during the postseason, when there are minimal days off, after a long season. Increasing days off and reducing a packed schedule will allow athletes to play rested and may lead to decreased injuries and improved performance for athletes at all levels (Orlando et al., 2011; Caparrós et al., 2016; Mason et al., 2022).

College athletes and amateur athletes face additional pressure and stress outside of the demands of sport. This stems from additional tasks such as maintaining grades and other extracurricular activities (Lopes Dos Santos et al., 2020). Stress can induce a state of change to many of the body's organ systems (Yaribeygi et al., 2017). This state of stress can lead to increased release of cortisol (Yaribeygi et al., 2017; Lee et al., 2015) as previously mentioned. Increased and prolonged states of elevated cortisol leads to fatigue, and the breakdown of muscles and bones (Hannibal & Bishop, 2014). It has long been shown that chronic stress can lead to reduced recovery and an increased risk of injuries in athletes (Perna & McDowell, 1995). Therefore, it is necessary that collegiate athletes have time to rest, in order to allow for the reduction of stress. This reduction of stress can lead to the normalization of cortisol levels, and a corresponding reduction in the negative effects of chronic cortisol.

Rest recommendations

Rest is a necessity for athletes. We highlight several key recommendations to improve rest. The first is to increase tracking of athletes practice hours. Currently, there are several devices that athletes can wear to track their overall workloads (Seshadri et al., 2019). These devices can be used to monitor workloads, in order to optimize the balance in workloads and recovery. Strength coaches, sport coaches, and athletes should work together to track practice hours, proper periodized training, and allow for days off to rest (Kreher, 2012). These steps have been noted as important in regards to the early detection of overtraining syndrome. There often may be disconnect between strength coaches and sport coaches at the collegiate and amateur levels regarding this; however, working together is crucial to ensure athletes do not experience overtraining syndrome.

The second recommendation that we have is for youth sport coaches to schedule time off from competition for youth athletes. With many youth athletes playing all year round or with excessive schedules (Luke et al., 2011 ;Bean et al., 2014; Jayanthi et al., 2013), they do not receive necessary time to rest. Scheduling time off from competition could be crucial for athletes to heal, and to properly allow time for them to train and implement injury prevention strategies. The third recommendation is for increased time intervals between competitions due to its ability to decrease injuries (Orlando et al., 2011; Caparrós et al., 2016; Lopes Dos Santos et al., 2020). All levels of sport should aim to maximize the interval between competitions, in order to optimize rest and recovery for athletes.

The final recommendation that we have is for athletes and coaches to work with their educational departments to create study plans, and mental wellness counselling. This study time will allow athletes to dedicate time to complete their course work and may help to reduce the stress that may come from cramming for an exam or to finish an assignment on time. Mental wellness resources should also be offered, due to its ability to help manage stress in other populations (Green & Kinchen, 2021). We believe that athletes and coaches should work on this from the youth level all the way to the collegiate level. Working together will allow for athletes to excel on the field and in the classroom, which is the goal of all student-athletes.

DISCUSSION AND CONCLUSIONS

Many studies have shown how important training and practice are for injury prevention (Beato et al., 2021; Petushek et al., 2019; Lauersen et al., 2018). It is true that these are critical for injury prevention; however, many other factors are also in play. Studies have individually looked at the effects of sleep, nutrition, hydration, and rest as they relate to injury epidemiology (Huang & Ihm, 2021; Turnagöl et al., 2021; Judge et al., 2021; Orlando et al., 2011), but data is lacking in regards to assessing these factors together in conjunction with training and practice. Knowing that all of these factors outside of training and practice have major effects on the body's hormonal regulation systems (Nollet et al., 2020; Dinu et al., 2020; Maughan & Meyer, 2013; Yaribeygi et al., 2017; Kreher, 2016; Kreher, 2012), it is important to consider that they may be equally important to an athlete's overall health. This is partially because athletes only spend a portion of their day at training and practice. With the majority of the day occurring outside of sport practice, it is crucial that we give the necessary attention to sleep, nutrition, hydration, and rest as critical players in injury prevention.

The literature compiled, as well as the recommendations, are a good starting place to initiate simple interventions that will help athletes and other related parties use these external factors for a clear advantage. The recommendations highlight many changes that athletes, coaches, and parents can easily incorporate into their plan. As technology advances and as our understanding of these external factors grows, these recommendations will adapt to follow the best available data. With modern day athletes continually pushing the ceiling of physical human capabilities, we must study and learn more about how to maximize these external factors for interventions in the future.

This paper highlighted some of the numerous effects that these outside factors can have in regards to physiological changes within the body's organ systems. A state of chronically high cortisol is clearly one that can cause numerous acute and chronic issues that could be detrimental to the body (Hannibal & Bishop, 2014). Chronically high cortisol levels can be due to a few of the external factors mentioned. While the body is good at attempting to adapt to acute and chronic stress, we know that too much stress can ultimately negatively impact the body's organ systems (Hannibal & Bishop, 2014). All of these external factors work together to play a role in controlling this hormonal balance, and when used properly, they can enhance injury prevention by allowing for recovery of the body. Due to the positive effects of these external factors, it is necessary that we give them more attention than they have received historically in comparison to training and practice. Training and practice have remained the biggest emphasis; however, a shift to emphasizing these external factors as equals should be the next big change to sports injury prevention strategies.

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SCIENTIFIC JOURNAL OF SPORT AND PERFORMANCE

ORIGINAL ARTICLE

Utilisation of transitional clusters exhibited within soccer game play to inform training design: Are we meeting the required demands?

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ABSTRACT

The aims of this study were to investigate the effect of 15min blocks on physical metrics during transitions, analyse frequency, type, duration, and recovery period between clusters of transitional activities (CTA) in elite football. During ten official matches 23 elite footballers were tracked using GPS devices. Metrics per minute ($m \cdot min^{-1}$) as well as absolute variables: total distance (TD), high-speed running distance (HSRD > 19.8 $km \cdot h^{-1}$), sprint distance (SD > 25.2 $km \cdot h^{-1}$), relative high-speed running distance (VelB4), relative sprint distance (VelB5), acceleration distance (AccB3 Dist, distance with variations in running speed > 3 $m \cdot s^{-2}$), the number of high-intensity accelerations (HI Acc > 3 $m \cdot s^{-2}$) and decelerations (HI Dec > 3 $m \cdot s^{-2}$) were quantified. Significant effects of 15min blocks were found for TD (m) (p < .001; ES = .078), TD ($m \cdot min^{-1}$) (p = .047; ES = .036), HSRD (m) (p = .033; ES = .039), VelB4 (m) (p < .001; ES = .132), and HI Dec ($n \cdot min^{-1}$) (p = .002; ES = .059). Transitional activities recovery period was found to be 108.5 ± 26.2 s, CTA recovery period was 25.7 ± 3.6 s, while CTA peak duration reached 53.3 ± 18.2 s. This study indicates that physical metrics decrease in the last 15min blocks during transitions and high-pressure activities in games. In conclusion, repeated high intensity / high velocity activities frequently occur during contextualized peak intensity periods (transitions) in football, which should be reflected in modern training design.

Keywords: Performance analysis of sport, Soccer, Transitions, Counterattack, High pressure, Peak demands, Repeated activities.

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INTRODUCTION

Modern soccer match play has been described as an intermittent sport where both aerobic and anaerobic energy systems are stimulated during intense activities (accelerations, decelerations, changes of direction and sprints), which are usually combined with football-specific technical actions (tackles, passes, headings, and shots) (Oliva-Lozano et al., 2020a). It has been shown that both physical and technical demands have increased within contemporary soccer, thus emphasizing the need to reflect these changes in training design and integrate physical conditioning with technical-tactical aspects to better prepare soccer players for the modern demands of match play (Barnes et al., 2014; Nassis et al., 2020). Previous work has shown the importance of the match physical output analysis to better inform coaches and performance staff and optimally prescribe training load for each playing position (Harper et al., 2019; Wass et al., 2019). For this very purpose, valid and reliable wearable technology has been extensively used in research and practice to measure and track different absolute and relative physical metrics in training and official competitions (Scott et al., 2016). However, most of the research has paid attention to total and average match physical metrics, which merely reflect the volume of activity, yet neglecting fluctuations in physical and technical-tactical intensity, which could underestimate the intensity of the most demanding passages of football match play (Martin-Garcia et al., 2018, Bortnik et al., 2022).

To overcome this issue in elite football, there has been an increased focus on peak match demands, also referred to as worst-case-scenarios (WCS) (Riboli et al., 2021; Riboli et al., 2022). Different WCS durations have been investigated, and shorter duration peak demands were shown to generate higher intensity in soccer, which posts a question whether modern training design bests prepares athletes for these short and specific high-intensity periods (Martin-Garcia et al., 2018; Bortnik et al., 2022). Still there is more information needed regarding the football context behind these peak intensity blocks as well as their pattern of occurrence within a modern match play (Novak et al., 2021; Bortnik et al., 2023). This knowledge would enable coaches and practitioners to design, implement, and apply conditioning drills integrating football-specific and tactical aspects (small-sided games, tactical and positional drills, transition games, etc.) to better replicate true match demands for each playing position (Novak et al., 2021; Riboli et al., 2022).

Recent work that analysed the physical demands during transitional activities (TA's) in elite football, found greater high velocity demands compared to the 90-minute averages (Bortnik et al., 2022). Although, this body of work analysed phases in isolation. Offensive (defence-to-attack) and defensive (attack-to-defence) transitions have been identified as the key match phases when goals are conceived and many risks undertaken (Tenga et al., 2010; Wass et al., 2020). Accordingly, high-pressure activities were shown to be effective in scoring goals and creating goal-scoring opportunities as well as impose high mechanical (accel/decel) demands on offensive players, emphasizing the need to be physically fit (Tenga et al., 2010; Bortnik et al., 2022). In fact, transitional activities occur when a team is in possession of the ball during an offensive collective team activity and/or out of possession trying to collectively win the ball back (defensive activity) (Bortnik et al., 2023). Thus, representing a high context within a modern football game. The increased body of knowledge on these specific match phases (clusters) might be crucial in modern physical preparation of football players potentially having a direct impact on their match performance as well as reducing the risk of injury.

Previous investigations have explored match average physical outputs taking into account different contextual factors (match half, match location, match outcome) (Oliva-Lozano et al., 2020b; Rhodes at al., 2021). Nevertheless, the effect of different contextual variables on the most demanding match passages has not been widely researched (Riboli et al., 2021; Oliva-Lozano et al., 2021; Bortnik et al., 2023). To the authors best knowledge there is no study investigating the effect of 15-minute blocks (intervals) on physical metrics during transitions in elite football. From a practical standpoint, comparing and knowing physical outputs in the first and last minutes of the match, might significantly influence the training drill design, potentially reduce a detrimental impact of fatigue on match performance and minimize risk of injury. In addition, there are no studies investigating frequency, type, duration, and recovery period between offensive/defensive repeated short high-intensity efforts (clusters) during transitional play in soccer (Aranda et al., 2019).

It is noteworthy that the ability to work intermittently and repeatedly produce high-intensity efforts collectively as a team over 90 minutes have been found a crucial aspect of successful performance in modern football (Carling et al., 2012; Ju et al., 2022). This knowledge about the number of repeated efforts and the rest interval between them would enhance training drill design for team collective tactical training and potentially improve football performance during key match phases (Bortnik et al., 2023). Therefore, the current study aims to 1) analyse the effect of 15min blocks (B1: 1'-15'; B2: 15'-30'; B3: 30'-45'; B4: 45'-60'; B5: 60'-75'; B6: 75'-90') on different absolute and relative physical metrics during TA's; 2) investigate clusters of transitional activities (CTA) in elite football; 3) explore the recovery period between clusters.

MATERIALS AND METHODS

Participants

Data were collected on all twenty-three elite outfield players (n = 23) during 2020-2021 1st Polish Division (Ekstraklasa) season. Players were categorized into the following playing positions: centre backs (n = 4), full backs (n = 5), central defensive midfielders (n = 2), central attacking midfielders (n = 2), central midfielders (n = 2), wingers (n = 5), and attackers (n = 3). Only starting players who completed minimum 60 min were analysed. Substitution players were not included in this study because they might produce higher physical outputs than starters due to pacing strategies (Wass et al., 2020). All subjects provided written and verbal informed consent for the use of their GPS data, in accordance with the Helsinki Declaration. To ensure player confidentiality, all data was anonymised. Ethical approval was provided by the University of Central Lancashire.

Procedures & experimental design

One UEFA CL qualifier and nine Polish domestic leagues (Ekstraklasa) between August and November of 2020 were investigated giving a total of ten games analysed (6 wins, 1 draw, and 3 losses). Analysis included 1164 offensive transitions, 1269 defensive transitions, 1120 fast attacks, and 696 high pressure activities, giving a total number of 4249 individual observations. The following number of observations per position were recorded: centre backs (n = 884), full backs (n = 972), central defensive midfielders (n = 236), central attacking midfielders (n = 270), central midfielders (n = 578), wingers (n = 778), and attackers (n = 531). During each match, all players wore portable MEMS (10 Hz; Vector S7, Catapult Sports, Melbourne, Australia) located between the scapulae in a custom-made vest underneath their playing shirt. All subjects were accustomed to the entire procedure since they used GPS devices daily as part of their routine monitoring strategy. All GPS units were turned on 15 mins before the start of the match to ensure satellite connection. The data was screened for satellite coverage and horizontal dilution of precision (HDOP) using an inclusion criterion of > 6 satellites and ≤ 1.0 respectively, to ensure acceptable GPS coverage as previously recommended (Malone et al., 2017). Each subject used the same GPS device for the entire period of investigation to avoid inter-unit error. The validity and reliability of these wearables have been shown previously (Johnston et al., 2014; Scott et al., 2016).

All analysed metrics were previously used in other studies (Wass et al., 2020; Riboli et al., 2021; Bortnik et al, 2022). They represented absolute distances covered per minute ($m \cdot min^{-1}$) in the following categories: total distance (TD), high-speed running distance (HSRD, > 19.8 $km \cdot h^{-1}$), sprint distance (SD, > 25.2 $km \cdot h^{-1}$), as well as the number of high-intensity accelerations and decelerations (A+D, > 3 $m \cdot s^{-2}$; $n \cdot min^{-1}$). In addition, the metrics depicted absolute distanced covered in the following categories: total distance (TD), high-speed running distance (HSRD), sprint distance (SD), the number of high-intensity accelerations (HI Acc, > 3 $m \cdot s^{-2}$), the number of high-intensity decelerations (HI Dec, > 3 $m \cdot s^{-2}$), and acceleration distance (AccB3 Dist, distance with variations in running speed > 3 $m \cdot s^{-2}$). Moreover, these variables reflected total relative high-speed running distance (VelB4) and relative sprint distance (VelB5), which have been claimed to represent the functional limits of endurance and sprint locomotor capacities (Mendez-Villanueva et al., 2012). As previously recommended, relative high-speed running distance (VelB4) and relative sprint distance (VelB5) was set as 100% maximal aerobic speed (MAS) – 30% (anaerobic speed reserve) ASR, and above MAS + 30% ASR, respectively (Mendez-Villanueva et al., 2012). An incremental running treadmill test was conducted by the club physiologist to measure VO_{2max} and MAS. The test was performed in the gym environment with a normal ambient temperature and took place on a mechanical treadmill (Technogym, Italy). It began with an initial speed of 10 km/h^{-1} and each stage was increases by 1.5 km/h−1. Five stages were set. Each stage lasted 4 minutes and it was separated by 1 minute passive break. The inclination was set at 1.5%. Polar heart rate monitors (Polar, Norway) and Polar M400 are used to record HR data. Expired gases were analysed breath-by-breath using an online automated gas analysis system (MetaLyzer® 3b-R2; Cortex Biophysik Gmbh, Leipzig, Germany) and accompanying software (MetaSoft® 3). Maximum oxygen uptake (VO_{2max}) was defined as the highest 15-s average oxygen uptake. Velocity (km/h^{-1}) during the maximum oxygen uptake (VO_{2max}) was recorded and set as the MAS.

After each match, transitional activities (TA's) were manually selected and tagged by the club's analysis team in the Catapult Vision video analysis system (Catapult Sports Ltd, Melbourne, Australia). Analysts used the observational methodology REOFUT theoretical framework to identify these periods (Collins et al., 2006), which was part of the club's analysis protocols utilized daily by the analysis team. Good to high intra- and inter-observer reliability of the current analysis method was previously shown (Tenga et al., 2010; Aranda et al., 2019; González-Rodenas et at., 2020). Data from the Catapult vision software were then downloaded and integrated into the manufacturer's software package (Openfield, version 3.2.0) and finally exported into Microsoft Excel (Microsoft Corporation, USA) to make additional calculations for each transitional play, clusters, and recovery periods. Clusters (CTA) were defined as two or more transitional activities that occurred within a period shorter than 61 secs as previously recommended (Buchheit et al., 2010; Carling et al., 2012, Bortnik et al., 2023). The transition mean count average for selected variables and clusters frequencies were calculated as the sum total of all TA's, divided by their number. To get the clusters' peak duration, the highest values in 10 games were found, and their average was calculated as the sum of all peak duration values during clusters, divided by their number. Transitions were categorized into the following activities: positive transition (PT), negative transition (NT), fast attack (FA), and high pressure (HP), which were previously investigated by other authors (Tenga et al., 2010; González-Rodenas et at., 2020; Bortnik et al., 2022). In addition, the game was divided into six 15min blocks: B1 (1'-15'), B2 (15'-30'), B3 (30'-45'), B4 (45'-60') B5 (60'-75') B6 (75'-90') to determine the effect of time on physical metrics during TA's.

Statistical analysis

The study used a descriptive analysis, and the results are depicted as mean ± standard deviation (SD). Between-matches, between-halves, and between 15-min blocks coefficient of variation (CV) values were calculated for transitions for selected metrics per minute.

Statistical analyses was performed using IBM Statistical Package for the Social Sciences (SPSS, Version 27.0, IBM Corporations, New York, USA) with the statistical significance accepted at the 0.05 level. A univariate analysis of variance (ANOVA) was conducted to quantify main effects for games, transition type, and time (15min blocks). Interaction effects were also quantified, and any significant main effects associated with games, transitions, and time were investigated using post hoc pairwise comparisons. The assumptions associated with the statistical model were assessed to ensure model adequacy. To assess residual normality for each dependent variable, q-q plots were generated using stacked standardised residuals. Scatterplots of the stacked unstandardized and standardised residuals were also utilised to assess the error of variance associated with the residuals. Mauchly's test of sphericity was also completed for all dependent variables, with a Greenhouse Geisser correction applied if the test was significant. Partial eta squared (η^2) were calculated to estimate effect sizes for all significant main effects and interactions. Partial eta squared was classified as small (0.01–0.059), moderate (0.06–0.137), and large (>0.138), as previously suggested (Cohen, 1988).

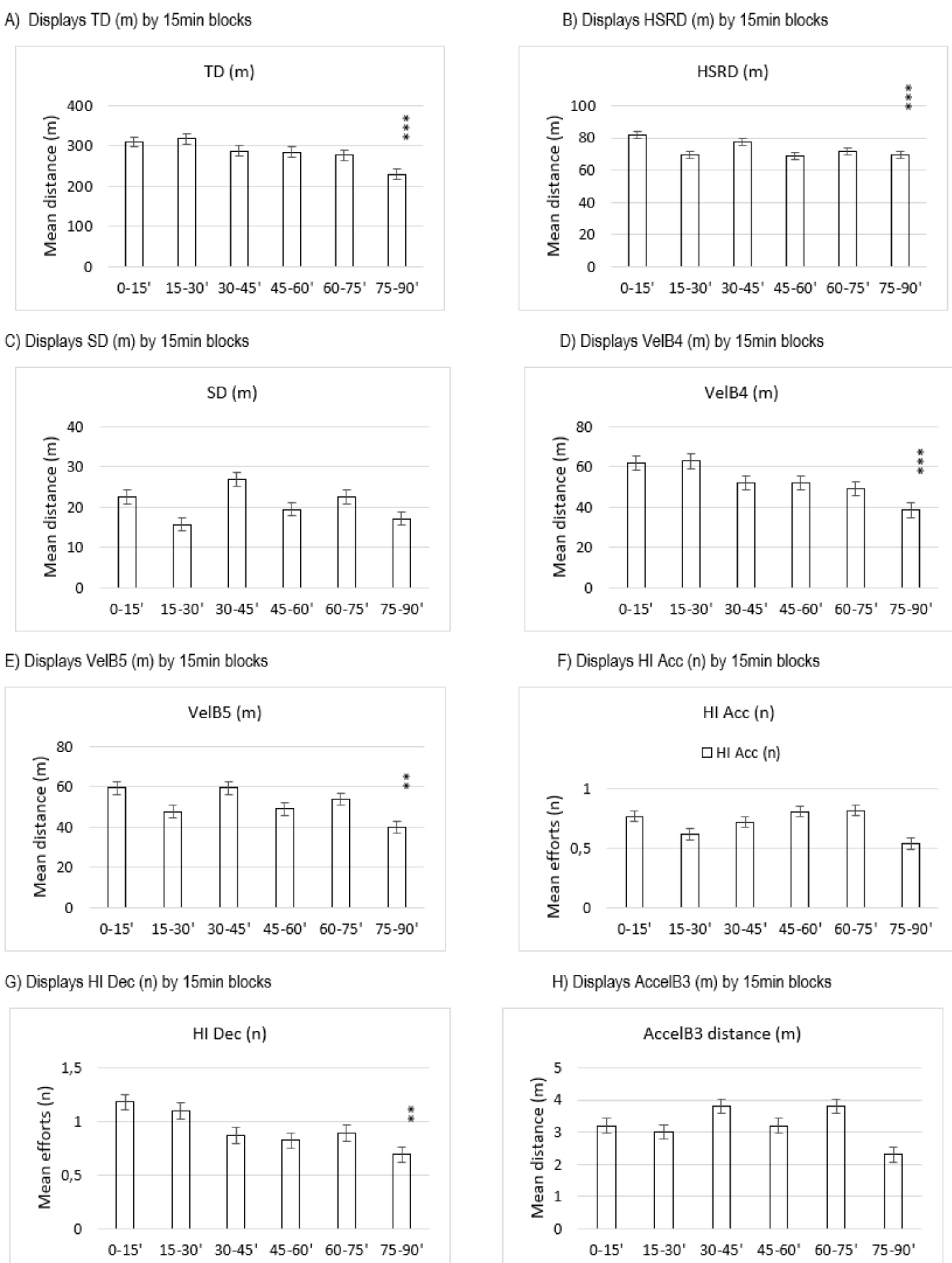
RESULTS

TD (m) analysis showed significant effects for game (F = 4.590, p < .001, partial η^2 = .071) and a transition type (F = 17.097, p < .001, partial η^2 = .109). Also, analysis of HSRD (m), SD (m), VelB4 (m), and VelB5 (m) identified significant effects for a transition type (HSRD: F = 15.298, p < .001, partial η^2 = .099; SD: F = 9.916, p < .001, partial η^2 = .066; VelB4: F = 15.471, p < .001, partial η^2 = .100; VelB5: F = 12.614, p < .001, partial η^2 = .083). In addition, TD (m·min^{-1}), HSRD (m·min^{-1}), SD (m·min^{-1}), and A+D (n·min^{-1}) analysis revealed significant effects for a transition type (TD: F = 29.754, p < .001, partial η^2 = .176; HSRD: F = 14.441, p < .001, partial η^2 = .094; SD: F = 6.248, p < .001, partial η^2 = .043; A+D: F = 4.453, p = .004, partial η^2 = .031). Moreover, a game x time interaction for HI Acc (n) (F = 3.511, p = .001, partial η^2 = .055) and A+D (n·min^{-1}) (F = 2.178, p = .035, partial η^2 = .035) was discovered. Interactions of game, transition type, and time were nor found for TD (m), TD (m·min^{-1}), HSRD (m), HSRD (m·min^{-1}), SD (m), SD (m·min^{-1}), VelB4 (m), VelB5 (m), HI Dec (n), and AccB3 distance (m) (p > .05).

15-min blocks

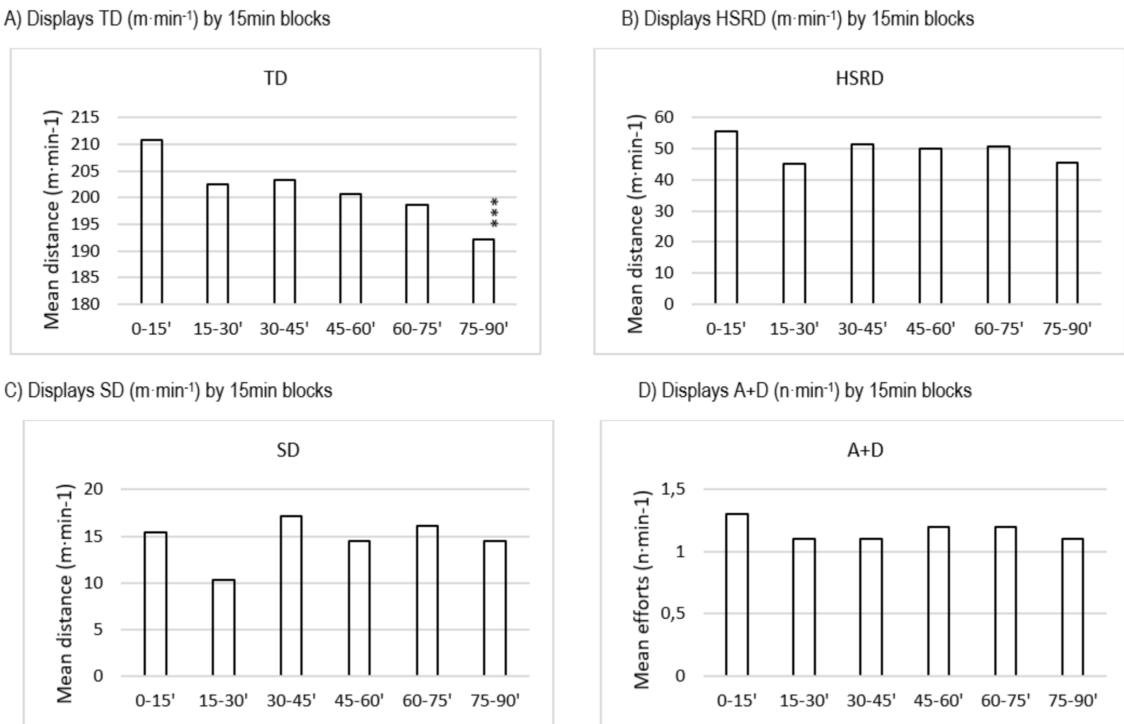
Analysis of TD (m), HSRD (m), SD (m), VelB4 (m), Vel B5 (m), HI accel (n), HI Dec (n) identified significant effects of game (TD: F = 3.865, p < .001, partial η^2 = .081; VelB5: F = 2.079, p = .046, partial η^2 = .046) and a transition type (TD: F = 16.361, p < .001, partial η^2 = .139; HSRD: F = 15.437, p < .001, partial η^2 = .132; SD: F = 7.766, p < .001, partial η^2 = .071; VelB4: F = 19.383, p < .001, partial η^2 = .160; VelB5: F = 12.041, p < .001, partial η^2 = .106; HI Accel: F = 3.009, p = .031, partial η^2 = .029; HI Dec: F = 2.998, p = .031, partial η^2 = .029). There was a game x time interaction (F = 1.536, p = .031, partial η^2 = .150) and a game x transition type x time interaction (F = 1.493, p = .018, partial η^2 = .218) for VelB4 (m). Also, a game x time interaction was found for HI Acc (n) (F = 2.580, p < .001, partial η^2 = .228) as well as a game x transition type x time interaction for HI Dec (n) (F = 1.493, p = .018, partial η^2 = .218). No interactions of game, transition type, and time were discovered for TD (m), HSRD (m), SD (m), VelB5 (m), AccB3 distance (m) (p > .05).

Additional analysis identified statistically significant effects of time (15min blocks) for TD (m), HSRD (m), Relative high-speed running distance (VelB4) (m), and high-intensity decelerations HI Dec (n·min^{-1}) (TD: $F(5,305)$ = 5.195, p < .001, partial η^2 = .078; HSRD: $F(5,305)$ = 2.263, p = .033, partial η^2 = .039; VelB4: $F(5,305)$ = 9.303, p < .001, partial η^2 = .132; HI Dec: $F(5,305)$ = 2.407, p = .002, partial η^2 = .0590). Further analysis of metrics per minute revealed only significant effects for TD (m·min^{-1}) (TD: $F(5,305)$ = 2.277, p = .047, partial η^2 = .036).



*Note. Different from 0-15' * p < .05; ** p < .01; *** p < .001.*

Figure 1. Effects of time (0-15', 15-30', 30-45', 45-60', 60-75' and 75-90') on a) mean total distance (TD), b) mean high-speed running distance (HSRD), c) mean sprint distance (SD), d) mean relative high-speed running distance (RelV4), e) mean relative sprint distance (RelV5), f) mean number of high-intensity accelerations (HI Acc), g) mean number of high-intensity decelerations (HI Dec), and h) mean high-intensity acceleration distance (AccB3) during transitions and high pressure activities.



*Note. Different from 0-15' * p < .05; ** p < .01; *** p < .001.*

Figure 2. Effects of time (0-15', 15-30', 30-45', 45-60', 60-75' and 75-90') on a) mean TD (m·min^{-1}), b) mean HSRD (m·min^{-1}), c) mean SD (m·min^{-1}), and d) mean A+D (n·min^{-1}) during transitions and high pressure activities across 10 matches.

Figure 3 displays the match-to-match variability for transitions in 1st and 2nd half, transitions in 15min blocks, and all transitions.

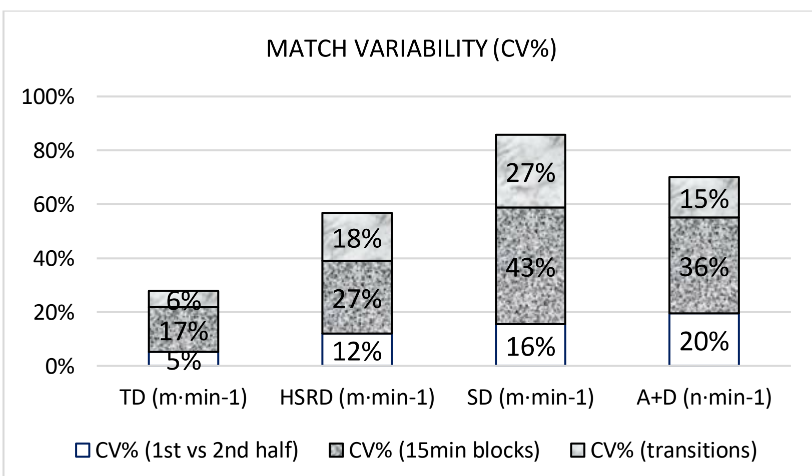


Figure 3. The match-to-match variability depicted as CV (%) for transitions in 1st vs. 2nd half (white), transitions in 15min blocks (granite), and all transitions (white marble) across 10 matches are shown for total distance – TD (m·min^{-1}), high-speed running distance – HSRD (m·min^{-1}), sprint distance – SD (m·min^{-1}), and number of accelerations/decelerations A+D (n·min^{-1}).

Post Hoc tests showed significant difference between the first and last 15min blocks for TD (m) and TD ($m \cdot min^{-1}$), HSRD (m), relative high-speed running distance (VelB4) (m), relative sprint distance (VelB5) (m) ($p < .001$) as well as number of HI Dec ($p = .006$). Other metrics did not reveal any significant differences between 15min blocks ($p > .05$).

Figure 1 highlights the effects of time (15min blocks) on absolute physical metrics that occur during transitions, accompanied with significant difference between 0-15' and 75-90'. The effect of time (15min blocks) on metrics per minute in all transitions across the games analysed, accompanied with the p-value for 0-15' and 75-90' is displayed in Figure 2.

Table 1 depicts duration-related metrics including recovery periods for transitional activities (TA's) and clusters, accompanied by the mean, standard deviations, confidence interval (CI), min and max. Frequency of clusters' transitional activities shown as the mean, standard deviations, percent, min, and max are detailed in Table 2. Table 3 highlights the frequencies of transitional activities in clusters and matches expressed as the mean, standard deviations, confidence interval (CI), and percent.

Table 1. Mean ± SD, 95% confidence intervals and minimum/maximum duration-related metrics including recovery periods for transitional activities (TA's) and clusters across 10 official matches.

Duration	Mean ± SD	95%CI	Minimum	Maximum
TAs recovery period (s)	108.5 ± 26.2	89.8 – 127.2	72.0	164.0
Cluster TAs duration (s)	9.9 ± 1.0	9.2 – 10.6	9.0	12.0
Cluster total duration (s)	28.0 ± 5.8	23.9 – 32.1	23.0	42.0
Cluster TA recovery period (s)	25.7 ± 3.6	23.1 – 28.3	21.0	32.0
Cluster peak duration (s)	53.3 ± 18.2	40.0 – 66.3	29.0	94.0

Table 2. Frequency of clusters' transitional activities.

Transition	Mean count ± SD (cluster)	Percent (%)	Minimum count	Maximum count
NT	10.1 ± 3.7	31	4	17
PT	8.3 ± 3.6	25	5	17
FA	7.9 ± 4.0	24	3	15
HP	6.4 ± 5.1	20	1	15
Total	32.7 ± 11.5	100	16	52

Note. PT = Positive transition; NT = Negative transition; FA = Fast attack; HP = High pressure depicted as a count and percent of transitions in clusters expressed as a mean ± SD and minimum/maximum count across 10 official matches.

Table 3. Comparisons between clusters' transitional activities and match TA'a frequencies.

Transition	Mean count ± SD (cluster)	Mean count ± SD (match)	Percent (%)
NT	10.1 ± 3.7	15.2 ± 4.6	66
PT	8.3 ± 3.6	13.7 ± 4.2	61
FA	7.9 ± 4.0	13.0 ± 3.6	61
HP	6.4 ± 5.1	7.7 ± 6.5	83
Total	32.7 ± 11.5	50.0 ± 11.1	66

Note. PT = Positive transition; NT = Negative transition; FA = Fast attack; HP = High pressure depicted as a count and percent of transitions in clusters expressed as a mean ± SD and percent across 10 official matches.

DISCUSSION

The aims of the present study were to investigate the effect of 15min blocks on physical metrics during transitions, analyse clusters of transitional activities (CTA), and explore the recovery period between clusters in elite football. This is the first study investigating frequency, type, duration, and recovery period between repeated TA's defined as clusters. Main findings revealed that out of 50 transitions that occurred on average across ten games (Bortnik et al., 2022), 33 were repeated activities (CTA), with a range of 16 to 52. In fact, on average 66% of all transitional activities were clusters, which in practical terms means that more than 2 TA's occurred within 1 min (Buchheit et al., 2010; Bortnik et al., 2023). Repeated high-intensity / high-velocity efforts during short and contextualized blocks of activity might be more frequent in modern football match play than previously reported (Carling et al., 2012). Thus, posing a question whether coaches and practitioners adequately prepare players for modern match play demands. Further work is required to determine this by comparing transitional work completed in training to game output. Negative transitions (NT) reached highest number (31%), followed by positive transitions (PT), and fast attacks (25%, and 24% respectively). High-pressure activities (HP) were least frequent (20%). However, 83% of all HP activities were repeated revealing the importance and an integrative meaning of these defensive actions in modern match play.

The current body of work found that mean cluster transitional activity (CTA) duration was no different from other transitional activities and lasted around 10 secs (Gonzalez-Rodenas et al., 2020; Bortnik, et al., 2022). CTA mean total duration was nearly three times longer (28 secs), with CTA peak duration found to be 53 secs. In addition, the study showed that the mean rest interval between all transitional activities was over four times longer than mean CTA recovery period (108.5 sec vs. 25.7 sec). An important consideration in relation to work:rest ratios, when specifically conditioning players.

This work revealed a novel concept of clusters described as > 2 transitional activities occurring within 1 minute (Buchheit et al., 2010; Bortnik et al., 2023). Football is an intermittent sport, and the ability to perform repeated actions has been found an important component of success in elite soccer (Carling et al., 2012). Short recovery between phases of high-intensity efforts might have a detrimental effect on physical performance (Balsom et al., 1992) and hence, gaining knowledge surrounding repeated high-intensity efforts (CTA) within match play in relation to the frequency, tactical context, and recovery periods informs training design, thus potentially influencing match performance, and injury risk (Carling et al., 2012; Nassis et al., 2020). Future research should consider the positional differences during these intensified blocks of activity.

Interestingly, absolute and relative physical metrics during transitions decreased as the game progressed in time. Recently, it has been reported that players generated the highest number of high-intensity actions in the first 15min blocks of each half (Oliva-Lozano et al., 2023). Fatigue and/or insufficient rest might be the main reason of a declined physical performance and potentially a higher risk of injury (Rhodes et al., 2021). These findings are consistent with previous studies exploring fatigue effects in elite football revealing physical performance differences existing between both halves and separate 15-minute periods in male and female footballers (Datson et al., 2017; Barrera et al., 2021; Bortnik et al., 2023). This could be due to non-specific approach to physical performance analysis. Demands of the games are influenced by individual team approach, individual capacity, level of opponent, and playing philosophy (Rampinini et al., 2007). Consideration of cluster analysis would provide vital information for practitioners to inform the physical demands required for each player and the prescribed work:rest ratios needed within training design. It is acknowledged that these demands were quantified over 10 games and further work is needed over a greater number of games across different leagues and clubs in a season.

Findings within the present study revealed a significant reduction in absolute metrics of TD (m), HSRD (m), VelB4 (m), and the number of HI Dec during TA's, when comparing the first and last 15min blocks. The detrimental impact of fatigue on muscle function due to repeated high velocity actions has been well documented (Harper et al., 2019; Rhodes et al., 2019; Rhodes et al; 2020). Suggesting that the repeated actions experienced in the clusters presented in the current body of work, result in a decrease in physical performance of these metrics over time. This reduction in high velocity running has been associated with inadequate training or preparation (Vasquez et al. (2021). It is proposed that this is a result of decreased insight into the current demands of transitional play (Bortnik et al., 2023), and the present study provides a deeper analysis of the true physical demands of contemporary football. Recently, there has been an increased focus on acceleration and deceleration performance due to their high neuromuscular demand and impact on match outcome (Rhodes et al., 2021; Djaoui et al., 2022). It is important to note that despite low running speed in game play these high intensity actions are repeatedly required (Gaudino et al., 2013). Increasing knowledge of the peak demands of these actions, will inform training design, potentially reducing the resultant fatigue effects demonstrated in this body of work. It is noteworthy to state that we explored absolute and relative locomotor metrics, and future work should also use individual acceleration / deceleration thresholds to better reflect players' individual physical performance capacities (Carling et al., 2012).

Interestingly, the current study demonstrated that 88% of HP activities were performed in conjunction with other transitional actions. Evidence identifies that HP activities are an aggressive approach to winning the ball back and creating goal scoring chances (Vogelbain et al., 2014). Resulting in higher mechanical loads (Bortnik et al., 2022). Incorporation of defensive tasks aiming at rapidly closing down space and pressing opponents with other offensive activities in possession to either keep the ball and/or initiate a fast attack and/or counter-attack, would provide specificity in preparing players for game play. This would potentially increase fatigue tolerance of repeated high velocity actions that can occur at any time within a game (Oliva-Lozano et al., 2021). Cluster analysis related to transitional activity provides practitioners with greater detail with regards the intensity and frequency of the blocks of activity and it is essential that training design incorporates this notion (Bortnik et al., 2023). This would maximise physical performance and specifically condition players, potentially reducing injury risk.

Previous studies reported that the mean transition performance ($m \cdot min^{-1}$) between official football games had around 16% match-to-match-variability (Rampinini et al., 2007; Riboli et al., 2021; Bortnik et al., 2022). Our findings showed lower variability between the first and second 45-min (13%), and higher between 15min blocks (31%). Hence, shorter high-intensity specific blocks of activity were revealing highest unpredictability within each game. Surprisingly, sprinting activities - SD ($m \cdot min^{-1}$) were found to be much more consistent between halves (16% variability) in contrast to the match transitions sprinting demands (27% variability) and 15min blocks that had the highest variance (43%). Data demonstrated that not high-velocity activities (Rampinini et al., 2007; Gregson et al., 2010), but A+D ($n \cdot min^{-1}$) represented the greatest unpredictability between both halves (20%). However, SD ($m \cdot min^{-1}$) had the highest overall variability across all metrics, which is consistent with previous studies (Riboli et al., 2021; Bortnik et al., 2022). These results show high dynamics and unpredictability of the contemporary game and hence, inform how challenging it is to design training for elite footballers in practical settings (Gregson et al., 2010). Nevertheless, the physical and tactical workload players are exposed to during peak intensity blocks in contemporary match play is not only dependent on opponent / teammate's activities (Bradley et al., 2020), but also on many different contextual factors such as match location, match half, score-line, match outcome, playing formation, etc., and other (Gregson et al., 2010, Bortnik et al., 2023). These important match-related contextual variables were not included in our analysis and future studies should investigate the impact of these factors on the physical demands during transitions in football.

Based on our main findings, transitional activities and transitional games in/out of possession (defence-to-offense transitions, offense-to-defence transitions, and fast attacks) could be considered a crucial component of a weekly training plan in modern training design (Ju et al., 2022b). Offensive transitions (counter-attacks) should be executed at maximum effort to surprise opponents and create chances to score a goal (Gonzalez-Rodenas, et al., 2020). From a practical standpoint, it would be important to add more space to reach near-maximum velocity while over/underlapping, running with ball, exploiting space, and breaking into penalty box (Riboli et al., 2020; Bortnik et al., 2022) since successful elite football teams were found to generate higher intensity during these activities (Ju et al., 2023). Offensive transitions have recently been found to significantly overload 90min sprinting demands and accumulate nearly half match sprint distance (Bortnik et al., 2022). These phases are full of technical-tactical context and a powerful ammunition to expose players to maximum velocity actions in training (Bortnik et al., 2022). Defensively, on the other hand, players should be able to react quickly, squeeze space, apply high pressure, cover, and perform a recovery run to stop the opposition attack (Gonzalez-Rodenas et al., 2020; Bortnik et al., 2022, Ju et al., 2022). Midweek sessions (MD-4 / MD-3) might offer an optimal timeframe to overload different locomotor and mechanical metrics and reflect the repeated high-intensity activity profile of modern match play (Martín-García et al., 2018; Martín-García et al., 2019; Vázquez et al., 2021; Oliva-Lozano et al., 2021).

Despite quite long mean recovery period between TA's found in our study (108 sec), the mean total duration of clusters and mean recovery periods between repeated transitional activities (CTA) indicated that speed endurance production mode could be effectively used with elite footballers integrating both physical and tactical aspects to improve performance during blocks of maximum intensity as previously reported in football (Mohr et al., 2016; 2017; Bradley et al., 2018). Repeated sprint training consisting of actions below 10 secs and sprint interval training using all-out efforts lasting around 20-30 secs might also be utilized to prepare players for CTA in competition (Hostrup et al., 2019). More research is needed to compare training to match transitional activities and determine if speed endurance training / sprint intervals positively impacts players physical performance during CTA.

CONCLUSIONS

It is highly important to understand the meaning of contextualized blocks of maximum intensity activities (transitions) within contemporary football match play. Modern football training design should move away from 90min averages and consider conditioning players for short blocks of repeated high intensity / high velocity activities that frequently occur together during transitional play in elite soccer. Such approach might counteract a detrimental impact of fatigue on team and individual physical / tactical performance in last stages of match play and potentially reduce the risk of injuries. This knowledge might prevent the mismatch between true match physical demands and training content during an overload weekly phase. Findings of this study could serve a high practical importance for coaches, practitioners, and physical therapists. It is important to note that any analysis of game demand and resultant training design is individually defined by the football philosophy of the club and coaching team.

Practical applications

Transitional activities in games expose players to repeated and intermittent high intensity / high velocity actions together. To reduce decline in physical output during contextualized blocks of maximum intensity at the end of match play, coaches and practitioners could apply different transitional games in and out of ball possession, tactical drills (offensive and defensive), and various sided games (pitch size, number of players, with/without goalkeepers) to adequately condition players for the modern physical demands of competition and potentially lower injury risk. During transitional games and tactical drills coaches might consider performing pressing high up in the opponent's half in conjunction with other transitional activities. For instance, pressing should be followed by a counterattack and/or fast attack within a short period of time. Additionally, speed endurance production, repeated sprints, and sprint intervals with appropriate work:rest ratios that integrate position-specific technical / tactical aspects might be considered during team / individual / return-to-play sessions to replicate the demands of clusters in training and optimally prepare players for the most physically demanding passages in games. It would be important in these sessions to create additional space to perform attacking actions and break into penalty box at high velocity. Finally, high-speed activities and high-intensity decelerations should be monitored closely during a weekly microcycle taking into a consideration position-specific needs in football to avoid over/underloading.

AUTHOR CONTRIBUTIONS

Conceptualization: Lukasz Bortnik and Dave Rhodes. Methodology: Lukasz Bortnik, Ryland Morgans, Dave Rhodes. Software: Joost Burger and Lukasz Bortnik. Validation: Lukasz Bortnik, Joost Burger and Dave Rhodes. Formal analysis: Lukasz Bortnik and Dave Rhodes. Investigation: Lukasz Bortnik, Joost Burger, Dave Rhodes. Resources: Lukasz Bortnik and Dave Rhodes. Data curation: Lukasz Bortnik and Dave Rhodes. Writing – original draft preparation: Lukasz Bortnik. Writing – review and editing: Dave Rhodes and Ryland Morgans.

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ORIGINAL ARTICLE

Relationship between throwing distance, shoulder joint range of motion, and upper limb muscle strength in boccia athletes: A preliminary study

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ABSTRACT

The purpose of this study was to examine the relationship between throwing distance, shoulder joint range of motion and upper limb muscle strength in boccia athletes. Participants were eight boccia athletes (cerebral palsy, cervical spinal cord injury, muscular dystrophy, spinal muscle atrophy) in whom throwing distance, ranges of motion at the shoulder joint, elbow joint and wrist joint and upper limb muscle strength were measured. Throwing distance was measured to the point where the ball landed so to remove any effect of the floor. Upper limb muscle strength was measured by isometric contraction using a handheld dynamometer. No correlation was found between throwing distance and range of motion of the shoulder joint, but correlations were found between throwing distance and strength of shoulder flexors (r = 0.76, $p < .05$), shoulder abductors (r = 0.84, $p < .01$), and elbow flexors (r = 0.77, $p < .05$). Active training to improve muscle strength around the shoulder joint, regardless of the underlying disease, was considered likely to lead to improvements in competitiveness. Due to the severe dysfunction of boccia athletes, training methods are often restricted. Verification of more effective training methods is needed while managing risks according to the physical function of the athlete and the type of disability.

Keywords: Performance analysis of sport, Paralympics, Sports performance, Physical function, Cerebral palsy, Cervical spinal cord injury.

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INTRODUCTION

Boccia is a Paralympic sport that was invented for individuals with severe cerebral palsy (CP) or similar severe limb dysfunctions. Competitors try to move 6 red and 6 blue balls to be as close as possible to the white "*jack*" ball. Boccia athletes are classified into 4 classes (BC1–4) according to physical function and disease. Athletes who have difficulty throwing the balls themselves fall into the BC3 class and participate in the competition using equipment called "*ramps*". Athletes who can roll the balls by throwing it themselves or kicking it with their feet are classified as BC1, 2, or 4. Athletes with motor dysfunction from a disease of cerebral origin, such as CP, are classified as BC1 or BC2. Athletes with severe disabilities are BC1. Athletes with limb dysfunction due to non-cerebral diseases such as cervical spinal cord injury and muscular dystrophy are classified as BC4. Boccia sports classes have a "*minimum impairment criteria*", and athletes with milder disabilities than these criteria do not fall under the BC class and are ineligible to participate in competitions that comply with international competition rules. Specifically, in the case of BC2 class athletes, as athletes in whom the main impairment is spasticity, confirmation of Grade 2 or higher spasticity using the Australian Spasticity Assessment Scale (ASAS) is required. In addition, in the BC4 class, the requirement is muscle strength (MS) in the upper limbs of 3 or less according to the Manual Muscle Test (MMT). Classifiers make a comprehensive judgement, including the degree to which dysfunction affects performance, but in principle, the criteria determine whether the level of dysfunction falls into that class. In any case, boccia is aimed at individuals with very severe disabilities, and how to improve competition performance efficiently is often unclear.

Studies on the competitive performance of boccia athletes remain scarce but include an analysis of the throwing motions in children with cerebral paralysis (Huang et al., 2014), a kinematic analysis of the relationship between throwing distance and accuracy (Reina et al., 2018) and analysis of the effect of seat angle on throwing accuracy (Tsai et al., 2014). All three studies were cross-sectional investigations with kinematic analysis. Few studies have revealed the kinds of training and practice boccia athletes need to improve performance, but a relationship clearly exists between boccia competitive performance and throwing distance (Kataoka et al., 2020). While boccia is not a competition of throwing distance, the ability to attain a long throwing distance can be considered to offer a competitive advantage. In particular, whether the individual can throw to a distance of 10 m appears to greatly affect win-loss ratios in boccia athletes. In addition, even athletes with central nervous system diseases such as CP may be less likely to have increased spasticity. Throwing distance is one indicator of boccia competitive performance, and training athletes with the aim of being able to throw farther may lead to improved performance. The purpose of this study was thus to examine the relationship between throwing distance by boccia athletes and physical function.

MATERIAL AND METHODS

Participants

The subjects were eight boccia athletes classed as BC2 or BC4. All were under-throwing players. Table 1 shows the subjects' characteristics. The primary conditions of the subjects were CP, cervical spinal cord injury (CSCI), muscular dystrophy (MD), and spinal muscular atrophy (SMA). Each participant was an athlete of Japanese national team level and had competition history of three years or more. This study measured the throwing distance of the participants, their ranges of motion (ROMs) in the upper limb, and MS in the upper limb. None of the study participants had orthopaedic disease or pain and the purpose of this study was explained to them both orally and in writing before obtaining their written consent. The participants were informed that there would be no disadvantage to withdrawing from the study.

Table 1. Subject characteristics.

Subject	Sex	Age (years)	Disease	Boccia class
A	Male	36	CP	BC2
B	Male	33	CP	BC2
C	Male	22	CP	BC2
D	Female	45	CP	BC2
E	Male	39	CSCI	BC4
F	Male	27	CSCI	BC4
G	Male	17	MD	BC4
H	Male	32	SMA	BC4
Mean ± SD		31.4 ± 9.1		

Measures

Throwing distance

Participants used a ball prepared by the examiner. The distance to the landing point of the ball was measured to avoid effects from the floor. The subjects were instructed to throw the ball as far as possible without bounding. After the athlete threw the ball, two researchers confirmed the landing point of the ball and measured the distance to that point with a tape measure. The athletes performed 10 throws, and the maximum distance was used for the analysis.

Range of motion of the shoulder joint

ROMs for shoulder joint flexion and extension, abduction, horizontal adduction, and horizontal abduction were measured using a goniometer and recorded to the nearest 5 degrees.

Muscle strength of upper limbs

A handheld dynamometer μ-TAS F1 (Anima Co., Tokyo, Japan) was used to measure the MS of participants. Resistance was applied in the direction perpendicular to the direction of joint movement, and MS during isometric contraction was measured. The measured MS was shoulder flexion/extension, shoulder abduction, elbow flexion/extension, and wrist dorsiflexion/palmar flexion.

Analysis

SPSS version 28 was used for statistical analysis. After testing the normality of Kolmogorov-Smirnov test, the relevance of findings was verified by Pearson's correlation coefficient. The significance level was set at $p < .05$.

RESULTS

The mean throwing distance of participants was 6.0 ± 1.7 m. Table 2 shows ROMs and Table 3 shows MSs of the shoulder, elbow, and wrist joints. Although throwing distance did not correlate significantly with ROM, a significant positive correlation was found between the MSs of shoulder flexion, shoulder abduction, and elbow flexion (Table 4).

DISCUSSION

This study was conducted to examine factors functionally associated with throwing distance, which is one measure of competitive performance in boccia players. Boccia was originally conceived as a sport in which individuals with CP could participate, but quadriplegics can now also participate, including those with CSCI and MD. As a result, the diseases and disabilities of players have become more diverse in recent years. In this study, we limited the evaluations to ROM and MS to examine factors related to competitive performance from a common functional assessment, regardless of the underlying disease, whether of cerebral or non-cerebral origin. Throwing distance has been shown to be related to competitive performance in boccia players (Kataoka et al., 2020). This study therefore examined whether ROM and MS of the upper limb are related to throwing distance. The results showed no relationship between throwing distance and ROM, but a relationship between throwing distance and MS in shoulder flexion, abduction, and elbow flexion.

Table 2. Maximum throwing distance and shoulder joint ROM on the throwing side.

Subject	Throwing distance (m)	Flexion (degrees)	Extension (degrees)	Adduction (degrees)	Abduction (degrees)	Horizontal adduction (degrees)	Horizontal abduction (degrees)
A	6.3	130	30	0	95	150	0
B	8.7	135	75	0	110	140	20
C	5.6	150	75	0	130	130	20
D	3.8	125	35	0	85	135	10
E	6.9	155	115	0	140	135	100
F	7.5	125	95	0	130	150	45
G	5.4	170	90	0	130	130	30
H	3.8	140	85	0	115	135	5
Mean	6.0	141.3	75	0	116.9	138.1	28.8
SD	1.7	16.0	29.2	-	19.3	8.0	32.2

Table 3. Maximum throwing distance and MS on the throwing side.

Subject	Throwing distance (m)	Shoulder flexion (kgf)	Shoulder extension (kgf)	Shoulder abduction (kgf)	Elbow flexion (kgf)	Elbow extension (kgf)	Wrist dorsiflexion (kgf)	Wrist palmar flexion (kgf)
A	6.3	46.0	64.7	38.2	53.9	50.0	40.2	29.4
B	8.7	123.5	152.9	150.0	199.0	141.2	85.8	149.0
C	5.6	88.0	122.0	58.0	99.0	77.0	70.6	32.3
D	3.8	31.3	46.0	35.3	53.9	61.7	40.2	41.1
E	6.9	82.3	33.3	87.2	110.8	0	0	0
F	7.5	48.0	25.4	48.0	72.5	4.9	0	4.9
G	5.4	6.8	10.7	20.5	4.9	7.8	17.6	17.6
H	3.8	7.8	9.8	4.9	17.6	0	7.8	13.7
Mean	6.0	54.2	58.1	55.3	76.5	42.8	32.8	36.0
SD	1.71	41.0	52.8	45.5	61.3	50.1	32.4	47.7

Most under-throwing boccia players launch the ball at the time of ball release in a posture in which the trunk is slightly more rotated to the non-throwing side than it is perpendicular to the throwing direction. That is, the throwing upper limb is positioned slightly forward. In this case, the upper limb swinging in the throwing direction is thought to produce complex motions of shoulder joint flexion and abduction. This may be one reason for the association between shoulder joint flexion, abduction, MS, and throwing distance.

Singh et al. reported that the anterior deltoid, posterior deltoid, and pectoralis major muscles are strongly associated with ball release velocity in underhand throwing (2019). Although ball speed was not measured in this study, longer throwing distance is probably linked to higher ball release velocity. In the present results as well, although no association with the posterior deltoid or pectoralis major was seen, a strong correlation was observed with the anterior deltoid. However, the study by Singh et al. did not find a strong correlation between underhand throwing and biceps brachii Electromyography (EMG) activity. Throwing distance in this study was measured from the throwing line to the point at which the ball landed, with the players asked to throw the ball to get it as far as possible before it landed on the ground. Therefore, players tended to "*throw high*" rather than "*roll*" the ball, which was thought to require stronger elbow flexion MS. Johann (2019) reported that mean EMG activity of the biceps brachii is high with underhand throws and precedes the activity of the antagonistic triceps brachii muscle. Since this study also verified the relationship with MS in underhand throwing, MS in elbow flexion may be strongly related to throwing distance.

Table 4. Mean values of ROM and MS and r value of correlations with maximum throwing distance.

	Value	
ROM of shoulder joint (°)		
Shoulder flexion	141.3 (16.0)	r = -0.075
Shoulder extension	75.0 (29.2)	r = 0.312
Shoulder adduction	0 (0)	-
Shoulder abduction	116.9 (19.3)	r = 0.330
Shoulder horizontal adduction	138.1 (8.0)	r = 0.474
Shoulder horizontal abduction	28.8 (32.2)	r = 0.395
MS of upper limbs (kgf)		
Shoulder flexion	54.2 (41.0)	r = 0.747*
Shoulder extension	58.1 (52.8)	r = 0.508
Shoulder abduction	55.3 (45.5)	r = 0.810*
Elbow flexion	76.5 (61.3)	r = 0.763*
Elbow extension	42.8 (50.1)	r = 0.386
Wrist dorsiflexion	32.8 (32.4)	r = 0.255
Wrist palmar flexion	36.0 (47.7)	r = 0.478

Note. *$p < .05$.

However, since many boccia players have CP, the effects of spasticity must also be considered. Spasticity depends on the velocity of joint movement (Lance et al., 1980). If the elbow extensor muscle, as the antagonistic muscle for elbow flexion, shows strong spasticity, the MS of the biceps brachii muscle may not sufficiently contribute to the throw, so it is necessary to verify this together with spasticity.

In the past, strength training for individuals with CP was considered inappropriate because of the risk of exacerbating spasticity. However, since the 1990s, strength training in individuals with CP has been reported as effective for physical performance (Damiano et al., 1995, Andersson et al., 2003). The effectiveness of training in individuals with severe CP, such as boccia players, has yet to be fully clarified. Boccia players are often limited in their training methods because of severe functional disabilities. We are currently examining training effectiveness in boccia players with severe CP and are now beginning to identify effective training methods and assess their effectiveness in improving performance.

The current study revealed physical functional factors related to the throwing distance achieved by boccia players; i.e., those factors related to improvement of competitive performance. The underlying diseases in the players studied were not limited to CP. The present results suggest that, regardless of the underlying disease, active training to improve MS around the shoulder joint is associated with an increase in throwing distance, and thus with an improvement in competitive performance. The results suggest that it is necessary to verify more effective training methods while managing risks, depending on the physical function and disability type of the athlete. Doewes (2023) analysed sex differences in the biomechanics of boccia underhand throws. That study did not measure throwing distance, but instead examined the relationship with throwing accuracy, reporting that female players required greater swing angles and power. Most subjects in the present study were male, but female athletes also participated, so consideration of differences in physical function due to sex may be necessary. Cornejo (2022) also reported that upper extremity motions in the sagittal plane involve static trunk control. In our study, only ROM and MS in the upper extremities were examined for associations with throwing distance, but associations with trunk function will need to be evaluated.

The key limitation of this study was that the number of players included in the study was small, and continued validation by increasing the sample size will be important in the future. In addition, since the athletes suffer from various diseases and have a wide variety of disorders such as central nervous system disorders and muscle weakness, we limited our research to ROM and MS in the upper extremities as related functional factors. A stronger relationship may be revealed by examining the relationship between sex, trunk function, functional evaluation such as spasticity, and basic movements and ADL.

CONCLUSIONS

This study examined relationships between throwing distance, upper limb joint ROM, and MS. We found that MS of the shoulder flexors, abductors, and elbow flexors are strongly associated in the throwing distance of underhand throwers. Since throwing distance reflects the competitive performance of boccia players, the present results suggest that training to improve these MSs is important, regardless of the underlying disease.

AUTHOR CONTRIBUTIONS

Conceptualization: M. Kataoka. Data curation: M. Kataoka and K. Yahagi. Methodology: M. Kataoka and K. Yahagi. Data Analysis and interpretation of the results: M. Kataoka, K. Yahagi and H. Sugano. Project administration and supervision: M. Murakami. Writing - original draft: M. Kataoka. All authors reviewed the manuscript draft and revised it critically on intellectual content. All authors approved the final version of the manuscript to be published.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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SCIENTIFIC JOURNAL OF SPORT AND PERFORMANCE

ORIGINAL ARTICLE

The influence of a COVID-19 induced reduction in game time on the match activity profiles of elite Australian Rules Football players

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ABSTRACT

Assess the influence of a 20% reduction in game time on the volume and intensity of elite AF players' match activity profiles. GPS technology was used to analyse the movement demands of 45 AF players from the same AFL club during 43 matches across the 2019 and 2020 seasons. GPS data were categorised into measures of volume (total match time [TMT] and total distance [TD]) and intensity (metres per minute [$m.min^{-1}$], high-intensity running [HIR] distance and $m.min^{-1}$ [>17 $km \cdot h^{-1}$], and very-high intensity running [VHIR] distance and $m.min^{-1}$ [>23 $km \cdot h^{-1}$]). Volume decreased in 2020 with reductions in TMT (effect size [ES] ± 95% confidence interval [CI] = -1.8 ± 0.2; $p < .001$) and TD (ES = -1.8 ± 0.2; $p < .001$) overall, across all positional groups, and quarters. Intensity increased, evidenced by increases in HIR $m.min^{-1}$ (ES = 0.3 ± 0.1; $p < .001$), and VHIR $m.min^{-1}$ (ES = 0.3 ± 0.2; $p = .006$). HIR $m.min^{-1}$ increased for midfielders (ES = 0.6 ± 0.3; $p = .017$). Defenders exhibited increases in HIR $m.min^{-1}$ (ES = 0.2 ± 0.2; $p = .007$), and VHIR $m.min^{-1}$ (ES = 0.4 ± 0.2; $p = .010$). Intensity of third quarters decreased at a greater rate in 2020 with reductions in $m.min^{-1}$ (ES = -0.2 ± 0.1; $p = .004$) and HIR $m.min^{-1}$ (ES = -0.2 ± 0.1; $p = .037$) compared to Q1. Systematic reductions in volume were found overall, across positional groups, and quarters. Average movement speed remained relatively stable overall, across quarters and positional groups. Increases in intensity were defined predominately by increases at high and very-high intensity speeds per minute, with defenders exhibiting the greatest increase in intensity and change to their match activity profiles. Longer quarter and three-quarter time breaks, and time between goals preserved intensity.
Keywords: Performance analysis of sport, Volume, Intensity, Global Positioning System, Physical performance, Professional team sports, COVID-19, Australian football.

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INTRODUCTION

Australian rules football (AF) is a physically demanding and complex team sport, requiring players to perform and recover from repeated high-intensity activities (Brewer et al., 2010; Dawson et al., 2004). Since 1994, AF matches have been played over four, 20-minute quarters of match play plus time on (being the additional time in each quarter to account for when match time is stopped by the umpire; for example, when the ball goes out of bounds, players are injured and need to leave the playing arena, or goals and behinds are scored). However, as a consequence of the novel coronavirus (COVID-19) pandemic in 2020, the Australian Football League (AFL) made the unprecedented decision to reduce its matches by 20% through shortening the length of quarters to 16 minutes, plus time on, to allow flexibility in a condensed fixture. Other non-traditional changes for the 2020 season included an increase in the length of quarter and three-quarter time breaks from six to eight minutes, an increase in the time at which play is restarted following a goal, as well as a compressed 17-game season in which the 18 professional teams played each other once. The condensed fixturing meant teams were, in some instances, required to play matches within three or four days of each other, departing from the traditional six to twelve-day breaks between matches in typical seasons.

Since the introduction of global positioning system (GPS) technology to the AFL in 2005, when clubs were first permitted to use these technologies to track and monitor the volume and intensity of their players' in-game movements (Gray & Jenkins, 2010), studies have investigated and analysed not only the individual movement demands and player characteristics (Black et al., 2016; Johnston et al., 2012; Montgomery & Wisbey, 2016; Mooney et al., 2011; Sullivan et al., 2014), but also team and match related factors (Johnston et al., 2012; Kempton et al., 2015; Ryan et al., 2017; Wisbey et al., 2008). It is suggested the historical changes in the volume and intensity of AFL matches since 2005 is primarily driven by rule changes, the evolution of game style(s) and the professionalism within the sport (Janetzki et al., 2021). Indeed, GPS analysis used to monitor player movement demands across quarters (Aughey, 2010, 2011; Brewer et al., 2010; Coutts et al., 2010; Hiscock et al., 2012; Mooney et al., 2013) of AF matches, has confirmed players typically exhibit a quantifiable reduction in both volume and intensity after the first quarter (Coutts et al., 2010; Mooney et al., 2013). Similar studies have also investigated the movement demands of various positional groups (Brewer et al., 2010; Coutts et al., 2015; Johnston et al., 2019; Kempton et al., 2015; Montgomery & Wisbey, 2016; B. Wisbey et al., 2010), with midfielders found to have the greatest physical requirements (Brewer et al., 2010; Hiscock et al., 2012; Wisbey et al., 2009). Whilst there has been marked improvement in the validity and interunit reliability of GPS technologies used in team sports, caution is still recommended when analysing movement demands in excess of 20 $km \cdot h^{-1}$ (Johnston et al., 2014), particularly with respect to measures of acceleration, deceleration and directional change (Bourdon et al., 2017).

Literature to this point has analysed and reported on GPS AFL match data based on 20-minute quarters (and overall playing time of 80 minutes). Indeed, the unprecedented 20% reduction of match time in the 2020 season will have implications for coaches and conditioning staff in understanding changes to the match activity profiles of their players. This information not only has implications during matches but is also of importance to inform training prescription and recovery, establish training intensities, assess different positional workloads (Loader et al., 2012; McLellan et al., 2011), and for lawmakers considering any potential future reductions to the playing time of AFL matches. Therefore this study sought to: 1) investigate the effect of reduced match time on measures of volume (total match time [TMT] and total distance [TD]) and intensity (metres per minute [$m.min^{-1}$], high-intensity running [HIR] distance, HIR $m.min^{-1}$, very-high intensity running [VHIR] distance, and VHIR $m.min^{-1}$) on the match activity profiles of AFL players, by comparing GPS match data from the 2019 and 2020 seasons, and 2) investigate the impact of longer quarter and three-quarter time breaks on player movement demands. It was hypothesised reduced game time would result in a reduction in volume but lead to an increase in player intensity, and that longer quarter and three-quarter time breaks would preserve intensity.

METHODS

Participants

Forty-five elite, male AF players (mean ± standard deviation = age: 25.6 ± 4.3 years, body mass: 87.9 ± 7.2 kg and height: 188.5 ± 7.2 cm) from one AFL club competing at the elite level across the 2019 and 2020 seasons participated in this study. The club provided written informed consent for retrospective analysis of deidentified data, and this analysis was approved by the University of South Australia's Human Research Ethics Committee.

Data analysis

Data were collected at 10 Hz using portable GPS devices (Catapult Innovations models S5 [2019] and Vector [2020], Melbourne, Australia). It has been established this GPS device provides a good level of interunit reliability and validity (Johnston et al., 2014), however the reliability of movement demands exceeding 20 $km{\cdot}h^{-1}$ remains questionable. Players wore the same GPS device in a custom-made pouch sewn into the back of their playing jumper between their scapulae.

Following each match, data were downloaded using Catapult Sprint (version 5.1.6; Catapult Innovations). Time between quarters and the time players spent on the interchange bench were removed. All data were exported to Microsoft Excel (Microsoft Corporation, NY, USA) where individual data profiles were de-identified by the AFL club before further analyses.

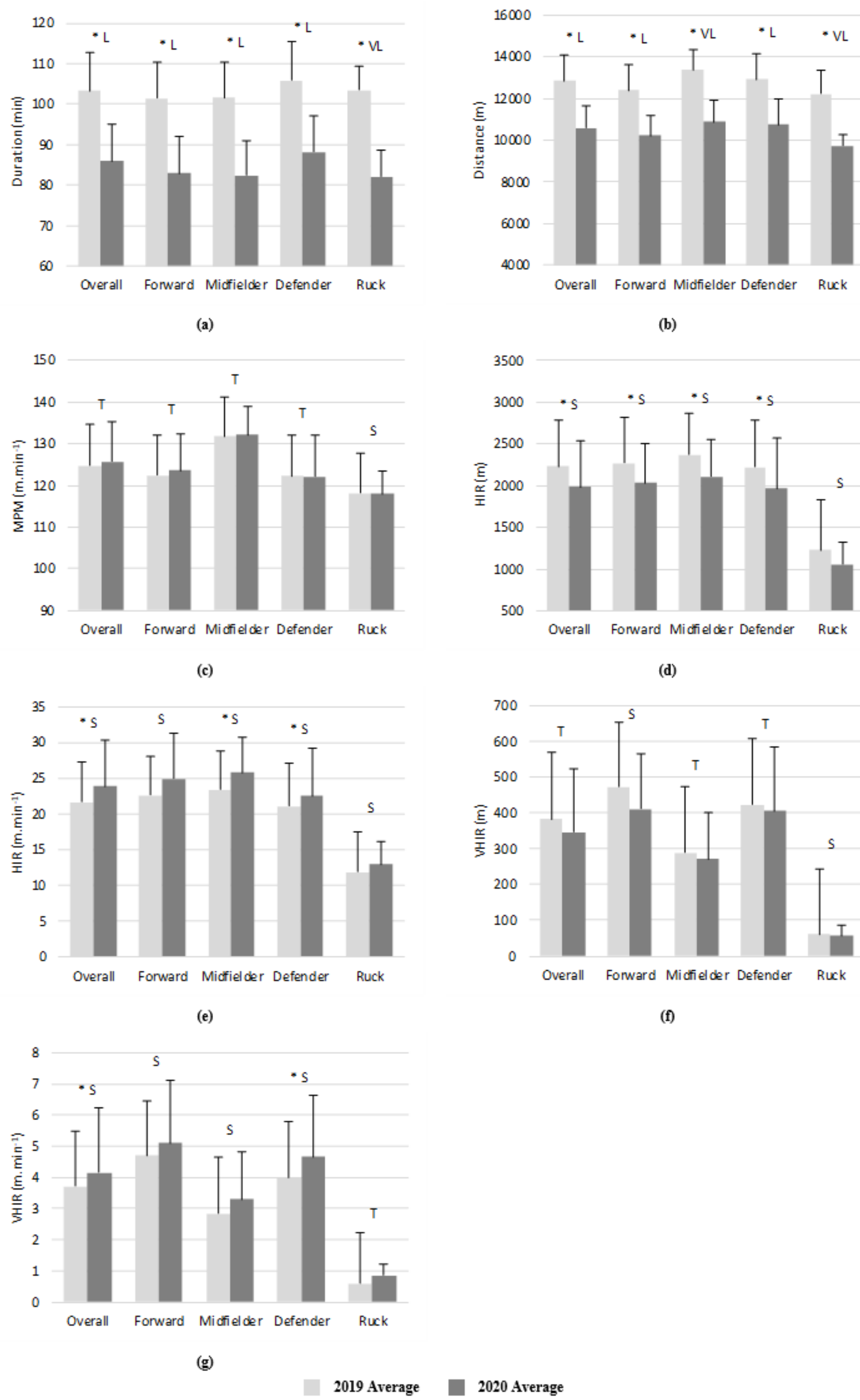
Changes in movement demand variables across seasons, as investigated by earlier studies (Aughey, 2013; Kempton et al., 2015; Ben Wisbey et al., 2010) including TD, TMT, $m.min^{-1}$, HIR (>17 $km{\cdot}h^{-1}$) and VHIR (>23 $km{\cdot}h^{-1}$), were analysed to assess the shift in the volume and intensity of matches from 2019 and 2020. HIR and VHIR metrics (volume of distance [m] covered in each speed band) were also expressed relative to individual match time as a means of standardising data across seasons with different match durations. Data were analysed for changes overall, across quarters and positional groups (forward, midfield, defensive and ruck), which were determined based on the greatest percentage of time played in one position. Acceleration and deceleration counts were not analysed due to large differences in the S5 and Vector Catapult units used in 2019 and 2020 respectively.

In accordance with earlier protocols (Coutts et al., 2010), data were only included in the analysis if players participated in a minimum of 75% of TMT, which provided 557 and 359 complete data files in 2019 and 2020 respectively. Due to the reduction in match and quarter durations in 2020, all data from the two seasons were filtered individually with the relevant applicable threshold (minimum 75% of TMT).

Statistical analysis

Data for each metric were presented as the mean and standard deviation for 2019 and 2020, which was used to calculate the percentage change between seasons. Statistical significance was set using an alpha level of $p < .05$. Linear mixed models in IBM SPSS Statistics (PASW Statistics 26.0, Chicago, IL, USA) were used to calculate the change between seasons and standardised effect size, expressed as mean and 95% confidence intervals [CI], which was used to calculate the respective percentage change between seasons. The comparison between seasons was defined as a fixed effect, while individual players were included as a random effect. Effect sizes were quantified as trivial ≤0.2, small >0.2, moderate >0.6, large >1.2, very large >2.0 (Cohen, 2013).

RESULTS



*Note. * Denotes statistical significance between 2019 and 2020 seasons (p < .05).*
Min: minutes, m: metres, MPM / m.min^{-1}: metres per minute, HIR: high-intensity running, VHIR: very-high intensity running, T: trivial, S: small, L: large, VL: very large effect sizes.

Figure 1. Mean comparison between seasons 2019 and 2020 and positional groups (x axis), and (**a**) total match time, (**b**) total distance, (**c**) metres per minute, (**d**) high-intensity running, (**e**) high-intensity running metres per minute (**f**) very-high intensity running (**g**) very-high intensity running metres per minute (y axis). Data are mean ± 95% confidence interval.

Table 1. Overall and quarter values for all metrics from 2019 to 2020 (Mean ± 95% CI).

		2019	**2020**	**Change**	**Effect Size**	***p*-value**
TMT (min)	Total	103.3 ± 9.4	86.0 ± 9.0	-16.7 ± 1.8	-1.8 ± 0.2	<.001
	Q1	26.1 ± 3.3	21.2 ± 2.7	-4.9 ± 0.5	-1.6 ± 0.2	<.001
	Q2	26.2 ± 3.0	21.2 ± 3.2	-4.8 ± 0.5	-1.5 ± 0.2	<.001
	Q3	26.5 ± 3.2	22.2 ± 3.6	-4.1 ± 0.4	-1.2 ± 0.1	<.001
	Q4	26.4 ± 3.5	22.1 ± 3.3	-4.2 ± 0.5	-1.2 ± 0.1	<.001
TD (m)	Total	12843 ± 1217	10562 ± 1105	-2061 ± 199	-1.8 ± 0.2	<.001
	Q1	3372 ± 434	2735 ± 361	-603 ± 59	-1.5 ± 0.2	<.001
	Q2	3265 ± 385	2692 ± 381	-548 ± 65	-1.4 ± 0.2	<.001
	Q3	3262 ± 399	2684 ± 378	-544 ± 62	-1.4 ± 0.2	<.001
	Q4	3135 ± 437	2599 ± 366	-501 ± 64	-1.3 ± 0.2	<.001
MPM ($m.min^{-1}$)	Total	124.7 ± 9.8	125.7 ± 9.5	-0.1 ± 1.0	0.0 ± 0.1	.907
	Q1	129.9 ± 12.4	131.9 ± 11.2	0.9 ± 1.4	0.1 ± 0.1	.212
	Q2	125.3 ± 11.5	128.5 ± 11.3	2.4 ± 1.3	0.2 ± 0.1	<.001
	Q3	123.8 ± 11.2	123.4 ± 13.3	-1.3 ± 1.3	-0.1 ± 0.1	.049
	Q4	119.5 ± 12.1	120.5 ± 12.1	-0.1 ± 1.3	0.0 ± 0.1	.930
HIR (m)	Total	2226 ± 556	1986 ± 546	-198 ± 53	-0.4 ± 0.1	<.001
	Q1	625 ± 182	552 ± 173	-73 ± 19	-0.4 ± 0.1	<.001
	Q2	570 ± 174	516 ± 164	-53 ± 22	-0.3 ± 0.1	<.001
	Q3	560 ±175	494 ± 154	-63 ± 19	-0.4 ± 0.1	<.001
	Q4	498 ± 169	463 ± 169	-26 ± 24	-0.2 ± 0.1	.046
HIR MPM ($m.min^{-1}$)	Total	21.7 ± 5.6	23.8 ± 6.5	1.9 ± 0.6	0.3 ± 0.1	<.001
	Q1	24.2 ± 7.0	26.8 ± 8.2	2.0 ± 0.8	0.3 ± 0.1	<.001
	Q2	21.9 ± 6.6	24.7 ± 7.4	2.4 ± 0.8	0.3 ± 0.1	<.001
	Q3	21.4 ± 7.0	23.0 ± 7.6	1.2 ± 0.8	0.2 ± 0.1	.004
	Q4	19.0 ± 6.3	21.7 ± 8.0	2.8 ± 1.2	0.4 ± 0.2	<.001
VHIR (m)	Total	382 ± 186	345 ± 179	-23 ± 29	-0.1 ± 0.2	.135
	Q1	107 ± 62	95 ± 63	-11 ± 8	-0.2 ± 0.1	.016
	Q2	102 ± 69	95 ± 63	-7 ± 9	-0.1 ± 0.1	.169
	Q3	96 ± 65	85 ± 56	-10 ± 8	-0.2 ± 0.1	.028
	Q4	82 ± 57	78 ± 59	-1 ± 11	0.0 ± 0.2	.847
VHIR MPM ($m.min^{-1}$)	Total	3.7 ± 1.8	4.2 ± 2.1	0.5 ± 0.3	0.3 ± 0.2	.006
	Q1	4.1 ± 2.4	4.6 ± 2.9	0.4 ± 0.4	0.2 ± 0.1	.028
	Q2	3.9 ± 2.6	4.5 ± 2.9	0.6 ± 0.4	0.2 ± 0.2	.017
	Q3	3.6 ± 2.5	4.0 ± 2.7	0.3 ± 0.3	0.1 ± 0.1	.125
	Q4	3.1 ± 2.2	3.6 ± 2.7	0.6 ± 0.5	0.2 ± 0.2	.023

Note. Total: total match values, Q1: quarter 1, Q2: quarter 2, Q3: quarter 3, Q4: quarter 4, TMT: total match time (min), TD: total distance (m), MPM: meters per minute ($m.min^{-1}$), HIR: high-intensity running (m), VHIR: very-high intensity running (m).

Table 2. Mean quarter change overall and from quarter one in 2019 and 2020 (Mean ± 95% CI).

		2019	*p*-value	2020	*p*-value	Difference	Effect Size	*p*-value
TMT (min)	Total	0.1 ± 0.1	.031	0.4 ± 0.1	<.001	0.3 ± 0.2	0.1 ± 0.1	.003
	Q1							
	Q2	0.1 ± 0.4	.481	0.1 ± 0.4	.630	0.0 ± 0.6	0.0 ± 0.2	.932
	Q3	0.4 ± 0.4	.022	1.1 ± 0.4	<.001	0.7 ± 0.6	0.2 ± 0.2	.016
	Q4	0.3 ± 0.4	.082	1.0 ± 0.4	<.001	0.7 ± 0.6	0.2 ± 0.2	.021
TD (m)	Total	-70 ± 14	<.001	-39 ± 15	<.001	31 ± 21	0.1 ± 0.1	.005
	Q1							
	Q2	-103 ± 45	<.001	-65 ± 47	.007	38 ± 67	0.1 ± 0.2	.271
	Q3	-108 ± 45	<.001	-63 ± 47	.009	46 ± 67	0.1 ± 0.2	.177
	Q4	-233 ± 45	<.001	-131 ± 47	<.001	100 ± 68	0.3 ± 0.2	.004
MPM ($m.min^{-1}$)	Total	-3.3 ± 0.3	<.001	-4.0 ± 0.4	<.001	-0.7 ± 0.5	-0.1 ± 0.0	.008
	Q1							
	Q2	-4.6 ± 1.0	<.001	-3.4 ± 1.4	<.001	1.2 ± 1.7	0.1 ± 0.2	.179
	Q3	-6.2 ± 1.0	<.001	-8.7 ± 1.4	<.001	-2.5 ± 1.7	-0.2 ± 0.1	.004
	Q4	-10.4 ± 1.1	<.001	-11.6 ± 1.4	<.001	-1.1 ± 1.7	-0.1 ± 0.1	.162
HIR (m)	Total	-39 ± 5	<.001	-29 ± 5	<.001	9 ± 8	0.1 ± 0.0	.018
	Q1							
	Q2	-55 ± 16	<.001	-40 ± 17	<.001	15 ± 25	0.1 ± 0.1	.240
	Q3	-66 ± 16	<.001	-63 ± 17	<.001	3 ± 24	0.0 ± 0.2	.835
	Q4	-126 ± 16	<.001	-90 ± 172	<.001	35 ± 25	0.2 ± 0.2	.005
HIR MPM ($m.min^{-1}$)	Total	-1.6 ± 0.2	<.001	-1.7 ± 0.3	<.001	-0.1 ± 0.3	0.0 ± 0.0	.432
	Q1							
	Q2	-2.3 ± 0.6	<.001	-2.1 ± 0.8	<.001	0.3 ± 1.0	0.0 ± 0.1	.621
	Q3	-2.8 ± 0.6	<.001	-3.9 ± 0.8	<.001	-1.1 ± 1.0	-0.2 ± 0.1	.037
	Q4	-2.3 ± 0.6	<.001	-5.1 ± 0.8	<.001	0.0 ± 1.0	0.0 ± 0.1	.969
VHIR (m)	Total	-8 ± 2	<.001	-6 ± 2	<.001	2 ± 3	0.0 ± 0.1	.267
	Q1							
	Q2	-5 ± 6	.099	0 ± 7	.991	5 ± 10	0.0 ± 0.2	.290
	Q3	-11 ± 6	<.001	-10 ± 7	.005	0 ± 10	0.0 ± 0.2	.906
	Q4	-24 ± 6	<.001	-17 ± 7	<.001	7 ± 10	0.1 ± 0.2	.137
VHIR MPM ($m.min^{-1}$)	Total	-0.3 ± 0.1	<.001	-0.3 ± 0.1	<.001	0.0 ± 0.1	0.0 ± 0.1	.680
	Q1							
	Q2	-0.2 ± 0.2	.055	-0.1 ± 0.3	.707	0.2 ± 0.4	0.1 ± 0.1	.412
	Q3	-0.5 ± 0.2	<.001	-0.6 ± 0.3	<.001	-0.2 ± 0.4	-0.1 ± 0.2	.441
	Q4	-1.0 ± 0.2	<.001	-0.9 ± 0.3	<.001	0.0 ± 0.4	0.0 ± 0.2	.920

Note. Total: overall mean quarter values, Q1: quarter 1, Q2: quarter 2, Q3: quarter 3, Q4: quarter 4, TMT: total match time (min), TD: total distance (m), MPM: meters per minute ($m.min^{-1}$), HIR: high-intensity running (m), VHIR: very-high intensity running (m).

Overall

There was a decrease in overall volume from 2019 to 2020, evidenced by large decreases in TMT and TD ($p < .001$; Figures 1a & b; Table 1). Despite a small decrease in HIR in 2020 ($p < .001$; Figure 1d; Table 1), intensity increased in 2020 with small increases in HIR $m.min^{-1}$ ($p < .001$; Figure 1e; Table 1), and VHIR $m.min^{-1}$ ($p = .006$; Figure 1g; Table 1).

Positions
All positional groups experienced decreases in TMT and TD (p < .001; Figures 1a & b). Defenders exhibited the greatest increase across high and very-high intensity speeds with small increases in HIR m.min^{-1} (p = .007; Figure 1e), and VHIR m.min^{-1} (p = .010; Figure 1g). Midfielders experienced a small increase in HIR m.min^{-1} (p = .017; Figure 1e). There was a tendency for a small increase in HIR m.min^{-1} for forwards (p = .053; Figure 1e).

Quarters
Large decreases in TMT and TD were found across all quarters (p < .001; Table 1), indicating a significant decrease in volume across quarters from 2019 to 2020. On average, the decrement in TMT (p = .003; Table 2) and TD (p = .005; Table 2) across quarters was less in 2020 compared to 2019. Similarly, TMT (p = .021; Table 2) and TD (p = .004; Table 2) declined at a smaller rate across fourth quarters in 2020.

HIR m.min^{-1} increased across all quarters in 2020 (p < .001; Table 1). VHIR m.min^{-1} increased across first, second and fourth quarters in 2020 (Table 1). MPM decreased in third quarters in 2020 (p = .049; Table 1).

MPM also decreased on average at a greater rate across quarters in 2020 (p = .008; Table 2), particularly third quarters (p = .004; Table 2). On average, the decrement in HIR m.min^{-1} across quarters was unchanged in 2020 (p = .432; Table 2), however HIR m.min^{-1} declined at a greater rate across third quarters in 2020 (p = .037; Table 2). The average rate of decline in HIR distance across quarters, however, was less in 2020 compared to 2019 (p = .018; Table 2), particularly in fourth quarters (p = .005; Table 2).

DISCUSSION

This study analysed the effect of reduced game time on the match activity profiles of elite AF players by comparing players' GPS match data from the 2019 and 2020 seasons. The main findings were that in 2020, overall volume decreased across all GPS metrics, and across quarters and positional groups. Small increases in intensity were recorded at high (i.e. >17 km·h^{-1}) and very-high (i.e. >23 km·h^{-1}) intensities overall (Figures 1e & g; Table 1), with defenders the only positional group to record increases at both intensities (Figures 1e & g). Midfielders also recorded a small increase in intensity but only at high-intensity speed, whilst forwards only exhibited a tendency for an increase in intensity at this threshold (Figure 1e). The increase in quarter and three-quarter time breaks had no impact on players' intensity in the subsequent quarter (Table 2). These results have implications for coaches, conditioning staff and players in understanding the increased intensity and physical match demands on players because of reduced game time and compressed fixturing of matches.

Unsurprisingly, the reduction in the length of quarters for the 2020 season, from 20 to 16 minutes and overall match playing time from 80 to 64 minutes, resulted in a reduction of overall volume, reflected across all positional groups and quarters. This is further evidenced by large decreases in TD and TMT overall, across quarters and for forwards and defenders (Figures 1a & b; Table 1). Ruckmen and midfielders exhibited the greatest reduction in volume with very large decreases in distance, along with very large and large decreases in duration respectively (Figures 1a & b). Therefore, these findings and the change(s) in GPS derived player output metrics between the 2019 and 2020 seasons are contextualised by the relevant measures of GPS intensity variables.

Overall changes

In 2020, player average movement speed at high and very-high intensity levels increased (Figures 1e & g; Table 1). Furthermore, the absence of a change in $m.min^{-1}$ and the amount of VHIR distance along with a reduction in HIR distance (Figures 1c, f & d; Table 1), suggests the reduction in match time for the 2020 season only increased the intensity of player output when made relative to playing time at high and very-high intensity speeds.

The somewhat randomised and flexible fixture implemented in 2020 saw 'clusters' of matches played within a very short period, where the focus between games was largely on recovery rather than recovery *and* training in preparation for the next match. Teams were sometimes afforded three- or four-day breaks between matches, departing from the traditional six to twelve-day breaks they had become accustomed to in preceding seasons. Research has found distance, acceleration and sprint output were at their highest in-season levels following a twelve-day break between matches, in comparison to six, seven and eight day turnarounds (Hiscock et al., 2012).

Positional changes

Forwards demonstrated the greatest reduction in TMT and TD (Figures 1a & b; Table 1), which is perhaps suggestive of an increased utilisation of the interchange bench for this positional group in 2020. It might have been expected forwards would therefore exhibit greater intensity across their activity profile (Burgess et al., 2012). However, the findings of this investigation suggest reduced match and possibly in-game time, had no impact on the intensity of forwards at all intensity speed measures, with no change in $m.min^{-1}$, HIR $m.min^{-1}$, and VHIR $m.min^{-1}$ (Figures 1c, e & g). This finding supports earlier research (Kempton et al., 2015) which found forwards exhibited the least variability in their match activity profile of any positional group, which has been attributed to their specific roles and constraints imposed by playing position.

Earlier research (Brewer et al., 2010; Hiscock et al., 2012; Wisbey et al., 2009) has established midfielders have higher in-game movement demands, cover greater distance, and record higher average speed values than other positions. The findings of this study provided mixed support for these earlier studies, depending on the measure of intensity. The present investigation found midfielders maintained a higher average of overall distance across the two seasons of interest and recorded the greatest increase in HIR $m.min^{-1}$ in 2020 (Figure 1e). The most likely explanation for this is the combined effect of superior aerobic capacities and a tendency to be rotated through the interchange bench more frequently compared to other playing positions, enabling them to fulfil their tactical roles at higher relative intensity (Coutts et al., 2015; Esmaeili et al., 2020; Mooney et al., 2011; B. Wisbey et al., 2010).

Despite spending more time on the ground and having the smallest reduction in TMT of any positional group in 2020, defenders experienced the greatest increase in very-high intensity (>23 $km \cdot h^{-1}$) measures than any other positional group, recording a small increase in VHIR $m.min^{-1}$ (Figure 1g). This may be explained by the finding detailed in Figure 1(a) whereby defenders spent, on average, more time on the ground relative to other positional groups, thereby affording them the opportunity to engage in more very-high intensity activity. The style of play adopted by the team and the diverse tactical roles of defenders (Kempton et al., 2015) may also confound this finding. However, given these findings are contextualised by analysis of relative movement speeds, it is concluded defenders experienced the greatest increase in intensity at very-high intensity speed than any other positional group as a consequence of reduced quarter and match time.

Other than the expected reduction in volume (TD and TMT) for ruckmen (Figures 1a & b), no significant changes in measures of intensity were found. This is potentially attributable to the small sample size of ruckmen analysed across the two seasons and the different game styles adopted by these athletes.

Quarter changes

Whilst players exhibited greater overall reductions in volume with decreases in TD and TMT in 2020 (Figures 1a & b; Table 1), this investigation found the decrement in distance and duration across quarters was greater in 2019 compared to 2020, particularly in fourth quarters (Table 2). This suggests reduced game time in 2020 stabilised the volume of players' match activity profiles.

Furthermore, whilst overall intensity increased in 2020, particularly at higher speeds, this study found $m.min^{-1}$ decreased on average at a greater rate across quarters in 2020 than in 2019 (Table 2). This was particularly evident in third quarters, in which the rate of decrement in $m.min^{-1}$ and HIR $m.min^{-1}$ was greater in 2020. These findings suggest increased intensity earlier in the match, which this investigation found to be a product of reduced match time, resulted in a greater reduction in intensity across the course of a match, which is in keeping with the findings of earlier research (Coutts et al., 2010). Interestingly, these decrements ensued despite an increase in time for recovery between the first and second, and third and fourth quarters.

At higher intensities (HIR and VHIR speeds), there was no change on average in the rate of decrement in relative intensity measures across quarters (Table 2). Interestingly in 2020, there was no significant change in the rate at which relative intensity measures of $m.min^{-1}$, HIR $m.min^{-1}$ and VHIR $m.min^{-1}$ decreased across second and fourth quarters (Table 2). These findings suggest the increase quarter and three-quarter time breaks, up from six to eight minutes in 2020, had no impact in relative terms on player intensity in the subsequent quarter. However, this investigation found the decrease in HIR distance across quarters on average, particularly in fourth quarters, to be significantly less in 2020 (Table 2). This change is perhaps attributable to the combined effect of reduced game time and the increased three-quarter time break.

Limitations

The data provided in this paper described and analysed the effect of reduced game time on the match activity profiles of elite AF players. However, the findings of this study are limited by the fact they are drawn from examination of data from one team. It should be acknowledged data were collected from different GPS models (from the same manufacturer) given the manufacturer's change in hardware at the end of 2019. Therefore, the extent of the analysis in this paper was limited to the GPS measures which were analysed, given the manufacturer's recommendation not to compare acceleration and deceleration data. A small pilot study was conducted to ascertain whether a correction factor could be applied, however the *adjusted R-squared* value of .0391 confirmed the correlation between these data was insufficient.

It is well established that player activity profiles are influenced by several confounding factors, such as time between matches, travel, and individual and team tactics. Future research should look at investigating the effect of these factors in the context of reduced game time on players' match output. These findings could also be contextualised with reference to injury incidence to assess this relationship with an increase in intensity, particularly at higher speeds, due to reduced game time.

CONCLUSIONS

The results show that a 20% reduction of game time produced an expected decrease in volume with TD and TMT declining. Interestingly, the hypothesised increase in intensity was not systematic, with increases in intensity predominantly found at high and very-high intensity speeds across matches, positional groups, and quarters. No real changes were found in average player movement speed. Defenders were the only positional group to record significant increases in their match activity profile at relative measures of high and very-high intensities. Furthermore, the impact of increased quarter and three-quarter time breaks had no influence on relative measures of intensity in the second and fourth quarters.

AUTHOR CONTRIBUTIONS

S. J. J., conceptualised the research question, analysed the data, and prepared the manuscript. C. R. B., conceptualised the research question and method of analysis, assisted with the analysis and interpretation of data, and substantively revised the manuscript. A. O. N., conceptualised the research question, undertook the data collection, and substantively revised the manuscript. N. P., conceptualised the research question, undertook the data collection, and substantively revised the manuscript. E. M. W. H., conceptualised the method of analysis, assisted with the interpretation of data and statistical analysis, and substantively revised the manuscript. P. C. B., conceptualised the research question and method of analysis, assisted with the analysis and interpretation of data, and substantively revised the manuscript.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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ORIGINAL ARTICLE

Interpersonal emotions in team sports: Effects of emotional contagion on emotional, social and performance outcomes of a team

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ABSTRACT

This research explores how emotional contagion within a team impacts emotions, team cohesion, collective efficacy perception, effort perception, perceived performance, and actual performance outcomes. Forty-seven non-competitive amateur cross-fit participants were split into two experimental groups: high pleasantness-high arousal (HH) and low pleasantness-low arousal (LL). To stimulate these mood states, two trained associates were engaged, which served as catalysts for the teams' "*emotional contagion*". Participants from the HH group outperformed and exerted more effort than those from the LL group, though they perceived their effort levels to be similar. They demonstrated greater collective efficacy and team cohesion, had a more positive emotional state, and perceived their team's performance as superior. Emotional contagion plays a significant role in team dynamics and physical outcomes. The practical implications of emotional contagion are discussed.

Keywords: Sport Psychology, Emotional contagion, Team cohesion, Collective efficacy, Perceived performance, Actual performance outcomes, Mood states in team sports.

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INTRODUCTION

Team performance depends on the motor and emotional synchronization of its team members (Hatfield et al., 1993). Synchronization can express itself in the form of emotions, thoughts, and motor actions, and is a product of the extent of task and social-emotional related knowledge shared by its members (i.e., team shared mental models; TMM; Eccles & Tenenbaum, 2004). A shared emotional experience among team members is imperative to their functioning as a team and to task accomplishment (Janelle, 2018). Shared emotions during social engagement are classically considered to evoke collective sensations and perceptions that strengthen common ideas, values, and actions (Durkheim, 1912). Emotions of team members influence the team's interpersonal relationships, and by extension their social and task cohesion and identification, coordinated efforts, and problem solving toward the achievement of common goals (Van Kleef & Fischer, 2015). However, despite their importance, emotions have mainly been studied in individuals before, during, and after competitive events (Hanin, 2000; Vallerand, 1983).

The purpose of the current study was to experimentally elucidate how emotion contagion changes team members' emotions, and affects team members' collective efficacy, team cohesion, perceived effort, perceived performance, and team performance. The process of transferring interpersonal emotions among members of a team (i.e., "*emotional contagion*") develops "*collective emotions*" (Barsade & Gibson, 1998, 2007), and takes place either intentionally or unintentionally. Several mechanisms contribute to emotion contagion. Mimicry and nonconscious emotional synchronization enable individuals to unconsciously mimic the emotional expressions and behaviours of other members, leading to shared emotional experiences. Empathy plays a crucial role, as individuals mentally simulate the emotional states of others, thus experiencing similar emotions (Barsade & Gibson, 1998, 2007). Moreover, through facial expressions, body language, and verbal communication, people enable other members of the team to observe and feel their own emotions, which are then transferred to them (Hatfield et al., 1994). For example, if one member of a team reflects the emotion of fear, this emotion is transferred to the other members. Emotional contagion is more robust in team members who identify with the team and its goals (Doosje et al., 1998; Leach et al., 2003), and affects the work dynamic of the team (Barsade, 2002).

Two mechanisms are thought to underlie emotion contagion: *imitation* and *feedback*.

When team members share the same positive emotion, this can make them united and persevere in achieving their common goals (Barsade & Gibson, 1998). Team members who manage their emotions efficiently increase the likelihood of achieving their goals because they invest more effort than teams whose members' emotions are negative and dysfunctional (Sy et al., 2005). Barsade (2002) demonstrated the ripple effect of emotional contagion on group behaviour, and Kramer et al. (2014) provided experimental evidence of massive-scale emotional contagion through social networks.

When team members watch each other, mirror neural circuits are activated and transfer to them similar moves or feelings which are expressed by them (Hatfield et al., 2011). Emotional contagion is thought to be triggered by mirror neurons that are activated by an action or observation of an action (Gallese, 2009), and enable the observer to see and feel what the other team member feel, in that they make it possible to sense empathy toward someone and anticipate other people's feelings, which in turn enable bodily and verbal communication (Lacoboni et al., 2005).

The current study examined team members' shared pleasant and unpleasant emotional valence. Specifically, we explored how pleasant and unpleasant emotional contagion along with high and low arousal level would affect members' perception of physical effort, team cohesion, collective efficacy, and the performance of physically demanding tasks. Pleasantness and arousal (i.e., activation) form the core concept of the current study's "*emotional contagion*" and stem from the Circumplex Model of affect (Russell, 1980). This two-dimensional model posits that all affective states arise from two fundamental neurophysiological systems; one related to valence and the other to arousal, or alertness. Accordingly, perceived experiences, and hence emotions within these dimensions, are not at the same level for all individuals. Arousal (or intensity) is the level of autonomic activation engendered by an event, and ranges from calm (or low) to excited (or high). Valence, on the other hand, is the level of pleasantness an event generates and is defined along a continuum from negative to positive. Discrete emotions extend from a positive through negative pleasantness valence accompanied by a low to high arousal/excitation state (see Russel, 1980 for details).

Mood states and team members' discrete emotions influence, and are influenced, by social-cognitive processes and the team's dynamics. Specifically, team members' collective efficacy beliefs are affected by the feelings the members convey to each other through mutual observations and communication (Bandura, 1997). Shared goals are usually accompanied by feelings of closeness and intimacy among the members, which in turn increase social and task cohesion (Duffy & Shaw, 2000). When faced with physically demanding tasks (e.g., workload), team members feel strong exertion, which stems from coping with aversive physiological sensations, the motivation to engage in the task, perceived exertion, attention allocation, and pleasantness (see Alvarez-Alvarado et al., 2019 for a review and research findings). Shared positive emotions among the members can positively affect their feelings, collective efficacy, feeling of cohesiveness, perceived exertion and even their perceived performance and collective outcomes.

Perceived team performance is related to shared feelings among team members (Rhee, 2007). For example, a team's mental toughness when linked with positive feelings was shown to enable team members to cope with aversive states, recover from distress and failure, and accomplish tasks more efficiently (Tugade & Fredrickson, 2004). Teams sharing positive emotions such as excitement, optimism, satisfaction, and serenity tended to accept new adventures and persevere longer on tasks (Meneghel et al., 2016). Thus, perceived, and actual team performances are associated with positive emotions, which can be intentionally transferred to the members of the team by a coach, a leader, or an external member of the team.

In most cases the team's leader plays a major role in shaping the emotions of the team members, but intentionally or unintentionally, each member can spark an emotional contagion in his/her team members (Sy et al., 2005). In the current study we recruited professional actors, who are experts in creating mood states, to convey pleasant feelings along with a high arousal level to team members in one condition, and unpleasant feelings along with low arousal level to another team in another condition, to test the notion that extremely different mood states will have a differential effect on the way team members perceive team cohesion, collective efficacy, perceived effort and performance, and actual physical performance.

This study is grounded in the conceptual assumption that positive or negative emotional contagion creates a state of mind that increases or decreases team members' perceived togetherness (i.e., social and task cohesion) and collective efficacy when engaged in a demanding task. For example, study of 143 teams for four months revealed that jealousy among team members resulted in team idleness and decreased collective efficacy in addition to lower team cohesion and engagement that negatively affected performance (Duffy & Shaw, 2000). Collective efficacy was also found to directly determine physical and motor performance (Myers et al., 2004), and along with team cohesion can mediate the relationship between shared team emotions and perceived and actual performance.

Because the team members in the current study were asked to perform a physically demanding CrossFit task together, the hypothesized conceptual relationship between the members' shared emotions and performance as mediated by collective efficacy and team cohesion needed to consider the members' perceived exertion during task engagement. Recently, Alvarez et al. (2019) tested rate of perceived exertion (RPE), attention allocation, feelings of pleasantness during an aerobic cycling task and on a dynamometer hand-grip squeeze until voluntary exhaustion. The findings indicated that in both tasks RPE increased linearly until voluntary exhaustion, but pleasantness increased until reaching the ventilatory threshold (VT) after which pleasantness decreased sharply. Attention allocation shifted flexibly from dissociative to associative until the VT and became strictly associative following the VT until voluntary exhaustion. These findings were replicated in a companion study showing that in addition to RPE, pleasantness, attention allocation, and motivation to adhere to the tasks decrease after reaching VT (Alvarez et al., 2019). Members who felt positive emotions became more determined to meet their common goals and could better overcome obstacles and adhere to the demanding conditions than their counterparts who experienced negative emotions (Tugade & Fredrickson, 2004; Meneghel et al., 2016; Rhee, 2007). Thus, we assumed that in a condition involving the contagion of pleasant emotions accompanied by high arousal, the perceived exertion of the task would be lower than for unpleasant emotional contagion accompanied by a low arousal state, despite the higher level of physical investment in the former condition.

Thus overall, the goal was to test the notion that the contagion of positive and negative mood states results in contrasting social state of minds (e.g., task and social team cohesion, collective efficacy), perception of exertion, which in turn would lead to contrasting perceived and actual physical performance. To test this notion, 47 team members were randomly assigned to two conditions: high pleasantness-high arousal (HH) and low pleasantness-low arousal (LL) and were exposed to positive or negative emotional contagion conditions, respectively and were asked to perform a demanding cross-fit physical task.

MATERIAL AND METHODS

Participants

A power analysis using G*Power 3 program (Faul et al., 2007) was performed to determine the sample size. Assuming a small-moderate effect size due to lack of comparable studies in the literature and using repeated measures (RM) ANOVA design with $f_{(V)} = 0.25$, $\alpha = .05$, power $(1-\beta) = .80$, two experimental conditions, yielded a required sample size of $N = 40$. Thus, forty-seven participants were recruited for the study. All participants were volunteers and received no compensation.

The participants were 47 men and women ranging in age from 18 - 53 ($M = 30.20$ years, $SD = 7.83$) who had worked out regularly at a cross-fit gym for more than one year, for four session per week. The participants were divided randomly into two experimental conditions: high arousal and high pleasantness (HH), and low arousal and low pleasantness (LL). Participants were first given a lecture on exercise psychology at a day and time of their convenience. The trainees were from middle-socio-economic backgrounds. Of the participants, 36% and 18.2% were women in the HH and LL conditions, respectively.

Measures

Demographic questionnaire

The questionnaire included the following items: gender, age, years doing cross-fit, number of hours of workout per week, weight, and height.

Arousal and pleasantness level (Russel ,1980; Larsen & Diener, 1992)

The two dimensions of the Circumplex Model were used to measure the degree of *pleasantness* and *arousal* on two independent continua. The two independent dimensions created a space where positive and negative emotions (which correlated), such as displeasure, distress, depression excitement and others are perceived by people experiencing them. The Circumplex Model with two orthogonal axis consists of one *displeasure-pleasure* continuum and another *level of arousal* continuum. A principal component analysis of 343 reports of current affective states validated the two-dimensional special concept (Russel ,1980). The two items are rated on a Likert-type scale, ranging from 1 (*very low*) to 10 (*very high*).

Emotional Contagion (EC; Doherty, 1997)

The EC measures the psychological disposition of emotional contagion using 15 items representing five dimensions: *happiness, love, fear, sadness, and anger*. Each dimension consists of 3 items rated on a 5-point Likert-type scale, ranging from 1 (*never*) to 5 (*always*). The average rating represents the emotional intensity on each dimension. The authors reported an internal consistency of Cronbach's α = .90 and the factor loadings ranged from .46 - .69. Positively related emotions were related to reactivity, emotionality, sensitivity to others, social function, and self-esteem. Negatively related emotions were correlated with alienation, self-assertiveness, and emotional stability. The EC was low to moderately correlated (.30 - .47) with measures of responsiveness and self-reports of emotional experiences following exposure to emotional expressions. Temporal stability after a 3- week interval ranged from .80 to.82 for positive and negative emotions, respectively and .84 for the entire scale. Women were found to be more susceptible to emotions than men.

Sport Emotion Questionnaire (SEQ; Jones et al., 2005)

This questionnaire consists of 22 items representing 5 dimensions: *anxiety, depression, anger, excitement,* and *happiness* to measure pre-competitive emotions. Participants respond to 22 emotions on a Likert-type 5-point scale ranging from 0 (*not at all*) to 4 (*extremely*). The questionnaire was successfully used to assess emotions athletes recalled in the context of sports (Vast et al., 2010). Face, factorial, and construct validities have been examined on hundreds of athletes. A CFA indicated that the 22 items and 5-factorial structure resulted in a satisfactory model-data fit (*RCFI* = 0.93, *RMSEA* = .07) and very strong factorial loadings. Concurrent validity was tested through the SEQ correlations with the BRUMS (Terry et al., 1999, 2003) and TOPS (Thomas et al., 1999), resulting in low to moderate correlations. The SEQ shared 77% items with the PNA, 50% with the POMS (McNair et al., 1971), 27% with the BRUMS, and 23 with the PANAS. The Cronbach's α internal consistency reliability coefficients were anxiety (α = .87), depression (α = .82), anger (α = .84), excitement (α = .81), and happiness (α = .88).

Physical Activity Group Environment Questionnaire (PAGEQ; Estabrooks & Carron, 2000)

The PAGEQ questionnaire measures the individual distribution of group cohesion in fitness groups (exercise classes). The questionnaire consists of 21 items that are divided into 4 dimensions: *group attraction - task* - 6 items, *group attraction - social* - 6 items, *group integration - task* - 5 items, and *group integration – social* - 4 items. Participants respond to 21 sentences pertaining to their group on a 9-point Likert scale, ranging from 1 (*strongly disagree*) to 9 (*strongly agree*). The average represents the score on each of the PAGEQ's four dimensions. The Cronbach's α reliability values reported by the authors were: *group attraction - task* (α = .90), *group attraction - social* (α = .91), *group integration - task* (α = .75), and *group integration - social* (α = .82).

Collective Efficacy (CE; Bandura, 1997)
Group Efficacy is measured by one item based on Bandura (1997) and Feltz and Chase (1998). Participants were asked to rate their perceptions that their team would perform the most effectively on the task. Specifically, *"How confident are you in the team's capacity to perform the task and complete as many rounds as possible?"* on a scale ranging from 0 (*not sure at all*) to 100 (*very sure*). The team's collective efficacy score consists of the mean ratings of its team members.

Rate of Perceived Effort (RPE; Borg, 1998)
Effort perception is rated on a scale ranging from 0 (*no effort*) to 10 (*very strong effort*). The RPE scale is used to measure effort perception during exercise. The higher the RPE rating, the higher the perceived effort level. Borg reported strong temporal stability (r = .83 - .94) and strong correlations with several physiological and biochemical measures of exertion including lactic acid (LA), heart rate (HR), and oxygen consumption VO_2 (Borg, 1982, 1998).

Perceived Performance in Team Sports Questionnaire (PPTSQ; Gershgoren et al., 2012)
The original PPTSQ consisted of 16 items and was designed to measure the perception of team members' performance on three factors: *perceived outcome* that includes 5 items, *perceived skill execution* that contains 5 items, and *perceived effort investment* represented by 6 items. Each item on the PPTSQ is rated on a Likert-type scale ranging from 1 (*disagree*) (1) to 5 (*strongly agree*). EFA and CFA were employed to test the validity and reliability of the 3-dimensional original construct. A 2-dimensional model-data fit emerged resulting in two dimensions: *perceived outcome* and *perceived effort investment*. McDonald's internal consistencies of the two scales were strong $.75 < \omega < .89$. A temporal stability of .80 and .85 were noted for perceived outcome and perceived effort investment, respectively. The PPTSQ correlated moderately with the GEQ and the Team Assessment Diagnostic Instrument; namely, 0.47 with objective performance, .56 with the TADI (shared mental model questionnaire), and .24 with the GEO.

Physical task performance
The physical task started with a 10-minute physical warmup. Immediately after the warmup, all members of the team were asked to complete four exercises together. The full completion of the four exercises was considered as one round and consisted of a total of 6,800 repetitions. The mission was to complete as many rounds as possible in 30 minutes. The four exercises were: (a) team rowing using four rowing machines simultaneously. The participants were required to complete 6 km before advancing to the next exercise (6,000 repetitions), (b) throwing a "*medicine ball*" weighing 9kg (20 lb.) for men and 6kg (14lb.) for women to a target (wall-ball). The goal was completing 400 repetitions in four stations – one ball per station, (c) burpees – the goal was accumulating a total of 200 repetitions, and (d) run - team members were required to complete a 200 meter run together (200 repetitions). To move from one exercise to the next, all 3 members of the team were required to complete the task. Upon completing the task, a 10-minute stretching and cooling down period took place.

Emotion contagion intervention
Two confederates conveyed the desired mood state of HH and LL with pleasantness and arousal, respectively. The confederates were certified cross fit trainers and amateur theatre actors who were experts in conveying verbal and non-verbal messages to an audience. Each confederate expressed a mood consistent with the HH or LL intervention conditions throughout the experiment. The two confederates detached themselves from the task demands and focused almost entirely on the emotional "*game*" they were assigned to reflect to the team members. The confederates had no personal interest in the experiment and

were not aware of the study's purpose and/or hypotheses. Because the LL and HH conditions were provided to two separate groups, each confederate performed two roles, one for LL and one for HH.

The confederates were given specific instructions regarding the transfer of pleasantness and arousal to the respective HH and LL experimental conditions members. The verbal and non-verbal communications were adapted from the behavioural protocols in Bartel and Saavedra (2000). For example, in the positive pleasantness and high arousal (HH) condition, the confederate was told to smile often, encourage team members, make hand gestures, talk extensively, make physical contact with all the members, make extensive eye contact, and speak loudly and quickly. In the LL condition the actor blinked slowly, his eyes were half closed, he sighed extensively, his gaze was detached from the team members, he hardly ever made eye contacts with anyone, he spoke monotonously, murmured, his voice was soft, and his reactions were delayed to some extent. The confederate was stationary during most of the training, his hands were paced statically when he spoke, and he refrained from making physical contact with the teammates. In addition, the confederate/actor refrained from encouraging the teammates. The confederate was instructed to behave this way as soon as he or she entered the cross-fit gym.

Prior to engaging in the team tasks, the confederates were given several key phrases which they were asked to memorize and convey to the team members. The confederates were asked to improvise and be creative but to follow the HH or LL protocols as precisely as possible. The confederates' behaviour in the HH and LL conditions are presented in Table 1.

Table 1. Confederate/actor behaviours in the HH and LL mood conditions.

	High Pleasantness-High Arousal - HH	**Low Pleasantness-Low Arousal - LL**
Experimental condition	*Cheerful Enthusiasm* Characterized by confederate acting pleasant, happy, warm, optimistic, energetic, active, alert, cheerful and enthusiastic.	*Depressed Sluggishness* Characterized by the confederate being unpleasant, unhappy, low energy, somewhat depressed, sluggish, dull, and lethargic.

Procedure

The experiment was approved by the ethics committee of the university. After receiving approval, the questionnaires were translated from English into Hebrew by independent specialists in both languages. Following the first round of translation, they discussed the translation until full agreement was reached.

The participants met with the researcher at the beginning of the experiment in which he informed them of the purpose and procedure. The participants were told that they could withdraw from the experiment at any time without any consequences. Because the cross-fit gym could accommodate up to 15 trainees in each session, it was decided to administer the physical task in smaller teams, i.e., two teams per experimental condition. Before beginning the task, the participants filled out an informed consent form and signed it. Then, they completed the demographic questionnaire, the two-item measure of the pleasantness arousal level, the trait emotional contagion questionnaire (EC), the emotion questionnaire that measures the participants' emotions (SEQ) in the "*here and now*", the physical activity group environment questionnaire to assess the team cohesion (PAGEQ), and the group collective efficacy question (CE). The researcher then explained the physical task to the team members. The confederate played the same role in the training; that is, he or she was always in the same position during the exercises, did the same exercises during the training and invested the same amount of effort throughout. Thus, the confederates exercised similarly in the two experimental conditions. For example, the confederates rowed similarly on the rowing machine in the HH and LL conditions. The confederate was treated identically by the researcher and was not perceived as the leader of the team. Following 30min of task engagement, the participants rated the "*arousal*" and "*pleasantness*" items (manipulation check), how they felt in the "*here and now*" (SEQ), the physical activity group environment questionnaire (PAGEQ), the collective efficacy (CE), the rate of perceived effort (RPE) and performance perception (PPTSQ). Upon completion of the experiments the participants were debriefed and thanked.

Data analysis

Emotional profile, team cohesion, collective efficacy, effort perception, and group performance were subjected to a mixed repeated measures (RM) MANOVA followed by a RM ANOVA, separately. The "*emotional contagion*" condition (LL vs HH) was considered the between-subject factor and time (pre-post intervention) as the repeated within- subject factor. Prior to performing the statistical tests, the variance in all variables from each condition (kurtosis, skewness) was examined. Levene's test was applied to examine variance differences between the two conditions. Cohen's d coefficients were computed to evaluate the magnitude of the significant (p <.05) effects. Means and standard deviations were calculated for all the variables for each condition in each time frame.

RESULTS

Testing the emotional contagion intervention

To test the impact of the confederates' arousal and pleasantness on their team participants (e.g., emotional contagion), the means and SDs of arousal and pleasantness were calculated before and after the respective interventions for the LL and HH conditions. RM ANOVAs performed on arousal and pleasantness separately resulted in significant time by condition interactions for arousal, *Wilks'λ* = .53, F (1,45) = 40.35, p =.00, η_p^2 = .47, and for pleasantness, *Wilks'λ* = .85, F (1,45) = 7.94, p < .01, η_p^2 = .15. These interactions are presented in Figure 1a,b.

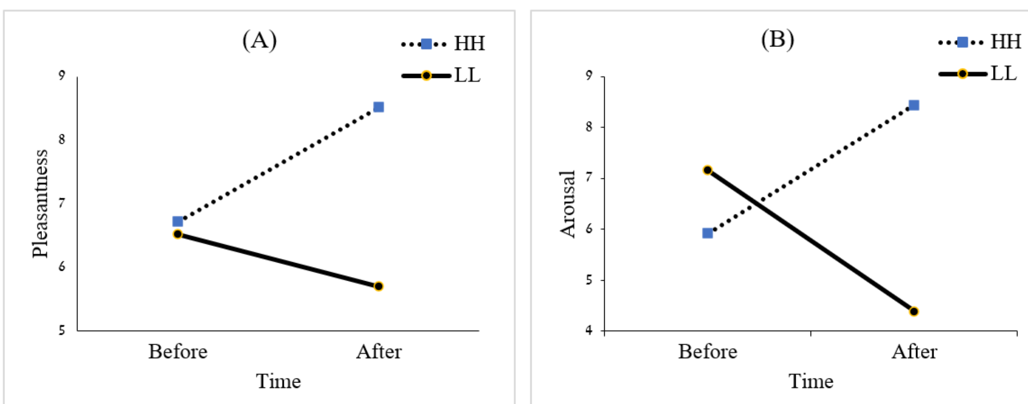

Figure 1. Means for pleasantness (A) and arousal (B) before and after the confederates' emotion contagion intervention for LL and HH conditions.

Pleasantness increased from M = 6.72, SD = 2.11 to M = 8.52, SD = 1.32, d = 1.02 in the HH condition and decreased from M = 6.52, SD = 2.12, M = 5.70, SD = 3.19, d = -.30 in the LL condition. The mean difference between the HH and LL conditions following the intervention and controlling for the pre- intervention differences was d = 1.24. Arousal increased from M = 5.92, SD = 2.00 to M = 8.44, SD = 2.12, d = 1.22 in the HH condition and decreased from M = 7.16, SD = 1.83 to M = 4.39, SD = 2.96, d = -1.13 in the LL condition. The mean difference between the HH and LL conditions following the intervention and controlling for the pre-intervention differences was *d* = 2.76. Thus, the HH team members felt higher arousal and pleasantness than the LL participants following the emotional contagion intervention.

Testing the equality of dispositional emotional contagion between the LL and HH conditions

The participants in the HH and LL conditions were compared on the dispositional measure of the emotional contagion (EC) scale using a MANOVA followed by a post-hoc LSD for each of the five emotional dimensions. The MANOVA revealed a non-significant condition effect, *Wilks' λ* =.84, F (5,41) = 1.50, p = .21, η_p^2 = .16.

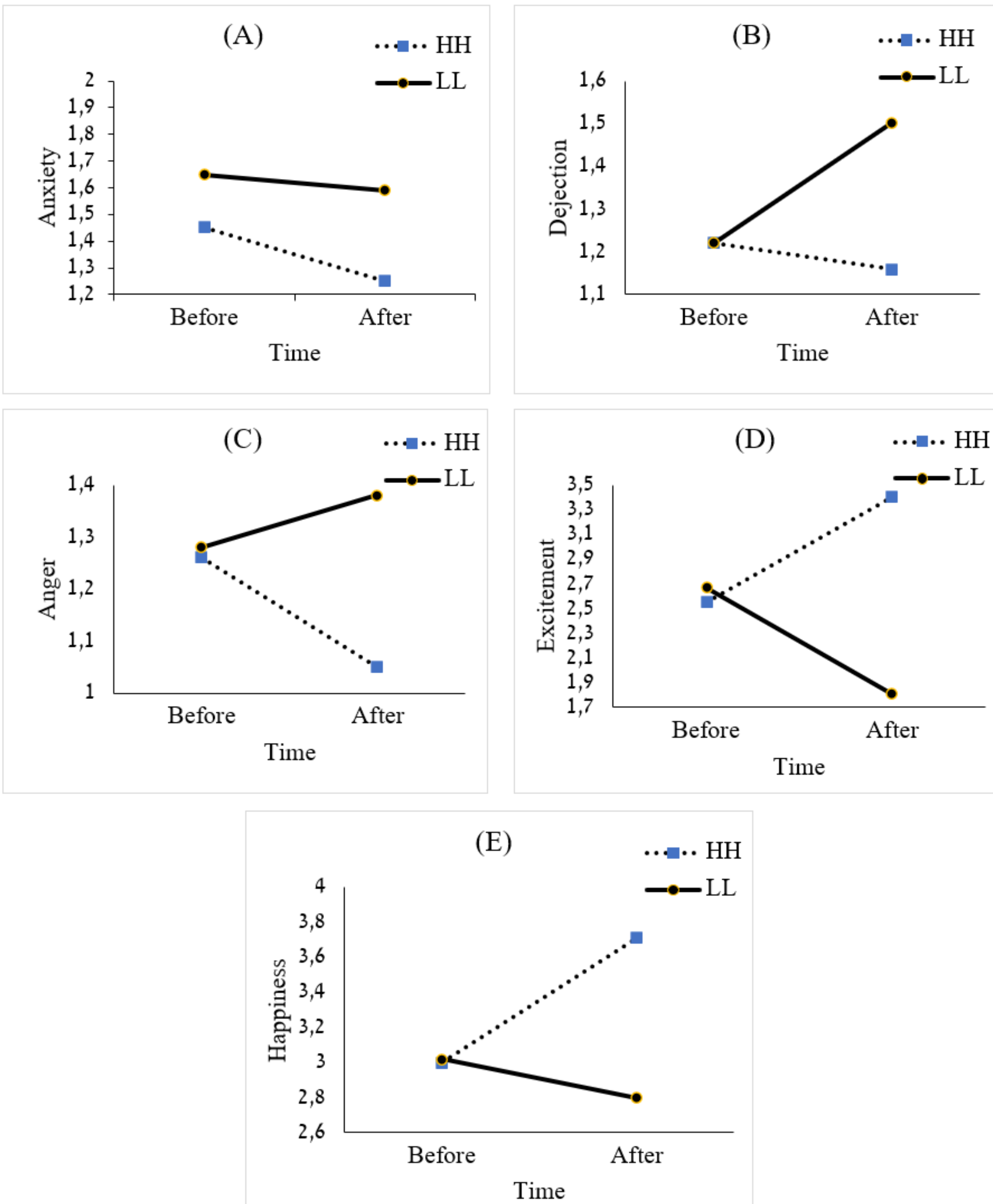

Figure 2. Emotions (anxiety, dejection, excitement, anger, happiness) before and after the EC intervention in the HH and LL conditions.

Emotional Contagion (EC) effect on emotional profile

To test the effect of the EC intervention on the emotional profile of the LL and HH participants, the means and SDs of anxiety, dejection, excitement, anger, and happiness before and after the intervention were subjected to RM MANOVAs. The means for each emotion before and after the EC intervention are presented in Figure 2a,b,c,d,e.

A significant time by emotional dimension by experimental condition effect was revealed for emotional profile, *Wilks' λ* =.49, *F* (4,42) = 10.82, *p* =.001, η_p^2=.51. Follow-up RM ANOVAs for each of the five emotional dimensions revealed a non-significant effect for time by experimental interaction effect for anxiety, *Wilks' λ* =.99, *F* (1,45) = .55, *p* =.46, η_p^2=.01. Similar anxiety reports were expressed by HH and LL participants. HH participants experienced less anxiety after the EC intervention than at the outset of the intervention, *M* = 1.45, *SD* = .51 vs. *M* = 1.25, *SD* = .32, *d* = .47 respectively, and participants in the LL condition also experienced lower anxiety at the end of their respective intervention, *M* = 1.65, *SD* = .69 vs. *M* = 1.59, *SD* = .60, *d* = .01. The mean difference between the HH and LL conditions following the intervention and controlling for the pre-intervention differences was *d* = -.33. The RM ANOVA for feeling dejection revealed a significant time by experimental condition interaction, *Wilks' λ* =.88, *F* (1,45) = 6.15, *p* =.02, η_p^2 =.12. HH participants felt less dejection after the EC intervention compared to the outset of the intervention, *M* = 1.22, *SD* = .32 vs. *M* = 1.16, *SD* = .20, *d* = .22, respectively, whereas LL participants felt increased dejection from the outset to the end of the intervention, M = 1.22, SD = .25 vs. *M* = 1.50, *SD* = .60, *d* = .61. The mean difference between the HH and LL conditions following the intervention and controlling for the pre- intervention differences was *d* = -1.17.

A significant experimental condition by time effect was revealed for the emotion of anger, *Wilks' λ* =.88, *F* (1,45) = 6.10, *p* = .02, η_p^2 = .12. HH participants reported less anger after the EC intervention, *M* = 1.26, *SD* = .40 vs. *M* = 1.05, *SD* = .22, *d* = .65, respectively, whereas LL participants reported increased anger from the outset to the end of the EC intervention, *M* = 1.23, SD = .35 vs. *M* = 1.38, *SD* = .64, *d* = -.29. The mean difference between the HH and LL conditions following the intervention and controlling for the pre-intervention differences was *d* = -.95. There was a time by experimental condition interaction effect for excitement, *Wilks' λ* =.56, *F* (1,45) = .35.99, *p* =.001, $\eta_p{}^2$=.44. HH participants experienced more excitement after the EC intervention, *M* = 2.55, *SD* = 1.11 vs. *M* = 3.40, *SD* = .90, *d* = -1.09 respectively, whereas LL participants felt decreased excitement from the outset to the end of the intervention, *M* = 2.67, *SD* = .81 vs. *M* = 1.81, *SD* = .77, *d* = 1.09. The mean difference between the HH and LL conditions following the intervention and controlling for the pre- intervention differences was *d* = 2.76.*d* = 2.11. Finally, a significant time by experimental condition was obtained for happiness, *Wilks' λ* = .81, *F* (1,45) = 10.38, *p* = .002, η_p^2 = .19. HH participants felt happier after the EC intervention compared to the outset of the intervention, *M* = 3.00, *SD* = .93 vs. *M* = 3.71, *SD* = .73, *d* = -.85, respectively, whereas LL participants felt less happiness from the outset to the end of the intervention, *M* = 3.02, *SD* = .74 vs. *M* = 2.79, *SD* = 1.04, *d* = .25. The mean difference between the HH and LL conditions following the intervention and controlling for the pre-intervention differences was *d* = 1.11.

Effect of the EC intervention on team cohesion

A RM MANOVA applied to the four dimensions of team cohesion by time and EC intervention indicated a significant experimental condition by time effect, *Wilks' λ* = .84, *F*(1,45) = 8.73, *p* =.005, η_p^2=.16., but not for the cohesion dimension by time by experimental condition, *Wilks' λ* = .86, *F*(3,43) = 2.31, *p* = .09, η_p^2=.14. The means for the four-dimensions before and after the EC interventions are shown in Figure 3a,b,c,d.

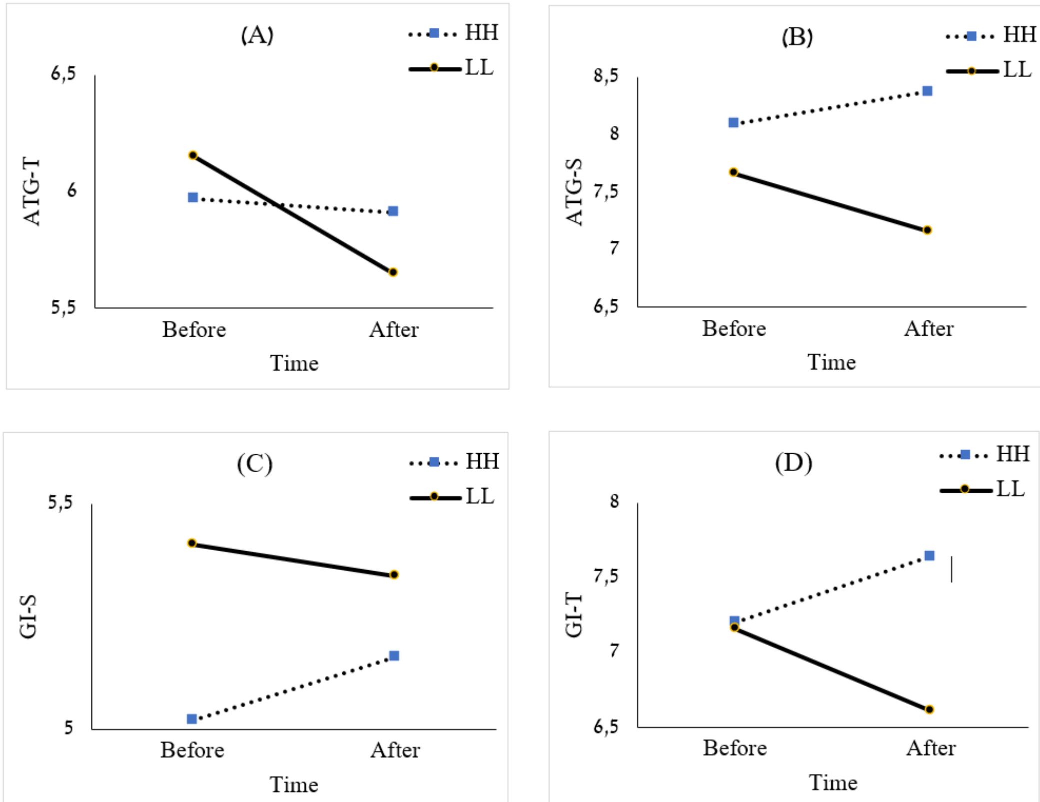

Figure 3. Means for ATG-S (A), ATG-T (B), GI-T (C), and GI-S (D) prior and after the EC intervention for the HH and LL experimental conditions.

A follow- up RM ANOVA for ATG-S revealed a significant experimental by time interaction effect, *Wilks' λ* = .91, *F* (1,45) = 4.50, *p* = .04, η_p^2 = .09. HH participants reported increased ATG-S after the EC intervention compared to the outset of the intervention, *M* = 8.09, *SD* = .89 vs. *M* = 8.37, *SD* = .72, *d* = -.35, respectively, whereas the LL participants reported decreased ATG-S from the outset to the end of the intervention, *M* = 7.66, *SD* = 1.49 vs. *M* = 7.16, *SD* = 1.74, *d* = .31. Moreover, the time by experimental condition interaction effect was significant for GI-T, *Wilks' λ* = .81, *F* (1,45) = 10.59, *p* = .002, η_p^2 = .19. HH participants felt increased GI-T after the EC intervention compared to the outset of the intervention, *M* = 7.20, *SD* = 1.18 vs. *M* = 7.64, *SD* = 1.03, *d* = -.40, respectively, whereas LL participants felt decreased GI-T from the outset to the end of the intervention, *M* = 7.16, *SD* = 1.40 vs. *M* = 6.61, *SD* = 1.50, *d* = .38. However, this interaction was non-significant for ATG-T, *Wilks' λ* = .97, *F* (1,45) = 1.60, *p* = .21, η_p^2 = .03. A non-significant interaction effect was also found for GI-S, *Wilks' λ* = .99, *F* (1,45) = 0.63, *p* = .43, η_p^2 = .01.

EC effect on collective efficacy

To test the effect of the EC intervention on the collective efficacy of the LL and HH participants, the means and SDs before and after the intervention were subjected to RM ANOVAs. A significant time by experimental interaction was revealed, *Wilks' λ* =.86, *F* (1,43) =7.16, *p* =.01, η_p^2=.14. HH participants experienced higher collective efficacy after the EC intervention than at the outset of the intervention, *M* = 7.48, *SD* = 1.90 vs. *M* = 8.66, *SD* = 1.12, *d* = -.76. respectively, whereas LL participants felt decreased collective efficacy from the outset to the end of the intervention, *M* = 7.45, *SD* = 1.53 vs. *M* = 6.82, *SD* = 2.73, *d* = .28. The mean difference between the HH and LL conditions following the intervention and controlling for the pre-intervention differences was *d* = 1.04. The interaction is presented in Figure 4.

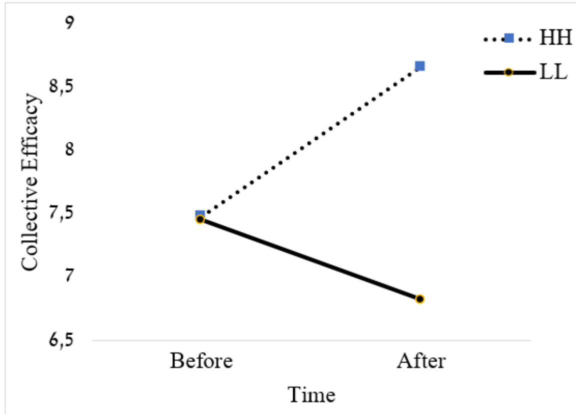

Figure 4. Means for collective efficacy before and after the EC intervention in HH and LL participants.

Effect of EC on effort perception

To test the effect of EC intervention on the perceived effort of the LL and HH participants, the means and SDs before and after the intervention were subjected to a one-way ANOVA. The HH participants perceived the same effort as the LL participants after the EC intervention, *M* = 7.62, *SD* = 2.90 vs *M* = 7.73, *SD* = 2.21, *d* = -.04, respectively.

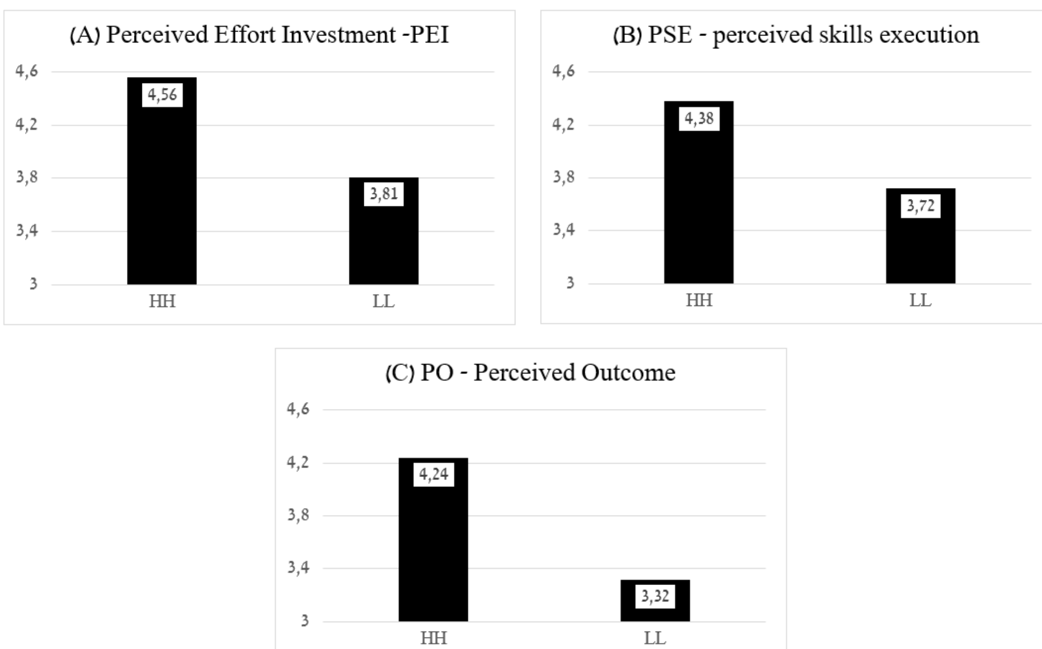

Figure 5. Perceived Performance dimensions means by experimental conditions.

Perceived performance

A MANOVA applied to the three perceived performance dimensions revealed a significant experimental condition effect, *Wilks' λ* =.72, *F* (3,43) = 5.59, *p* = .001, η_p^2 = .28. The means of the three perceived performance dimensions for HH and LL participants are presented in Figure 5a,b,c.

Follow-up ANOVAs for each of the perceived performance dimensions resulted in a significant experimental condition effect for perceived effort investment (PEI), F (1,45) = 11.73, p =.001, η_p^2=.21. HH participants reported making more effort following the EC intervention than the LL participants, M = 4.56, SD = .57 vs. M = 3.81, SD = .91, d = .99. Moreover, a significant EC intervention effect on perceived skill execution (PSE) was revealed, F (1,45) = 9.34, p =.004, η_p^2=.17. HH participants perceived their skill execution as higher following the EC intervention than their LL counterparts, M = 4.38, SD = .55 vs. M =3.72, SD = .92, d = .87. Finally, HH participants reported a higher perceived outcome (PO) after the EC intervention than the LL participants, F (1,45) = 14.38, p = .001, η_p^2=.24. M = 4.24, SD = .70, vs. M = 3.32, SD = .96, d = 1.09.

Performance outcomes of the team

The performance scores for the LL and HH conditions are shown in Figure 6. The HH participants scored higher than the LL participants by 27%.

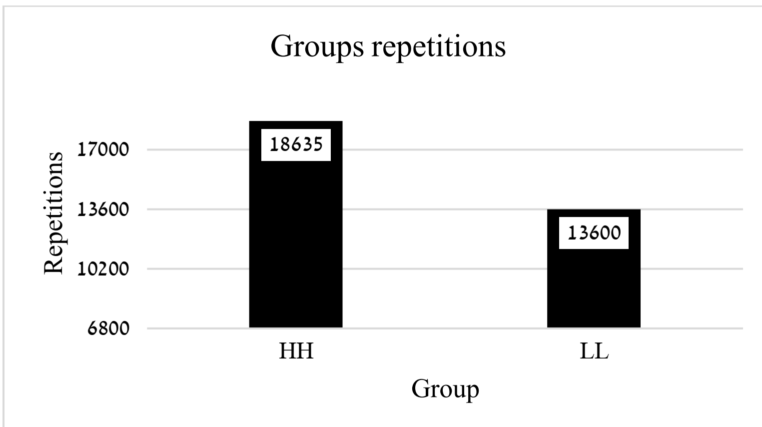

Figure 6. HH and LL physical performance scoring.

DISCUSSION

The goal of this study was to test the notion that when team members share emotions, this affects a broad range of social, cognitive, and physical factors related to accomplishing their goal. To do so, we applied a mood contagion intervention, which created a "*collective emotional state*" (Barsade & Gibson, 1998, 2007; Barsade, 2002). Through facial expressions, body language, and verbal communication (Hatfield et al., 1994), actors allowed "*their*" team members to observe their mood and successfully transmit it to the other team members. In previous studies, collective emotions were found to play an essential role in determining team performance (Barsade, 2002). Team members who harness emotions effectively felt stronger in accomplishing the tasks they performed together (Rhee, 2007). In contrast, team members who shared unpleasant emotions struggled when faced with challenging tasks (Barsade & Gibson, 1998). However, the effect of emotional contagion on team physical task performance has rarely been studied, if at all (Van Kleef & Fischer, 2015). The current study was designed to examine the effect of mood contagion on emotions, team cohesion, collective efficacy, effort perception, perception of performance, and teams' work outcome in two conditions: high pleasantness - high arousal (HH) and low pleasantness - low arousal (LL) as generated by mood contagion of an actor to the other team members.

The findings revealed that mood contagion affected the team members' emotional state in a manner consistent with the mood state transmitted through the collaborator. Emotional profile, team cohesion, collective efficacy, perception of performance, effort perception, and task outcome changed in a way that positively affected team dynamics and performance under HH mood contagion and negatively impacted team dynamics and performance under the LL mood contagion. Specifically, the level of pleasantness and arousal conveyed by the actor affected the members' four discrete emotions (e.g., anger, dejection, happiness, excitement) but not anxiety in each of the experimental conditions. Emotional contagion, which was transferred to the members by the actor through the processes of empathy, mimicry, identification, understanding and affiliation with the intentions of others (Hess & Fischer, 2014), resulted in a corresponding emotional profile in the HH and LL mood conditions, respectively. When the actor transferred high pleasantness and arousal, the members felt elevated excitement and happiness, and lower levels of anger and dejection, whereas the opposite was evidenced when the actor transferred low pleasantness and low arousal. LL contagion resulted in experiencing low levels of excitement and happiness, and stronger feelings of dejection and anger. These results support the claim that direct perception-action mapping can take place via mirror neurons (Gallese, 2009), where the mood state of one member is transferred to others, and then shared through mimicry and empathy among the team members.

Mirror neurons function in a way that enables members to feel empathy, identification, and sensitivity to each other via mimicry of bodily and verbal expressions (Lacoboni et al.,2005). Consequently, the empathy of the team members with the actor in the HH and LL conditions elevated positive and negative feelings in their respective conditions. As in Sy et al. (2005), the emotions conveyed by the actor were felt by the team members whether positively or negatively. Research has shown that a dominant member of a team can affect the team members' emotions (Price & Weiss, 2011), a phenomenon evidenced clearly in the current study. The process and outcome of emotional contagion has been supported elsewhere in the literature (Barsade, 2002; Barsade & Gibson, 1998, 2007; Hatfield et al., 1993).

Tasks that require collaborative effort increase teammates' perceived relationships and social support (Garcia & Rime, 2019), and ultimately reduce stress responses prior and during task engagement (Cohen et al., 2009). Moreover, emotions shared among team members play a significant role in developing and maintaining interpersonal relationships, developing team cohesion and identity, sharing responsibilities, negotiating power roles, solving ongoing problems, and coordinating joint efforts to achieve common goals (Van Kleef & Fischer, 2015). The findings here revealed that low pleasantness and arousal increased feelings of anger and dejection while decreasing feelings of happiness and excitement. Concurrently, the emotional changes were associated with decreased perceptions of collective efficacy, team cohesion and perception of task difficulty, which resulted in performance decline. In contrast, emotional contagion which resulted in a state of high pleasantness and high arousal led to elevated positive emotions and the suppression of negative ones, which positively affected team dynamics (e.g., elevated collective efficacy and team cohesion) as well as its members' perceived performance and physical output.

The findings also indicated that positive emotions facilitated and negative emotion hampered the dynamic, social, and motor performance outcomes of the team members engaged in the CrossFit collaborative task. A decline in team cohesion was experienced by the participants who experienced a drop in pleasantness and arousal. In this condition, an increase in anger and dejection were shared by the team members; feelings of happiness and excitement declined. Under these conditions the team's sense of cohesion, commitment, and performance suffered (Daffy & Shaw,2000). Daffy and Shaw found that intergroup jealousy led to a decline in collective efficacy, social loafing, and low cohesion, which together were linked to the team's performance decline. Similarly, emotions and collective efficacy were found to determine the group members' well-being and functioning (Barsade, 2002; Gully et al., 2002). Comparable team dynamic processes were evident in the current study when team members were exposed to either HH or LL mood contagion conditions.

The results here suggest that emotional contagion affected the emotional, social, and physical states of the team members, but also buffered the degree of effort perception. Effort perception under high pleasantness and high arousal condition was reported at a high level of exertion 7.62/10, whereas under low pleasantness and low arousal (LL), it averaged 7.73/10. Thus, a similar perception of effort was reported in the two teams, although one outperformed the other significantly (e.g., physical effort investment). Specifically, team members who experienced high pleasantness and arousal produced significantly more work and felt a similar effort as their counterparts who felt a decline in both feelings of arousal and pleasantness. Thus, feeling highly pleasant and excited reduced the team members' perceived effort and exertion and equalized it to members of a team who produced a lower work output. These findings may hint that teammates' feelings can buffer physical effort through both team dynamics and the teams' shared emotions.

Studies on adaptation to physical effort have explicitly shown that an adverse change in emotional pleasantness occurs after reaching the respiratory threshold (Alvarez-Alvarado et al., 2019). Perceived effort, visual attention (from dissociative to associative), and the rate of perceived exertion were shown to increase linearly to allow for adequate coping with physical workload, whereas emotional pleasantness greatly declined as the feelings of exertion and fatigue increased. The perceived effort reported by members of both the HH and LL mood contagion conditions was rated as 'hard.' Under these physical conditions, the motivation to continue the effort and the feeling of pleasantness decreased, and attention turned to the internal and associative mode (Alvarez-Alvarado et al., 2019; Tenenbaum, 2001). However, these findings pertained to individuals who were engaged in incremental physical effort which lacked any social facilitating or hampering effects. When required to work out collaboratively, the team members who felt high pleasantness and high arousal (HH) resulting from mood contagion, invested more effort in the task and perceived their accomplishment more positively. The sense of "*togetherness*" led to an increase in collective efficacy, social and task cohesion, and as a result, higher teams' outcomes. In contrast, when the emotional contagion resulted in low pleasantness and low arousal, the team members felt anger and dejection that adversely affected teamwork and hence their perceived outcomes. These findings further support the notion that emotional contagion influences both individual-level attitudes and group processes. The group members exposed to positive emotional contagion experienced improved cooperation, decreased conflict, and increased perceived task performance (Barsade, 2002). Other studies have shown that teams sharing positive emotions such as excitement, optimism, satisfaction, and serenity accepted new adventures and persevered longer on tasks (Meneghel et al., 2016), suggesting that perceived team performance is related to the shared team members' feelings (Rhee, 2007).

CONCLUSIONS

Team coaches and leaders can affect their team members' emotional state, and hence enhance their self and collective efficacy, as well as their sense of social and task cohesion, effort investment and competitive outcomes. Performers under positive emotional contagion will invest more effort in the task they are committed to accomplish. Coaches can convey emotions and efficacy by themselves or by using the team captain or other teammates who enjoy a leadership status among their team members. Emotional contagion is a process which is unconsciously present in team locker rooms, but also on the field and in practice. The findings here show that this process can be deliberately and intentionally practiced and contribute significantly to a team's emotional, social, and physical functions.

Research limitations and future studies

Several limitations of this study must be noted. First, the findings pertain to CrossFit, and should be tested on other tasks tapping team members' common goals and combined efforts. Second, the low familiarity among the team members may not fully represent teams where members already know each other, and an external actor may be perceived in less favourable manner. Thus, different team settings, gender composition, and age cohorts must be studied to further explore the influence of emotional contagion on teams' social, emotional, cognitive, and physical outcomes. Professional athletics as well as the recent rise in electronic sports (e-sport) should be examined to better comprehend the relationships between how members of a team feel, and their common performance processes and outcomes as mediated by team dynamics and collective efficacy.

AUTHOR CONTRIBUTIONS

Omer Eldadi: conceptualization, data collection, analysis, writing, funding acquisition, project management. Omer Eldadi is the lead researcher and was instrumental in formulating the original idea for the research. Hila Sharon-David: data collection, analysis, writing, reviewing. Collaborated closely with the lead and co-researcher in all phases of the research process. Gershon Tenenbaum: analysis, reviewing. Collaborated closely with the lead and co-researcher in all phases of the research process. All authors have read and approved the final manuscript.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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SCIENTIFIC JOURNAL OF SPORT AND PERFORMANCE

ORIGINAL ARTICLE

An analysis of the impact of pressure on performance among professional darts players

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ABSTRACT

The aim of the study was to examine whether and to what extent increased levels of pressure affect the performance quality of the world's top darts players. This investigation contributes to the understanding of the psychological factors that influence performance in professional darts and in professional sports overall. Data was collected from over sixty professional tournaments held over a period of two years. The players were divided into 5 groups based on the quality of their performance during the studied period. The point values were divided into 7 groups, where the criterion was the difficulty of finishing the leg at a given score. The level of pressure was primarily determined by the opponent's score situation in a given moment. Data analysis using statistical methods such as tests of proportions and the Cochran-Armitage test did not indicate any statistically significant impacts of pressure on performance among professional players – neither positive nor negative. The results indicate a high level of mental resilience among professional darts players.
Keywords: Sports psychology, Mental resilience, Test of proportion, Cochran-Armitage test.

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INTRODUCTION

Darts belongs to a group of sports where the role of the mental factor is frequently discussed. To be more precise, when discussing the mental aspect in this context, it generally refers to a specific set of psychological traits. Possessing or lacking these traits has a positive or negative effect on a player's performance. However, the emphasis on psychology in darts is less surprising when we consider the opinions of the most prominent experts in the field: the players themselves. For example, Dr. Linda Duffy, a two-time British Open champion, argues that at a certain level of the sport, all players become experts at hitting any target on the board. Therefore, the factor that determines the final hierarchy is the mental aspect. She highlights higher levels of mental toughness, concentration, and the ability to stay composed separate the "*winners*" from the rest ('The psychology of darts' with Dr Linda Duffy, 2017). Raymond Smith, a participant in the Last 16 of the World Championship and one of Australia's top players, makes a similar point. He believes that the subconscious is responsible for calculations such as the strength of the throw or correct hand placement, while the conscious mind introduces unnecessary elements into the equation, leading to overthinking, stress, or even panic (Smith, 2019). In contrast, Robert Thornton, the World Grand Prix and UK Open champion, describes high self-confidence as the main characteristic of the best players (Strength and weakness - Darts interview with Robert Thornton). Mensur Suljović, the Champions League winner, claims that 60% of skills can be developed through training, while the remaining 40% rely on the player's psyche (Mensur Suljović: Players think training mentally for games is weak – it's not, 2018). Taking an even stronger stance, Peter Wright, the two-time world champion, firmly asserts that mentality accounts for 90% of a player's success (Peter Wright: I'd be as good as Taylor if I hadn't quit darts, 2018). The above opinions also seem to be supported by an occasional psychological affliction among darters known within the community as "*dartitis*". Dr. Linda Duffy defines dartitis as a psychological disorder that hinders the execution of the movement required to throw a dart, without any prior physical injury. Athletes experiencing this condition often describe it as a fear of failure. It is worth noting that similar phenomena, known as the "*yips*", can also affect individuals in sports such as golf or snooker (Clarke et al., 2015).

The role of psychology in darts can also be explored from an objective perspective, based on research conducted on the subject. However, it is important to note that these studies are usually conducted on beginners who have limited prior experience with the sport. While the findings from such experiments may not directly translate to the professional level, they can still offer valuable insights and serve as an interesting point of reference. Some studies examine the impact of employing mental imagery and self-talk on performance levels in darts. These studies measure performance using both objective metrics, such as accuracy of throws, and subjective evaluations of one's own play. These analyses generally demonstrate a positive effect of positive imagery and self-talk on objective performance (Cumming et al., 2006). However, there is no consensus regarding the subjective assessment of performance. While some experiments indicate a positive effect in this area (Afsanepurak et al., 2012), the findings are not universally consistent. On the other hand, concerning the objective measurement of performance level, it is worth noting that negative mental imagery and negative self-talk can have the opposite effect, potentially hindering performance (Van Raalte et al., 1995). Also, another variation of internal dialogue known as "*instructional self-talk*" has been explored, particularly in research involving younger players. Findings indicate that instructing oneself on the proper technique and approach to throwing can lead to noticeably faster progression (Aghdasi & Touba, 2012). Furthermore, certain studies aim to determine the influence of psychological training on the overall quality of the game. They indicate that mental training, which includes various components such as relaxation techniques, goal-setting, emotional control exercises, concentration improvement, as well as enhancing self-esteem and self-confidence, can compensate for potential deficiencies from fewer physical training sessions (Straub, 1989). Beneficial effects have also been noted from the MAC (mindfulness-acceptance-commitment) approach, which, rather than attempting to control, replace or eliminate negative emotions and feelings, emphasizes full awareness and non-judgmental acceptance of these emotions, ultimately leading to the development of the ability to overcome obstacles (Zhang et al., 2016). Additionally, traits such as anxiety management and anger control have also been identified as crucial for darts players (Low, 1994). Research also indicates the positive impact of "*external focus*" for players, whereby directing attention to a specific point on the dartboard, rather than focusing on one's own body movements, has been shown to yield better results (Lohse et al., 2010).

Having recognized the significant role of the mental aspect in the realm of darts, the question naturally arises: how mentally strong are the best players? Answering such a question is as complex as defining what constitutes a "*mentally strong person*". However, in the context of darts games, particularly the 501 double-out formats analysed in this study, two specific characteristics allow for a more focused investigation:

- Over the course of numerous games, it becomes possible to identify regularly recurring events,
- All players' actions can ultimately be measured by the number of points they score.

The first characteristic provides ample data to be collected and formulated into a research problem, while the second characteristic allows for an investigation of that problem. These aspects converge on the core issue and central topic of this study: Do professional darts players exhibit decreased (or increased) performance under heightened pressure from their opponents?

In the world of darts, the word "*pressure*" most often appears in the context of the following situation:

- Player A is set on a low finish, e.g. 32 points,
- Player B, who is currently throwing, does not have the opportunity to finish the leg (for example, he has 196 points left on the counter).

In such a situation, sports commentators often remark that the only thing Player B can do is to hit a high-value score (preferably 180, which would leave 16 points) to put pressure on the opponent. Assuming Player B performs flawlessly, the question then arises regarding how Player A will react to this situation. There are three possible options for Player A's response:

1) Player A may feel the additional pressure of having to hit the required score, which could potentially decrease their chances of a successful checkout and result in a loss of the leg.
2) The need to hit the required score may increase Player A's concentration level, thereby increasing their chances of a successful checkout.
3) The opponent's score may have no effect on Player A's performance.

While the first answer probably appears to be the most intuitive and the most widespread among fans and experts, it is crucial to examine the general tendency among players in similar situations to uncover the truth. Does the additional pressure from the opponent truly lead to a decrease in the effectiveness of finishing the leg, or does it have the opposite effect? The aim is to answer the question of how susceptible the world's best players are to stressful situations.

The study to be presented will be divided into two main parts. The first part will involve the compilation of preliminary statistics, while the second part will focus on finding an answer to the main question at hand.

METHODOLOGY

The study presented here is based on a comprehensive statistical analysis of over 710,000 situations, meticulously collected from nearly 7,600 darts games in the 501 double-out game formats played during the PDC Players Championship in the years 2021 – 2022. Among these situations, approximately 185,000 of them allowed players to attempt to close out a leg, representing a significant sample size for analysis. Each individual situation in this study refers to a single turn at the board made by a player, involving a maximum of three dart throws. It is important to note that the data collected was not manipulated or orchestrated for the purposes of the study; it naturally occurred during the course of the games. The information for each turn was recorded using Python and Visual Basic for Applications (VBA) scripts to minimize any potential data completion errors. The entire dataset, available in .xlsx format, is available to download via Dropbox (PDC Players Championship 2021 – 2022 database, 2023).

All the data was sourced from the DartConnect service, a scoring application that provides detailed information on the progression of all games played during the series. As the majority of Players Championship games are not broadcasted by the PDC via pdc.tv, DartConnect is the primary and most comprehensive source of information on how all games are played. It offers real-time match information in text format, which seems to be sufficient for conducting the necessary analyses in this study. Figure 1. presents an excerpt from the recording of a sample leg, representing a single part of a game.

Game 1.1 - 501 SIDO				32 - 0				01:47
!	Player	Turn	Score	Rnd	Score	Turn	Player	!
100	Rusty-Jake Rodriguez	100	401	1	401	100	John Michael	100
140	Rusty-Jake Rodriguez	140	261	2	301	100	John Michael	100
140	Rusty-Jake Rodriguez	140	121	3	161	140	John Michael	140
	Rusty-Jake Rodriguez	57	64	4	71	90	John Michael	
	Rusty-Jake Rodriguez	32	32	5	0	71	John Michael	DO
93.80				3 Dart Avg			Darts: 15	100.20

Source: https://recap.dartconnect.com/games/61fe772d5c196703f8a22f91

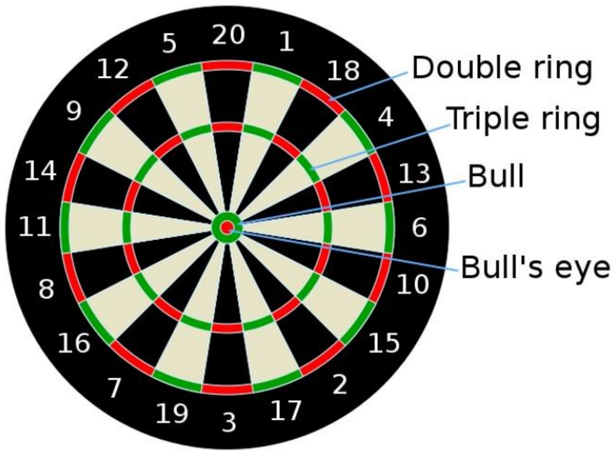
Figure 1. Excerpt from a record of a darts game (DartConnect system).

The excerpt contains a lot of useful data, including:

- The number of points on both counters before every turn at the board,
- The number of points scored in three darts in every turn in the leg,
- The number of darts needed to finish the leg.

Darts rules

Given that darts remains relatively niche on a global scale, let's briefly outline the rules of the game for the 501 double-out formats, which will be the focus of the study. In this format, commonly used in tournaments organized by the PDC, the objective for each player is to reduce their score from 501 points to 0. During each turn at the dartboard, players have three darts at their disposal. The number of points they score with each dart is subtracted from their current score. For instance, if a player scores 140 points in their first attempt, their counter will be reduced to 361 points. Subsequent throws are deducted accordingly. A leg, which denotes a single game within a match, commences with both players having 501 points each. The leg continues until one player reaches 0 points and wins it. Figure 2. can be referred for a visual representation of the standard dartboard used in the game.



Source: https://commons.wikimedia.org/wiki/File:Dartboard.svg

Figure 2. Standard dartboard.

Scoring on the dartboard is determined by the following rules:

- The red centre of the board (bull's eye) awards the player 50 points,
- The green centre of the board (bull) awards the player 25 points,
- The narrow inner circle (triple ring) triples the value of the corresponding segment. For example, hitting a triple 18 would yield 54 points,
- The wider outer ring (double ring) doubles the value of the corresponding segment. For example, hitting a double 20 would result in 40 points,
- The large black or white fields grant the player the points assigned to the outer sections of the board.

Each leg must conclude with a double value or a hit on the red centre (a successful attempt is called "*checkout*"). For instance, if a player has 32 points remaining, they must hit a double 16 to finish the leg (hence the term "*double-out*" in this format of the game).

In the Players Championship tour, which served as the data source for this study, games are played until one player wins 6, 7 or 8 legs (depending on the tournament phase).

Introductory statistics

The main part of the analysis will involve the creation of introductory statistics, which are essential for ensuring the readability of the findings. Introductory statistics will be divided into two parts:

1) A summary of the groups of point values based on the probability of checkout, distinguishing between the easiest and most difficult values to finish.
2) A ranking of players participating in the Players Championship tour, evaluating their efficiency in closing out legs and the scoring efficiency of their first 9 darts in each leg.

The probability of checkout at different score values

In this study (and exclusively for the purposes of this study), the probability of checkout from a specific value will be defined as the percentage of situations where players participating in the Players Championship tour successfully closed a leg with that particular number of points remaining. For example, if there were a total of 1,000 instances in the competition (years 2021 – 2022) where a player had 64 points left, and out of those, 450 legs were closed, the probability of the checkout with 64 points would be calculated as 45%. The determination of probability in this study does not take into account which player was approaching the board; instead, it focuses on the average success rate. Additionally, the determination of probability does not consider whether a player actually attempted to close the leg at a given time. For example, situations may arise where one player has a high value to finish, such as 170, while the other player has no chance of finishing if they return to the board. In such cases, the first player may choose to set up their score on a comfortable double rather than forcefully attempting to finish the game. Due to the lack of available video footage of the games (as only a small proportion of Players Championship series games are broadcasted), it is not possible to determine the players' intentions in individual situations, and therefore this factor will be ignored. Consequently, the determined probabilities may slightly underestimate some of actual values, especially the highest ones. However, these differences should not significantly impact the results of the study, as the determined probabilities primarily serve to just categorize the various possibilities of ending a leg into groups ranging from easiest to most difficult.

Table 1. Checkout probabilities for all possible values (based on success rate).

Value	Success rate	Attempts	Value	Success rate	Attempts	Value	Success rate	Attempts
27	80.95%	21	**8**	77.64%	2080	**32**	77.50%	6921
24	76.29%	2269	**16**	75.91%	4841	**40**	75.87%	11771
28	74.18%	705	**12**	73.81%	1115	**20**	73.38%	6160
36	73.27%	3393	**4**	72.04%	1080	**26**	70.63%	143
21	70.37%	27	**22**	68.50%	200	**14**	68.23%	384
18	67.28%	1134	**51**	65.33%	323	**34**	64.93%	134
53	64.77%	193	**46**	64.73%	638	**49**	64.71%	238
30	64.46%	287	**48**	64.38%	1415	**42**	64.06%	473
35	63.77%	207	**25**	63.52%	3013	**44**	63.44%	651
50	63.43%	990	**13**	62.96%	81	**41**	62.90%	1105
54	62.88%	590	**10**	62.84%	1741	**38**	62.52%	643
6	62.01%	458	**52**	62.00%	1513	**47**	61.96%	552
11	61.43%	140	**45**	61.10%	365	**31**	60.14%	138
58	59.13%	739	**56**	58.69%	2089	**9**	58.47%	248
29	58.33%	12	**60**	57.28%	2336	**39**	57.24%	145
23	57.14%	14	**43**	56.72%	238	**57**	56.49%	439
59	56.33%	245	**7**	56.31%	103	**5**	55.62%	543
33	55.14%	107	**15**	55.08%	118	**2**	54.72%	424
55	53.31%	272	**19**	52.38%	84	**37**	52.00%	50
67	49.31%	436	**64**	48.80%	1752	**66**	47.75%	890
65	47.62%	861	**62**	47.25%	965	**61**	46.06%	584
68	45.98%	1816	**75**	45.67%	473	**3**	44.93%	69
70	44.81%	1571	**71**	44.40%	545	**72**	44.19%	1851
73	43.63%	259	**74**	43.26%	1149	**69**	42.58%	209
76	42.41%	2153	**63**	41.74%	218	**78**	41.63%	1165
17	41.18%	51	**82**	39.95%	1159	**80**	39.84%	2430
77	38.89%	360	**88**	37.38%	1022	**87**	36.91%	1035
93	35.70%	381	**84**	35.40%	1435	**81**	35.37%	2587
85	35.00%	860	**89**	34.62%	439	**79**	34.62%	286
86	33.98%	1289	**83**	33.68%	582	**90**	33.46%	1315
96	32.03%	1848	**94**	31.84%	716	**92**	30.83%	827
91	29.60%	625	**100**	29.04%	2190	**97**	28.77%	577
95	27.29%	590	**103**	25.16%	465	**98**	24.58%	655
109	23.01%	478	**105**	22.76%	681	**113**	22.22%	378
101	22.15%	1133	**99**	21.90%	274	**110**	21.39%	1566

108	21.17%	1181	**111**	21.13%	478	**104**	20.92%	1463
102	20.70%	773	**106**	20.59%	1146	**107**	20.55%	730
112	20.31%	1172	**116**	20.29%	1735	**117**	19.21%	505
118	19.07%	713	**115**	19.00%	442	**120**	17.67%	2162
114	16.30%	681	**119**	15.23%	302	**122**	13.07%	918
126	12.50%	1240	**127**	12.33%	1144	**124**	11.97%	2030
121	11.56%	4066	**123**	11.21%	562	**130**	10.75%	2055
128	9.53%	986	**125**	8.13%	836	**135**	7.89%	672
132	6.82%	1378	**134**	6.71%	834	**129**	6.69%	703
149	6.40%	422	**138**	6.33%	1058	**144**	6.23%	1461
143	6.21%	773	**157**	6.09%	558	**142**	6.06%	1287
140	6.02%	2177	**151**	5.92%	507	**156**	5.91%	1235
133	5.90%	373	**131**	5.68%	651	**136**	5.68%	1742
148	5.43%	976	**145**	5.33%	1051	**160**	5.31%	2184
146	5.18%	1275	**150**	5.09%	1278	**152**	5.01%	779
137	4.99%	541	**141**	4.98%	2149	**147**	4.87%	678
154	4.54%	573	**153**	3.99%	351	**139**	3.78%	502
158	3.70%	676	**170**	3.20%	5813	**155**	3.16%	475
164	2.22%	3745	**167**	2.13%	2720	**161**	2.10%	4519

Source: original work based on: https://tv.dartconnect.com/events/pdc

After obtaining a comprehensive summary of the values and their corresponding probabilities, they were categorized into distinct groups based on the frequency of checkouts (Table 2.)

Table 2. Values grouped by checkout probability.

Checkout probability						
> 70%	50 - 70%	40 - 50 %	25 - 40%	10 - 25%	3 - 10%	0 - 3%
4, 8, 12, 16, 20, 24, 28, 32, 36, 40	2, 5, 6, 7, 9, 10, 11, 13, 14, 15, 17, 18, 19, 21, 22, 23, 25, 26, 27, 29, 30, 31, 33, 34, 35, 37, 38, 39, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60	3, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 80	79, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 100	99, 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, 124, 126, 127, 130	125, 128, 129, 131, 132, 133, 134, 135, 136, 137, 138, 139, 140, 141, 142, 143, 144, 145, 146, 147, 148, 149, 150, 151, 152, 153, 154, 155, 156, 157, 158, 160	170, 164, 167, 161

Source: original work based on: https://tv.dartconnect.com/events/pdc

In compiling the above summary, several adjustments were made:
- Values 17 and 27 were assigned to the 50 – 70% group due to the low number of samples,
- Values 80 and 77 were assigned to the 40 – 50% group due to probability oscillating at the border of the interval and similarity to values already present in this group,
- Value 98 was allocated to the 25 – 40% group, also due to probability oscillating at the border of the interval and similarity to values already present in this group,
- Value 155 was assigned to the 3 – 10% group due to similarity to values already present in this group.

Similarly, value 170 was assigned to the 0 – 3% group.

This resulted in 7 groups of values with the following characteristics:
- Group I: > 70%: all the easiest opportunities to close a leg, allowing the turn to be completed with only one dart. Even if there is a mistake inside the board (e.g., hitting S16 at a value of 32), there is no need to split the value to access a double,

- Group II: 50 – 70%: uncharacteristically left doubles (e.g. 26, 38 etc.) and values which also require one single to be thrown first to close a leg (e.g. 52, 60),
- Group III: 40 – 50%: values which require either two singles or a triple hit in the first dart to finish without the need for a bull's eye. For example, 67 can be closed by hitting T17-D8 or S17-S18-D16,
- Group IV: 25 – 40%: values which, if a treble is missed, will require an attempt to finish the leg on a bull's eye (e.g., 88 = S20 + S18 + 50). All the values in this group can be closed in two darts if the first dart falls into a triple value (e.g., 92 = T20 + D16). Also, the tricky 79 finish is included,
- Group V: 10 – 25%: these values cannot be finished in two darts (or are rarely done so) and generally require hitting at least one treble. For example, 120 = T20 + S20 + D20,
- Group VI: 3 – 10%: this group consists of all other values (except those in group VII) that require two trebles to finish (e.g., 148 = T20 + T20 + D14) or the use of the centre of the board at some point (e.g., 129 = S19 + T20 + 50),
- Group VII: 0 – 3%: all the most complicated values to finish, requiring hitting two trebles and a bull's eye.

By making the above corrections, the groups become more homogeneous – each group contains a set of values that are similar to each other in terms of their characteristics.

Ranking of players

A second useful action would be to divide players into groups based on their skill level, similar to the division of values. Although it may seem that the simplest way would be to rank players based on their achievements over the studied period, such an approach would have one major problem – the studied period covers two years, while some players only participated in the circuit for one year or played irregularly (due to an increasingly busy tournament schedule, it happens that top players intentionally skip certain tournaments). In this case, the better way will be to assess a player's skill by evaluating their performance in two phases that occur in each leg:

- The scoring phase, which occurs at the beginning and middle of the leg, where the player's objective is to accumulate as many points as possible,
- The closing phase, which takes place at the end of the leg, where the player's goal is to execute a finishing combination.

In darts statistics, the efficiency in the scoring phase is commonly measured by the average of the first 9 darts thrown in a leg. This measure is used because it's extremely uncommon for a leg to be finished within 9 throws. Hence, the player's "*scoring power*" is defined as the average of the first 9 darts thrown in legs over a two-year period of play.

On the other hand, the efficiency of a player in the closing phase will be determined by their finishing efficiency in three groups of values: > 50%, 25 – 50%, 3 – 25%. These groups were formed by combining the previous groups. However, the highest values, specifically 170, 167, 164 and 161, are excluded from the analysis. This is due to the variation in players' preferences when faced with such values. Some players prefer to set themselves up for a comfortable double, even if the opponent has the possibility to finish on their next turn (which is unlikely to happen).

Table 3. provides a summary of the highest scoring players, including only those who had a minimum of 300 attempts to close a leg.

Table 3. Players Championship 2021 – 2022: Ranking of players based on first 9 darts average.

Rank	Player	First 9	Rank	Player	First 9	Rank	Player	First 9
1	Gerwyn Price	108.08	**2**	Michael van Gerwen	107.86	**3**	Josh Rock	107.32
4	Jonny Clayton	107.31	**5**	José de Sousa	107.30	**6**	Damon Heta	107.20
7	Dirk van Duijvenbode	107.15	**8**	Gary Anderson	106.98	**9**	Peter Wright	106.65
10	Dave Chisnall	106.28	**11**	Michael Smith	105.94	**12**	Krzysztof Ratajski	105.70
13	Rob Cross	105.68	**13**	Luke Humphries	105.68	**15**	Chris Dobey	105.52
16	Dimitri Van den Bergh	105.14	**17**	Nathan Aspinall	104.90	**18**	Callan Rydz	104.84
19	Ryan Searle	104.70	**20**	Joe Cullen	104.66	**21**	Danny Noppert	104.62
22	Stephen Bunting	104.59	**23**	Adrian Lewis	104.50	**24**	Martin Schindler	104.48
25	Ross Smith	104.40	**26**	Ian White	103.07	**27**	Daryl Gurney	102.69
28	Mensur Suljovic	102.39	**29**	Brendan Dolan	102.10	**30**	Steve Lennon	102.00
31	Jim Williams	101.99	**32**	Gian van Veen	101.96	**33**	Raymond van Barneveld	101.61
34	Gabriel Clemens	101.37	**35**	Simon Whitlock	101.27	**36**	Alan Soutar	101.23
37	Kim Huybrechts	101.22	**38**	Cameron Menzies	101.19	**39**	Scott Williams	101.13
40	James Wade	101.13	**41**	Andrew Gilding	100.98	**42**	Mervyn King	100.89
43	Mike De Decker	100.80	**44**	Boris Krcmar	100.71	**45**	Florian Hempel	100.56
46	Jermaine Wattimena	100.49	**46**	Scott Mitchell	100.49	**48**	Jamie Hughes	100.39
49	Kevin Doets	100.19	**50**	Matt Campbell	100.17	**51**	Jason Lowe	100.17
52	Rusty-Jake Rodriguez	100.16	**53**	Mario Vandenbogaerde	100.11	**54**	Ryan Joyce	100.05
55	James Wilson	100.02	**56**	Maik Kuivenhoven	99.98	**57**	William O'Connor	99.93
58	Keane Barry	99.89	**59**	Geert Nentjes	99.81	**59**	Luke Woodhouse	99.81
61	Vincent van der Voort	99.73	**62**	Ron Meulenkamp	99.54	**63**	Jeffrey De Zwaan	99.45
64	Rowby-John Rodriguez	99.44	**65**	Mickey Mansell	99.40	**66**	Ritchie Edhouse	99.33
67	Karel Sedlacek	99.32	**68**	Steve Beaton	99.29	**69**	Madars Razma	99.19
70	Lee Evans	99.15	**71**	Niels Zonneveld	99.14	**72**	Andy Boulton	99.10
73	Jamie Clark	99.00	**74**	Richie Burnett	98.98	**75**	Ricky Evans	98.97
75	Scott Waites	98.87	**77**	Keegan Brown	98.84	**78**	Darius Labanauskas	98.81
79	Lewy Williams	98.76	**80**	Robert Thornton	98.71	**81**	Justin Pipe	98.56
82	John Henderson	98.49	**83**	Alan Tabern	98.47	**84**	Ricardo Pietreczko	98.43
85	Ryan Meikle	98.41	**86**	Chas Barstow	98.38	**87**	Martijn Kleermaker	98.32
88	Ryan Murray	98.29	**89**	John O'Shea	98.19	**90**	Krzysztof Kciuk	98.18
91	Tony Martinez	98.09	**92**	Kai Fan Leung	98.07	**92**	Joe Murnan	98.07
94	Ted Evetts	98.06	**95**	Connor Scutt	97.91	**95**	Martin Lukeman	97.91
97	Nathan Rafferty	97.83	**98**	Stephen Burton	97.78	**99**	Jason Heaver	97.68
100	Jelle Klaasen	97.55	**101**	Peter Jacques	97.48	**102**	George Killington	97.41
103	Jesus Noguera	97.39	**104**	Devon Petersen	97.30	**105**	Jeff Smith	97.14
106	Max Hopp	96.78	**107**	Jim McEwan	96.74	**108**	Danny Baggish	96.48
109	Radek Szagański	96.47	**110**	Steve West	96.42	**111**	Gordon Mathers	96.38
112	Geert De Vos	96.35	**113**	Danny Jansen	96.21	**114**	Darren Webster	96.10
115	José Justicia	96.04	**116**	Eddie Lovely	95.90	**117**	Adam Gawlas	95.81
118	Shaun Wilkinson	95.76	**119**	Jules van Dongen	95.65	**120**	Berry van Peer	95.56
121	Pete Burgoyne	95.53	**122**	Martin Atkins	95.37	**123**	Matthew Edgar	95.28
124	Danny van Trijp	95.15	**125**	Martin Thomas	95.02	**126**	Brian Raman	94.84
127	Zoran Lerchbacher	94.82	**128**	William Borland	94.73	**129**	Gary Blades	94.72
130	Bradley Brooks	94.43	**131**	Adam Hunt	94.39	**132**	Luc Peters	94.27
133	Brett Claydon	94.21	**134**	Nick Kenny	94.18	**135**	Ross Montgomery	94.16
136	Jack Main	94.08	**137**	Steve Brown	94.03	**138**	Kevin Burness	94.00
139	Josh Payne	93.97	**140**	Damian Mol	93.81	**141**	Boris Koltsov	93.77
142	Wayne Jones	93.64	**143**	Jon Worsley	93.52	**144**	David Evans	93.48
145	Michael Rasztovits	93.13	**146**	Nick Fullwell	93.00	**147**	John Michael	92.56
148	Andy Hamilton	92.50	**149**	Jimmy Hendriks	91.87	**150**	Derk Telnekes	91.66
151	Ciaran Teehan	91.61	**152**	Peter Hudson	91.57	**153**	Lisa Ashton	91.32
154	Aaron Beeney	91.01	**155**	Jake Jones	90.52	**156**	John Brown	88.94
157	Glen Durrant	87.66						

Source: original work based on: https://tv.dartconnect.com/events/pdc

The second ranking, which assesses the efficiency of finishing, involves three sub-rankings based on different value groups. These sub-rankings are as follows:

- Ranking of checkout efficiency for values in the first and second groups (> 50%),

- Ranking of checkout efficiency for values in the third and fourth groups (25 – 50%),
- Ranking of checkout efficiency for values in the fifth and sixth groups (3 – 25%).

Due to the extensive amount of data, the complete rankings cannot be included in this paper. However, a comprehensive file containing all the collected statistics, including the full rankings, is also available for download via Dropbox. To provide a glimpse of the results, Tables 4., 5. and 6. present the Top 10 players in each of the aforementioned groups of values.

Table 4. Players Championship 2021 – 2022: Top 10 players with highest checkout efficiency (values from groups I and II).

Rank	Player	Efficiency (I. II)	Attempts
1	Michael van Gerwen	78.39%	620
2	Brendan Dolan	77.65%	707
3	Damon Heta	77.38%	924
4	James Wade	76.94%	633
5	Ryan Joyce	76.02%	563
6	Peter Wright	75.80%	785
7	Brian Raman	75.53%	188
8	Lee Evans	75.52%	143
9	Andy Boulton	75.34%	446
10	Michael Smith	75.08%	935

Source: original work based on: https://tv.dartconnect.com/events/pdc

Table 5. Players Championship 2021 – 2022: Top 10 players with highest checkout efficiency (values from groups III and IV).

Rank	Player	Efficiency (III. IV)	Attempts
1	Cameron Menzies	50.76%	132
2	Matt Campbell	48.13%	160
3	Brendan Dolan	47.82%	458
4	James Wade	47.59%	374
5	Danny Noppert	46.59%	455
6	José de Sousa	46.29%	499
7	Ryan Meikle	46.28%	309
8	Jonny Clayton	46.07%	484
9	Karel Sedlacek	45.95%	222
10	Ritchie Edhouse	45.89%	316

Source: original work based on: https://tv.dartconnect.com/events/pdc

Table 6. Players Championship 2021 – 2022: Top 10 players with highest checkout efficiency (values from groups V and VI)

Rank	Player	Efficiency (V. VI)	Attempts
1	Matt Campbell	16.67%	258
2	Peter Wright	16.46%	723
3	Gerwyn Price	16.29%	528
4	Damon Heta	15.77%	799
5	Jonny Clayton	15.66%	613
6	Rob Cross	15.63%	768
7	Joe Cullen	15.44%	609
8	Michael van Gerwen	15.38%	520
9	Scott Waites	15.00%	380
10	Josh Rock	14.83%	290

Source: original work based on: https://tv.dartconnect.com/events/pdc

From the sub-tables provided above, it is possible to calculate the average ranking position for each player in the three aforementioned rankings. By considering these average positions, the final ranking of efficiency in finishing can be determined.

This method of ranking players is more relevant compared to evaluating overall checkout efficiency without considering different groups of values. The latter approach may favour high-scoring players who frequently encounter lower-value finishes, thereby inflating their overall efficiency. This aspect is often overlooked, despite its relevance when comparing two different players. For instance, among the top three highest-scoring players, the percentage of attempts to close values from group I accounted for 24.7%, 24.7% and 22.1% of their total attempts, respectively. In contrast, among the three lowest-scoring players, it accounted for 16.4%, 17.7% and 17.4%. Thus, weaker scorers are further disadvantaged in terms of their checkout efficiency, as they are less likely to encounter the simplest finishing scenarios.

The method presented here, while more accurate, may still be subject to potential limitations due to the possibility of insufficient data, despite analysing almost 170,000 attempts to close a leg. When examining the rankings, there are instances where individual players have achieved high positions with a noticeably lower number of attempts compared to other players in the top positions. This observation might raise concerns. However, it is important to consider that the final finishing efficiency ranking is composed of three sub-rankings, which to some extent mitigates the impact of individual positions that may not fully reflect the reality. It is also worth noting that the primary purpose of creating an overall ranking is to estimate the skill level of individual players in order to categorize them into different groups, rather than providing an exact analysis. To achieve a more precise evaluation, as previously mentioned, a larger dataset would be required. The full ranking of checkout efficiency is presented in Table 7.

Table 7. Players Championship 2021 – 2022: Overall rankings of players based on checkout efficiency.

Rank	Player	Avg rank	Rank	Player	Avg rank	Rank	Player	Avg rank
1	Damon Heta	7.33	**2**	Brendan Dolan	8.33	**3**	Jonny Clayton	9.00
4	Peter Wright	10.33	**4**	James Wade	10.33	**6**	Rob Cross	12.00
7	Matt Campbell	13.00	**8**	José de Sousa	14.67	**9**	Ryan Meikle	15.00
10	Luke Humphries	15.67	**11**	Michael van Gerwen	16.33	**11**	Danny Noppert	16.33
13	Gerwyn Price	18.00	**14**	Michael Smith	18.33	**15**	Ryan Searle	20.00
16	Josh Rock	21.00	**16**	Ryan Joyce	21.00	**18**	Nathan Aspinall	23.67
19	Ritchie Edhouse	24.33	**20**	Raymond van Barneveld	26.33	**21**	Andrew Gilding	29.67
22	Martin Lukeman	31.67	**23**	Krzysztof Kciuk	33.33	**24**	Joe Cullen	36.33
24	Dimitri Van den Bergh	36.33	**26**	Darius Labanauskas	37.33	**27**	Callan Rydz	38.67
28	Alan Soutar	41.33	**29**	Chris Dobey	41.67	**30**	Mervyn King	43.00
31	Kim Huybrechts	44.67	**31**	Keane Barry	44.67	**33**	Jim Williams	45.33
34	Krzysztof Ratajski	45.67	**35**	Gian van Veen	46.33	**36**	Rowby-John Rodriguez	47.33
37	Kevin Doets	48.67	**38**	Stephen Bunting	50.67	**39**	Jeff Smith	52.67
40	Nathan Rafferty	53.00	**41**	Luke Woodhouse	53.33	**41**	Dave Chisnall	53.33
43	Martin Schindler	54.00	**44**	Joe Murnan	57.67	**45**	Andy Boulton	58.00
45	Scott Mitchell	58.00	**47**	Scott Waites	58.33	**47**	Scott Williams	58.33
47	Vincent van der Voort	58.33	**50**	Brian Raman	61.33	**51**	Dirk van Duijvenbode	62.00
52	Jamie Hughes	63.33	**53**	Ross Smith	66.00	**53**	Mario Vandenbogaerde	66.00
53	Jermaine Wattimena	66.00	**56**	Nick Kenny	66.33	**57**	Gabriel Clemens	66.67
58	Chas Barstow	67.00	**59**	Florian Hempel	68.67	**59**	James Wilson	68.67
59	Shaun Wilkinson	68.67	**62**	Keegan Brown	69.00	**63**	Karel Sedlacek	69.33
64	Adrian Lewis	69.67	**65**	Mike De Decker	71.00	**65**	Lee Evans	71.00
65	William O'Connor	71.00	**68**	Madars Razma	71.67	**69**	Jelle Klaasen	74.00
70	Martijn Kleermaker	74.33	**70**	Mensur Suljovic	74.33	**72**	Cameron Menzies	74.67
73	Robert Thornton	75.00	**74**	John O'Shea	75.33	**75**	Boris Koltsov	76.67
76	Daryl Gurney	77.00	**77**	Max Hopp	78.33	**78**	William Borland	79.67
79	Gary Anderson	80.33	**80**	John Henderson	81.00	**81**	Martin Thomas	81.67

82	Connor Scutt	83.00	**83**	Andy Hamilton	84.67	**83**	Jason Lowe	84.67
85	Jamie Clark	86.00	**86**	Steve Beaton	86.33	**87**	Radek Szagański	87.33
88	George Killington	88.00	**89**	Maik Kuivenhoven	91.33	**90**	Danny Baggish	91.67
91	Ricardo Pietreczko	92.00	**92**	Geert Nentjes	92.33	**93**	Rusty-Jake Rodriguez	94.67
94	Boris Krcmar	95.67	**94**	Steve Brown	95.67	**96**	Berry van Peer	96.00
96	Jimmy Hendriks	96.00	**96**	Matthew Edgar	96.00	**99**	Justin Pipe	96.67
99	Ian White	96.67	**101**	Niels Zonneveld	97.33	**102**	Steve Lennon	98.67
103	Lewy Williams	99.33	**104**	Ricky Evans	100.00	**105**	Danny van Trijp	100.33
106	Simon Whitlock	101.00	**107**	José Justicia	101.67	**108**	Danny Jansen	103.67
109	Gordon Mathers	104.00	**110**	Mickey Mansell	104.33	**111**	Jason Heaver	105.00
111	Jon Worsley	105.00	**113**	Kai Fan Leung	107.00	**113**	Kevin Burness	107.00
115	Ted Evetts	108.33	**115**	Devon Petersen	108.33	**117**	Geert De Vos	109.00
118	Adam Gawlas	109.67	**119**	Josh Payne	110.00	**120**	Steve West	113.00
120	Ron Meulenkamp	113.00	**122**	Tony Martinez	114.00	**123**	Martin Atkins	115.33
124	Jules van Dongen	115.67	**125**	Aaron Beeney	116.00	**126**	John Michael	116.33
126	Alan Tabern	116.33	**128**	John Brown	116.67	**128**	Jack Main	116.67
130	Zoran Lerchbacher	117.00	**131**	Wayne Jones	117.33	**132**	Jake Jones	117.67
133	Richie Burnett	118.00	**133**	Eddie Lovely	118.00	**135**	Peter Jacques	118.33
136	Stephen Burton	119.00	**136**	Jim McEwan	119.00	**138**	Damian Mol	120.00
139	Luc Peters	120.67	**140**	Jeffrey De Zwaan	121.00	**141**	David Evans	122.00
142	Jesus Noguera	122.67	**143**	Ross Montgomery	123.00	**144**	Pete Burgoyne	123.67
145	Adam Hunt	124.33	**146**	Ryan Murray	126.67	**147**	Derk Telnekes	128.33
148	Bradley Brooks	129.67	**149**	Glen Durrant	132.00	**150**	Darren Webster	132.67
151	Peter Hudson	133.33	**152**	Lisa Ashton	135.33	**153**	Gary Blades	135.67
154	Brett Claydon	139.00	**155**	Nick Fullwell	147.33	**156**	Ciaran Teehan	147.67
157	Michael Rasztovits	155.33						

Source: original work based on: https://tv.dartconnect.com/events/pdc

The table above highlights that Damon Heta emerges as the top player in terms of finishing, as indicated by his consistently high average position across all three sub-rankings. It is important to note that this ranking does not solely reflect the efficiency of hitting doubles (as it would require detailed information about each dart thrown), but obviously there is a correlation here.

By combining the scoring ranking and the checkout ranking, an overall ranking that assesses players based on their performance can be created. It considers players who had a minimum of 300 potential checkout attempts throughout the period (highest-ranked 76 players are presented in Table 8., full ranking is available in .xlsx file).

Table 8. Players Championship 2021 – 2022: Overall ranking of players (Top 76 players).

Rank	Player	Scoring	Finishing	Rank	Player	Scoring	Finishing
1	Jonny Clayton	4	3	**1**	Damon Heta	6	1
3	Michael van Gerwen	2	11	**3**	José de Sousa	5	8
3	Peter Wright	9	4	**6**	Gerwyn Price	1	13
7	Josh Rock	3	16	**7**	Rob Cross	13	6
9	Luke Humphries	14	10	**10**	Michael Smith	11	14
11	Brendan Dolan	29	2	**12**	Danny Noppert	21	11
13	Ryan Searle	19	15	**14**	Nathan Aspinall	17	18
15	Dimitri Van den Bergh	16	24	**16**	Chris Dobey	15	29
16	Joe Cullen	20	24	**16**	James Wade	40	4
19	Callan Rydz	18	27	**20**	Krzysztof Ratajski	12	34
21	Dave Chisnall	10	41	**22**	Raymond van Barneveld	33	20
23	Matt Campbell	50	7	**24**	Dirk van Duijvenbode	7	51
25	Stephen Bunting	22	38	**26**	Andrew Gilding	41	21
27	Jim Williams	31	33	**27**	Alan Soutar	36	28
29	Martin Schindler	24	43	**29**	Gian van Veen	32	35
31	Kim Huybrechts	37	31	**32**	Ryan Joyce	54	16
33	Mervyn King	42	30	**34**	Ross Smith	25	53
35	Ritchie Edhouse	66	19	**36**	Scott Williams	39	47

36	Kevin Doets	49	37	**38**	Gary Anderson	8	79
38	Adrian Lewis	23	64	**40**	Keane Barry	58	31
41	Gabriel Clemens	34	57	**42**	Scott Mitchell	47	45
43	Ryan Meikle	85	9	**44**	Mensur Suljovic	28	70
45	Jermaine Wattimena	46	53	**46**	Jamie Hughes	48	52
46	Rowby-John Rodriguez	64	36	**48**	Luke Woodhouse	60	41
49	Daryl Gurney	27	76	**50**	Florian Hempel	45	59
50	Darius Labanauskas	78	26	**52**	Mario Vandenbogaerde	53	53
53	Mike De Decker	43	65	**53**	Vincent van der Voort	61	47
55	Cameron Menzies	38	72	**56**	Krzysztof Kciuk	90	23
57	James Wilson	55	59	**58**	Andy Boulton	72	45
59	Martin Lukeman	96	22	**60**	William O'Connor	57	65
61	Scott Waites	76	47	**62**	Ian White	26	99
63	Karel Sedlacek	67	63	**64**	Steve Lennon	30	102
65	Jason Lowe	51	83	**66**	Lee Evans	70	65
67	Madars Razma	69	68	**67**	Joe Murnan	93	44
67	Nathan Rafferty	97	40	**70**	Boris Krcmar	44	94
71	Keegan Brown	77	62	**72**	Simon Whitlock	35	106
73	Chas Barstow	86	58	**73**	Jeff Smith	105	39
75	Rusty-Jake Rodriguez	52	93	**75**	Maik Kuivenhoven	56	89

Source: original work based on: https://tv.dartconnect.com/events/pdc

The table above displays data regarding the players' rankings in scoring and finishing. The first place is shared by Jonny Clayton and Damon Heta, as their average rank is the lowest at 3.5. While it is generally assumed that high-scoring correlates with finishing ability, this relationship is not always guaranteed. Nevertheless, the current rankings seem to support common opinions about certain players. James Wade, for instance, is renowned for his exceptional finishing skills but does not exhibit the same level of brilliance in scoring - as reflected in the ranking. Brendan Dolan is another player perceived similarly. Conversely, Dave Chisnall, Simon Whitlock and Gary Anderson are known for their excellent scoring capabilities, yet their finishing skills are considered less remarkable. Gary Anderson's case is particularly peculiar, as he ranks 8th in scoring but only 79th in finishing.

Based on the provided rankings, the players have been categorized into five groups according to their final positions:

1. Players in the Top 15 (e.g., Jonny Clayton, Michael van Gerwen, Dimitri Van den Bergh, etc.),
2. Players ranked 16 – 40,
3. Players ranked 41 – 70,
4. Players ranked 71 – 110,
5. Players ranked 111 – 157.

Table 9. Number of collected situations for individual groups of players.

	Number of situations	Including: possible to finish
Top 15	112.887	30.865
16 - 40	149.642	40.373
41 - 70	147.461	38.096
71 - 110	147.761	37.667
111 - 157	128.444	31.051
Others	29.009	6.906
SUM	715.204	184.958

Source: original work based on: https://tv.dartconnect.com/events/pdc

Although the chosen boundaries for these groups are somewhat arbitrary, an effort was made to ensure a slightly larger number of players in each successive group. Lower-ranked players generally have fewer opportunities to play games, so the selected ranges had to be wider to gather sufficient data.

As indicated in the table, the ranges in terms of volume are relatively close to each other. The "*others*" category in the table includes darters who played too few matches to be categorized.

With the initial statistics now compiled, it is high time to analyse the impact of pressure on the performance of the top players.

RESULTS

In the study, the effect of pressure on players' efficiency will be examined in two ways:

1) Tests of proportions will be conducted for extreme cases, comparing the frequency of successful checkouts in the absence of pressure to those under maximum level of pressure.
2) Cochran-Armitage tests will be utilized to investigate the presence of a linear relationship between the level of pressure and the success rate.

Table 10. An exemplary set of situations.

.xlsx row	Points scored	Opponent's counter	Decider?	Successful checkout?	Group of checkouts - player	Group of checkouts - opponent	Level - player
3510	57	201	No	No	10 – 25%	0%	Top 15
3512	64	141	No	Yes	40 – 50%	3 – 10%	Top 15
3520	137	145	No	No	0 – 3%	3 – 10%	Top 15
3522	24	20	No	Yes	> 70%	> 70%	Top 15
3540	118	25	No	Yes	10 – 25%	50 – 70%	Top 15
3549	66	28	No	Yes	40 – 50%	> 70%	Top 15
3559	50	36	No	No	40 – 50%	> 70%	Top 15
3561	12	18	No	No	> 70%	50 – 70%	Top 15
3571	81	139	No	Yes	25 – 40%	3 – 10%	Top 15
3589	28	64	No	Yes	> 70%	40 – 50%	Top 15
7549	59	170	no	No	25 – 40%	0 – 3%	Top 15
7551	25	25	No	Yes	50 – 70%	50 – 70%	Top 15
7561	36	32	No	Yes	> 70%	> 70%	Top 15
7570	18	104	No	No	50 – 70%	10 – 25%	Top 15
7579	108	36	No	No	10 – 25%	> 70%	Top 15
7589	58	198	No	No	10 – 25%	0%	Top 15
7591	48	140	No	Yes	50 – 70%	3 – 10%	Top 15
7601	74	5	No	No	10 – 25%	50 – 70%	Top 15
7603	32	2	No	Yes	> 70%	50 – 70%	Top 15
7610	100	184	No	No	0 – 3%	0%	Top 15
7612	70	84	No	Yes	40 – 50%	25 – 40%	Top 15
7622	80	117	No	No	25 – 40%	10 – 25%	Top 15
7624	20	20	No	Yes	> 70%	> 70%	Top 15

Source: original work based on: https://tv.dartconnect.com/events/pdc

In the case of checking the checkout efficiency under two types of situations (e.g., high-pressure situations and low-pressure situations), it was necessary to involve the same players in both scenarios. Although this may seem unusual, it is a result of the specific nature of the study. Darts players are regularly confronted with various situations. Within a single game, each player usually encounters both high and low-pressure situations. These occur alternately, depending on the course of the game. To analyse the impact of pressure on players' performance, it was necessary to compare their achievements in different conditions. This approach was chosen to precisely assess their efficiency under varying pressure contexts. Additionally, using the same players, the confounding factor of individual differences is eliminated. However, it should be noted that this research methodology is unique and stems from the distinctive nature of the study. To provide context, Table 10. presents a compilation of exemplary situations in which Jonny Clayton, one of the leaders of the ranking mentioned earlier, was the player at the dartboard. The data is sourced from an .xlsx file, which is available for download.

Although the data above comes from just two matches, it is noteworthy how the player encountered a variety of levels of pressure.

It is also worth noting that studies conducted in the field of darts do not allow for a definitive determination of whether the level of pressure certainly should affect players positively or negatively. Therefore, the conducted tests will be two-tailed, examining both the positive and negative impact of additional pressure. Due to the large amount of available data, a significance level of .05 will be applied for hypothesis testing.

Darts and "tilting"

Before proceeding with the main analysis, it is worth considering a phenomenon in darts that can be likened to "*tilting*" in poker. Tilting refers to moments of emotional upset where a poker player makes irrational decisions influenced by past failures (Torrance et al., 2022). In the context of darts, whether similar emotional factors affect players' performance can also be examined. In darts, there are instances where players struggle to hit even the simplest doubles, despite having multiple attempts. This raises the question of whether emotional upset, similar to tilting in poker, can make it difficult for a player to finish the leg successfully in subsequent attempts. In other words, it should be explored whether misses in previous visits significantly impact a player's ability to hit doubles in subsequent attempts within the same leg. If emotional factors, or "*tilting*" as it is understood here, are indeed important, then observations where players cannot close simple values for several attempts will not be independent. The influence of previous missed attempts can affect subsequent ones, potentially distorting performance results and leading to incorrect conclusions. This is particularly relevant when analysing situations where both players are already on low values, as their mistakes can collectively reduce effectiveness in that specific group of situations (e.g., both players failing to finish 40 points in six attempts). However, it is crucial to differentiate between tilting and independent events driven by probability. Sequential failures can occur regardless of emotional factors, merely as a result of probability. Therefore, it is essential to determine the cause behind these events. If the cause is not tilting, the situations can be considered independent of each other. Consequently, the ultimate question to address is whether the efficiency statistics in situations where both players have low values will be artificially lowered due to tilting.

The examination of the aforementioned problem involves comparing the efficiency of players in two different scenarios:

a) Suspected tilting situations: these are situations where a player, in a previous visit to the same leg, failed to close a value from the first group (e.g., 24, 32 or 40).
b) Other situations: these include other cases where a player has a value from the first group to finish.

If the efficiency is significantly different in the first group of situations, it would indicate that the failure to close a low value in a given leg reduces the probability of successfully finishing the leg in subsequent attempts. The results of efficiency are presented in Table 11. Only situations where players had a value from group I on the counter were considered for these results. One group comprises suspected tilting situations, while the other group encompasses all other scenarios.

Table 11. Comparison of checkout efficiency in situations suspected of "*tilting*" and in other situations (I group of values).

	Efficiency		
	Potential "*tilting*" situations	"*Normal*" situations	Attempts
Top 15	79.26%	80.26%	6956 (487 + 6469)
16 - 40	75.25%	77.24%	9167 (788 + 8379)
41 - 70	76.34%	75.63%	8267 (672 + 7595)
71 - 110	73.88%	73.55%	8036 (716 + 7320)
111 - 157	72.62%	71.70%	6457 (716 + 5858)
Others	67.53%	68.96%	1449 (1295 + 154)
Average	74.94%	75.54%	40332 (3416 + 36916)

Source: original work based on: https://tv.dartconnect.com/events/pdc

The data indicates that there is no significant difference in efficiency between "*suspicious*" situations and "*normal*" situations. In fact, the efficiency in suspected tilting situations is even higher in some groups. Based on this, it can be assumed that within a given leg, failing to hit an easy double does not decrease the likelihood of hitting a double on the next visit. To confirm this, a parametric test for proportions can be conducted using the Z statistic to compare two large independent samples. This test will determine if the difference between the results of the two groups is statistically significant. The number of attempts is relatively equal for each group (except for the group on unclassified players), so the total number of occasions for all groups will be considered. In this case, the hypotheses are as follows:

- Null hypothesis: there is no difference between the proportions in the two groups,
- Alternative hypothesis: there is a difference between the proportions in the two groups.

The Z statistic in this case is calculated as -0,7768 (p = .437). Therefore, there is insufficient evidence to reject the null hypothesis at a significance level of .05. The small difference in proportions is also the main cause of the low power of the conducted test ($1 - \beta = 0.12$). *This means that in this case, there is a high risk of committing a Type II error. However, in such a situation, the question automatically arises regarding the practicality of detecting such small differences. Let's assume that in objective reality, in situations suspected of tilting, players indeed have a slightly lower efficiency, for example, by 0.6 percentage point, but the test was unable to detect it (huge sample sizes would be required for such differences). However, in the context of darts, such a difference is unimportant, and its practical consequences are essentially zero. Considering the scale, the potential occurrence of a Type II error seems to be a marginal issue in this case.*

Just to mention: it does not imply the absence of good or bad series of darts. The conclusion drawn is that, based on the performed analysis, the data does not seem to be artificially influenced by potential tilting.

The level of pressure exerted by an opponent and the checkout efficiency – tests of proportions for extreme cases

An analysis of two types of situations was conducted to examine the effect of pressure on the checkout efficiency. The two types of situations considered are as follows:

- High-pressure situation: in this scenario, the thrower and the opponent both have a value from group I to finish,
- Zero-pressure situation: in this case, the player has a value from group I, while the opponent would be unable to finish even if they returned to the board.

Each set of situations was analysed separately for each group of players. For each set, a test of proportion based on the Z-statistic was conducted to determine if the difference in average efficiency of finishing between the two cases was statically significant. The results of these tests are presented in Table 12.

Table 12. Checkout efficiency in high and low-pressure situations – results of tests of proportions for individual groups of players.

	Efficiency		Attempts		Tests of proportions	
	Player: > 70%. Opponent: > 70% (High pressure)	Player: > 70%. Opponent: 0% (Low pressure)	Player: > 70%. Opponent: > 70% (High pressure)	Player: > 70%. Opponent: 0% (Low pressure)	Z-score	*p*-value
Top 15	78.92%	80.69%	1954	751	-1.023	.305
16 - 40	76.15%	76.27%	2763	906	-0.073	.941
41 - 70	74.64%	75.67%	2662	670	-0.548	.583
71 - 110	73.24%	75.58%	2724	602	-1.181	.237
111 - 157	70.74%	70.33%	2273	428	0.173	.862

Source: original work based on: https://tv.dartconnect.com/events/pdc

For each of the analyses, two hypotheses were formulated:

- Null hypothesis: there is no difference in checkout efficiency between the two types of situations,
- Alternative hypothesis: there is a difference in checkout efficiency between the two types of situations.

According to the conducted test, the observed differences for neither group were big enough to be considered statistically significant. Therefore, the tests of proportions did not provide compelling evidence to conclude that the high level or pressure exerted by the opponent influences the probability of the thrower hitting a double. However, it is worth noting that for 4 out of 5 groups, the efficiency in high-pressure situations was marginally lower, with differences ranging from 0.12 to 2.34 percentage points. Additionally, the power of the conducted tests was again very low, ranging from 0.05 to 0.23. Despite a relatively large number of observations in each case, the differences were so small that they cannot be considered statistically significant. However, this raises the question once again – would rejecting the null hypothesis with such a small effect size have any real significance? The sample sizes are relatively large, and the results were similar across all groups, suggesting that increased samples could indeed increase the power of the test and potentially demonstrate statistical significance, but the proportions themselves should not change significantly. This, in turn, would indicate a very minimal, negative impact of pressure on players' efficiency, particularly considering that extreme situations were compared. This impact may not be zero, but it is so low that it can be deemed marginal.

Furthermore, it will be useful to also explore the potential impact of pressure resulting from the state of the match, specifically the current result. In this case, high-pressure situations occur in final legs, typically at scores of 5-5, 6-6 or 7-7, depending on the phase of the tournament. However, there is a significant disparity in the sample sizes, as deciding legs (deciders) are relatively rare. Over the two-year duration of the tour, nearly 185,000 checkout attempts were recorded, but only around 4,500 took place in deciders. Therefore, in this context, only the success rates will be compared based on the remaining value on the counter, without further breakdown by groups of players (which would be also irrelevant in this case). A comprehensive summary, including the tests of proportions conducted using the Z-statistic, is provided in Table 13.

Table 13. Checkout efficiency in deciding legs compared to efficiency in other cases.

	Deciding legs			Other legs			Tests of proportions	
	Successful attempts	Unsuccessful attempts	Efficiency	Successful attempts	Unsuccessful attempts	Efficiency	Z-score	*p*-value
> 70%	743	252	74.67%	29702	9635	75.51%	-0.603	.546
50 - 70%	392	264	59.76%	15668	9729	61.69%	-1.007	.314
40 - 50%	170	249	40.57%	7494	9052	45.29%	-1.917	.055
25 - 40%	172	373	31.56%	7732	14929	34.12%	-1.247	.213
10 - 25%	114	593	16.12%	5060	24702	17.00%	-0.614	.539
3 - 10%	50	714	6.54%	1759	28614	5.79%	0.879	.379
0 - 3%	11	369	2.89%	411	16005	2.50%	0.482	.63
In overall	1652	2814	36.99%	67826	112666	37.58%	0.801	.423

Source: original work based on: https://tv.dartconnect.com/events/pdc

With the following hypotheses:

- Null hypothesis: there is no difference in checkout efficiency between the two types of situations,
- Alternative hypothesis: there is a difference in checkout efficiency between the two types of situations.

The results of the concluded tests do not provide sufficient evidence to reject the null hypothesis in favour of the alternative hypothesis. This conclusion applies to each group. Therefore, the statistical analysis does not indicate any statistically significant impact of the additional pressure resulting from the deciding legs.

The level of pressure exerted by an opponent and the checkout efficiency – the Cochran-Armitage test

In one of the previous analyses, only two extreme types of cases were examined: situations with maximum and minimum levels of pressure. However, there exist numerous other scenarios between these extremes. For instance, the finishing player may be set on the easiest double, while the opponent's remaining score indicates a possible but less probable finish (e.g., 120). In such cases where the variables are categorical (e.g., yes / no, hit / missed) and the categories of variables are ordinal (e.g., high pressure, medium pressure, low pressure), the Cochran-Armitage test can be utilized to determine if there is a linear relationship between the proportions in each category (Kwasiborski & Sobol, 2011). The test itself does not determine the direction of the trend, but this issue will be addressed a bit later.

When examining the checkout efficiency at various levels of pressure, it is reasonable to expect that the level of pressure imposed will increase as the opponent's remaining score decreases. In other words, the level of pressure can be ranked according to the group into which the opponent's value falls at any given time. For example, a value of 40 on the opponent's counter would be categorized as group I, indicating a very high level of pressure. On the other hand, a value of 90 might be considered as medium pressure. To illustrate this point, Table 14. presents the checkout efficiency of the Top 15 players at different levels of pressure (all tables are available in .xlsx file).

It is worth noting, however, that the analysis of efficiency will only consider data from the first three groups of values from the thrower's perspective (represented by the blue bar to the left side of the table), as indicated by the data highlighted in green in the table. This is because, in these specific value ranges, it can be assumed that the player is fully committed to finishing the leg during that particular turn. This commitment is not as apparent in other cases. To illustrate this issue, let's consider a scenario where the player has 90 points to close (group IV), and their opponent has 151 points remaining on the counter. In such a situation, it is likely that the thrower will not attempt to close the leg at any cost, but instead may consider setting themselves up comfortably on a double. For example, instead of starting the turn with 20s (to potentially leave a bull's-eye finish with the last dart), the thrower might choose to start with 18s, which reduces the chance of setting up the finish, but, given the opponent's low chance of successfully finishing, allows for a more comfortable setup in the next turn. Additionally, in this case, the 0 – 3% and 0% groups will be combined due to the limited number of observations in the 0 – 3% range.

Table 14. Checkout efficiency by Top 15 players based on the level of pressure.

	Top 15	**Group – opponent** > 70%	50 - 70%	40 - 50%	25 - 40%	10 - 25%	3 - 10%	0 - 3%	0%	Attempts
		High pressure			Medium pressure			Low pressure		
Group – player	> 70%	78.92%	79.81%	80.17%	80.87%	80.88%	81.31%	88.19%	80.69%	6956
	50 - 70%	66.67%	68.90%	65.08%	64.10%	60.41%	63.69%	70.59%	65.13%	4422
	40 - 50%	50.35%	52.38%	52.08%	57.14%	48.49%	54.73%	47.83%	52.72%	2813
	25 - 40%	39.67%	40.61%	43.00%	41.43%	40.85%	43.39%	37.91%	36.05%	4001
	10 - 25%	22.71%	25.15%	18.98%	25.00%	25.98%	20.24%	17.39%	14.19%	4977
	3 - 10%	7.37%	8.27%	9.38%	8.45%	8.41%	8.78%	10.26%	8.08%	4782
	0 - 3%	3.18%	3.20%	2.17%	4.45%	5.52%	5.04%	5.20%	2.11%	2914
	Attempts	**6557**	**5057**	**2516**	**2765**	**3432**	**3029**	**1038**	**6471**	

Source: original work based on: https://tv.dartconnect.com/events/pdc

Therefore, the analysis will test the presence of a linear relationship between pressure level and efficiency within the seven groups ranked according to pressure level. These groups are categorized as follows: group I – opponent waiting on a value from the group > 70% (high pressure), group VII – opponent waiting on a value from the group < 3% or 0% (low pressure). The results of the analyses are presented in Table 15.

Table 15. Checkout efficiency and level of pressure exerted by the opponent – analysis based on Cochran-Armitage tests.

	Does level of pressure impact checkout efficiency?								
	Checkout attempts: group of values: > 70%			Checkout attempts: group of values: 50 – 70%			Checkout attempts: group of values: 40 - 50%		
Group of Players	Chi-square value	*p*-value	Attempts	Chi-square value	*p*-value	Attempts	Chi-square value	*p*-value	Attempts
Top 15	4.255	.039*	6956	3.193	.074	4422	0.374	.541	2813
16 - 40	0.088	.766	9167	0.127	.91	5674	0.011	.918	3681
41 - 70	5.262	.022*	8267	3.026	.082	5317	0.049	.825	3611
71 - 110	0.606	.436	8036	0.034	.853	5328	0.912	.34	3443
111 - 157	0.265	.607	6457	0.545	.46	4346	2.478	.115	2812

Source: original work based on: https://tv.dartconnect.com/events/pdc

*Note. * Indicates cases for which p < .05 (indicating statistical significance).*

The analysis of each individual case includes a minimum of 230 situations. The lowest number of observations occurred for players ranked 111 – 157 in the value group of 50 – 70%, where the opponent's value fell within group 3 – 10%. Conversely, the highest number of observations was recorded for players ranked 16 – 40 in the value group > 70%, where the opponent's value also fell within group > 70%.

For the aforementioned analysis, the following hypotheses are considered:

- null hypothesis: there is no linear relationship between the level of pressure and the checkout efficiency,
- alternative hypothesis: there is a linear relationship between the level of pressure and the checkout efficiency.

The results of the analysis for different groups of values are as follows:

1. Closing values with a probability > 70% (group I): at a significance level of .05, a linear relationship between checkout efficiency and the level of pressure imposed by the opponent was observed for two out of five groups of players. In both cases, the direction of this relationship was consistent, indicating that higher pressure leads to lower efficiency. No such relationship was observed for the other three groups of players.
2. Closing values with a probability between 50% and 70% (group II): the relationship between efficiency and the level of pressure was not statistically significant for any of the groups of players, although the p-value for the Top 15 group was 0.074.
3. Closing values with a probability between 40% and 50% (group III): the relationship between efficiency and the level of pressure was not statistically significant for any group of players.

In summary out of the 15 sub-analyses, there were grounds to reject the null hypothesis in favour of the alternative hypothesis in only two cases. Based on these findings, there is insufficient evidence to conclude that there is a linear relationship between pressure level and checkout efficiency among professional players.

Although Cochran-Armitage tests did not provide information about the direction of the trend, it can be examined using simple linear regression. In 10 out of 15 cases, the slope coefficient of the line had a positive value, while in the remaining cases, it had a negative value. However, disregarding the very low values of the coefficient of determination (R-squared) in most cases, it is even difficult to provide a definitive answer as to whether increased pressure would have a positive or negative impact on a player's performance (data is available in .xlsx file).

DISCUSSION AND CONCLUSIONS

Both the analysis of extreme cases using tests of proportions and the analysis of linear relationship using Cochran-Armitage tests failed to provide sufficient evidence to indicate a statistically significant effect of pressure on the playing performance of professional darts players. The data also does not suggest a significant impact of pressure when playing in the deciding leg of the match. However, the issue of power in the conducted tests remains somewhat problematic, particularly in the case of tests of proportions. The differences in performance between the examined situations were so small that even with a large database of data, detecting them proved to be unlikely. On the other hand, regularly recurring such small differences indicate that increased pressure does not have such an impact on players' efficiency that would have any real significance.

These findings align with the conclusions of a study published in the article "*Performance under pressure in skill tasks: An analysis of professional darts*" (Ötting et. al., 2020), in which the authors analysed over 32,000 throws into a dartboard. Both the present work and the cited article demonstrate the remarkable mental toughness displayed by top players in the world. The opinions expressed in the introduction seem to be supported by reality, highlighting the necessity for players to possess high level of composure, concentration and overall mastery of the situation to compete at the highest level and overcome additional pressure factors.

However, it is important to acknowledge that the investigation into the impact of pressure on the playing quality of top darters is still far from complete. While the Players Championship series is widely recognized for its prestige and gathering of the world's best players, certain characteristics should be taken into account, such as low number of broadcasted games, the lack of fans in the venue and relatively lower stakes compared to the most significant tournaments worldwide. It is not certain that the study's results would have been the same if the data had been sourced from tournaments played on the stage, surrounded by TV cameras and passionate fans. Further exploration of the topic is warranted, encompassing more than just Players Championship games. However, it should be noted that other tournaments may suffer from limited amount of data. For instance, two years of Players Championship games accounted for over 7,500 matches, whereas the more prestigious European Tour only comprises approximately 1,200 in such a time interval. Given the wide range of potential scenarios, this may be insufficient in some cases.

Moreover, it is essential to acknowledge that the concept of pressure has been narrowly addressed in the present work. Pressure originates not only from the opponent's situation but also from factors such as the tournament phase or the quality of the opponent faced by the player. Thus, future research on the topic should encompass a broader examination of other pressure-inducing factors that have not been considered here. Players do not seem to be bothered by this particular kind of pressure, but this conclusion cannot be considered as universal.

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ORIGINAL ARTICLE

Influence of a long-term WB-EMS intervention on parameters of body composition and physical performance among individuals of different age decades between 19 and 81 years

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ABSTRACT

Lifelong fitness training plays an essential role in building and maintaining health. Whole-body electromyostimulation (WB-EMS) is a time-efficient training method that could be used as an adequate training intervention for different persons due to the intensive, involuntary contraction of the musculature and the resulting increases in muscular performance. Therefore, the aim of the study was to investigate if WB-EMS has positive effects on body composition and physical performance parameters of individuals of different age decades. Subjects from age decades 20-80 years participated in a 24-week WB-EMS training intervention. PRE and POST diagnostics of trunk extension and flexion, knee extension and flexion, hand grip strength, skeletal muscle mass (SMM) and body fat were performed on three consecutive days and the daily maximum values were summarized as the total mean value and were used for the descriptive data interpretation. Strength parameters were summarized in an unweighted additive index, the muscular change index (MCI). Regarding the results obtained by using the MCI, remarkable increases were observed in participants from all decades (20: +12.02%; 30: +6.59%; 40: +6.85%; 50: +3.96%; 60: +10.95%; 70: +20.26%; 80: +20.86%). Therefore, WB-EMS seems to be a time-efficient and adequate form of training that can be conducted to enhance muscular performance at different ages.
Keywords: Performance analysis of sport, Physical fitness, Strength training, Whole-body electromyostimulation, Lifespan.

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INTRODUCTION

Regular fitness and health training plays an important role in building and maintaining health throughout the lifespan. In addition to aerobic performance, the systematic development of strength performance is essential, as age-appropriate strength training has positive effects on the development of athletic and everyday motor performance as well as on the health and psychosocial well-being of adolescents and young adults (Büsch et al., 2017). As individuals age, they engage in physical exercise to prevent various diseases and enhance their general physical performance. A lack of exercise due to long periods of sitting at work as well as a general reduction in physical activity in everyday life can have a negative impact on health and can be seen as an independent risk factor for the development of chronic diseases (Finger et al., 2017a, 2017b). From the age of 30, the physical loss of muscle mass is about 3-8% per decade, which increases further from the age of 60 (Volpi et al., 2004). This involuntary loss of muscle mass, strength and function (which is called sarcopenia), is a strong risk factor for diseases in the elderly. Furthermore, reduced muscle mass considerably increases the risk of falls and injury, which may subsequently lead to functional dependence or permanent disability due to immobility and long-term rehabilitation processes, and thus to restrictions in daily life (Tinetti & Williams, 1997; Wolfson et al., 1995). Increased immobility and decreased physical activity are frequently accompanied by changes in body composition that result in an increase in fat mass, which can often lead to increased insulin resistance and advanced metabolic diseases in the elderly (Holloszy, 2000; Melton et al., 2000). An active lifestyle and regular physical activity have been proven to prevent this age-related loss of muscle mass and health impairments (Macaluso & Vito, 2004; Peterson et al., 2011). However, the training should be performed several times a week at a moderate to high intensity, which is often not possible due to physical limitations or a lack of motivation or opportunities to perform strength-oriented training (Kemmler & Stengel, 2012). Even if one´s physical constitution allows them to partake in strength training, factors such as time or training support are aspects that, regardless of age, are often cited as a reason not to train, even in younger generations. A potential solution to these problems could be whole-body electromyostimulation (WB-EMS) training due to its efficient and effective training characterization.

WB-EMS has been established as a time-efficient form of training for several years in various settings and for different groups of people; it causes the simultaneous stimulation of all the large muscle groups (through at least six applied current channels) with an effective stimulus that induces adaptations (Kemmler et al., 2020). In WB-EMS, the electrodes applied to the skin deliver an impulse to the underlying muscles, which causes an involuntarily contraction. One of the major advantages of this involuntary way of contraction is reduced joint stress. In contrast to conventional strength training, no weights have to be moved over one or more muscle-joint systems to trigger a training stimulus. All main muscle groups (8-12 with an electrode area of up to 2.8 m^2) as well as the deeper lying muscles can be stimulated simultaneously to the individual maximum, resulting in a shorter training duration and frequency (Stengel et al., 2015). Therefore, applying WB-EMS once a week for 20 minutes is common in commercial settings (the frequency can be increased to two sessions per week) (Kemmler et al., 2022). Training content can be adapted to the performance level of individuals from strictly static to slightly dynamic exercises and complex movement executions. This allows the best possible individualization based on the physical constitution of the individual being trained. For this reason, WB-EMS is also used as medical WB-EMS by qualified professionals as a therapeutic intervention in the healthcare sector (Berger et al., 2022). Despite the low training duration and frequency, the effectiveness of WB-EMS has been extensively proven with regard to various aspects. Among other things, increases in muscular strength capabilities, enhancements in body composition, and increases in motor performance have been observed in individuals of different ages (Berger, Ludwig, Becker, Backfisch et al., 2020; Götz et al., 2022; Kemmler et al., 2022; Kemmler et al., 2021; Ludwig et al., 2020).

Despite these findings on WB-EMS, to the authors' knowledge, no study exists whereby the authors explored the effectiveness of WB-EMS in individuals from all decades and genders and applied the identical stimulation protocol and training content, as these often remarkably differ from each other (Berger, Ludwig, Becker, Backfisch et al., 2020). For this reason, the aim of the present pilot study was to examine whether 24 weeks of WB-EMS training has a positive influence on different body composition and muscular performance parameters in untrained individuals of different ages.

MATERIALS AND METHODS

Participants

The study was conducted by using a quasiexperimental trial with a pretest–post-test design. This study was conducted between July 2021 and February 2022 in two centres at the RPTU Kaiserslautern, Germany, and the Friedrich–Alexander University Erlangen–Nürnberg, Germany. The aim of the study was to examine whether 24 weeks of WB-EMS training has a positive influence on different body composition and muscular performance parameters in untrained individuals of different ages. For this purpose, one male and one female person from each age decade between 20-80 years were integrated into the study. The search for test persons was carried out by means of e-mails, flyers and personal contacts. For each decade group, a variance of 1 year was tolerated, so persons in the 20 years age decade could be 19-21 years old, for example. In total 14 subjects between 19 and 81 years of age participated in this study. The inclusion criteria were an age between 19 and 81 years, no previous WB-EMS experience and no internal and orthopaedic limitations. The subjects did not engage in regular exercise for at least 24 months prior to the start of the study. Regular exercise was defined as moderate to intense activities lasting more than 20 minutes at a time and performed at least once a week for several weeks. Before the study began, the participants were informed of the relative and absolute contraindications according to the current guidelines for WB-EMS applications, and the potential exclusion criteria were verified (Kemmler et al., 2019). Hence, only subjects who were completely healthy and had no contraindications to exercise or specifically to WB-EMS were included. Furthermore, the subjects were asked to maintain their habitual lifestyle as much as possible and to not participate in any other sport in addition to the weekly guided WB-EMS training sessions. Before the start of the study, the subjects were informed in detail about the content of the experiment and signed a data protection and consent form. Due to health complications that were not associated with WB-EMS, only 12 people were able to complete the study.

Measures

Before and after the 24-week intervention (T1 and T2) three measurements were recorded on three consecutive days at similar times. These multiple measurements were carried out to minimize the probability of day-dependent variations and resulting inaccurate results. On each of the test days, all measurements were performed 3 times in a row with one minute rest in between, and the maximum value was included in the evaluation. The three measurement days were combined into one mean value, so each recorded data point consisted of several individual values (Backman et al., 1997).

Body composition was measured by using bioelectrical impedance analysis (BIA; InBody770, Biospace CO., Seoul, Korea). The parameters recorded were weight, body fat (BF), and skeletal muscle mass (SMM). Prior to the study, key information about the participants such as their age, gender, medication intake, and illnesses were requested. In addition, none of the test participants wore electrical or metal implants and none were pregnant. None of the participants had symptoms of infection at the diagnosis time; this was examined because infection can alter metabolic processes and blood flow, which could have an influence on the measurement results of the BIA (González-Correa & Caicedo-Eraso, 2012). Regarding the measurement preparation, the participants did not eat any food in the last two hours before the diagnostics and 500 ml of water should be drunk during this period. It was ensured that all the measurements took place at a similar time of day and that the room temperature was always around 22 degrees Celsius to keep the body's blood circulation as constant as possible.

A warmup consisting of a 5 min cycle on an ergometer at 100 W was performed to prepare the organism for the upcoming performance diagnostics. Subsequently, for subjects under 60 years of age, the concentric force of their knee flexion and extension of the nondominant side was measured in a sitting position by using IsoMed 2000 (D&R Ferstl GmbH, Hemau, Germany). Two sets of 12 repetitions each were performed with a 1 min rest in between the sets. The angular velocity was set to 60 °/s. The force of the hip- and knee extension and flexion of the subjects that were 60 years and older was determined in a closed kinetic chain setting by using Contrex LP (Physiomed Elektromedizin AG, Laipersdorf). A bilateral concentric leg extension (and flexion) was performed in a sitting, slightly supine position (15°), that was supported by chest and hip straps. The ROM was selected between 30 and 90° (knee angle), with the ankle flexed 90° and positioned on a flexible sliding foot-plate. The standard default setting of 0.5 m/s was used. After the warm-up and familiarization with the movement pattern, participants were asked to conduct five concentric repetitions (flexion and extension) with maximum voluntary effort. The participants completed two maximum trials with two minutes of rest in between; the higher value was used for data analysis. The use of different devices was due to the fact that the participating persons of the age decades 20-50 and 60-80 were tested at different universities. Different devices for diagnosing the maximum strength of the lower extremities were available at the bases, which, however, does not limit the comparability of the percentage change in performance in the further course.

Static trunk extension and flexion (isometric force test) were measured by using the Back Check 607 (Dr. Wolff GmbH, Arnsberg, Germany). Participants were standing with their arms dangling and knee joints slightly bent. They were secured in the iliac crest area with one dorsal and one ventral pad in the sagittal plane. Two pads with force transducers were placed without pressure on the sternum and between the shoulder blades to record isometric forces. Maximum isometric force was measured in both directions. Tests were performed three times (30-second rest between), with the maximum value used for analysis (Weissenfels et al., 2019). Hand force of the dominant hand was measured using the Jamar hydraulic hand dynamometer (JLW Instruments, Chicago, USA). The measurement was performed seated with an elbow positioned at 90° flexion, forearm supported, shoulder at 0° of flexion and wrist in a neutral position.

Procedures

The training sessions took place once a week over a period of 24 weeks for 20 minutes each using the Miha Bodytec II device (Miha Bodytec, Augsburg, Germany). A creeping pulse of 0.4 seconds was set, as training was carried out with beginners. The other pulse parameters were based on the settings commonly used (pulse time: 6 s, pulse pause: 4 s, frequency: 85 Hz, pulse width: 350 μs) (Kemmler, 2022; Kemmler et al., 2022). During the WB-EMS training, the subjects wore a special EMS underwear provided by the device manufacturer. An electrode vest was used to stimulate the lower back, latissimus, upper back, abdomen, and chest. In addition, a waist belt, which stimulates the gluteal muscles, and electrode belts around the upper arms and thighs were applied. The training was standardized and consisted of six different exercises, which were performed during the impulse. The training exercises performed are shown in Table 1, the exercise sequence was performed twice. An impulse familiarization session was completed prior to the start of the first training session. Intensity control of WB-EMS was performed using subjective load (RPE scale), which is the most accurate way to control the intensity in WB-EMS (Berger et al., 2019). An intensity between six (strenuous) and seven (very strenuous) on the RPE scale was aimed and regularly checked. Impulse intensity was requested and adjusted several times during the training (Kemmler et al., 2016).

Table 1. Training exercises in the intervention.

Exercise	Repetitions
Lateral lunges with elbow flexion	3 per side
Squats with elbow flexion	6
Standing one-legged superman	6 per side
Squats with arms extended above head followed by latissimus pulldown movement	6
Lunge followed by trunk rotation, extended arms in 90 degree flexion, hands holding 3 kg medicine ball	6 per side
Standing crunches with diagonal trunk rotation, extended arms in elongation of the upper body, hands holding 3 kg medicine ball	6 per side

The aim of creating and selecting the training content was to intensively challenge all participating individuals, while at the same time enabling the implementation of the training content across all age decades. The limited number of exercises played an essential role in this process, as a clear selection of exercises avoids a possible overload and enables an adequate execution. Figure 1 shows an example of lunges followed by a trunk rotation, arms being extended at 90 degrees of flexion, and a 3 kg medicine ball being held.

Figure 1 Example of one of the performed exercises with a 3 kg medicine ball.

Analysis

No inferential statistical analysis was performed due to the small number of subjects. The descriptive data enables a decade-specific analysis and was used to interpret the present pilot study. Furthermore, to provide a decade-specific overview of the strength increases, the percentage changes in trunk extension and -flexion, knee extension and -flexion and hand force were combined into an unweighted additive index, which is consecutively referred to as the muscular change index (MCI).

RESULTS

One woman that was 61 years old lost interest in participating in the study and quit after 4 months. In addition, another woman 69 years old was hospitalized for 3 months during follow-up assessments and was thus lost to follow-up. Attendance was close to 100% for the participants from all decades. Compliance with the impulse intensity prescription was high. All participants stated RPEs of at least 6 (strenuous) during the WB-EMS session. No adverse effects related to WB-EMS application were determined or reported by the participants.

Table 2 shows the descriptive values of all recorded parameters at T1 and T2 as well as the percentage change from T1 to T2 as % Delta. The data of knee extension and knee flexion were separated due to different measurement systems being used on the individuals aged 20-50 and 60-80, but they were combined when determining the percentage change between the measurement times. Furthermore, a gender-specific representation was included to identify potential descriptive differences between the genders.

Table 2. Descriptive of all parameters including percentual changes between the measurements.

Parameter	Group	T1	T2	% Delta T1 – T2
Weight [%]	Overall	79.44 ± 17.06	79.25 ± 17.36	-0.34 ± 2.92
	Male	82.52 ± 19.38	81.84 ± 19.51	-0.92 ± 3.42
	Female	75.13 ± 14.03	75.63 ± 15.16	0.47 ± 2.15
Body Fat [%]	Overall	28.59 ± 6.67	27.69 ± 6.22	-2.91 ± 4.62
	Male	29.46 ± 6.80	28.47 ± 6.51	-3.27 ± 5.52
	Female	27.38 ± 7.03	26.6 ± 6.36	-2.40 ± 3.53
SMM [kg]	Overall	31.61 ± 8.17	32.01 ± 8.21	1.3 ± 1.5
	Male	32.03 ± 7.89	32.26 ± 7.76	0.85 ± 1.79
	Female	31.03 ± 9.45	31.65 ± 9.73	1.92 ± 0.7
Trunk Extension [kg]	Overall	66.79 ± 22.64	71.97 ± 21.94	8.85 ± 9.31
	Male	78.01 ± 21.92	83.29 ± 19.97	7.86 ± 6.45
	Female	51.10 ± 12.65	56.13 ± 13.73	10.23 ± 13.11
Trunk Flexion [kg]	Overall	47.22 ± 14.95	54.44 ± 18.21	16.59 ± 22.08
	Male	49.44 ± 14.22	59.18 ± 19.78	18.96 ± 20.56
	Female	44.12 ± 17.01	47.8 ± 15.2	13.28 ± 26.12
Knee Extension 20-50 years [Nm]	Overall	157.25 ± 68.99	172.88 ± 62.43	*Overall*
	Male	149.08 ± 72.18	161.33 ± 56.24	15.35 ± 12.71
	Female	165.42 ± 75.62	184.42 ± 74.66	*Male*
Knee Extension 60-80 years [N]	Overall	2064.83 ± 969.74	2352.58 ± 838.72	15.69 ± 15.53
	Male	2275.89 ± 1069.26	2578.67 ± 865.16	*Female*
	Female (n = 1)	1431.67	1674.33	14.87 ± 9.04
Knee Flexion 20-50 years [Nm]	Overall	102.79 ± 34.94	109.08 ± 37.37	*Overall*
	Male	9833 ± 41.61	103.00 ± 46.02	7.92 ±6.96
	Female	106.75 ± 32.78	115.17 ± 32.28	*Male*
Knee Flexion 60-80 years [N]	Overall	517.58 ± 203.86	565.75 ± 192.49	5.70 ± 6.01
	Male	612.22 ± 92.73	659.78 ± 60.74	*Female*
	Female (n = 1)	233.67	283.67	11.03 ± 7.65
Hand Force [N]	Overall	41.66 ± 13.63	43.11 ± 13.29	4.06 ± 7.61
	Male	43.15 ± 13.90	45.09 ± 12.61	5.67 ± 6.93
	Female	39.58 ± 14.54	40.33 ± 15.17	1.80 ± 8.74

Note. Values are presented as means (± SD). % Delta is shown for all age decades.

Table 3 shows the percentage changes of the individual parameters in relation to the decades 20-80. As stated above, the 60 and 70 decade group contained only one male each.

Table 3. Percentual changes of the parameters for each decade.

Decade	Weight [%]	BF [%]	SMM [%]	Trunk Extension [%]	Trunk Flexion [%]
20.00	2.16	1.22	1.93	15.47	10.19
30.00	-3.17	-7.66	1.25	5.41	-0.33
40.00	1.11	0.45	1.36	9.50	2.57
50.00	0.99	-4.90	2.90	3.14	1.93
60 (n = 1)	-1.11	-3.59	0.33	10.04	33.71
70 (n = 1)	-3.72	-1.84	-2.40	15.33	56.93
80.00	-0.71	-3.84	1.37	6.88	39.87
All	-0.64	-2.88	0.96	9.40	20.70

Decade	Knee Extension [%]	Knee Flexion [%]	Hand Force [%]	MCI [%]
20.00	14.91	11.65	11.32	12.02
30.00	21.95	5.43	-0.69	6.59
40.00	11.96	6.84	6.02	6.85
50.00	7.76	0.21	5.94	3.96
60 (n = 1)	2.25	2.48	5.37	10.95
70 (n = 1)	14.69	5.70	3.72	20.26
80.00	27.04	19.31	-2.78	20.86
All	14.37	7.37	4.13	11.64

Note. BF = Body Fat; SMM = Skeletal Muscle Mass; MCI = Muscular Change Index.

DISCUSSION

WB-EMS is considered an intensive, effective and time-saving training method in many areas of application and for different groups of people. The present study observed the influence of a 24-week WB-EMS training on body composition and physical performance parameters. To the authors' knowledge, this is the first study that exemplarily examined the effectiveness of WB-EMS in individuals from all decades with ages ranging from 19 to 81 years, which enables comparability regarding the examined parameters. Furthermore, the same training content and stimulation protocols were applied to all participants, which has not been the case in previous studies with subjects of such a broad age spectrum.

In summary, although differences between the decades were observed (Table 3), all participants benefited from the intervention at least with respect to overall muscle strength increases. Substantial descriptive enhancements in trunk flexion and extension, knee flexion and extension, and skeletal muscle mass were examined, clearly demonstrating a positive effect of WB-EMS over a 6-month training period. Looking at the individual decades, it is noticeable that an increase in strength performance measured by the recorded parameters was observed over all decades (excepted trunk flexion in the 30-year-olds). If one considers the MCI (% changes in trunk flexion and extension, knee flexion and extension and hand force), increases of 12.02% in the decade 20, 6.59% in the decade 30, 6.85% in the decade 40, 3.96% in the decade 50, 10.95% in the decade 60, 20.26% in the decade 70 and 20.86% in the decade of the 80-year-olds were observed for the individual decades, which in total equals a mean of 11.64% across all decades. The results show that all age decades examined benefited from WB-EMS training in terms of strength gains generated. In comparison to each other, the biggest improvements were observed in the two highest age decades, which confirms a use as well as applicability of WB-EMS also at a high age.

Previous studies observed positive results with various participants, even in young age groups. For example, Ludwig et al. (2020) found significant increases in performance of the knee extensors and flexors, hip adductors, and trunk flexors after 10 weeks of WB-EMS training (once a week) with adolescent soccer players (Ludwig et al., 2020).]. Although adolescent participants were not included in the present study as the focus was on adult individuals, these previous findings demonstrate the wide-ranging potential applications of WB-EMS, even in adolescent athletes. These findings are supported by a study of Berger et al. (2020) in which an 8-week WB-EMS intervention was conducted with a 17-year-old road cycling athlete, resulting in reductions in subjectively perceived back pain, improvements in recorded postural parameters, and increases in the maximal strength capacity of trunk flexors and extensors (Berger, Ludwig, Becker, Kemmler & Fröhlich, 2020). A study by Dörmann et al. (2019), in contrast to the studies presented above which were conducted with male subjects, was carried out with a trained, female cohort aged 20.5 ± 2.3 years. The effects of WB-EMS training twice a week over a 4-week intervention period on the parameters of speed, jumping power and lower extremity strength were observed and compared with the effects of a similarly structured conventional strength training. The WB-EMS training intervention resulted in enhancements in sprint speed (≤ 6.3%), change of direction speed (≤ 5.7%), vertical jump height (≤ 13.2%), and maximum strength of knee extensors (≤ 13.5%) and flexors (≤ 18.2%) (Dörmann et al., 2019).

The youngest subjects that participated in the present study were 19-21 years old, with an increase of 15.47% in trunk extension, 10.19% in trunk flexion, 14.91% in knee extension, and 11.65% in knee flexion, 11.32% in hand force and an MCI of 12.02%, which is similar to performance increases reported in the studies described previously. Therefore, it can be summarized that already in comparatively young age an increase in the muscular capacity by WB-EMS can be observed.

In the middle age decades 30, 40 and 50, the 24-week WB-EMS intervention resulted in a similar development of the examined parameters, although the extent of the increase in their performance was much lower than that experienced by the younger individuals. Individuals from these decades represent the largest user group of conventional WB-EMS applications according to a survey by Rodrigues-Santana et al. (2022) (Rodrigues-Santana et al., 2023). However, the number of studies including non-athletic adults of this age range is rather low (Kemmler et al., 2021). During this period of life, one´s daily life is often predominantly spent in a sitting or standing position, which is considered an independent risk factor for the development of chronic diseases and often leads to poor posture and back pain (Finger et al., 2017b). WB-EMS has proven to be an efficient and effective method to alleviate back pain and is considered a successful method to improve it (Kemmler, 2022; Weissenfels et al., 2019). Even though back pain was not directly measured during the present study, in many cases a correlation between undeveloped back muscles and occurring back pain exists, which is why the observed increase in trunk muscle strength may also influence potential back pain (Kemmler, 2022; Weissenfels et al., 2018). In comparison to an investigation by Ludwig et al. (2019), whereby the authors examined subjects between 18 and 40 years of age, similar tendencies of performance increases were observed in the present study. Even if the results with increases of up to 17.1% of back flexion and 21.4% of back extension (depending on the WB-EMS training group) were clearly above the results generated here for the age decades 30-50, the subjects integrated were able to benefit from the intervention, showing increases of the MCI from 3.96-6.85% (Ludwig et al., 2019). Furthermore, appropriate strength training through WB-EMS seems to be a suitable method to enhance performance and counteracts the physiological loss of muscle mass after the age of 30. For the present study, improvements of 1.25 - 2.9% in SMM were observed for the decades 30-50 (Volpi et al., 2004).

The most comprehensive literature base can be found for people with the age of 60 years and older (Kemmler et al., 2021). In many cases, older people are unable or unwilling to perform intensive strength training due to physical limitations or lack of motivation, even if it positively influences their daily activity and has preventive benefits such as reducing falls and the incidence of various diseases such as sarcopenia (Kemmler & Stengel, 2012). The elderly can remarkably benefit from the specific way of the WB-EMS application due to the involuntary contraction and potential training execution in a static or lying position without additional loads (Kemmler et al., 2015). In the present study, increases in strength were observed, MCI improved by 10.65 to 20.86%, which represents among the largest increases in performance in the present intervention. Similar percentage increases were observed for maximum isokinetic leg and hip extensor strength (MIES) and maximum isokinetic leg and hip flexor strength (MIFS) by von Stengel and Kemmler (2018). During this investigation, 118 males aged 27-89 years old trained with WB-EMS over a period of 14-16 weeks. Increases in MIES of 9.1 ± 7.3% and MIFS of 18.1 ± 11.0% were observed for the people 65-79 of age (Stengel & Kemmler, 2018). These performance increases generated by WB-EMS are consistent with a study by Kemmler et al. (2012), whereby considerable increases in the maximal trunk extension (+9.9%) and leg extension (+9.8%) were detected after 14 weeks of WB-EMS training in postmenopausal women aged 65 ± 5 years old (Kemmler et al., 2010). Even in female patients over 70 years old that were suffering from sarcopenia and not able to perform an adequate conventional strength training, a 12 week WB-EMS intervention occurring once a week resulted in a considerable increase in the maximum strength of their leg extension and -flexion. With this study, the universal and individually adjustable training design of the WB-EMS became clear, as the training was performed in a lying position with primarily static and slightly dynamic exercises, which nevertheless led to an enhancement in muscular performance (Kemmler et al., 2015). Therefore, in accordance with the current evidence, the present results confirm the beneficial possibility of using WB-EMS with an older population.

Apart from the positive results, methodological points that concern the general implementation and limit the transferability of the results to the general population must be mentioned. The intervention was conducted as a pilot study whereby one participant of each gender per age decade 20-80 was included in the intervention, no control group was observed. For reasons not related to WB-EMS, only one person in each of the decades 60 and 70 was able to complete the intervention. Furthermore, the sample collected was relatively small, only a total of 14 subjects were included in the evaluation. Correspondingly, from a biometrical point of view, we are unable to clearly answer the research question of whether age or gender modifies the effects of WB-EMS on outcomes related to strength and body composition—nevertheless, the overall strength changes (MCI) were enhanced in participants from all age groups. Further, the physical activity in everyday life was not controlled, integrating this as a covariate impossible, and its potential influence on the outcome parameters cannot be excluded. The use of different measurement systems at the different study centres further complicates the comparison of the recorded parameters; future studies should ideally test all participants with the identical diagnostics and devices.

Nevertheless, it could be shown that the investigated results are in accordance with the literature and that a positive influence of a WB-EMS intervention on all age decades 20-80 can be observed.

CONCLUSIONS

In summary, it can be concluded that positive effects of a 24-week WB-EMS intervention were observed across all age decades in the present pilot study. Apart from the increase in muscular performance and SMM, the training was performed by individuals from all age groups and genders with high adherence, acceptance and without any adverse effects, which clearly shows the universal applicability of the training. Older persons especially benefit from WB-EMS, as the involuntary stimulation of the musculature can be performed without high voluntary effort. However, regardless of age and gender, WB-EMS seems to be an adequate way to enhance performance over a long period of time.

AUTHOR CONTRIBUTIONS

Conceptualization: Joshua Berger; Data curation: Joshua Berger, Elena Janowicz and Markus Weineck; Formal analysis: Joshua Berger; Funding acquisition: Michael Fröhlich and Wolfgang Kemmler; Investigation: Joshua Berger, Elena Janowicz and Markus Weineck; Methodology: Joshua Berger, Oliver Ludwig and Michael Fröhlich; Project administration: Wolfgang Kemmler; Software: Oliver Ludwig; Supervision: Oliver Ludwig, Michael Fröhlich and Wolfgang Kemmler; Visualization: Joshua Berger and Elena Janowicz; Writing – original draft: Joshua Berger and Elena Janowicz; Writing – review & editing: Oliver Ludwig, Michael Fröhlich and Wolfgang Kemmler.

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No funding agencies were reported by the author.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the author.

INSTITUTIONAL REVIEW BOARD STATEMENT

The study was conducted in accordance with the Declaration of Helsinki and approved by the ethics committee of the German University for Prevention and Health Management (02/17, 11.09.2017).

INFORMED CONSENT STATEMENT

Informed consent was obtained from all subjects involved in the study.

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The experiments comply with the current laws of the country in which they were performed.

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ORIGINAL ARTICLE

Impact of short term training on morphological, physical fitness and physiological variables of middle distance runners

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ABSTRACT

Purpose: The present study was designed to investigate the effects of short term training on morphological, physical fitness and physiological determinants of middle distance runners. Method: Total of 97 male volunteers (age: 18-20 yrs.) (40- sedentary control, and 57- middle distance runners) were included randomly, and 17 middle distance runners were excluded. The rest were divided into (a) Sedentary Control Group (SCG, n = 40) and (b) Middle Distance Runners Group (MDR, n = 40). The volunteers of MDR followed a training schedule of 2 hrs/d, 5days/wk., for 6 wks.; no training was given in SCG. Results: A significant ($p < .05$) increase in strength (of grip, back, leg, upper body strength, abdominal), anaerobic power, flexibility, VO_{2max}, FEV_1, FVC, PEFR; and decrease ($p < .05$) in body mass, body fat and sprint time, heart rate (during rest, sub-maximal exercise and recovery) among the volunteers of MDR after 6 weeks of training. This study showed positive correlation between standing broad jump and height ($r = +0.51$, $p < .05$); and between speed and leg strength ($r = +0.52$, $p < .05$). Conclusion: Training have a positive impact on morphological, physical fitness and physiological variables of middle distance runners. Further research would provide conclusive results that can be extrapolated to general population.
Keywords: Performance analysis of sport, Body fat, Strength, Power, VO_{2max}, Training, Middle distance runners.

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INTRODUCTION

The middle distance running are popular worldwide and covers a distance of 800 meter to 1500 meter. The duration of mid-range runs ranges from two minutes to eight minutes (Mooses et al., 2013). The physiological demands of middle distance runners are different from those of short distance and long distance runners. The success in middle distance running is dependent on both aerobic and anaerobic determinants which allow the athlete to maintain a rapid velocity during a race (Mooses et al., 2013; Berryman et al., 2018).

The body composition has a significant contribution of performance of the middle distance runners (Mooses et al., 2013). It has been observed that the shorter events, particularly 800 meters; there is a tendency towards greater mesomorphy among the athletes (Mooses et al., 2013). The larger fat-free mass may enable runners to perform efficiently (Esco et al., 2018; Stefani, 2006). The strength, anaerobic power, speed, flexibility are the important variables which may limit the performance of the middle distance runners (Nikolaidis et al., 2018). The VO_{2max} and aerobic endurance are crucial factors in middle distance running performance (Legaz-Arrese et al., 2007; Helgerud et al., 2007; Galbraith, 2021). Training plays an important role in improvement of fitness variables of the athletes (Mcardle et al., 2015; Bompa & Buzzichelli, 2021). Middle-distance running requires a balance in different fitness variables, which include endurance, power, strength and technique (Mooses et al., 2013). Heart rate plays a significant role for assessment of training load and may be used as a tool for monitoring of training of the athletes (McArdle et al., 2015). The performance determinants of the middle distance runners must be evaluated at regular intervals in order to achieve better performance. On the basis of the above the present study has been designed to find out the effects of short term training on morphological, physical fitness and physiological variables of middle distance runners.

MATERIALS AND METHODS

Subjects

Ninety seven healthy male volunteers (age: 18-20 yrs.) (forty- sedentary control, and fifty seven- middle distance runners) were included randomly from Midnapore, W.B., India. The sample size was determined by G*Power software and the total sample size were found fifty four (Faul et al., 2009; Kang, 2021). In this study ninety seven volunteers were taken to avoid drop out of the volunteers. All the volunteers were undergoing a medical checkup performed by physicians, and based on their decision seventeen middle distance runners were excluded from this study. The rest were divided into (a) Sedentary Control Group (SCG, *n* = 40) and (b) Middle Distance Runners (MDR, *n* = 40).

Training and experimental design

General and specific training related to middle distance running was given by the qualified coaches to the volunteers of middle distance runners group, whereas the volunteers of sedentary control group did not receive any training. Training includes speed training, strength and power training, flexibility training, interval training, endurance training etc. and were given following the schedule (2 hrs/day, 05 days/week for 06 weeks) (Bompa & Buzzichelli, 2021). The selected morphological, physical fitness and physiological variables were measured at the beginning of the training (baseline data, 0 week) and at the end of training programme (06 weeks). Statistical analysis was performed to find out the significant differences among the variables.

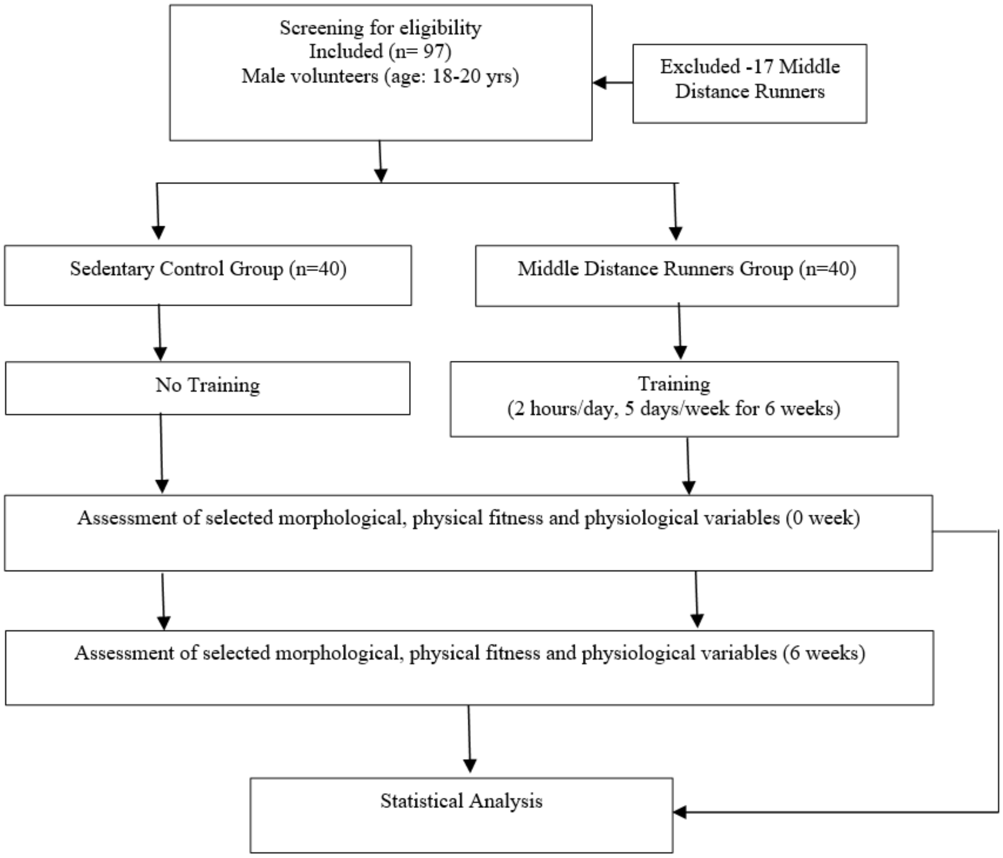

Figure 1. The experimental design of the study.

Table 1. Training plan for middle distance runner.

Phases			**6 Weeks plan**		
Phases of Training			Baseline	Preparatory Phase	
Sub-phases			Zero level baseline	General Preparation (Physical Preparation)	Specific Preparation (Technical and tactical Preparation)
Periodization	Strength		-	Anatomical adaptation	Maximal Strength
	Endurance		-	Aerobic	Anaerobic
	Speed		-	Specific high	
	Skills		-	Foundation	Advanced
Macro Cycles			0 weeks	1-3 weeks	3-6 weeks
Training Factors	Volume	100%	-	80-90%	
	Intensity	90%	-	70-80%	
	Peaking	80%	-	70-75%	
	Physical Preparation	70%	-	50-55%	40-45%
	Technical Preparation	60%	-	40-45%	40-45%
	Tactical Preparation	50%	-	10%	10%
	Psychological Preparation	40%	-		10%

Ethical considerations

The subjects were informed about the possible complications of the study and a written informed consent was taken from them. All volunteers were asked to maintain their normal diet and stay away from alcohol and smoking. The Institutional Ethical Committee (Human Studies) approved this study.

Measurement of morphological variables

Measurement of height (stature) and body mass

The height (stature) was recorded by the stadiometer (Seca 220, UK) and expressed in centimetres (cm) (Jonson & Nelson, 1996). The body mass was measured by using electronic weighing machine (Seca Alpha 770, UK) and expressed in kilogram (kg) (Jonson & Nelson, 1996). The body mass index (BMI) and body surface area (BSA) was calculated using the standard equations from the values of height and body mass (Jonson & Nelson, 1996).

Determination of subcutaneous fat

The skin fold thickness was taken from biceps, triceps, sub-scapular and suprailiac skin fold sites by using skin fold calliper (Cescorf, Brazil) for determination of body density (Durnin & Womersley 1974). The body density score was used for assessment of percent body fat (Siri, 1956). The total fat mass and lean body mass (LBM) was calculated by using standard equation (Jonson & Nelson, 1996).

Determination of waist-hip ratio

The waist and hip circumference was measured with a non-stretchable tape and the waist-hip ratio was determined (Jonson & Nelson, 1996).

Measurements of physical fitness variables

Measurement of hand grip strength

The hand grip strength was measured using the hand grip dynamometer (Baseline, USA) in both the hands. The subject was asked to hold the dynamometer using palm and the handle rest on fingers. The arm was at the right angle with elbow parallel to the ground. After that the subject was asked to squeeze the dynamometer with maximum strength and maintained it for 5 seconds, the measurement was recorded in kilogram (kg) (Lee & Gong, 2020).

Measurements of back and leg strength

The back and leg strength was measured using the back and leg dynamometer (Baseline, USA) (Coldwells et al., 1994). The subject was asked to stand on the base of dynamometer keeping both feet apart and hold the centre of the bar mounted at the end of the chain with the palm facing upwards to the head. Then without bending and jerking the athlete pulled the bar with maximum force for 5 seconds. For measurement of leg strength same procedure was followed. The knees of the subject were bent at approximately 110°. The subject pulled the chain as hard as possible while straighten the legs and arms. The back and leg strength was recorded in kilogram (kg).

Measurement of upper body strength (push up test)

The subject was asked to maintain a position and his toes touches the floor, the body and legs maintaining a line. The subject performed push up as fast as possible for one minute. The number of the push-ups in one minute was counted (Jonson & Nelson, 1996).

Measurement of abdominal strength (sit up test)
The abdominal muscles strength of the subjects was measured by sit up test. The subject performed sit up as fast as possible for one minute. The number of the sit ups in one minute was counted (Jonson & Nelson, 1996).

Determination of anaerobic power
The running based anaerobic sprint test (RAST) was performed to assess anaerobic power of the subject (Andrade et al., 2015). The subject had undertaken six 35 meter sprints with 10 seconds recovery between each sprint, for this a non-slip ground surface 35 meters was marked with cones. The subject warmed up for 10 minutes, then the subject was asked to take a stand at the starting position and start running to the second cone when whistle was heard by him. The time taken by the subject to cover 35 meter was recorded. The subject was taken rest for 10 seconds and came back 35 meters to the first cone, and the time taken was recorded. The test was repeated 3 times and time taken for six sprints was recorded for determination of anaerobic power following standard equations.

Measurement of leg muscle power (vertical jump)
The vertical jump test was conducted following standard procedure (Jonson & Nelson, 1996). The subject was asked to stand side on to a wall and raise his hand up and the highest point the figure touched was marked. The subject was asked to stand away from the wall and leaps vertically as high as possible and touched the wall at the highest point of the jump, and measurement was taken.

Measurement of explosive power of legs (standing board jump)
The subject was asked to stand on a line with feet slightly apart. The subject performed the jump with maximum effort and landing both feet without falling backwards. The distance from the line to the nearest point of contact was record (Jonson & Nelson, 1996).

Measurement of speed
The speed was measured by 30 meter sprint test (Jonson & Nelson, 1996). The subject ran for a specified distance of 30 meter from the standing start. The time taken for completing 30 meter sprint was noted.

Assessment of flexibility
The flexibility of the volunteer was assessed by modified sit and reach test using sit and reach box (Baseline, USA) (Jonson & Nelson, 1996). The subject was asked to seat, stretching the leg ahead and keeping the knees flat against the floor and try to touch the feet. The fingertip of both hands of the subject was placed on the ruler on the box after adjusting the zero mark on the ruler. Placing the hands side by side the subject was asked to lean forward slowly as far as possible maintaining fingertips at the same level and keeping the legs flat, and the measurement was taken in cm.

Measurements of physiological variables
Determination of maximum aerobic capacity (VO_{2max})
The Yo-Yo Intermittent Recovery Test 1 (YYR1) was used for determination of maximum oxygen uptake (VO_{2max}) of the subject (Bangsbo et al., 2008). The subject was asked to run for 20 m distance, for this a track was created for 20 m and 5 m for recovery. The subject ran on the track maintaining a rhythm and with the advancement of duration the speed was increased. The test was continued until subject was exhausted. The specific lap and shuttle was noted for determination of VO_{2max} using standard equation.

Measurement of heart rate and blood pressure

The subject was asked to take rest in a seating position for 15 min. The resting heart rate and blood pressure was measured by using digital sphygmomanometer (Omron, Japan) (McArdle et al., 2015). The pulse pressure and mean pressure were calculated. The heart rate was also recorded during sub-maximal exercise, maximal exercise and recovery following the Yo-Yo intermittent recovery test 1 (YYIR1) (McArdle et al., 2015; Bangsbo et al., 2008).

Determination of lung functions

The lung functions of the subject including force vital capacity (FVC), force expiratory volume in 1st sec (FEV_1) and peak expiratory flow rate (PEFR) were measured by using a digital spirometer (CareFusion, Japan) (Gallucci et al., 2019).

Measurement of blood lactate

The subject was asked to sit quietly for 15 min, and 2 ml of 12 hour fasting blood sample was taken from the fingertip for measurement of resting blood lactate. For the measurement of peak lactate, blood sample was taken 3 min after the completion of running based anaerobic sprint test (RAST). The blood lactate analysis was done using portable blood lactate analyser (Lactate Scout 4, EKF Diagnostics, USA) (Bosquet et al., 2001).

Statistical analysis

The computerised software package SPSS-20 for Windows (IBM, USA) was used for statistical analysis. Descriptive statistics were performed for selected morphological, physical fitness and physiological variables. To find out the within group and between group difference in selected variables Paired sample t-test was performed. In each case the significant level was chosen at .05 levels (Banerjee, 2018).

RESULTS

Impact of short term training on morphological variables of middle distance runners

In the present study, a significant ($p < .05$) reduction in body mass, percent body fat and total fat mass was noted after six weeks of training among the volunteers of middle distance runners group. No significant difference was noted in height, BMI, BSA, LBM and WHR among the volunteers following the training programme. The volunteers of middle distance runners group had possessed lower ($p < .05$) body mass and body fat than the control group volunteers (Table 2).

Table 2. Impact of short term training programme on morphological variables of middle distance runners.

Parameter	Sedentary Control Group (SCG, n = 40)		Middle Distance Runners (MDR, n = 40)	
	0 Wk.	6 Wk.	0 Wk.	6 Wk.
Height (cm)	171.4 ± 7.0	171.6 ± 7.0	171.5 ± 7.0	171.5 ± 7.1
Weight (Kg)	59.7 ± 4.6	60.5 ± 4.2	58.7 ± 4.6	$56.0^{*\#}$ ± 4.7
BMI (kg/m^2)	20.3 ± 1.2	20.6 ± 1.2	20.4 ± 1.2	20.0 ± 1.3
BSA (m^2)	1.70 ± 0.11	1.71 ± 0.13	1.70 ± 0.11	1.69 ± 0.12
Body fat (%)	13.7 ± 1.8	13.8 ± 1.6	13.8 ± 1.8	$12.6^{*\#}$ ± 1.6
Fat mass (kg)	8.2 ± 1.7	8.2 ± 1.7	8.3 ± 1.6	7.3^{*} ± 1.8
LBM (kg)	50.9 ± 3.8	50.9 ± 3.8	51.0 ± 3.7	50.4 ± 3.5
WHR	0.85 ± 0.08	0.86 ± 0.08	0.84 ± 0.07	0.84 ± 0.08

*Data presented as mean ± SD, n = 40, paired sample t-test was performed; when compared to '0 week' and '6 week- *p < .05; when compared to CG and EG- #p < .05; SD = Standard deviation, BMI = Body mass index, BSA = Body surface area, LBM = lean body mass, WHR - Waist Hip ratio.*

Impact of short term training on physical fitness variables of middle distance runners

A significant ($p < .05$) increase in strength (of grip, back, leg strength, upper body, abdominal muscles), highest power output, lowest power output, average power output, anaerobic capacity, fatigue index and flexibility; and a decrease ($p < .05$) in 30 meter sprint time among the volunteers of middle distance runners group after six weeks of training. No significant difference was noted in leg muscle power and explosive power of legs among the volunteers following the training programme. Further, the volunteers of middle distance runners group had higher ($p < .05$) strength (of grip, back, leg strength, upper body, abdominal muscles), highest power output, lowest power output, average power output, anaerobic capacity, fatigue index and flexibility when compared to volunteers of sedentary control group (Table 3). The positive correlations were obtained in (a) standing broad jump vs height (r = 0.51, $p < .05$); (b) speed vs leg strength (r = 0.52, $p < .05$).

Table 3. Impact of short term training programme on physical fitness variables of middle distance runners.

Parameter	Sedentary Control Group (SCG, n = 40)		Middle Distance Runners (MDR, n = 40)	
	0 Wk.	6 Wk.	0 Wk.	6 Wk.
GSTR (kg)	34.4 ± 3.6	34.7 ± 3.5	34.9 ± 3.7	36.9 $^{*\#}$ ± 3.4
GSTL (kg)	32.7 ± 3.2	31.6 ± 3.4	33.5 ± 3.1	35.2 $^{*\#}$ ± 3.2
Back strength (kg)	101.3 ± 7.8	102.1 ± 8.2	100.8 ± 7.8	104.9* ± 7.5
Leg strength (kg)	112.5 ± 11.7	113.4 ± 11.8	112.3 ± 11.1	119.8$^{*\#}$ ± 11.4
Push up test (no/min)	25.7 ± 3.3	25.4 ± 3.4	26.2 ± 3.1	28.9$^{*\#}$ ± 3.2
Sit up (no/min)	24.8 ± 3.0	24.6 ± 3.4	24.4 ± 3.2	26.3*± 3.1
30m sprint test (sec)	4.6 ± 0.4	4.6 ± 0.4	4.6 ± 0.3	4.4$^{*\#}$ ± 0.3
Standing broad jump (m)	2.8 ± 0.5	2.8 ± 0.4	2.8 ± 0.5	2.9 ± 0.5
Vertical jump (m)	0.46 ± 0.08	0.46 ± 0.07	0.47 ± 0.07	0.48 ± 0.06
HPO (watt)	771.6 ± 64.4	774.3 ± 62.4	779.4 ± 68.5	816.4$^{*\#}$ ± 69.3
LPO (watt)	356.4 ± 32.4	368.3 ± 35.3	364.7 ± 42.3	398.2$^{*\#}$ ± 41.5
APO (watt)	565.2 ± 51.3	572.4 ± 59.7	573.1 ± 52.4	607.4$^{*\#}$ ± 53.3
AC (watt)	3391.1 ± 102.2	3434.2 ± 112.6	3438.8 ± 114.6	3644.3$^{*\#}$ ± 108.8
Fatigue Index (watt/second)	8.5 ± 1.8	8.4 ± 1.7	8.5 ± 1.9	9.6$^{*\#}$ ± 1.8
Flexibility (cm)	33.5 ± 4.2	33.7 ± 4.5	32.7 ± 4.1	35.9* ± 4.2

*Data presented as mean ± SD, n = 40, paired sample t-test was performed; when compared to '0 week' and '6 week- *p < .05; when compared to CG and EG- #p < .05; SD = Standard deviation, GSTRH = Grip strength of right hand, GSTLH = Grip strength of left hand, HPO = Highest power output, LPO = Lowest power output, APO = Average power output, AC = Anaerobic capacity.*

Impact of short term training on physiological variables of middle distance runners

In the present study, a significant ($p < .05$) increase in maximum aerobic capacity (VO_{2max}), force expiratory volume in 1st sec (FEV_1), force vital capacity (FVC), peak expiratory flow rate (PEFR); and decrease ($p < .05$) in heart rate (during rest, sub-maximal exercise, and recovery) was noted after six weeks of training among the volunteers of middle distance runners group. No significant difference was noted in systolic blood pressure (SBP), diastolic blood pressure (DBP), pulse pressure (PP), mean pressure (MP), maximum heart rate (HR_{max}), resting blood lactate (BL_{rest}), peak blood lactate (BL_{peak}) among the volunteers of middle distance runners group following the training programme. In addition, the volunteers of middle distance runners group had higher ($p < .05$) VO_{2max} and FVC; and lower ($p < .05$) heart rate (during rest, sub-maximal exercise, and recovery) tan the volunteers of sedentary control group (Table 4).

Table 4. Impact of short term training programme on physiological variables of middle distance runners.

Parameter	Sedentary Control Group (SCG, n = 40)		Middle Distance Runners (MDR, n = 40)	
	0 Wk.	6 Wk.	0 Wk.	6 Wk.
SBP (mmHg)	115.0 ± 6.2	117.0 ± 6.1	116.5 ± 5.2	114.0 ± 6.0
DBP (mmHg)	68.2 ± 6.9	69.5 ± 7.0	68.6 ± 7.0	67.2 ± 6.5
PP (mmHg)	46.8 ± 6.5	47.5 ± 6.8	48.9 ± 5.3	46.8 ± 6.0
MP (mmHg)	83.5 ± 5.5	84.5 ± 5.4	83.9 ± 5.9	82.6 ± 5.2
HR_{rest} (bpm)	65.2 ± 3.3	65.8 ± 4.2	64.7± 3.2	62.9 $^{*\#}$ ± 3.3
$HR_{submax1}$ (bpm)	125.7 ± 4.1	126.6 ± 4.0	126.7 ± 4.1	122.8$^{*\#}$ ± 4.2
$HR_{submax2}$ (bpm)	137.5 ± 4.8	139.2 ± 4.5	138.5 ± 4.7	135.5$^{*\#}$ ± 4.8
HR_{max} (bpm)	195.4 ± 7.7	196.5 ± 7.6	196.3 ± 7.5	194.2 ± 7.8
HR_{rec1} (bpm)	168.5 ± 6.5	166.2 ± 6.6	167.4 ± 6.4	161.5$^{*\#}$ ± 6.1
HR_{rec2} (bpm)	134.3 ± 5.1	132.3 ± 5.2	132.3 ± 5.5	125.4$^{*\#}$ ± 5.4
HR_{rec3} (bpm)	108.5 ± 5.2	106.2 ± 5.4	109.5 ± 5.1	104.3* ± 5.2
VO_{2max} (ml/kg/min)	51.8 ± 5.4	51.3 ± 5.3	52.7 ± 5.9	55.8 $^{*\#}$ ± 5.7
FEV_1 (l)	3.6 ± 0.3	3.6 ± 0.3	3.6 ± 0.3	3.8 * ± 0.3
FVC (l)	3.7 ± 0.3	3.7 ± 0.4	3.7 ± 0.3	3.9 * ± 0.3
FEV_1/FVC	96.8 ± 1.5	96.9 ± 1.5	97.1 ± 1.4	97.8$^{\#}$ ± 1.4
PEFR (l/min)	460.2 ± 33.5	461.8 ± 34.5	457.6 ± 32.1	478.2* ± 30.3
BL_{rest} (mmol/l)	2.5 ± 0.8	2.5 ± 0.7	2.4 ± 0.7	2.1 ± 0.9
BL_{peak} (mmol/l)	18.3 ± 2.7	19.1 ± 2.4	18.7 ± 2.7	19.3 ± 2.5

*Data presented as mean ± SD, n = 40,paired sample t-test was performed; when compare to '0 week' and '6 week- *p < .05; when compare to CG and EG- #p < .05; SD = Standard deviation, SBP = Systolic blood pressure, DBP = Diastolic blood pressure, PP = Pulse pressure, MP = Mean pressure, HR_{rest} = Resting heart rate, $HR_{submax1}$ = Sub maximal heart rate 1st load, $HR_{submax2}$ = Sub maximal heart rate 2nd load, HR_{max} = Maximum heart rate, HR_{rec1} = Recovery heart rate in 1st min, HR_{rec2} = Recovery heart rate in 2nd min, HR_{rec3} = Recovery heart rate in 3rd min, VO_{2max} = Maximum aerobic capacity, FEV_1 = Force expiratory volume in 1st sec, FVC = Force vital capacity, PEFR = Peak expiratory flow rate. BL_{rest} = Resting blood lactate, BL_{peak} = Peak blood lactate.*

DISCUSSION

The morphological variables include body mass, height, body fat, lean body mass and circumferences are used for predictions of body composition of the athletes (Mooses et al., 2013; Knechtle, 2014; Molla, 2017). Theses variables are associated with the performance of middle distance runners (Munoz et al., 2020). In the present study, a significant decline in body mass, percent body fat and total fat mass was noted after six weeks of training among the volunteers of middle distance runners group. These changes in body mass, subcutaneous fat and total fat mass might be due to athletic training programme. The control group volunteers did not receive any training, therefore, higher body mass and percent body fat was noted in this group than the middle distance runners. It has been reported that the sports training, specifically aerobic training leads to greater utilization of fat as fuel which may reduce body fat (Esco et al., 2018; Stefani, 2006). The previous studies indicated that body fat plays a crucial role in endurance running, as excess body fat increases the body mass of the athlete and causes difficulty to perform skilful activities during the athletic event (Esco et al., 2018; Knechtle, 2014; Molla, 2017).

Middle distance running involves high intensity activities which required high levels of physical fitness. The athletes execute running skills throughout the race which require high levels of strength, power, speed and flexibility (Berryman et al., 2018; Nikolaidis et al., 2018; Galbraith, 2021). It can be stated that in international races, athletes took approximately 50 seconds for the first lap of an 800 meter run, which may need similar duration for 400m performance. Therefore, high level of strength, power and speed is desirable for the runners (Berryman et al., 2018; Nikolaidis et al., 2018; Guariglia et al., 2011). The present study showed a significant increase in strength (of grip, back, leg strength, upper body, abdominal muscles), highest power output, lowest power output, average power output, anaerobic capacity, fatigue index and flexibility; and decrease in 30 meter sprint time among the middle distance runners after six weeks of training. It can be stated that the increase in strength (of grip, back, leg strength, upper body, abdominal muscles), highest power output, lowest power output, average power output, anaerobic capacity, fatigue index and flexibility; and decrease in 30 meter sprint time among the middle distance runners might be due to the effects of training. The control group volunteers did not receive any training, therefore, lower strength (of grip, back, leg strength, upper body, abdominal muscles), highest power output, lowest power output, average power output, anaerobic capacity, fatigue index and flexibility was note among these volunteers than the middle distance runners. This study showed a positive correlation between standing broad jump and height. This suggested that tall athletes has longer stride length and thus requires less time to reach the distance (Trowell et al., 2022; Blagrove et al., 2018). In addition, a positive correlation has been found between speed and leg strength. This indicted that higher strength helps to achieve maximum speed and maintain the speed throughout the race (Trowell et al., 2022; Blagrove et al., 2018). Some recent studies have reported that resistance training and weight training may increase the strength of the muscles (Trowell et al., 2022; Lum & Barbosa, 2019) . It is suggested that the enhanced anaerobic capacity by the ATP – creatine phosphate energy system is responsible for improvement of anaerobic power of the athletes (Trowell et al., 2022; Lum & Barbosa, 2019; Driss & Vandewalle, 2013) It has been stated that training increased muscle strength and power in limbs and trunk, which may improve the running efficiency and maintain speed throughout the race (Nikolaidis et al., 2018; Beattie et al., 2017). High level of power helps to maintain the high pace required for racing, it can increase the sprint speed and power in the final phase of the race ((Trowell et al., 2022; Blagrove et al., 2018).

Physiological factors including VO_{2max}, lung functions, heart rate, blood lactate levels etc. may limit the performance of middle distance runners (Rabadan et al., 2011; Thompson, 2017). Success in middle distance running is dependent on contribution from both aerobic and anaerobic components which allows a runner to maintain a rapid velocity during a race, thus contributions of the two energy systems are essential (Thompson, 2017; Wiriawan & Kes, 2020). In the present study, a significant increase in VO_{2max}, FEV_1, FVC, PEFR; and decrease in heart rate (during rest, sub-maximal exercise and recovery) was noted after six weeks of training among the middle distance runners. These changes might be because of training. Earlier studies reported that aerobic training has significant role in improvement in VO_{2max} and pulmonary functions of the athletes (Thompson, 2017; Wiriawan & Kes, 2020). The increase in VO_{2max} might be due to increase in cardiac output, increase oxygen delivery to the exercising muscle and increase in utilization of oxygen for aerobic metabolism (Thompson, 2017; Wiriawan & Kes, 2020). Regular exercise might increase the strength of the respiratory muscles, thus making them more efficient, this might be the reason that the FEV_1, FVC and PEFR increased after training (Galbraith, 2021; McArdle et al., 2015). The quick acceleration and deceleration is related to recovery process (Galbraith, 2021; McArdle et al., 2015). The faster recovery helps the athletes to perform repeated activities (Galbraith, 2021; McArdle et al., 2015). It has been noted that the resting heart rate and the recovery heart rate of the athletes reduced after the training. It has been found that the parasympathetic activation leads to quick recovery after the exercise (Plews et al., 2017). Previous studies have reported that endurance training is responsible for reduction in resting and sub-maximal heart rate, but maximum heart rate slightly decrease or remain constant (Borresen & Lambert, 2008). Similar investigations have reported that exercise training at a variety of intensities increases VO_{2max} (Milanovic et al., 2015; Scribbans et al., 2016). No significant difference was noted in systolic blood pressure (SBP), diastolic blood pressure (DBP), pulse pressure (PP), mean pressure (MP), maximum heart rate (HR_{max}), resting blood lactate (BL_{rest}), peak blood lactate (BL_{peak}) among the volunteers of middle distance runners group following the training programme. This might be because of limited time for the training. The control group volunteers did not receive any training, thus lower VO_{2max} and FVC; and higher heart rate (during rest, sub-maximal exercise and recovery) was note in theses volunteers than the middle distance runners. It can be suggested that a well-developed VO_{2max} and lung functions improve the performance of the athletes.

CONCLUSION

Training was found to have a positive impact on morphological, physical fitness and physiological variables of middle distance runners. The specific training is required for improvement in each fitness components required for the success in middle distance running. The findings of the proposed study may help the athletes, coaches and scientific community to modify training programme in order to improve performance of the athlete. The findings of present study may be used as a frame of reference for the future investigations. Further research in this field would provide conclusive results that can be extrapolated to general population.

AUTHOR CONTRIBUTIONS

Study design, IM.; Data collection, SG, KG, SJB, PS, AJ; Statistical analysis, SG, SJB; Data interpretation, IM; Manuscript preparation, SG, SJB; Literature search, PS, AJ.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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SCIENTIFIC JOURNAL OF SPORT AND PERFORMANCE

ORIGINAL ARTICLE

Inclusion of a connected adaptive resistance exercise machine in a 6-week training regimen with collegiate basketball players: A double-blind randomized controlled trial

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ABSTRACT

In this study, we aimed to determine the effects of incorporating connected adaptive resistance exercise (CARE) into a training regimen with collegiate basketball players on lower body performance metrics. Thirty-two male participants (aged 18-26) with collegiate basketball experience trained thrice weekly for 6 weeks with a periodized training program that included CARE and were randomized 1:1 and blinded to an intervention group (n = 16; where the CARE used accentuated eccentric loading (AEL)) or an active control group (n = 16; where the CARE did not use accentuated eccentric loading (ACTL)). Standard anthropomorphic measures along with one repetition maximum (1-RM) back squat, vertical jump height, and peak power were assessed prior to and following completion of the training regimen. Both groups demonstrated significant increases in 1-RM back squat, jump height, and peak power (both $p < .001$). However, AEL yielded significantly greater improvements compared to ACTL across these measures ($p <.001$, g = 0.91; $p <.001$, g = 0.89; $p <.001$, g = 0.92, respectively). The findings of the present study demonstrate that the inclusion of CARE may be a superior strategy for improving performance variables of lower-body strength, peak power and jump height for male collegiate basketball players.
Keywords: Performance analysis of sport, Eccentric, Power, Jump height.

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INTRODUCTION

Resistance training is widely used by many facets of the population with the goal of enhancing athletic performance, preventing injuries and maintaining a healthy lifestyle. As the fitness industry continues to develop within the mainstream culture, new technologies are integrating with long-established resistance training modalities (e.g., free weights, machines, bodyweight) to augment training, convenience, efficiency, and accessibility to developed fitness regimens. Those who use these novel technology-driven machines have claimed to demonstrate their potential for improved training through continuous maximal load-bearing movements and heightened eccentric resistance.

Eccentric-biased training protocols are long-established (Vogt et al., 1985) and routinely used in protocols involving sports performance enhancement, athletic rehabilitation, injury prevention, and management of tendinopathies (Lorenz and Reiman, 2011). Incorporating eccentric resistance within workout routines has been demonstrated to increase strength, as greater maximum force – almost 50% more – can be developed during maximal eccentric muscle action with each repetition (rep) (Higbie et al., 1985). Subsequently, when compared to concentric or concentric-eccentric training, it possesses unique neural, molecular, and metabolic responses that potentiate a greater adaptation in muscular strength and power (Merrigan et al., 2022).

Eccentric overloading methods began with plyometrics (Wilt, 1978) and over the years burgeoned, sprawling out to the likes of tempo eccentric training (Suchomel et al., 2019), flywheel inertial training (Fiorilli et al., 2020), accentuated eccentric loading (Moore and Schilling, 2005), forced eccentric repetitions (Paddon-Jones and Abernethy, 2001), supramaximal eccentric loading (Mike et al., 2015), and, more recently, stepwise load reduction training (SLRT) (Ozaki et al., 2020). These forms of training can be particularly useful for basketball players. Based on their high frequency of high impact vertical jumping, basketball players have an increased risk of developing chronic patellar tendinopathy (Lian et al., 2005), commonly referred to as "*jumper's knee*" (Blazina et al., 1973). Eccentric training is often used to treat chronic patellar tendinopathy, in addition to other basketball-related injuries such as Achilles tendinopathy, lateral elbow tendinopathy, and rotator cuff tendon disorders (Murtaugh and Ihm, 2013). Beyond its utility for tendinopathy treatment and prevention, eccentric training can also be useful from a performance standpoint. A weekly eccentric overload squat training regimen with basketball and volleyball players was able to elicit significant improvements in countermovement jumping and eccentric and concentric squat test performance without aggravating patellar tendon complaints (Gual et al., 2016). Furthermore, a systematic review conducted by Younes-Egana et al. (2023) found that eccentric overload training via inertial flywheel can confer significant improvements in vertical jump height, change of direction, and running speed.

However, despite these benefits, many forms of eccentric-biased training have been limited to being performed through isolated, non-standard resistance-training exercises that make it challenging to incorporate into routine workout sessions (Harris-Love et al., 2021). For example, SLRT requires constant adjustments in weight, that often are inaccurately measured leading to sub-maximal load-bearing movement. Moreover, the broad implementation into training regimes has not been feasible for most people for a variety of reasons such as lacking a training partner who can assist with lowering weights in a safe manner, the inability of adapting certain exercises to perform in eccentric form, and lack of knowledge of how to implement eccentric overloads, among others.

In this context, a whole new generation of training devices are pushing the eccentric-biased training further. Recently, a novel connected adaptive resistance exercise (CARE) machine (Vitruvian Form; Perth, Australia), was developed that employs the use of a supercharged electro-magnetic motor along with a cable-drawn mechanism that allows for both concentric and eccentric movement. The machine-learning device utilizes neural networks, and other classification algorithms to constantly adjust the resistance based on velocity, force and displacement during the movement and can make minor adjustments to the load, ensuring the user is performing at their maximal load (Nuzzo and Nosaka, 2022). Furthermore, the ability of the AI mediated algorithm to adapt and progress resistance within and between exercise sets accentuates eccentric loading while maintaining concentric loading.

It is speculated that CARE machines are able to overcome the limitations of traditional resistance training modalities by providing different resistances within a given repetition as fatigue occurs (Nuzzo and Nosaka, 2022). Moreover, the addition of the different resistances and the algorithmic load-switching may confer greater strength and power than resistance training alone, which requires further scientific scrutiny. We elected to select elite calibre basketball players to evaluate the efficacy of this novel CARE device, as it was hypothesized that this specific population would be able to maximize intervention-induced benefits.

To the best of our knowledge, no published literature exists on the utilization of CARE devices as an adjunct form of exercise intervention, or the subsequent effects of the different types of resistance on physical/sports performance outcome measures. This study investigated, using a double-blinded, randomized controlled study design, the effects of a novel CARE device during a 6-week training regimen on muscular strength, vertical jump and lower body peak power in collegiate-level male basketball players. We hypothesized that participants who received the accentuated eccentric loading as part of their conditioning program would demonstrate greater improvement in all three performance variables than those engaged in the conditioning program without accentuated eccentric loading.

METHODS

Participants

Thirty-two male volunteers (aged 18-26 years) were recruited by word-of-mouth in the Los Angeles community that met the following inclusion criteria: (i) apparently healthy men, (ii) 18-26 years of age, (iii) collegiate-level basketball player (i.e., Junior college, Division 1-3 college) and (iv) history of exercising >2 workouts/weekly the past 12-months. Exclusion criteria included the presence of musculoskeletal, cardiovascular, pulmonary, metabolic, or other disorders that would preclude moderate-to-high intensity exercise participation and testing and (ii) use of any drug or supplement known to enhance anabolic responses. All volunteers completed a pre-participation physical activity readiness questionnaire (PAR-Q) (Bredin et al., 2013) and an exercise history questionnaire. Sample size of n = 32 was calculated based on a pre-hoc power analysis using the vertical jump reported in a previous study of similar design (Baum et al., 2020) assuming a = 0.05 and b = 0.2. The study was performed in accordance with the ethical standards of the Helsinki Declaration and was approved by the UCLA Institutional Review Board. All participants provided written informed consent.

Study design

This was a prospective, double-blinded, randomized placebo-controlled trial. Using a parallel research design and an online random number generator, 32 participants all trained for 6 weeks with periodized training program that included CARE and were randomized 1:1 and blinded to *(i)* an intervention group (n = 16; where the CARE used accentuated eccentric loading (AEL) or *(ii)* an active control group (n = 16; where the CARE did not use accentuated eccentric loading (ACTL). To guarantee investigator blinding, the provider of the intervention, data collector and data assessor were separate individuals that were masked from knowing those assigned to the intervention and active control groups. All assessments and training were administered off-site (at a sports conditioning facility) by trained research personnel under the direction of the lab director from the UC Fit Digital Health – Exercise Physiology Research Laboratory. Dietary intake and macronutrient portions were not controlled apart from the requirement of not starting a dietary supplement or weight loss/gain diet that might affect fat and fat-free body mass.

CARE Machine

The CARE machine consists of motorized winches on a platform that applies forces to two independent cables with attached handles that exit the top. A mobile application and integrated machine software control the winches. During the exercise, participants exert force against the cables as the winches retract them. The machine's proprietary algorithm adjusts the resistance between 0 to 100 kg per cable in real time at 50 Hz. Herein, the term 'adaptive resistance' will be defined as the magnitude of this resistance adjustment, which is dependent on the participant's force generating capacity, movement velocity, exercise mode, and initial resistance selected (Nuzzo and Nosaka, 2022). Each participant had their own account set up beforehand and only a user's own account was used during each training session. This allowed for the individualized adjustments to be incorporated for all of the participants.

Figure 1. The connective adaptive resistance exercise machine consisting of motorized winches on a platform that are controlled by integrated machine software.

Procedures

To ensure accuracy, reliability and consistency in test administration, all pre-and post-testing occurred in the same location and time of the day (*i.e.*, early evening to optimize diurnal effect on strength) by the same investigator. Based on energy system requirements and the skill demand of the tests, the following sequence was followed (Bredin et al., 2013):

1. *Anthropometrics:* Height was determined using a precision stadiometer (Seca, Hanover, MD). Body mass and percentage body fat (BF%) was measured using a validated (Dolezal et al., 2013) octipolar, multi-frequency, multi-segmental bioelectrical impedance device (270; InBody Co., Seoul, South Korea). Since hydration state has a marked influence on bioelectrical impedance analysis (BIA) results, participants were instructed to remain hydrated and avoid caffeine and heavy exercise during the 12-hour period before testing. Data were collected after at least three hours of fasting and voiding.
2. *Muscle strength:* Lower-body isotonic muscle strength was measured by determining 1-repetition maximum (1-RM) of a free-weight back squat using standardized procedure (Grgic et al., 2020). The 1-RM is defined as the highest weight lifted through one full range of motion after reaching volitional or momentary failure. Briefly, subjects performed a light warm-up including whole body exercise on a treadmill or cycle ergometer, followed by light stretching. Participants were allowed several practice

trials of each exercise with minimum resistance to ensure good form, full range of motion, and good breathing technique. The resistance was progressively increased by trained researchers following standard procedure, leading to an attempt to complete 1–2 repetitions at a load estimated to be near maximum. Subsequently, the participant rested for 2 minutes and then attempted to achieve the 1-RM. For each 1-RM trial, participants attempted 2 repetitions. If participants were able to complete 2 repetitions, they were given a 2-minute rest and the load was increased. If participants failed the 1-RM attempt at the given weight, 2-minute rest was provided, and the load was decreased to the midpoint between the last successful lift and the failed lift.

3. *Jump height and lower-body peak power:* Leg power was estimated using a previously validated (Leard et al., 2007) electronic jump mat (Just Jump; Probotics, Inc., Huntsville, AL, USA). To minimize the effects of fatigue from the strength and endurance test, a 30-minute rest period was implemented prior to this testing. Participants stood on the mat with feet at hip width and then performed a countermovement jump (CMJ) for maximal height. Jump height was recorded with a handheld computer interfaced with the jump mat. Three trials were given with 30-second rest between trials. The best trial was used to calculate peak and average leg power using published equations that required jump height and the subject's body mass (Harman et al., 1991). Jump height (Wright et al., 2012) was determined from "*hang time*" defined as time (s) from the feet leaving the mat to their return and the following equation: Ht = t^2 x 1.227, where t is hanging time in seconds and 1.227 is a constant derived from the acceleration of gravity.

Supervised, periodized, lower-body strength-power resistance training regimen

The six-week training provided to all randomized participants integrated portions of an evidenced-based lower-body strength-power resistance training program that is effective for increasing muscular strength, jump height and lower-body power output (Schoenfeld et al., 2021). Table 1 describes the typical workout sequence and exercises performed in circuit totalling approximately 20 min, three times weekly on non-consecutive days for 6 weeks (18 sessions). Participants were given a brief, standardized description and demonstration of each exercise prior to study commencement. The participants were instructed before each session to perform all exercises at maximal intensity with correct form throughout. Trainers supervised each workout session individually and recorded workout data as well as training compliance.

Both study research arms performed identical training programs with the exception of the CARE accentuated or non-accentuated eccentric loading in order to directly assess the potential improvements in performance associated with the inclusion of two CARE exercises, the Bulgarian split squat and Bilateral deadlift. For every repetition performed, the AEL group performed 'accentuated eccentric' loads at 1:1.5 (or 150%) of the concentric load while the ACTL group performed normal eccentric loads at 1:1 (or 100%). The CARE machine was connected via Bluetooth to an iPad. The app (Vitruvian Form) tracked the Bulgarian split squat and Bilateral deadlift as well as 'set' the starting loads depending on concentric and eccentric loads from the prior warm-up session performed a day earlier. An unblinded investigator at the study start set the appropriate mode for the AEL and ACTL groups and assigned the first session load according to 1-RM back squat at baseline testing. Thereafter, the machine AI set new starting loads for subsequent workouts to adjust to training adaptations. Although the exercises are shown synchronously on the iPad app as the participant performs the movement, it was not utilized for this study.

Table 1. 6-week lower-body strength-power resistance training circuit including CARE.

Warm-Up • Forward and Back Leg Swing • Side to Side Leg Swing • Jog-in-Place w/High Knees	**Tempo/Timing** • 20 Repetitions each, 1 circuit • Performed at a comfortable tempo
Circuit 1. Squat Jumps w/15-25 lb vest 2. **Bulgarian Split Squat @ wt = 60-150% 1-RM concentric-eccentric (CARE Machine)** 3. Plyometric Box Jumps w/15-25 lb vest 4. **Bilateral Deadlift @ wt = 60-150% 1-RM concentric-eccentric (CARE Machine)** 5. Split Lunges w/15-25 lb vest 6. Deadmill Sprints	**Tempo/Timing** • Work-to-rest ratio; wk. 1-2 was 30 s work, 20 s rest and wk. 3-5 was 40 s work, 20 s rest and wk. 6 was 60 s work, 20 s rest • 2 circuits with 3-minute rest period between circuit • Performed at maximum effort • Under control, slowly complete the CARE during the eccentric component
Cool Down • Brisk walk for ~2 min	**Timing** • 2 minutes

Note. lb = pound; s = second; CARE = Connected Adaptive Resistance Exercise; 1-RM = 1-Repetition Maximum.

Statistical analysis

Descriptive statistics are presented as mean ± standard deviation (SD). Statistical significance was determined based on $\alpha = .05$ and all tests were two-tailed. Continuous variables were first assessed for normality via Shapiro-Wilk tests. Within-group comparisons at baseline and after 6 weeks were made by paired *t*-tests and Wilcoxon signed-rank tests for normally and non-normally distributed variables respectively. Changes between groups after 6-weeks of training were made by Welch's *t*-tests if data were normally distributed and Wilcoxon rank-sum tests if data deviated significantly from normality. A Holm-Bonferroni correction to control the familywise error rate was applied. Effect sizes were measured by Hedges' *g*. Analysis was performed in Excel (Microsoft Corporation, Redmond, Washington) and R (version 3.5.1; R Foundation for Statistical Computing, Vienna, Austria).

RESULTS

All thirty-two participants successfully completed the 6-week training program with no missed sessions. Demographic and performance measures were collected at both baseline and post-training for all participants (Table 2). No significant change in body mass or body fat percentage was detected within either group or between groups. In contrast, both groups demonstrated significant increases in 1-RM after 6 weeks (both $p < .001$), with AEL showing a significantly greater increase compared to the ACTL group ($p < .001$, $g = 0.91$). Both groups showed significant increases in jump height (both $p < .001$) and peak power (both $p < .001$). For all performance variables, AEL demonstrated significantly greater increases compared to ACTL ($p < .001$, g = 0.89; $p < .001$, $g = 0.92$; for jump height and peak power, respectively).

DISCUSSION

This study serves as the first of its kind in assessing the efficacy of CARE technology on lower body strength and power measures in elite-level basketball athletes. Although conventional eccentric overload training (EOT) protocols have been proven to increase lower body hypertrophy, power as well as eccentric and concentric force (Harris-Love et al., 2021), to our knowledge, there are no performance studies available examining the implementation of EOT via CARE technology. Therefore, this study provides a preliminary

Table 2. Demographic and performance variables at baseline and after 6 weeks for all participants.

	Control Group (n = 16)				Intervention Group (n = 16)					
	Baseline	**Post**	**Change**	***p*-within†**	**Baseline**	**Post**	**Change**	***p*-within†**	***p*-between†**	**Hedges *g***
Age (y)	20.5 ± 2.0	-	-	-	19.8 ± 2.1	-	-	-	-	-
Height (cm)	187.9 ± 2.7	-	-	-	188.2 ± 4.2	-	-	-	-	-
Body mass (kg)	84.1 ± 6.3	84.3 ± 5.7	0.2 ± 0.4	1.000	83.4 ± 4.3	83.3 ± 6.7	0.1 ± 0.7	1.000	1.000	0.13
Body fat (%)	8.4 ± 3.1	8.3 ± 2.2	-0.1 ± 0.6	1.000	8.7 ± 3.2	8.5 ± 4.8	-0.1 ± 0.2	1.000	1.000	0.10
1-RM (kg)	84.1 ± 11.5	103.1 ± 8.3	21.3 ± 2.4	<.001	85.4 ± 7.1	115.8 ± 10.9	30.4 ± 8.5	<.001	<.001	0.91
Jump height (cm)	59.8 ± 5.4	71.4 ± 6.2	11.6 ± 3.2	<.001	60.2 ± 4.5	78.6 ± 6.5	18.4 ± 3.2	<.001	<.001	0.89
Peak power (W)	4866 ± 334	5716 ± 275	850 ± 237	<.001	4655 ± 255	6635 ± 217	1980 ± 120	<.001	<.001	0.92

Note. Values are mean ± SD. No significant differences were observed at baseline between groups. 1-RM = one repetition maximum; †after correcting for multiple comparisons.

understanding of the viability of utilizing CARE training to enhance lower body strength and power. As expected, there were significant increases across all of the performance measures from the 6-week training regimen in both ACTL and AEL groups, including 1-RM back squat, CMJ height, and peak power. However, the intervention group produced significantly greater increases than the control group across all performance variables.

The increases in 1-RM back squat may be attributed to the greater eccentric overload occurring during the training. With the use of CARE technology, the electro-mechanic motor in conjunction with a proprietary AI-based software alters the eccentric and concentric force based on the rep number, concentric speed, and eccentric speed. This allows for each rep to be utilized for its maximum force and hypertrophy benefit, with varying weights used throughout the rep for the concentric and eccentric phases (Nuzzo and Nosaka, 2022). Optimal training requires variation in the weight throughout the set to maximize both phases of the movement, with the eccentric force being substantially greater than the concentric force. In the present study, this form of training incorporated through CARE set the initial load at the maximum for the eccentric and reduced the load throughout the concentric, allowing for maximum effort throughout each repetition. Conversely, traditional weights cannot alter the load throughout the set, which limits their overall hypertrophic benefits. Since eccentric force significantly contributes to muscle growth, in this study, CARE training may have provided a hypertrophic advantage through an actively changing eccentric overload without the typical concentric limitation. In turn, this may have resulted in benefits often associated with eccentric overload training, such as increased muscle excitability and activation due to greater muscle fibre utilization, that translated into the 1-RM back squat increases (Douglas et al., 2017).

Furthermore, CARE training yielded promising improvements in total jump height and peak power metrics. Recent research has shown that lower extremity strength serves as a strong contributor to jump height, with increases in lower body hypertrophy translating into improvements in jump height and power (Stephenson et al., 2015). Consequently, a potential mechanism for the increases in jump height and power metrics within the AEL group may be the increased muscle hypertrophy, which acts secondary to optimized eccentric exercise. The stretch-shortening cycle (SSC), which refers to the eccentric phase prior to an explosive concentric action (Turner and Jeffreys, 2010), has been shown to increase jump height and lower body power in response to eccentric overload training. In comparison to an eight-week SSC exercise training regimen conducted by Malisoux et al. (1985), the present study produced a significantly higher increase in peak power (42.5% versus 9%, respectively). Although other training studies differed in terms of training protocol (*i.e.*, Duration, frequency, volume, etc.), when compared to these results, previous results yielded lower jump height and peak power improvements than those associated with the present study (Tomioka et al., 2001). This finding suggests that CARE training has the potential to induce performance improvements greater than SSC training alone through the use of eccentric overload for greater hypertrophic benefits and power production.

CARE draws upon the benefits of both supramaximal EOT as well as stepwise load reduction training (SLRT). While supramaximal EOT has shown slight improvements in lower body 1-RM performance, there are several limitations of this method. A study by Buskard et al. (2018) found no significant differences between supramaximal EOT and traditional resistance training, even noting increased injury risk, soreness, muscle damage, and temporarily reduced force-production capacity associated with supramaximal EOT. The CARE system addresses this by including a concentric element at a submaximal load followed by a greater load through the eccentric phase, drawing upon the effects of supramaximal EOT. Furthermore, invoking the benefits of CARE technology is possible due to the utilization of a key principle of SLRT. SLRT requires an individual to begin an exercise set near or at their maximal load, complete as many repetitions as possible in a given time frame, then progress to additional sets at lighter loads in a stepwise manner (Nuzzo and Nosaka, 2022). Utilizing a CARE device provides two distinct advantages, the first of which augments this principle of SLRT by reducing resistance within a set to compensate for the force generation loss caused by volitional fatigue. In doing so, this can allow the user to exercise with their maximal effort at every moment during the set. The second benefit connects to the first, as the ability for the CARE device to adapt the resistance to a user's force-generating capacity allows a user to perform an optimal multi-movement exercise in a single repetition. For instance, a user has the ability to perform a deadlift, transition to a bicep curl, then complete the movement with a front squat while at or near maximal resistance throughout each component of the repetition. Such a unique capability enables a user to perform a diverse range of movements and exercises at an optimal resistance throughout.

In comparison to previously established eccentric-focused training protocols, the CARE protocol in the present study produced higher increases in selected outcome measures. Compared to a six-week eccentric overload program examining the effects of a unilateral and bilateral training approach using an inertial flywheel, increases in power in the present study were higher than those corresponding to the unilateral and bilateral training regimens (43% compared to 19% and 39%, respectively) (Nunez et al., 2018). Additionally, an eight-week isokinetic resistance and eccentric overload training protocol utilizing a customized Smith machine yielded a lower increase in post-training 1-RM squat performance in comparison to the present study (12.6% versus 35.6%) (Horwath et al., 2019). Varying the tempo of the eccentric training in a six-week protocol, whether it be through completing fast or slow repetitions, also produced less of an improvement in 1-RM squat performance in comparison (14.5 ± 7.0% and 5.4 ± 5.1% versus 35.6%, respectively) (Stasinaki et al., 2019). Beyond this, unloaded and loaded plyometric training has been shown to produce far less of an improvement in CMJ height (3.5 ± 4.0 cm and 1.9 ± 4.1 cm, respectively versus 18.4 ± 3.2 cm associated with CARE) (Kobal et al., 2017).

There are several limitations pertaining to this study. In the present study, the training protocol only integrated two CARE exercises into a proven battery of other exercises that can increase jump height in addition to strength and power in the lower body (Table 1). Although the results may be partially attributed to the inclusion of CARE training, they may be confounded with the other exercises as a whole in the overall training program. Future research should be conducted to determine if CARE exercise can induce the same benefits on its own or if it is best suited to complement established training regimens. Furthermore, in contrast to our results, a systematic review on AEL by Ojasto and Häkkinen (2009) noted decreases in 1-RM performance and concentric force production during supramaximal AEL. This decline in performance was partially attributed to fatigue, which led to the proposition that supramaximal loads may be suboptimal in practice (Wagle et al., 2017). Additionally, the trade-off between the increased time under tension and reduced involvement of the SSC associated with supramaximal EOT has been posited to limit the development of explosive lower body power (Harden et al., 2018). The potential for reduced engagement of the SSC and exercise-induced constraints of fatigue may have affected the performance of the participants in the present study. Although the participants yielded considerable improvements, the true extent of these may not have been shown due to these limitations. These potential drawbacks warrant further investigation as CARE technology evolves. Another limitation is the makeup of the cohorts, which consisted of young elite-level male basketball players. Given that these individuals were highly motivated, and both completed the workout in a timely manner and strongly adhered to it, the results of this study may not be generalizable to common populations (i.e.. Females, sedentary individuals, etc.). These study results suggest that continued research with CARE technology in the field of athletics and sports conditioning may be beneficial, especially for those with an emphasis on lower body performance metrics. Lastly, conducting further research with more participants would help substantiate these findings and add statistical power.

CONCLUSION

The findings of the present study demonstrate that CARE training can induce the same benefits associated with other conventional eccentric overload training regimens but to an even larger degree among elite male basketball players. With notable improvements across jump height, lower-body peak power, and muscle strength, the efficacy of CARE training warrants consideration for being implemented in EOT protocols and training regimes.

AUTHOR CONTRIBUTIONS

The study was conceived and designed by T.Y., B.P., M.V., C.M., M.S.M., and B.A.D. B.A.D., T.Y., B.P., E.M., C.G., M.J., I.U., and A.K. performed data collection. T.Y., B.P., and B.A.D. completed data analysis. T.Y., B.P., and B.A.D. interpreted data and composed the manuscript while M.S.M. and B.A.D. made crucial edits. All authors have read and agreed to the published version of the manuscript.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

ETHICS COMMITTEE APPROVAL

This study was performed in accordance with the ethical standards of the Helsinki Declaration and was approved by the UCLA Institutional Review Board (#11-003190). All participants provided written informed consent.

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SCIENTIFIC JOURNAL OF SPORT AND PERFORMANCE

ORIGINAL ARTICLE

Sex differences regarding the effects of arm swing on ground reaction force and trunk movements between track and field athletes: Focusing on the difference in the direction of arm swing

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ABSTRACT

The purpose of this study was to clarify the sex difference in the effects of arm swing movements of track and field athletes on ground reaction force and trunk movement. Seven male and nine female athletes belonging to a university track and field team were asked to perform arm swings for 10 seconds each under three different conditions (longitudinal, lateral, and original) while in the standing position. Three-dimensional coordinate data for each experimental trial was collected using an automatic optical motion analyser, and ground reaction forces were measured using a force plate. Under the longitudinal condition, the mean acceleration force was greater for males than for females ($p < .05$), and the operating range of trunk twist angle was significantly greater for females than for males ($p < .05$). However, under the original condition, there were no significant differences between the sexes in mean acceleration force, but there were significant differences in maximum twist angle and minimum and maximum shoulder abduction angles ($p < .05$). These results indicate that there are sex differences in trunk movement and ground reaction force depending on the direction of arm swing.

Keywords: Performance analysis of sport, Sprint running, Coaching, Twist angle.

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INTRODUCTION

It is important to increase the maximum sprinting speed for superior performance in sprint running (Volkov and Lapin, 1979). Therefore, the most crucial priority to improve sprinting performance is to improve the ability to accelerate sprinting until maximum speed is reached (Doolittle & Tellez, 1984).

Biomechanical studies have revealed characteristics of athletes with high sprinting performance from various perspectives, providing useful knowledge for training. For example, with regard to lower limb movements, the following measures were taken: increasing the extension of the supporting leg hip joint and the swing speed of the thigh backward (Mann & Herman 1985), shortening the horizontal distance between both knee joints during ground contact (Bushnell & Hunter 2007), and decrease the knee joint angle at take-off (Mann & Hermann 1985). In reference to trunk movement, it has been shown that small thoracic obliquity and twisting the trunk are associated with higher running speed (Nagahara et al., 2017). Data on ground reaction force using force plates have also shown that it is important to exert a large horizontal backward force at each step throughout the acceleration phase and that athletes with the highest running speeds can exert greater acceleration forces against the ground (Brughelli et al., 2011 ; Nagahara et al., 2021 ; Rabita et al., 2015).

Thus, while much research has been conducted on findings related to the lower limbs and trunk, relatively little research has been conducted on the upper limbs, and there are still many unknowns. Previous studies on the upper extremities have primarily examined the role of arm swing, specifically, in improving balance by counteracting the angular momentum produced when swinging the leg about the vertical axis, reducing the side-to-side motion of the centre of mass (Hinrichs, 1987), preventing trunk rotation, reducing energy metabolism (Arellano and Kram, 2014), and increasing stride and ground reaction forces (Sayers, 2000).

These studies compared arm swing with no arm swing, and there is significant evidence that suggests that arm swing is better than no arm swing during sprinting. However, in the actual evaluation and instruction of arm swing during sprinting, the magnitude of arm swing (shoulder joint angle), elbow joint flex-ion/extension angle, angular velocity, and direction of arm swing (longitudinal, lateral, or diagonal) are addressed (Hiruma and Kariyama, 2019 ; Mann and Herman, 1985), rather than comparing "*swing*" or "*no swing*", and these may influence sprint performance. For example, Mann and Herman (1985) analysed the biomechanics of sprinting movements and reported that superior sprinters had a greater range of motion in shoulder and elbow joint angles and a greater shoulder joint angular velocity. In addition, Hiruma and Kariyama (2019) examined the direction of arm swing of general elementary school-age to top adult sprinters using observational evaluation methods. The percentage of "*longitudinal swing*" was high among males throughout all generations; alternatively, the percentage of "*lateral swing*" was high among females from junior high school age onward the authors also reported that the percentage of "*lateral swing*" was high among top sprinters in Japan who have relatively high sprinting speeds. Generally, the arm swing motion in sprinting should be a vertical swing without it crossing in front of the chest (Tellez et al., 2020). However, the results for females in a previous study (Hiruma and Kariyama, 2019) were different from generalizations (Tellez et al., 2020) such as "*arms should swing longitudinally*".

Previous studies have indicated that factors affecting sprinting performance differ between male and female sprinters (Gleadhill and Nagahara, 2021). In addition, running movements (Takabayashi et al., 2017), lower limb movements in one-legged squat and landing movements (Jacobs et al., 2007 ; McBride and Nimphius, 2020 ; Russel et al., 2006 ; Zeller et al., 2003), and upper limb movements in throwing (Liue et al., 2010) all differ between males and females. These studies imply that males and females have different mechanisms in body response when performing similar exercises, and they suggest that different approaches may be needed for males and females to prevent injury and improve athletic performance.

Based on the given information, it is possible that differences in kinematics and kinetics data between males and females may be observed in arm swing movements when performed under the same conditions (e.g., longitudinal or lateral). If these findings can be clarified, it will provide useful information for coaching arm swing movements that take sex differences into account.

Therefore, the purpose of this study was to clarify the sex difference in the effects of arm swing movements of athletes on ground reaction force and trunk movement. To this end, we address the following hypothesis: when the conditions for arm swing are same conditions between male and female athletes, there are sex differences in ground reaction force and trunk movement. In light of previous research (Hiruma and Kariyama, 2019), it is expected that males may be positively affected when arms are swung longitudinally and females may be positively affected when arms are swung laterally.

MATERIAL AND METHODS

Participants

The participants were seven male amateurs track and field sprinters and jumpers (body height, 173.6 ± 6.6 cm; body mass, 66.1 ± 6.9 kg) and nine female amateurs track and field sprinters and jumpers (body height, 164.4 ± 3.1 cm; body mass, 54.7 ± 4.4 kg). After obtaining approval from the ethics committee of the affiliated institution, all participants were fully informed of the purpose, methods, and safety of the experiment, and their consent was obtained to participate in the experiment.

Experimental procedures

Since arm swing movements in the standing position are also incorporated as part of sprint training (Tellez et al., 2020), in this study, arm swing movements were performed in a standing position, without sprinting, in order to examine the effects of arm swing movements alone and to facilitate control of the arm swing direction. The arm swing in the standing position was performed for 10 seconds under the three conditions of “*longitudinal*", "*lateral*", and "*original*". One examiner provided an oral explanation of the trial to the participant along with a demonstration. Under the "*longitudinal*" condition, the participants were in-structed to "*swing straight, longitudinally*", and as a guide, the left and right forearms were supposed to be roughly parallel to the sagittal plane on swinging (Figure 1-A). Under the "*lateral*" condition, the participants were instructed to "*swing laterally*" and as a guide, when they swung their arms forward, the left and right hands had to reach reflex markers attached to the upper border of the sternum (as described below) (Figure 1-B). Under the "*original*" condition, no specific instruction was given regarding the direction of the arm swing, and only the verbal instruction was given to perform the arm swing motion peculiar to the participant. An examiner, positioned in front of the participants, checked the movements during the pre-trial practice and during the measured trials. In all conditions, the speed and magnitude of the arm swing was set to 120 BPM (Beats Per Minute) using a metronome (metronome: Tempo Lite) in order to keep the speed and magnitude of the arm swing as close as possible among the participants. All participants were verbally instructed to swing their arms to the metronome tempo. To eliminate in-fluence of the order of trials, the order of trials in each condition was randomly assigned to each participant.

Data analysis

Referring to previous studies (Kariyama et al., 2017), kinematic and kinetic data were calculated using the data by a motion capture system and force platforms. Reflective markers were affixed to the participants on eighteen points of the body : the end of the third metacarpal (left), ulnar eminence (left), radial eminence (left), lateral humeral epicondyle (left), medial humeral epicondyle (left), anterior scapulohumeral joint (left and right), posterior scapulohumeral joint (left and right), acromion (left and right), superior sternal border, greater trochanter (left and right), superior anterior iliac spine (left and right), and superior posterior iliac spine (left and right).

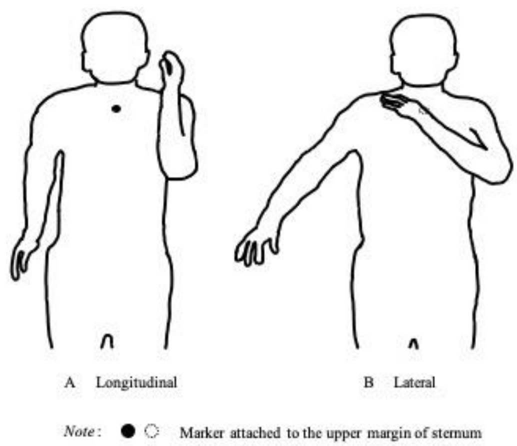

Figure 1. Examples of longitudinal and lateral swings.

Three-dimensional coordinate data for each experimental trial were collected using an automatic optical motion analyser (Vicon Motion Systems, 250 Hz) that included ten infrared cameras. The static coordinate system was defined as a right-hand coordinate system with the Y-axis in front of the participant at the start of the trial, the X-axis orthogonal to the Y-axis, and the Z-axis pointing vertically upward. The obtained coordinate values for each body part were smoothed using the Butterworth Low-Pass Digital Filter after determining the optimal cutoff frequency (7.5-15.0 Hz) for each coordinate com-ponent based on the method of Wells and Winter (1980). Ground reaction forces were measured using a force platform (Kistler, 9287C) placed under the left leg, converted at a sampling frequency of 1,000 Hz, and then captured into a personal computer.

Analysis range

One cycle consisted of swinging the left arm forward from the most posterior position of the elbow joint centre (the midpoint of the markers attached to the lateral humeral epicondyle and medial humeral epicondyle) during arm swing in the XZ plane to the most posterior position of the elbow joint centre again. The analysis range for the calculated items was 2 cycles, 5 seconds after the start of the test.

Study variables

Based on the data obtained from the motion capture and force platform described above, the following data were calculated. Referring to previous studies (Arellano and Kram, 2014 ; Kariyama et al., 2018), the following procedures were used to calculate the pelvic segment angle (hereafter, pelvic angle), both shoulder segment angles (here after, shoulder angle), trunk twist angle (hereafter, twist angle), and shoulder joint abduction angle.

Vectors from the right hip joint centre to the left hip joint centre and from the right shoulder joint centre to the left shoulder joint centre were projected onto the XY plane of the stationary coordinate system. The angle of each vector with the X axis was defined as the pelvic angle and shoulder angle, and the difference between them was defined as the twist angle. The hip joint centre was determined with reference to a previous study, and the shoulder joint centre was the midpoint of the markers attached to the anterior and posterior scapulohumeral joints. The range of motion (ROM) was then calculated after determining the maximum and minimum angles within the analysis range. The shoulder joint abduction angle was defined as the angle between the vector from the midpoint of both shoulders (midpoint of the vector from the centre of the right shoulder joint to the centre of the left shoulder joint) to the midpoint of the hip joint (midpoint of the vector from the centre of the right hip joint to the centre of the left hip joint) in the YZ plane of the stationary coordinate system and the vector from the shoulder joint to the elbow joint. The maximum and minimum angles within the analysis range were then determined. The left arm was used as the target for the shoulder joint abduction angle.

In addition, referring to previous studies (Brughelli et al., 2011 ; Nagahara et al., 2021; Rabita et al., 2015), of the ground reaction forces obtained with the force plate the average of the positive values of the horizontal component, which is closely related to sprinting ability ("*acceleration average force*"), was calculated. The data from the force plate placed under the left leg were used, and the average of two consecutive cycles at 5 seconds after the start of the trial was used as the acceleration average force for each participant.

In addition, shoulder width and pelvic width (Tanner, 1951), which are physical characteristics of males and females, were determined as follows. Shoulder width was the horizontal distance between markers attached to the left and right acromion in a stationary upright posture, and pelvic width was the horizontal distance between markers attached to the left and right superior anterior iliac spine.

Statistical analysis

Descriptive statistics are presented as mean values ± standard deviation. Statistical processing software (SPSS ver. 25, IBM, Armonk, NY, USA) was used for all statistical processing. The Shapiro-Wilks test was used to confirm normality for each variable; when normality was confirmed, an uncorrelated t-test was used to assess differences in the variables between the two groups. If a deviation from normality was determined, Mann-Whitney's test was used to test the difference in variables between the two groups. In addition, Pearson's product-rate correlation analysis was used to calculate correlation coefficients between items when normality was confirmed, and Spearman's rank correlation coefficient was used when deviation from normality was determined. The significance level was set at 5%.

RESULTS

Physical characteristics of the participants (Table 1) showed sex differences in all items except pelvic width, which was significantly greater in males than in females ($p < .05$), and the shoulder abduction angle (Figure 2) showed a sex difference only under the original condition, with females having a significantly larger angle than males ($p < .05$).

Table 1. Characteristics of the participants.

	Male	Female
Height (cm)	173.6 ± 6.6	164.4 ± 3.1*
Weight (kg)	66.1 ± 6.9	57.4 ± 4.4*
Breadth of shoulder (cm)	39.7 ± 0.1	34.5 ± 0.1*
Breadth of pelvis (cm)	26.8 ± 0.1	26.7 ± 0.1

*Note: * Significant difference between the male and female, p < .05.*

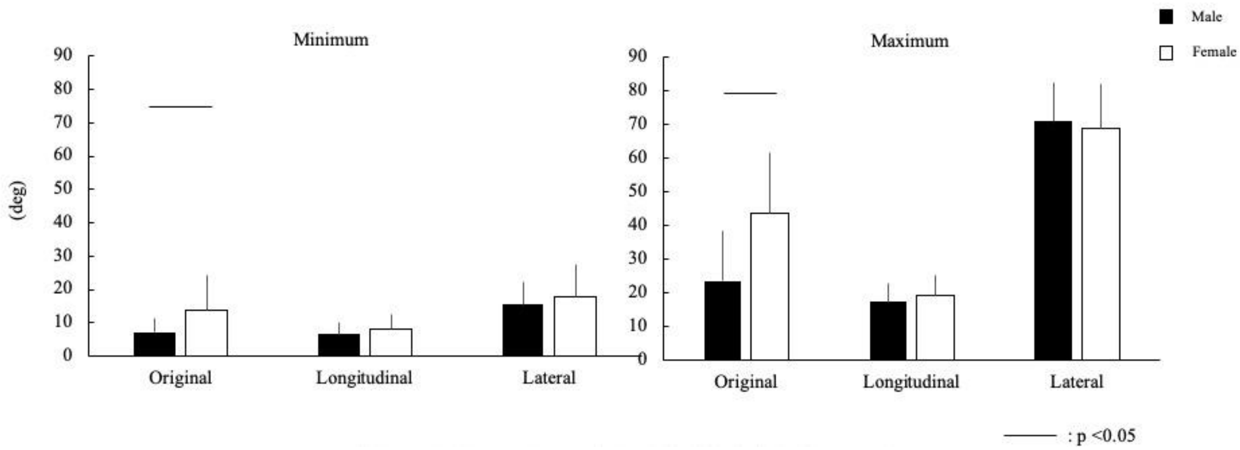

Figure 2. Comparison of shoulder joint abduction angles.

Table 2 shows the mean acceleration forces for each condition by sex. There was a sex difference under the longitudinal condition, with males being significantly larger than females (*p* < .05).

Table 2. Average propulsive force under each condition.

		Original	Longitudinal	Lateral
Average force (N/kg)	Male	0.33 ± 0.19	0.46[a] ± 0.20*	0.44 ± 0.21
	Female	0.23 ± 0.15	0.32 ± 0.10	0.39 ± 0.09

*Note: All data were normal and tested via two-tailed paired t-test except for those indicated by the superscript a, which were not normally distributed and were tested using the Wilcoxon test. *Significant difference between Male and Female, p < .05.*

Table 3. Comparison of minimum, maximum and ROM of pelvis angle, shoulder angles and twist angle.

			Original	Longitudinal	Lateral
Pelvis	Maximum angle (deg)	Male	8.08 ± 3.32	11.56 ± 5.09	10.61 ± 5.13
		Female	11.69 [a] ± 7.85	9.60 ± 3.97	10.46 ± 2.97
	Minimum angle (deg)	Male	-8.03 ± 6.76	-4.92 ± 2.70	-7.10 ± 5.94
		Female	-6.80 ± 5.93	-6.45 ± 4.17	-7.22 ± 2.84
	ROM (deg)	Male	16.96 ± 6.09	17.71 ± 6.46	17.71 ± 7.85
		Female	19.29 [a] ± 11.80	17.68 ± 6.87	17.68 ± 4.18
Shoulder	Maximum angle (deg)	Male	8.63 ± 2.73	12.21 ± 3.64	8.59 ± 3.03
		Female	7.46 ± 2.52	12.92 ± 4.32	9.63 ± 3.36
	Minimum angle (deg)	Male	-3.05 ± 3.16	-3.89 ± 3.39	-6.15 ± 3.18
		Female	-5.47 ± 2.58	-5.13 ± 4.00	-5.45[a] ± 4.25
	ROM (deg)	Male	12.21 ± 4.63	13.40 ± 5.31	14.74 ± 4.91
		Female	12.92 ± 3.22	15.18 ± 1.84	15.17 ± 3.50
Twist	Maximum angle (deg)	Male	6.35* ± 3.16	9.05 ± 3.22	11.92[a] ± 5.57
		Female	10.77[a] ± 5.95	11.00 ± 4.75	9.62 ± 6.13
	Minimum angle (deg)	Male	-12.87 ± 9.20	-8.34 ± 3.95	-15.08 ± 8.42
		Female	-12.12 ± 4.72	-13.43 ± 9.16	-11.00 ± 5.73
	ROM (deg)	Male	19.22 ± 10.57	17.39* ± 5.02	27.01 ± 11.18
		Female	22.90 ± 8.56	24.43 ± 8.77	20.61 ± 8.30

*Note: All data were normal and tested via two-tailed paired t-test except for those indicated by the superscript a, which were not normally distributed and were tested using the Wilcoxon test. *Significant difference between Male and Female, p < .05.*

Table 3 shows the minimum and maximum values of twist angle, and ROM for each condition by sex. Sex differences were observed in the maximum twist angle under the original condition and twist ROM under the longitudinal condition, both of which were significantly greater in females than in males ($p < .05$).

The relationship between the minimum and maximum values of pelvic angle, shoulder angle and twist angle, ROM, and acceleration mean force under each condition were examined (Table 4), and a significant negative correlation (r = -0.606, $p < .05$) was found between twist ROM and acceleration mean force in females under the original condition. Under the longitudinal condition, a significant negative correlation (male: r = -0.668, female: r = -0.604, $p < .05$) was found between twist ROM and acceleration mean force for both males and females, and a significant positive correlation (r = 0.691, $p < .05$) was found between minimum twist angle and acceleration mean force for males. Under the lateral condition, significant correlations were found only in females, and significant positive correlations were found between bilateral shoulder ROM, maximum twist angle, and twist ROM and acceleration average force.

Table 4. Correlation coefficient between kinematics data and average propulsive force.

		Original		**Longitudinal**		**Lateral**	
		Male	Female	Male	Female	Male	Female
Pelvis	Maximum angle	-0.463	-0.353	-0.073	-0.080	-0.139	0.201
	Minimum angle	0.085	0.453	0.231	0.452	0.031	-0.153
	RoM	-0.391	-0.438	-0.154	-0.321	-0.114	0.246
Shoulder	Maximum angle	-0.187	0.177	-0.290	-0.327	-0.337	0.059
	Minimum angle	-0.033	-0.430	-0.091	-0.289	0.136	-0.600
	RoM	-0.116	0.489	-0.140	-0.052	-0.296	0.760**
Twist	Maximum angle	-0.493	-0.399	-0.055	-0.027	0.328	0.676*
	Minimum angle	0.290	0.587	0.691*	0.527	0.229	-0.303
	RoM	-0.400	-0.606*	-0.668*	-0.604*	-0.009	0.708*

*Note. **: p < .01, *: p < .05.*

DISCUSSION

We found no significant difference in shoulder joint abduction angle between the sexes under the longitudinal condition; however, acceleration mean force was greater in males than in females (Table 2), while twist ROM was significantly greater in females than in males (Table 3). These results support our hypothesis that a male arm swinging longitudinally has a more positive effect on ground reaction force and trunk movements than a female arm swinging longitudinally. In the lateral condition, however, there were no significant differences between the sexes in mean acceleration force, pelvis angle, shoulder angle, twist angle, or shoulder abduction angle. This result was in contrast with our hypothesis that swinging the arms laterally would positively affect ground reaction force and trunk movements, which are known to affect females than males in sprinting.

Several studies have found sex differences in trunk movements during exercise, and a study examining walking movements (Bruening, et al., 2015) found that the pattern of pelvic and torso angle changes during one cycle differed between males and females and that torso ROM was greater in females than that in males. The results of this study (Bruening, et al., 2015) suggests that males and females use different control strategies during walking. In our study, sex differences were observed in twist ROM under the longitudinal condition (Table 3). It has also been reported that the ROM of the torso during running was significantly greater for females than for males (Bruening, et al., 2020). In sprinting, it has been noted that a trunk twist greater than necessary negatively affects sprinting performance (Nagahara et al., 2017) ; thus, this is considered an action to avoid. In the present study, the correlation coefficient between twist ROM and average acceleration force in the longitudinal condition showed a significant negative correlation for both males and females (Table 4), and the acceleration force ap-plied to the ground was greater for those with less twisting of the trunk. According to Kreighbaum and Barthels (1985) stated that the role of the trunk is to be a source of energy due to the presence of large muscles and also support energy transfer due to its large mass and moment of inertia. If priority is given to the function energy transfer of the trunk, it is conceivable that the less the distortion of the trunk segment, the more efficient is the energy transfer. In other words, it is thought that energy transfer efficiency can be improved by reducing the phase shift between the pelvis and shoulders in trunk movements and by preventing twist from occurring.

As shown in Table 1, there were differences between males and females in terms of height, weight, and shoulder width; however, pelvic width was similar. However, considering the significant differences in height and weight between males and females, it is assumed that the relative pelvic width was greater among females. In other words, shoulder width was larger in males and pelvic width was larger in females; these are the body shapes typical of these sexes even in the general population (Tanner, 1951). There were no significant differences in either the maximum or minimum shoulder joint abduction angles between the sexes under the longitudinal condition. Further-more, although muscle mass was not measured in this study, it has been shown that when physical characteristics are taken into account, there are sex differences in the muscle cross-sectional area of the upper limbs and trunk, with males having a larger muscle cross-sectional area than females (Abe et al., 2003). Therefore, when both males and females perform arm swings under the same conditions (longitudinal), the moment of inertia around the long axis of the body is smaller for females than for males because females have smaller shoulder width relative to pelvic width and less muscle mass in the upper limbs and trunk than males. Therefore, the upper body is expected to rotate more easily. Consequently, females are more likely to have a greater phase shift between the pelvis and shoulders than males, and the twist may result in less efficient energy transfer. This could be the explanation for sex difference in mean acceleration force.

In contrast, under the lateral condition, there were no significant differences between the sexes in mean acceleration force, pelvis angle, shoulder angle, and twist angle, as well as shoulder abduction angle. A significant negative correlation was found between mean acceleration force and twist ROM under the longitudinal and original conditions, but no such trend was observed under the lateral condition (Table 4). Considering the positive effects of suppressing trunk twisting on acceleration and sprinting performance under the original and longitudinal conditions, as well as during sprinting, it is assumed that the arm swinging motion under the lateral condition was very different from the actual arm swinging motion in sprinting. In fact, the maximum shoulder joint abduction angle under the lateral condition was greater than that under the other conditions for both males and females. Therefore, it is reasonable to assume that both males and females may have been unfamiliar with the movement. As a result, no sex differences in acceleration and trunk movement were observed. Therefore, it may be necessary to reconsider the condition setting of the lateral swing in future investigations.

Under the original condition, there was no difference in mean acceleration force between males and females, but there were significant differences in maximum twist angle and minimum and maximum shoulder abduction angles. The relationship between pelvis angle, shoulder angle, and twist angle and acceleration average force (Table 4) also showed different trends between males and females, with a significant negative correlation between twist ROM and mean acceleration force for females; however, no significant correlation was noted for males. The significant difference between the sexes in shoulder joint abduction angle indicates that arm swing movements differ between the sexes. This result is consistent with that of a previous study on running movements (Hiruma and Kariyama, 2019) in which females tended to swing arms more lateral. This may be related to the difference in correlation coefficients between males and females in relation to the pelvis angle, shoulder angle, twist angle and mean acceleration force. In other words, it is possible that females who were able to control their trunk twisting to some extents were able to increase their mean acceleration force, even though more of them swung their arms lateral than males. It has been mentioned previously that swinging the arms lateral is an undesirable action in sprinting (Tellez et al., 2020) ; however, it is possible that females, due to their body shape and muscle mass, prioritized preventing trunk twisting by swinging their arms lateral more than male, although it is unclear whether this was consciously or unconsciously. Therefore, it is necessary to evaluate the arm swinging motion in sprinting in relation to the trunk twisting motion, rather than simply negatively considering the arm swinging to the lateral.

Finally, there are certain factors that must be acknowledged when interpreting the results of the current study. Since this study investigated the effects of only arm swing movements in a stationary state, the results cannot be generalized to those obtained during actual running movements. Therefore, it is necessary to collect data in an experimental setting that more closely resembles sprinting in the future. Finally, there are certain factors that must be acknowledged when interpreting the results of the current study. Since this study investigated the effects of only arm swing movements in a stationary state, the results cannot be generalized to those obtained during actual running movements. Therefore, it is necessary to collect data in an experimental setting that more closely resembles sprinting in the future. And, as far as the measurement is concerned, it was performed during the winter season (from December to February) when the athletes are not taking part in athletics competitions and are in process of recovering physical and mental stress or injury. As matter of fact, the latter made it difficult to recruit a larger number of participants. Furthermore, it should be noted that this study result is limited to college students sprint and jump athletes who are amateurs in the sense that they have practiced this modality as students but have been receiving specialized coaching in track and field in order to compete in official events. Therefore, the results obtained in this study may not apply to top athletes, athletes of other disciplines, or other age groups. These points were limitations of this study.

However, the fact that sex differences were observed in mean acceleration force and trunk motion when arm swinging was performed the same experimental and measurement conditions is interesting and is an important finding to consider during training and motion instruction so that sex differences are also taken into account.

CONCLUSIONS

Under the longitudinal arm swing condition, females showed greater twist ROM and lower mean acceleration force compared to males. One of the factors that may have contributed to this is the difference in body shape between males and females. Therefore, when females aim for longitudinal swinging, these factors should be taken into consideration in their decision-making. In addition, the comparison under the original conditions suggests that if females can control the twist ROM, even if they swing their arms more laterally than males, they may be able to obtain the same mean acceleration force as males. Therefore, it may not be necessary to consider the female lateral swing as a negative factor.

AUTHOR CONTRIBUTIONS

Conceptualization, K.H. and Y.K.; investigation, K.H. and Y.K.; methodology, K.H. and Y.K.; formal analysis K.H.; writing—original draft preparation K.H.; writing—review and editing K.H. and Y.K.; visualization; K.H.

project administration K.H. and Y.K.; funding acquisition, K.H. All authors have read and agreed to the published version of the manuscript.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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SCIENTIFIC JOURNAL OF SPORT AND PERFORMANCE

ORIGINAL ARTICLE

Assessing aerobic endurance in elite female cricket players: A comparative study of Bangladeshi and Indian athletes

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ABSTRACT

To assess and compare the aerobic endurance levels of elite female cricket players from Bangladesh and India. This study's participants were 50 elite female cricket players (ages 18-30 years), with 25 players from each country. They were all considered elite players based on their performance and experience in national and international cricket tournaments. To measure aerobic endurance fitness, the participants underwent a Yo-Yo Intermittent Recovery Test Level 1 (YYIRT1), which is widely used to measure an individual's maximal oxygen uptake (VO_{2max}) and aerobic capacity. The data collected were analysed using descriptive statistics and inferential statistics. The test of Normality, mean, and standard deviation were calculated for each group, and a t-test was used to compare the mean scores of the two groups. A p-value of less than .05 is considered statistically significant. The data were analysed using the statistical software SPSS version 26. The study found that the Indian female cricket players had a significantly higher aerobic endurance fitness level than the Bangladeshi players. The mean VO_{2max} of the Indian players was 46.76 ml/kg/min, while the Bangladeshi players' mean VO_{2max} was 43.60 ml/kg/min. Additionally, the Indian players had a higher mean score in total distance covered in YYIRT1 (1233.6 m) than the Bangladeshi players (857.6). These differences were found to be statistically significant ($p < .05$). These findings suggest that there may be a difference in the training and preparation methods between the two countries, leading to a higher aerobic endurance fitness level among Indian players.

Keywords: Performance analysis of sport, Aerobic endurance fitness, Female cricket players, Elite athletes, Fitness field test, YYIRTL-1.

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INTRODUCTION

Physical fitness refers to a group of physical qualities that allow the body to respond to and adjust to the demands and stress of physical exercise (Wuest & Bucher, 1995). A player's level of fitness determines how much speed, endurance, strength, and physical strain he can withstand (Barth et al., 2007). A player's ability to engage in a game without being overly exhausted, as well as their capability to leap far and high, run swiftly in all directions, change directions quickly, and completely stretch their joints, are examples of physical fitness in sports (Haskell et al., 2007). Physical fitness qualities are the most important factors contributing to successful performance (Marques et al., 2009). Cricket is an intermittent game, with intervals of high-intensity movements like bowling and batting interspersed with extended stretches of low-intensity activity (Jeffreys & Moody, 2021; Noakes & Durandt, 2000; Sholto-Douglas et al., 2020; Stretch et al., 2000). Physical fitness is crucial in all forms of cricket, but the demands on players can vary depending on the format of the game. Like test cricketers need to have a high level of aerobic fitness, as they may need to bat or bowl for extended periods of time. Likewise, the ODI format emphasizes explosive power and speed, as players need to score runs quickly and take wickets at regular intervals. Players need to have good anaerobic fitness, as they may need to sprint and perform explosive movements, such as diving and throwing, throughout the match (C. Petersen et al., 2009; C. J. Petersen et al., 2010, 2011; Sholto-Douglas et al., 2020). In contrast to T20 format cricket, T20 cricket is the shortest format of the game, lasting just 20 overs per side. This format requires players to have exceptional explosive power and agility, as they need to score runs quickly and field effectively. Players need to have good anaerobic fitness, as they may need to sprint, dive, and change direction frequently throughout the match (C. J. Petersen et al., 2010). The performance of physically fit cricket players has been found to be better, more reliable, and less injury-prone (Smita Wagh et al., 2022). Aerobic endurance fitness is critical for cricket players as it helps them maintain their energy levels throughout a game that can last for several hours (Raja, 2019). Cricket involves a combination of short bursts of high-intensity activity, such as sprinting between the wickets, and longer periods of low-intensity activity, such as standing in the field (Weldon et al., 2021). Having good aerobic endurance fitness allows players to recover quickly between these bouts of activity and perform at a high level for the entire game (Ahamad et al., 2015; Orchard et al., 2005; Panwar & Chandel, 2019). It also helps to reduce the risk of injury and improves overall physical health (Paoli et al., 2013). In addition to improving performance on the field, aerobic endurance fitness can also have long-term health benefits for cricket players (Vickery et al., 2018). Cricket is a popular sport in South Asia, and both Bangladesh and India have a significant presence in international cricket. In recent years, female cricket players from both countries have shown promising performances, and there has been growing interest in their fitness levels. This study aimed to compare the aerobic endurance fitness levels of elite female cricket players from Bangladesh and India.

METHODOLOGY

Subject

For this study, fifty (50) female cricket players were chosen at random, 25 of them were Senior Women's Cricket Players of Punjab Cricket Association of India and the remaining 25 were Divisional Cricket Players of Bangladesh. They have 4-15 years of training age at the time of collection of data.

Variables

The dependent variable in this study was aerobic endurance fitness, and the independent variable was nationality. Aerobic endurance fitness were measured using the Yo-Yo Intermittent Recovery Test level 1 (Yo-Yo IR1). This test has been validated for cricket players and is widely used in sports science research.

Procedure

The participants were informed about the purpose of the study and the testing procedures. They signed a consent form before participating in the study. The Yo-Yo IR1 test conducted on a standard cricket field. The test involved running back and forth between two cones placed 20 meters apart along with 5 meter recovery area, following an audio signal. The running speed gradually increased, and the participants had to reach the cones before the audio signal to continue the test. The test continued until the participant couldn’t keep up with the audio signal or complete two consecutive levels.

Statistical analysis

The data collected were analysed using descriptive statistics and inferential statistics. The test of Normality, mean and standard deviation calculated for each group, and a t-test used to compare the mean scores of the two groups. A p-value of less than .05 considered statistically significant. The data were analysed using statistical software SPSS version 26.

Ethical considerations

The study conducted in accordance with ethical principles and guidelines for research involving human subjects. The participants were informed about the purpose and procedures of the study, and their consent were obtained before participation. Confidentiality of the participants' information had maintained throughout the study.

Limitations

The study limited by the sample size and the representativeness of the participants. The study might not be generalizable to all female cricket players from Bangladesh and India. The results might also be affected by factors such as training and nutrition, which were not controlled in this study.

RESULTS

Table 1. Normality test of collected data.

Tests of Normality						
	Kolmogorov-Smirnova			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
India	.186	25	.025	.931	25	.093
Bangladesh	.161	25	.094	.961	25	.428

Note. a. Lilliefors Significance Correction.

The above Table 1 present the results from two well-known tests of normality namely the Kolmogorov-Smirnov test and Shapiro-Wilk test. The Kolmogorov-Smirnov and Shapiro-Wilk test is more appropriate for small sample size (<50) but can also handle sample size large as 2000. For this reason, we have been used the Kolmogorov-Smirnov and Shapiro-Wilk test for our numerical means of assessing normality. It is seen from the above Table 1 that the collected data were normally distributed. As Kolmogorov-Smirnov and Shapiro-Wilk test is ($p \geq .05$), data is normal. If it is ($p \leq .05$), then significantly deviate from normal distribution. So, Kolmogorov-Smirnov and Shapiro-Wilk suggest that the data is normally distributed and statistically confirmed for the comparative inferential parameter treatment.

According to Table 2, the average distance run by female cricketers from Bangladesh and India was 857.6 m and 1233.6 m, respectively. The resulting 't' ratio of 4.631 exceeds the table value of 2.009 for df 48 necessary for significance at .05 levels. The female cricketers from India and Bangladesh were found to have significantly different in total distance run.

Table 2. Calculated "*t*" values of female cricketers from Bangladesh and India in total distance run.

		Mean (m)	N	Std. Deviation	Std. Error Mean	df	t
Total distance covered	India	1233.6	25	330.99	66.20	48	4.631
	Bangladesh	857.6	25	234.96	46.99		

*Note. *Significant at .05 level.*

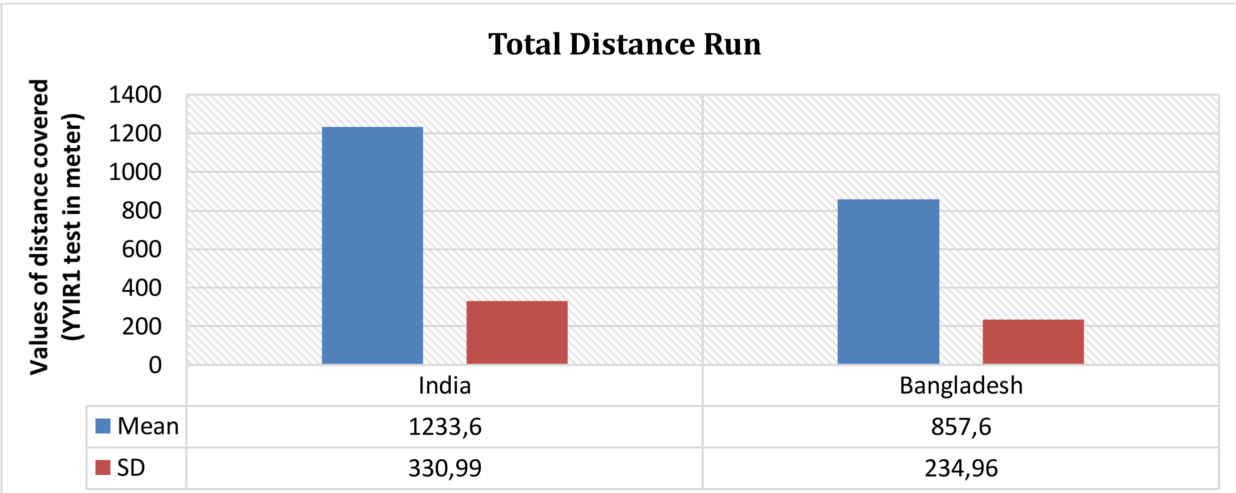

Figure 1. Values of total distance run of female cricketers from Bangladesh and India.

Table 2. Average VO_{2max} and calculated "*t*" values of female cricketers from Bangladesh and India.

		Mean	N	Std. Deviation	Std. Error Mean	df	t
VO_{2max}	India	46.76	25	1.96	.62	48	4.688
	Bangladesh	43.60	25	1.79	.57		

*Note. *Significant at .05 level.*

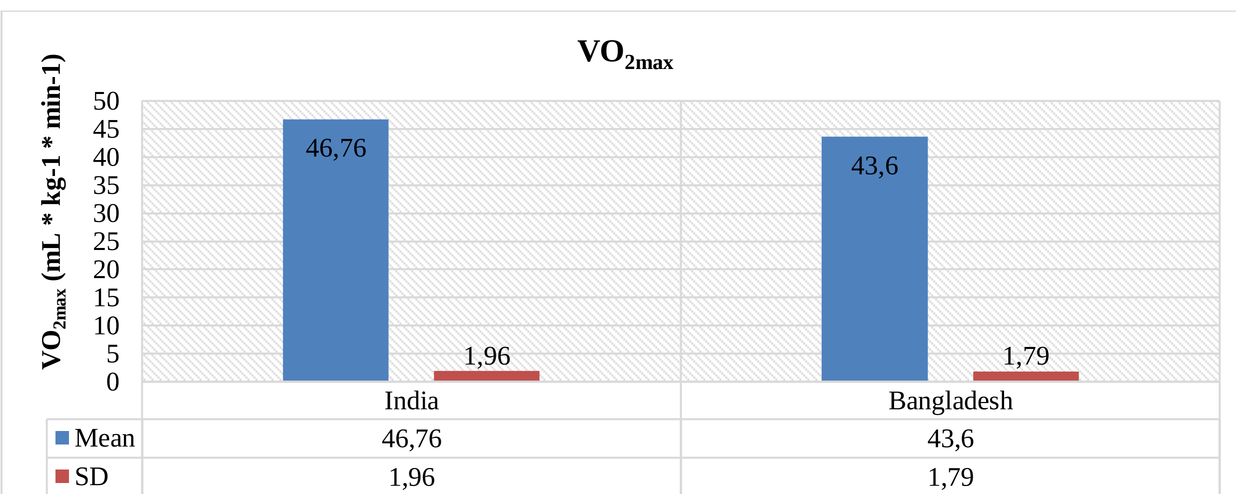

Figure 2. VO_{2max} values of female cricketers from Bangladesh and India

According to Table 3, the average VO_{2max} values for female cricketers from Bangladesh and India were 43.60 mL * kg-1 * min-1 and 46.76 mL * kg-1 * min-1, respectively. The calculated 't' ratio of 4.688 is higher than the 2.009 in the tabulated value for df 48 needed for significance at .05 levels. It was determined that the female cricketers from Bangladesh and India had significantly different in VO_{2max} values.

DISCUSSION

The results of the study showed that the Indian Women's Cricket Players had a significantly better YYIRT1 performance than the Bangladeshi Women Cricket Players. On average, the Indian Women's Cricket Players were able to run 300 meters further than the Bangladeshi Women Cricket Players before stopping due to fatigue. There could be several reasons for this difference in performance. The Indian Women's Cricket Players have more experience and training, which could contribute to better aerobic capacity and recovery. Additionally, the Indian Women's Cricket Players may have access to better resources such as coaches and training facilities.

The Yo-Yo Intermittent Recovery Test level 1 (Yo-Yo IR1) is a commonly used field-based test to measure an individual's ability to perform repeated high-intensity exercise with brief recovery periods. It is often used to assess an athlete's aerobic endurance and has been found to be a good predictor of VO_{2max} in athletes (Castagna et al., 2005; Deprez et al., 2014; Krustrup et al., 2003; Souhail et al., 2010). Research has shown a positive correlation between the distance covered in the Yo-Yo IR1 and VO_{2max}. This means that athletes who perform well on the Yo-Yo IR1 test tend to have higher VO_{2max} scores, indicating better aerobic fitness and endurance capacity (Karakoç et al., 2012; Thomas et al., 2006). Therefore, the Yo-Yo IR1 test is a valuable tool for coaches and trainers to use in assessing an athlete's aerobic fitness and endurance capacity, as well as tracking improvements in these areas over time. VO_{2max}, also known as maximal oxygen uptake, is a measure of the maximum amount of oxygen that an individual can consume during intense exercise. It is an important indicator of cardiovascular fitness and endurance performance in athletes, including cricketers (Krustrup et al., 2003). Table 3 showed that the female cricketers from India and Bangladesh were found to have significantly different in VO_{2max}. The Indian female cricketers performed better than Bangladeshi female cricketers in VO_{2max}. This difference in VO_{2max} levels between the two groups of female cricketers might have implications for their performance and training programs. The results of this study concur with the research of Sandhu & Singh (2018), who made it abundantly evident that in terms of the Yo-Yo Intermittent Recovery Test Level 1 (YYIRTL1), Punjab (India) women cricketers perform more frequently high-intensity aerobic activities than Dhaka (Bangladesh) women cricketers (Sandhu & Singh, 2018). In female cricketers, VO_{2max} has been found to be particularly important for performance in the fielding aspect of the game. This is because fielding requires a lot of running and sprinting, and athletes with higher VO_{2max} scores are better able to sustain high-intensity exercise for longer periods of time without experiencing fatigue. Improving VO_{2max} can be achieved through a variety of training methods, including aerobic exercise (such as running or cycling), interval training, and high-intensity interval training. However, it's important for cricket players to work with qualified coaches and trainers to develop a training program that is specifically tailored to their individual needs and goals.

CONCLUSION

The findings of this study conclude that there is a significant difference in endurance fitness levels between Indian Women Cricket Players and Bangladeshi Women's Cricket Players where Indian female cricket players perform better than Bangladeshi female cricketers. This is indicating that there may be a need for further training and resources for the Bangladeshi Women Cricket Players to improve their performance. This study provides valuable insights for coaches and trainers to design more effective training programs for female cricket players at different levels.

AUTHOR CONTRIBUTIONS

Farjana Akter Boby often conducted the literature search, experiments, gathered data, wrote the initial draft, handling revisions, and ensuring the manuscript's submission and publication process. She was often the lead researcher who supervised the project, secured funding, and provided overall guidance. Manisha Badhan made unique contributions to the study, such as proofreading the article and helping with the data collection, data analysis and experiment design.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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SCIENTIFIC JOURNAL OF SPORT AND PERFORMANCE

ORIGINAL ARTICLE

Sporting bodies, societal norms in history: Examining body image and identity

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ABSTRACT

The historical exploration of the body in sports hinges upon the value attributed to the body throughout time and converges various social science approaches, encompassing philosophical, religious, educational perspectives, and intersecting histories that involve political, sociological, economic, and medical dimensions. Sports, as a multifaceted cultural phenomenon, hold profound sociocultural significance, reflecting prevailing attitudes towards the human body. The study of body image in sports history becomes a nexus where anthropology, sociology, psychology, and sports science converge, offering valuable insights into the evolution of body ideals and their implications on athlete identity. This examination delves deep into the annals of sports history, unearthing the evolving notions of body image and its impact on athlete identity, shedding light on the implications of historical body image ideals for contemporary sports culture and proposing recommendations for fostering a positive body image and identity in sports. The objectives of this narrative review include unearthing the historical evolution of body image ideals, examining the influence of societal norms on perceptions of athletic bodies throughout history, unravelling the role of media, technology, and popular culture in shaping body image ideals in sports, and identifying the intimate connection between body image and athlete identity, exploring its profound ramifications on athletic performance and overall well-being. By synthesizing findings from existing systematic reviews and scholarly works, this exploration aims to illuminate the intricate interplay between sporting bodies and societal norms throughout history and their enduring legacy on sports culture in the present day.
Keywords: Sport history, Sporting bodies, Societal norms, Body image, Athlete identity, Historical evolution.

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INTRODUCTION

Within the realm of sports, the human body emerges as a ubiquitous factor. Its capabilities are revered, celebrated, and often desired. Moreover, the human body becomes a focal point of substantial debate and regulation. This includes contentious deliberations concerning the classification of disabled bodies for competitive purposes, as well as the rigidly upheld binary sex categorization, which is subject to seemingly insurmountable challenges and exclusions. While sociologists and philosophers of sports have actively pursued scholarly endeavours related to the body across diverse contexts, historians have displayed comparatively diminished enthusiasm. Nonetheless, a substantial body of work pertaining to the body in physical education, and often extending into the realm of sports, has been carefully examined by educationalists and sport historians (refer to History of Education, Volume 36, Issue 2, 2007).

The historical exploration of the body in sports inevitably relies on the underlying principles of the body's philosophy and sociology throughout time. Crucially, it hinges upon the value attributed to the body, or specific bodies, during various periods. A convergence of social science approaches converges in the analysis of the body, encompassing philosophical, religious, and educational perspectives, alongside intersecting histories of the body that encompass political, sociological, economic, and medical dimensions, among others.

The significance of the body becomes evident, as keenly acknowledged by Douglas Booth, who remarks that "*the body is the primary means by which individuals announce who they are to the world*" (Booth, 2001). In the immediate and contemporary context, the body, whether in person or through mediated means, serves as a central vehicle for self-identification, self-representation (Elben & Stieglitz, 2018), alignment with ideologies, a means of attracting like-minded individuals, and a medium for conveying countless other messages.

In the realm of human endeavours, sports have evolved into a multifaceted cultural phenomenon, encompassing diverse disciplines, talented athletes, and enthusiastic spectators. Beyond the physical prowess displayed on the field, sports hold profound sociocultural significance, shaping and reflecting prevailing attitudes towards the human body. As a conduit for societal norms and values, sports history serves as a unique lens through which we can explore the intricate relationship between body image and identity.

Body image, a multifarious construct, encompasses an individual's perception, thoughts, and feelings regarding their own body. Historically, the embodiment of an athlete has been central to their identity, reflecting a wide array of aesthetic and functional ideals. From ancient times to the present day, the perception of sporting bodies has undergone dynamic shifts, often mirroring the broader sociocultural landscape.

The significance of body image in the context of sports history is evident in the mounting body of research exploring its role in physical activity and sports engagement. A systematic review conducted by Foley Davelaar (2021) highlighted the critical link between body image and participation in physical activity, emphasizing the reciprocal influence of body image on athletic involvement. Similarly, Zaccagni and Gualdi-Russo (2023) conducted a comprehensive meta-analysis, underlining the impact of sports involvement on body image perception and ideals.

Sports history, as an interdisciplinary field, delves into the complex interplay between the human body and societal norms across different historical periods. The study of body image in sports history is a nexus where anthropology, sociology, psychology, and sports science converge, offering valuable insights into the evolution of body ideals and their implications on athlete identity.

Historical explorations into the body in sports are embedded within a broader historical context. Vigarello (2013) emphasized the dynamic nature of societal representations of the body, demonstrating how these representations have continuously evolved over time. Understanding the body in sports history necessitates a nuanced analysis that considers the cultural, political, and philosophical forces that have shaped body ideals and perceptions.

From classical antiquity to the Renaissance and the modern age, diverse civilizations have endowed athletic bodies with particular virtues, often intertwined with prevailing ideals of beauty, strength, and discipline. Osborne and Litchfield (2022) emphasized the historical underpinnings of the cultural significance of sports bodies, shedding light on how sports became a powerful arena for the negotiation and expression of societal norms.

The construction of body image in sports history has also been shaped by gender norms, race, and power dynamics. The works of Imhof (1984) and Stolberg (2001) provide valuable insights into the ways in which sports have been entwined with notions of masculinity, femininity, and racial hierarchies, affecting how athletes perceived themselves and were perceived by others.

In the modern era, the mass media, advertising, and technological advancements have significantly impacted body image ideals in sports. The works of Cash (2004) and Thompson et al. (2022) underscore the profound influence of media representations, raising questions about the potential consequences of these portrayals on athletes' self-perception and societal expectations.

As society progresses, so too must our understanding of the multifaceted relationship between body image and identity in sports history. While previous research has laid essential groundwork, there remain gaps and opportunities for further exploration. Understanding how body image ideals have shaped sports participation, performance, and overall well-being provides a basis for fostering healthier athletic environments and promoting positive athlete identity.

Thus, this narrative review aims to delve deep into the annals of sports history, unearthing the evolving notions of body image and its profound impact on athlete identity. By synthesizing findings from existing systematic reviews and scholarly works, this exploration aims to provide a comprehensive understanding of how societal norms have influenced body image in sports history. Additionally, it endeavours to shed light on the implications of historical body image ideals for contemporary sports culture and to propose recommendations for fostering a positive body image and identity in sports.

In the following sections, this narrative review will detail the research objectives, the methodological approach, the presented results, and, finally, the conclusions derived from this endeavour. The aim of this examination is to try to illuminate the intricate interplay between sporting bodies and societal norms throughout history and their enduring legacy on sports culture in the present day.

Objectives

The historical evolution of body image ideals will be unearthed in this narrative review. Primary sources, historical accounts, and expert analyses will be explored to discern the ancient celebrations and sculpting of the athletic form, intertwined into the tapestry of sporting history. Shifting body image perceptions across time, from the gladiatorial arenas of Rome to the courtly competitions of medieval Europe and beyond, will be unravelled. The objective is to reveal the ethereal beauty and stringent demands imposed by historical body image ideals upon athletes and society.

The influence of societal norms on the perception of athletic bodies throughout history will be examined through the analysis of cultural, religious, and political forces, with the aim to understand how certain body types were accentuated as ideals of physical prowess and beauty. The collective gaze upon the athletic physique will be illuminated by juxtaposing societal norms against the backdrop of sports history.

The transformative role of media, technology, and popular culture in shaping body image ideals in sports. The intricate interplay between imagery and identity will be unravelled through exploration of archival records, contemporary media sources, and technological advancements. The impact of visual representations in print, film, and digital media on societal perceptions of sporting bodies across time will be untangled.

The fourth objective aims to identify the intimate connection between body image and athlete identity, including its profound ramifications on athletic performance and overall well-being. Thorough examination of academic studies and empirical evidence will strive to uncover how an athlete's perception of their own body influences their self-concept, mental fortitude, and dedication to their craft. The impact of body image on an athlete's resilience, determination, and capacity to thrive within the realm of sports will be explored.

METHODOLOGY

To accomplish this narrative review, appropriate keywords were identified to find individual studies that were pertinent to the current aim of the review. The search used the terms "*body image history*" OR "*sports culture evolution*" OR "*athlete identity*" AND "*body image*". In the last 20 years (January 2004–June 2023), a search of the literature has been conducted drawing from the databases MEDLINE (PubMed) (n = 7), ERIC (n = 177) as primary sources, and Google Scholar (n = 785) as a secondary source. Abstracts and main texts have been reviewed immediately after all duplicates were removed. The overall 73 articles focusing on body image history, sports culture evolution, athlete identity, and body image have been synthesised and integrated into the main text, which was organised in sections following a narrative style (Demiris, Parker, Oliver & Washington, 2019).

The inclusion criteria for selected studies will be based on relevance to body image through history. Data has been extracted from the selected studies and organised thematically to address the specific objectives of the review.

The synthesis of findings will be conducted using a narrative approach, providing a comprehensive overview of the current state of body image through history. The review will also consider the cultural and regional diversity across epochs.

The limitations of this review include potential language bias, as prevalent English-language publications will be considered, and the possibility of publication bias, where positive results are more likely to be published (McShane, Böckenholt & Hansen, 2016).

The synthesis carefully considers the contexts, cultural nuances, and societal forces that have shaped the embodiment of sporting ideals throughout history, steering away from undue speculation and adhering to the grounded insights derived from the literature.

RESULTS

Historical overview of body image ideals in ancient and early modern periods

Numerous scholarly works in the domain of sport and bodies have focused on specific historical contexts and regions. Notably, these include investigations into Ancient Greek athletic bodies, bodies in sport during nineteenth-century England, and works pertaining to the first half of the twentieth century, particularly concentrating on Nazi Germany and the idealized Aryan physique (Heck, 2011; Daley, 2003; Bale, 2002; Bandy, Hoffman & Krüger, 2008).

The historical overview of body image ideals in ancient sports and early modern periods unveils a fascinating tapestry of beliefs and practices that shaped the embodiment of athletes and societal perceptions of physical prowess. In the ancient Greek world, health and physical excellence were esteemed virtues, evident in the writings of Hippocrates, the father of medicine. His works emphasized the harmonious relationship between body and mind, advocating for a balanced lifestyle and moderation in athletic pursuits (Kleisiaris et al., 2014).

Sports in ancient Greece were infused with cultural and religious significance, transcending mere physical contests. The ancient Olympic Games, held from as early as 776 BCE, became a platform for displaying human potential and embodied ideals. Athletes endeavoured to sculpt their bodies to conform to an aesthetic standard, emphasizing symmetry and proportion (Mosz, 2009). The portrayal of athletes in ancient art exemplifies the admiration of the human form, with sculptors capturing the grace and strength of athletic bodies.

The philosophical musings of Plato and Aristotle further contributed to the discourse on sports and the human body. Plato, in his "*Republic*," advocated for physical education as a means of producing a well-rounded citizenry, while Aristotle acknowledged the importance of physical training in cultivating virtue and character (García Romero, 2013). Their writings underscored the inseparable connection between the cultivation of the body and the development of the individual's moral and intellectual faculties.

Considerable academic efforts have been dedicated to exploring the Ancient Greeks' fascination with athletics and their pursuit of shaping male bodies to mirror the physical perfection of the gods. The Ancient Greeks were one of the few civilizations that embraced nudity during athletic performances, and they portrayed athletic bodies through various artistic representations (Mouratidis, 1985). Many of the studies examining Ancient Greek athletics originated from the works of classical historians with a specific interest in sports and athletic endeavours (Christesen, 2012; Golden, 1998).

Within ancient cultures, depictions of corporeality as patterns of the sporting body can be observed, particularly in Greek sculpture and vase painting. Among the preserved Greek cultural artifacts, three examples of male corporeality patterns and one example of female corporeality related to the sporting world are worth noting. These examples include Polyclitus's sculptures "*Doryphorus*" and "*Diadoumenos*," Myron's sculpture "*Discus Thrower*," Lysippus's sculpture of "*Heracles Farnese*," and a painting featuring Atalanta. These ancient patterns of the sporting body have persisted in the European cultural landscape from the Renaissance to the 20th century. Each artifact embodies distinct aspects of the sporting world: Polyclitus's sculptures portray the beauty of the body, Myron's sculpture captures sporting movement, Lysippus's sculpture symbolizes power, and the figure of Atalanta represents the first gender pattern in the realm of sports. These ancient patterns serve as cultural archetypes in the contemporary world of sports. The modern sporting body is perceived and interpreted through the symbolic layer of ancient corporeal images. Some of these corporeal patterns have lost their sporting references in European culture, which were evident in Greek civilization. This is particularly applicable to Polyclitus's sculptures and the figure of Atalanta, which acquired different semantic contexts through Renaissance and Baroque art.

As the ancient world gave way to the early modern period, the Renaissance witnessed a revival of interest in human anatomy and artistic representations of the body. Artists such as Leonardo da Vinci dissected cadavers to gain a deeper understanding of human anatomy, leading to more anatomically accurate portrayals of the human body in art. This newfound appreciation for the physical form extended to sports, as the Renaissance saw the emergence of organized sports competitions and the glorification of athletic achievements.

The Enlightenment period introduced a shift in the perception of the body, aligning with the rationalistic ideals of the time. The emphasis on reason and intellect led to a devaluation of physicality, with the mind prioritized over the body. However, this perspective was not universal, and some philosophers, such as Jean-Jacques Rousseau, championed the natural state of the human body and its connection to physical activity and outdoor pursuits.

In the late 19th and early 20th centuries, the emergence of modern sports and the influence of industrialization brought new dimensions to body image ideals. Sports began to be organized for mass participation, and the focus shifted from aesthetic ideals to performance-based achievements. With the advent of photography and mass media, the athletic body became a spectacle for the public, further shaping societal perceptions of physical beauty and athleticism.

Investigating the cultural aspects of sports necessitates reconstructing their sporting genealogy to establish broader interpretative contexts for contemporary corporeality. The concept of the "*archetype of the sporting body*" in European culture is enriched with a differentiated objective layer, comprising ancient patterns of the sporting body ingrained in the social consciousness of European art. Additionally, nineteenth-century England has been a focal point for historical research on sport and the body. During the latter half of the Victorian era, sport, athleticism, and muscularity were interconnected themes that captured the attention of sport historians in the final quarter of the twentieth century. The concept of Muscular Christianity played a significant role in connecting sport education and nationalism, promoting the idea of a strong, healthy, and, above all, manly body achievable through sports participation. Team sports, thriving in English public schools, were embraced under this educational philosophy, which linked character development and appropriate religious beliefs to the appearance and performance of the body. This period and location stimulated the interest of sport and education historians, particularly regarding the cultivation of the masculine body through sports (Chandler, 1996; Dunning & Sheard, 2005).

The historical journey of body image ideals in ancient sports and early modern periods reveals the intricate interplay between cultural, philosophical, and societal factors in shaping perceptions of the human body. From the reverence for physical excellence in ancient Greece to the rationalistic approaches of the Enlightenment and the advent of modern sports, the ever-changing landscape of body ideals reflects the evolving values and aspirations of human societies (Osborne & Litchfield, 2022).

The historical overview presented invites to contemplate the profound impact of cultural and intellectual currents on the perception of the human body in the realm of sports. The journey through time illuminates how the embodiment of athletic ideals has been intertwined with broader philosophical, artistic, and societal developments, leaving an indelible mark on the multifaceted relationship between the sporting body and the human experience.

Analysis of body image representations during significant eras in history

The analysis of body image representations during significant eras in history offers a captivating journey through time, exploring the diverse perceptions of the human body in various epochs.

The ideal body type in Ancient Greece was highly valued and considered a symbol of physical and moral superiority. The male athletic body was frequently stereotyped as a central attribute of manliness and a token of physical and moral superiority (Papakonstantinou, 2012). In Athens, masculinity was enacted through group displays of physical fitness and coordination performed at the Panathenaea festival. However, there also existed a different strand, visible in genres such as comedy and medical literature, which viewed the athletic body as food-devouring, over-trained, and muscularly disfigured (Papakonstantinou, 2012). Polyklitus, a Greek sculptor, represented the ideal male form by means of superimposition of anatomical parts of twenty individuals (Michels, 2000; Kruszewski, 2023). Sculptors suddenly set out to depict the details and proportions of the human body with mathematical precision and deliberate exaggeration (Gunther & Bagna-Dulyachinda, 2020). The ideal female beauty was also highly valued in Ancient Greece, and the extant remains from both Classical and Hellenistic periods portray a body of a Greek woman in all its beauty (Korečková, 2019). The ideals of physical beauty in Ancient Greece were characterized by physical fitness, coordination, proportionality, and youthfulness. The extant remains from both Classical and Hellenistic periods portray a body of a Greek woman in all its beauty. The ideal female beauty was characterized by a youthful appearance, a small waist, and a full bust. Greek tombstone inscriptions captured female beauty for future generations, and they show that a beautiful woman had a high value in the ancient society. However, the freedom of expression gradually disappeared, and a body was exposed only when portraying a woman with a colourful past to show her failures. Emerging Christianity also reacted to the Greek ideal of beauty, and some ideas were adopted while others were firmly rejected (Korečková, 2019). The ideal male form was represented by means of superimposition of anatomical parts of twenty individuals. The male athletic body was frequently stereotyped as a token of physical and moral superiority and as a central attribute of manliness (Papakonstantinou, 2012).

During Roman period the perception of the body underwent influences from a diverse range of factors, encompassing cultural, social, and religious beliefs. Within this context, certain key aspects emerge. The ancient Roman society bestowed considerable importance upon physical beauty, particularly within the higher echelons of society. A well-proportioned and healthy body was regarded as a reflection of an individual's moral character and social standing. Both genders strove to attain an ideal physique by means of exercise, grooming, and adhering to a proper diet. Contrary to modern taboos, nudity held a different connotation in ancient Rome, especially in specific social settings such as public baths and athletic events. It symbolized freedom and a natural state of being. Nevertheless, modesty remained an expectation in everyday life, with public nudity outside of designated contexts generally disapproved of. Personal grooming and hygiene held a paramount place in Roman culture. Daily bathing rituals were a customary practice, and the Romans gained renown for their elaborate public bathhouses. They also employed an array of cosmetics, perfumes, and oils to enhance their appearance and maintain cleanliness. Attire in ancient Rome served as a means to signify social status and identity. For instance, the toga, worn by Roman citizens, was associated with respectability and authority. Distinct garments were worn based on gender, age, and occupation. The Romans adhered to a robust belief in preserving good health. They engaged in diverse physical exercises such as swimming, running, and wrestling. Although their understanding of medicine was rudimentary, they recognized the significance of a balanced diet and proper hygiene for overall well-being. Religion played a pivotal role in shaping the perception of the body in ancient Rome. The Romans espoused the concept of numina, divine spirits believed to inhabit all aspects of life, including the human body. Rituals and sacrifices were practiced appeasing the gods and maintain spiritual and physical harmony.

The body and health during the Middle Ages were shaped by a combination of spiritual and medical ideas. The body was seen as a vessel for the soul, and health was closely linked to spiritual well-being. The four humours theory and the miasma theory of disease were dominant medical beliefs, and the body was seen as vulnerable to external influences. The importance of diet and exercise was recognized, but moderation was emphasized. The body was seen as a vessel for the soul, and health was closely linked to spiritual well-being. Illness was often seen as a punishment for sin, and prayer and religious rituals were used to treat ailments (Karim-Cooper, 2016). The four humours theory was a dominant medical belief during this period. It held that the body was made up of four humours (blood, phlegm, yellow bile, and black bile), and that an imbalance of these humours caused illness. Treatments focused on restoring balance through diet, exercise, and bloodletting The miasma theory of disease was also prevalent during the Middle Ages. It held that disease was caused by bad air or "*miasma*" that arose from decaying organic matter. This led to a focus on cleanliness and hygiene as a means of preventing illness. The body was seen as vulnerable to external influences, such as the weather, the alignment of the planets, and supernatural forces. Astrology and other forms of divination were used to predict and prevent illness (Pryor, 2020). The importance of diet and exercise was recognized, but the emphasis was on moderation rather than extremes. Overindulgence in food or drink was seen as a cause of illness, and excessive exercise was thought to be harmful.

As stated by Paluzzi et al. (2007) the perception of the human body during the Renaissance was multifaceted, encompassing scientific inquiry, artistic beauty, symbolism, and a connection to the divine. The body was seen as a source of inspiration and a subject of study, leading to advancements in both art and science. Renaissance scholars realized the importance of direct observations on dissected cadavers. Artists and scientists, such as Leonardo da Vinci, conducted experiments to reveal the anatomy of the human body, including the brain and its ventricular system. This led to a greater understanding of the structure and function of the body. The Renaissance was characterized by a renewed interest in the human form and its beauty. Artists studied anatomy to create realistic and proportionate depictions of the body. The concept of ideal proportions, such as the "*Vitruvian Man*" by Leonardo da Vinci, became popular. The human body was often used symbolically in Renaissance art. Artists incorporated anatomical details to convey deeper meanings or allegorical messages. For example, the heart was often depicted as a symbol of love or the soul. Connection to the Divine made a shift from a purely religious view of the body to a more humanistic perspective. The body was seen as a creation of God, but also as a vessel for human potential and expression. This led to a greater emphasis on individualism and the celebration of the human body. The Renaissance was a period of intellectual curiosity and scientific exploration. The human body was studied through dissection and observation, leading to advancements in the understanding of anatomy and physiology. This scientific approach to the body contributed to the development of fields such as physiology and medicine. The intellectuals of Humanism and the Renaissance, ideally reconnecting with classical antiquity, presented a new and modern vision of physical activities and arts based on the expressiveness of the human body. They embarked on this journey driven by a profound interest in the totality of man, reevaluating the psychophysical unity and regarding the perfection of the body (reproduced in sculpture and painting) as a reflection of inner virtue. The educational systems conceived during the Renaissance, therefore, aimed to cultivate both the physical and spiritual aspects of individuals, shaping them into skilled statesmen, military leaders, and accomplished courtiers (Aiello, 2004, p. 114-115). The Renaissance era witnessed the rediscovery of the preservative and therapeutic value of physical exercise and medical gymnastics (Mercuriale, 2006). Furthermore, it encompassed the description and theorization of physical and sporting activities that the Middle Ages had preserved and transmitted, or even independently developed. However, these activities were generally stripped of their original political and civil significance and reduced to mere games and forms of entertainment.

During the Enlightenment period, which took place in the 18th century, there was a shift in the perception of the body from a religious and spiritual perspective to a more scientific and rational one. The body was seen as a machine that could be studied and understood through scientific inquiry. This led to a greater emphasis on anatomy and physiology, and the development of new medical technologies and practices. The perception of the body emphasized reason, individualism, and human rights. The body was seen as an individual possession, and there was a growing interest in personal health and hygiene. Additionally, the idea of the "*perfect*" body became more prevalent, with a focus on physical fitness and beauty (Aiello, 2004, p. 147). The body image in the 18th century, is inspired by a materialistic or naturalistic conception. According to the philosophers of nature, man receives a priori, that is, before the intervention of reason and experience, a natural impulse that directs his behaviour and should simply be followed through education. The materialists, on the other hand, liken man to a blank slate. A suitable education should then guide his psychophysical development. The philosopher who has had the most influence on the pedagogy of that time was Jean Jacques Rousseau.

In the 19th century, the body image was shaped by various cultural, social, and ideological conceptions of the time (Reel, 2013, p. 76). Notably, perceptions of beauty and bodily expectations varied significantly depending on the social and geographical context. However, several key points regarding the body image in the 19th century can be highlighted. The concept of feminine beauty was often linked to an ideal of fragility and delicacy. Women were encouraged to present themselves as slender and graceful, epitomizing an idealized form characterized by a small waist, full bust, and rounded hips. To achieve this shape, corsets were popular, moulding the figure and cinching the waist inward (Martin, 1984). Fair and pale skin was deemed a sign of beauty and refinement, particularly among women. Women sought to shield their skin from the sun and utilized various remedies to achieve a pale appearance. The fashion trends of the era played a significant role in shaping ideas of beauty and body image. Garments of the time often accentuated the desired figure, with voluminous upper-body attire and wide skirts creating the illusion of a narrower waist and rounder hips (Skårderud, 1994). Even for men, physical appearance was emphasized, but expectations for the male body were less stringent compared to those for women. Men were frequently associated with an ideal of robustness and strength, yet the male body image was not subjected to as much aesthetic pressure as the female body image (Bojorquez & Unikel, 2012). The body image in the 19th century was also influenced by social status and class conventions. Women of different social classes had distinct standards of beauty and body expectations, with members of the upper class often associated with an image of elegance and refinement (Moeschl, 2004). Bodybuilding, which emerged in the late 19th and early 20th centuries, introduced a paradigm shift in body image representations. Pioneers like Eugen Sandow, considered the father of modern bodybuilding, celebrated the sculpted and muscular physique as a testament to physical prowess and strength. The advent of bodybuilding competitions showcased bodies meticulously chiselled through rigorous training and discipline. This era marked the popularization of muscular physiques as a symbol of aesthetic beauty and fitness. The portrayal of bodybuilders in art, photography, and media further influenced societal perceptions of the ideal body (Cereda, 2023).

The body image in the 20th century has been characterized by augmented intricacy and diversity compared to the preceding century, with a fusion of cultural, media, and social influences that have melded the perception of physical appearance and the ever-changing ideal of beauty. The trends of feminine beauty have undergone remarkable transformations. From the 1920s, with the emergence of "*flappers*" sporting more androgynous physiques and short hairstyles, to the 1950s, epitomizing the curvaceous and shapely woman, to the leaner and slender fashions of the 1960s and 1970s, and further evolving into the fitness-oriented and slender trends of the 1980s and 1990s. These shifts have contributed to the continual evolution of beauty ideals (Polenghi, Németh & Kasper, 2021).

The advent of mass media, such as television and advertising, has exerted a significant impact on body image. Images of retouched women and men moulded according to unrealistic standards of beauty have propagated unattainable ideals and influenced the perception of one's own body (Harris & Sanborn, 2014). Throughout the twentieth century, movements for women's rights and female emancipation have brought about a change in the perception of women's roles in society. This has also influenced the portrayal of the female body, advocating for greater acceptance of individuality and diverse body shapes (Mattioni, 2021). With the increasing awareness of health and physical exercise in the twentieth century, a culture of body and physical fitness has emerged. The focus on health and fitness has led to a growing interest in the athletic and toned body as an ideal of beauty (Thompson, Schaefer & Menzel, 2012; Hale & Smith, 2012).

Societal influences on body image perception in sports

Sport provides a significant, albeit underutilized, contribution to the physical activity of individuals of all ages (WHO, 2018). Athletes engage in structured and planned physical activity with important influences on their physical and mental health. In general, a positive Body Image (BI) is associated with increased participation in physical activity and sports (Sabiston et al., 2019). BI is considered a multidimensional construct centred on the aspect and function of the body. Body dissatisfaction regarding one's physical appearance and body size, as well as the discrepancies between actual and ideal dimensions, are cognitive, affective, and perceptual indicators of a negative BI (Marschin & Herbert, 2021). Essentially, a negative or positive BI is manifested through the perceptual dimension (how I see myself) and the cognitive and affective dimensions (how I think and feel about my physical appearance).

In a sports context, a more favourable BI would depend on actual physical changes resulting from the practiced sport (e.g., body shape), perceived physical changes, and the development of self-efficacy and confidence. However, this relationship is far from simple: while engaging in physical activity contributes to increased self-confidence through perceivable physical changes (e.g., an increase in lean mass) leading to improved BI satisfaction, BI can, in turn, influence motivation or deterrence toward physical activity and sports participation. For example, exercise dependence arises from a misguided perception of BI (Badau & Badau, 2018) and can also result in reduced performance due to physical overload and burnout (Angeli et al., 2004).

An important aspect to consider is whether dissatisfaction is influenced by the type of exercise practiced. Some differences in body dissatisfaction observed among practitioners of different sports (Morano, Colella & Capranica, 2011) might be linked to the significance of body weight and leanness within that sport (Dyremyhr, Diaz & Meland, 2014). A particular relevance of physical appearance can be found in aesthetic sports, such as rhythmic gymnastics. In this case, the evaluation of the athlete takes into account their morphokinetic abilities based on well-codified aesthetic requirements. Therefore, apart from performance, the athlete's physical appearance heavily contributes to the assessment, resulting in several studies reporting a prevalence of dissatisfaction among athletes engaged in aesthetic sports (Lepage & Crowther, 2010; Francisco, Alarcão & Narciso, 2012). Specifically, regarding the female gender, a higher risk of physical problems has been observed in gymnastics compared to long-distance swimming and running (Varnes et al., 2013). However, in these cases, it is important to distinguish between "*sport-specific*" body image dissatisfaction (sport-BID = perceived discrepancy between the current body size and the ideal size for the sport) and general body image dissatisfaction (BID) (de Bruin et al., 2011; Zaccagni, Barbieri & Gualdi-Russo, 2014). Literature shows that athletes, especially in aesthetic sports, are driven not towards pathological dieting and weight control due to general BID, but rather due to the specific demands of the sport they practice (Greenleaf, 2002). Greenleaf distinguishes an athlete's body image within an athletic context from a social body image, which relates to everyday life. Therefore, satisfaction/dissatisfaction with one's body image will depend not only on their physical appearance but also on the social or sportive environment of reference.

While athletes tend to be more satisfied than non-athletes in the social environment (Hausenblas & Symons Downs, 2001), in the sporting context, athletes are often under pressure from coaches and athletic trainers to achieve and maintain a body that is favourable to their respective sport (Brown, Muir & Gammage, 2023). For instance, in aesthetic sports, it has been found that the ideal athletic figure for female gymnasts does not coincide with the ideal figure in everyday life, being leaner (Zaccagni et al., 2014).

Influence of media, advertising, and technology on shaping body image ideals in athletes

Body image is a critical aspect of an athlete's self-perception and performance. In recent years, the media, advertising, and technology have become powerful influencers in shaping body image ideals among athletes (Holland & Tiggemann, 2016)

Social media has emerged as a dominant platform that significantly influences body image perception in athletes. Studies such as the work by Klier et al. (2022) and Vandenbosch et al. (2022) have explored the concept of "*#fitspiration*" on social media platforms. These studies found that fitness-focused content, which often idealizes lean and muscular body types, can lead to body dissatisfaction and negative body image among young athletes. The constant exposure to edited and curated images of athletic bodies on social media can create unrealistic beauty standards that athletes feel compelled to conform to.

Advertising also plays a crucial role in shaping body image ideals among athletes. Cataldo et al. (2021) conducted a narrative review, highlighting the risks associated with "*fitspiration*" on social media. They pointed out that advertisements featuring highly toned and athletic bodies can contribute to feelings of inadequacy and pressure to attain similar physiques. Such advertisements promote the notion that achieving a specific body type is essential for athletic success, which may lead to unhealthy behaviours and attitudes towards body image.

Moreover, technology, particularly the use of mobile devices and apps, has magnified the impact of media and advertising on athletes' body image. Leggett-James and Laursen (2023) explored the effects of social media use during the transition into adolescence. They found that excessive screen time and social media use were associated with increased body dissatisfaction and decreased physical activity in adolescents. The constant comparison with others' bodies on social media platforms may lead to body dissatisfaction and a distorted self-perception among athletes.

Fat talk, a form of negative body-related conversation, has been linked to social media use and body image among young women (Kennedy et al., 2023). Social media platforms may perpetuate fat talk among athletes, leading to increased body dissatisfaction and a focus on physical appearance rather than performance. The pressure to conform to body image ideals portrayed on social media can negatively impact an athlete's mental well-being and self-esteem.

Moreover, social identities and user characteristics can modulate the effects of social media on body image (Rodgers & Rousseau, 2022). Athletes belonging to specific sports communities may experience unique pressures related to body image ideals within their respective sports. For instance, sports that prioritize aesthetics and physical appearance, such as gymnastics or figure skating, may foster different body image ideals compared to sports that emphasize strength and power, like weightlifting.

The media, advertising, and technology significantly influence body image ideals among athletes. Social media, with its constant stream of curated content, can promote unrealistic beauty standards and contribute to body dissatisfaction (Fioravanti, Bocci Benucci & Casale, 2022). Advertising reinforces the importance of attaining specific body types for athletic success, leading to negative self-perceptions. The use of technology and social media may intensify these influences, affecting an athlete's mental well-being and self-esteem. Athletes, coaches, and sports organizations must be aware of these influences and work towards promoting a healthy body image and positive self-perception in sports environments. Encouraging a focus on performance, skill development, and overall well-being, rather than just physical appearance, can help athletes develop a more balanced and positive body image.

CONCLUSIONS

The journey through the historical overview and analysis of body image representations in sports history reveals a dynamic and multifaceted relationship between the human body, societal norms, and cultural influences. Throughout different eras, body image ideals in sports have evolved, reflecting the values, beliefs, and aspirations of the societies in which they emerged.

The exploration of ancient sports and the early modern period highlights the reverence for physical excellence in ancient Greece, where the harmony between body and mind was celebrated. Sports in ancient Greece transcended mere physical contests, becoming a platform for displaying human potential and embodied ideals. Philosophers like Plato and Aristotle further emphasized the inseparable connection between the cultivation of the body and the development of an individual's moral and intellectual faculties. The Renaissance witnessed a revival of interest in human anatomy and artistic representations of the body, leading to more anatomically accurate portrayals of the human form in art. The Enlightenment period introduced a shift in the perception of the body, prioritizing reason and intellect over physicality, although some philosophers like Rousseau championed the importance of physical activity and outdoor pursuits.

The age of bodybuilding heralded a paradigm shift in body image representations, celebrating the sculpted and muscular physique as a symbol of physical prowess and strength. Bodybuilding competitions showcased bodies meticulously chiselled through rigorous training and discipline, influencing societal perceptions of the ideal body. The mid-20th century witnessed the rise of women's liberation movements, impacting body image representations in sports and beyond. Female athletes defied conventional norms, challenging traditional notions of femininity and athleticism. The athletic body became a symbol of empowerment and liberation, shaping a new ideal of the strong and capable woman.

As sports progressed into the latter half of the 20th century and the 21st century, the focus shifted towards performance and achievement, embracing a broader acceptance of various body types. The athletic body was no longer confined to a singular aesthetic but celebrated the unique attributes necessary for excelling in a particular sport. Athletes from different disciplines displayed a wide range of body shapes and sizes, each exemplifying the specific demands of their respective sports.

The advent of digital media and social platforms in the 21^{s}t century further transformed body image representations in sports. Athletes had more agency in shaping their image, using platforms like Instagram and YouTube to share their training routines, nutrition practices, and personal experiences. This direct connection with fans allowed athletes to challenge traditional beauty norms and advocate for body positivity and inclusivity.

The analysis of body image representations in significant eras of sports history also underscores the power of sports in shaping societal perceptions of physical beauty, strength, and human potential. Sports have served as a canvas on which cultural, social, and historical values are depicted and celebrated. From ancient

Greece to modern times, the human body in sports has been an emblem of the ideals and aspirations of the time.

Body image ideals are not fixed or universal but rather dynamic and influenced by the ever-changing landscapes of culture and society. The historical overview and analysis highlight the importance of considering the broader context in understanding body image representations in sports. It is crucial to recognize the impact of societal norms, cultural beliefs, and historical developments on the perception of the human body throughout different eras.

Furthermore, this exploration sheds light on the importance of promoting a more inclusive and positive body image culture in sports. As athletes continue to inspire and influence society, it is essential to embrace the diversity of body types and celebrate the unique attributes that contribute to excellence in sports. By challenging unrealistic beauty standards and promoting body positivity, sports can play a pivotal role in fostering a healthier and more inclusive understanding of body image.

The analysis of body image representations in sports history invites to appreciate the ever-evolving nature of human perceptions of the body. From the ancient reverence for physical excellence to the modern celebration of diverse body types, sports have been a mirror reflecting the values and ideals of their time. As we move forward, let us continue to promote a more positive and inclusive body image culture in sports, celebrating the unique beauty and capabilities of every athlete, regardless of societal norms or aesthetic standards. In doing so, sports can truly become a powerful force for empowerment, inspiration, and unity, transcending boundaries and uniting individuals from all walks of life under the universal banner of human potential.

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