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SportMont

ORIGINAL SCIENTIFIC PAPER

# Knee bracing vs Taping as an Adjunct to Rehabilitative Exercise in Patellofemoral Pain Syndrome Management among Basketball Players: A Prospective Study

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**Abstract**

Patellofemoral pain syndrome (PFPS) is a common source of knee problems found mostly in physically active young adults. Causative factors are multifactorial, including lower extremity weakness, especially quadriceps muscles. Conservative treatment of PFPS consists mainly of knee bracing and knee taping combined with physical therapy. This study was aimed to analyse the outcome comparison between knee bracing and knee taping in combination with rehabilitative exercise for PFPS management. A prospective study was performed involving twenty-five basketball players suffering from PFPS, aged 19–30 years old with regular practice sessions. The subjects were each grouped randomly into a taping or a bracing group. Follow-up evaluations in term of Kujala patellofemoral score were done in the 1st, 2nd, and 4th weeks after treatment. Unpaired t-test and chi-square were used to analyse the difference between both groups in pre- and post-intervention. Baseline characteristics of each group did not differ significantly ($p>0.05$). Both groups had significantly higher functional scores after the 1st, 2nd, and 4th weeks of intervention ($p<0.05$). Significantly higher functional scores were found in the bracing group on the 2nd ($p=0.013$) and 4th weeks ($p=0.002$). No significant differences were found in functional scores between both groups in the 1st week ($p=0.142$). While both methods were efficacious, knee bracing is more effective compared to knee taping in improving functional outcomes as an adjunct to rehabilitative exercise in PFPS management.

***Keywords:*** *patellofemoral, taping, bracing, exercise, Kujala score*

## Introduction

Patellofemoral pain syndrome (PFPS) is defined as pain of the anterior knee joint and/or soft tissues surrounding the knee joint. It is a commonly found cause of knee pain in physically active young adults (Aghapour, Kamali, & Sinaei, 2017). As has been mentioned by Crossley et al. (2016) and Logan et al. (2017), the syndrome is characterized as pain in the anterior patellar or retropatellar region, which worsens during physical activity, such as squatting, running, and extended sitting sessions. Higher prevalence of PFPS was found in athletes that participate in sports that require rapid hip adduction and internal rotation and subsequent knee abduction and external rotation, such as basketball (Almeida et al., 2015; Petersen, Rembitzki, & Liebau, 2017; Powers, Bolgla, Callaghan, Collins, & Sheehan, 2012; Willy et al., 2019). In one study (Willy et al., 2019), the aetiology of PFPS is thought to be poorly understood and considered to be multifactorial, including anatomical derangements, decreased muscle strength, even pain sensitization and psychological factors. Witvrouw, Lysens, Bellemans, Cambier, and Vanderstraeten (2000) also summarized that a decreased quadriceps flexibility, a

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shorter reflex response time of the vastus medialis oblique muscle, a reduction of vertical jump height, and higher than normal medial patellar mobility is associated with PFPS occurrence.

Management of PFPS may be initiated conservatively or surgically; the former is the first-line of treatment, with the latter only initiated if the prior conservative treatment had failed to alleviate the symptoms related to PFPS (Barton, Lack, Hemmings, Tufail, & Morrissey, 2015; Petersen et al., 2017). Doyle (2000) stated that conservative treatment of PFPS consists mainly of rehabilitative exercise. The goal of muscle strengthening and exercises is to address muscle performance deficits, movement coordination deficits, and mobility impairments (Willy et al., 2019). Several immobilization techniques have been introduced for reducing pain during functional tasks, such as patellar taping and knee bracing. Knee bracing redistributes loads to the entire joint and may alleviate pain associated with PFPS. Knee taping functions as a limiter to patella movement during rehabilitation and aids in the movement of the oblique vastus medialis during physical activity. Both of the methods have limitations; knee taping was proven to be efficacious in the short term (<4 weeks), yet its long-term efficacy has yet to be studied; knee bracing is the most recent addition to the alternative to treating PFPS, as such, limited data were available in terms of efficacy in comparison to the knee taping (Willy et al., 2019).

Recent published studies have implied that there is insufficient data regarding the optimal immobilization technique for PFPS. According to our literature review, no prior studies focused on the efficacy of knee bracing and taping combined with rehabilitative exercise, specifically evaluated according to an assessment tool such as the Kujala patellofemoral score (Kujala et al., 1993). This study aimed to analyse the comparison in efficacy between knee bracing and knee taping, both in combination with rehabilitative exercise, in managing PFPS, specifically in basketball athletes.

## Methods

A prospective randomized study was performed in basketball players with PFPS as the target population. The Independent variable was the immobilization technique, either taping or knee bracing, and the dependent variable was the Kujala patellofemoral score. Variables collected in the study included baseline characteristics and baseline functional score.

The Kujala score is a self-administered questionnaire consisting of thirteen questions regarding knee pain symptoms (Table 1), six of which were associated with individuals with PFPS. The score range from 0 to 100; a higher score indicates a higher functional score (Kujala et al., 1993). The inclusion criteria of the study were basketball athletes that practice regularly (at least 3 times a week), aged 19–30 years old, body mass index of 18.5 to 24.9 kg/m², confirmed PFPS diagnosed prior to the study, and baseline Kujala score of 50–70. In this study, we used the Indonesian version of the Kujala score, as developed by Mustamsir et al. (2020). The subject would be excluded from the study if he had a previous history of other knee injuries (dislocation and/or fracture of the knee joint), congenital disease, an autoimmune disease of the knee joint, infectious disease of the knee joint.

**Table 1.** Kujala patellofemoral score chart

| Variable | Score | Variable | Score |
|---|---|---|---|
| | | Prolonged sitting with the knees flexed | |
| Limp | | No difficulty | 10 |
| None | 5 | Pain after exercise | 8 |
| Slight or periodical | 3 | Constant pain | 6 |
| Constant | 0 | Pain forces subject to extend knees temporarily | 3 |
| | | Unable | 0 |
| | | Pain | |
| Support | | None | 10 |
| Full support without pain | 5 | Slight and occasional | 8 |
| Painful | 3 | Interferes with sleep | 6 |
| Weight-bearing impossible | 0 | Occasionally severe | 3 |
| | | Constant and severe | 0 |
| | | Swelling | |
| Walking | | None | 10 |
| Unlimited | 5 | After severe exertion | 8 |
| More than 2 km | 3 | After daily activities | 6 |
| 1-2 km | 2 | Every evening | 4 |
| Unable | 0 | Constant | 0 |
| | | Abnormal painful kneecap movement (subluxations) | |
| Stairs | | None | 10 |
| No difficulty | 10 | Occasionally in sport activities | 6 |
| Slight pain when descending | 8 | Occasionally in daily activities | 4 |
| Pain both when descending and ascending | 5 | At least one documented dislocation | 2 |
| Unable | 0 | More than two dislocation | 0 |
| Squatting | | | |
| No difficulty | 10 | Atrophy of thigh | |
| Repeated squatting painful | 4 | None | 5 |
| Painful each time | 3 | Slight | 3 |
| Possible with partial weight bearing | 2 | Sever | 0 |

*(Continued on next page)*

*(continued from previous page)*

| Variable | Score | Variable | Score |
|---|---|---|---|
| Running | | | |
| No difficulty | 10 | Flexion deficiency | |
| Pain after more than 2 km | 8 | None | 5 |
| Slight pain from start | 6 | Slight | 3 |
| Severe pain | 3 | Severe | 0 |
| Unable | 0 | | |
| Jumping | | | |
| No difficulty | 10 | | |
| Slight difficulty | 7 | | |
| Constant pain | 2 | | |
| Unable | 0 | | |

Total score: 95–100 Excellent; 800–94 Good; 60–79 Fair; 0–60 Poor

A simple random sampling of amateur basketball athletes with PFPS in Bandung was performed. Each participant was assigned to either bracing using LP 758 Open Patella Knee Support (Trans-Global Sports, United Kingdom) or taping (BSN Leukotape, Essity, Sweden), as shown in Figure 1. The knee tape was applied in a standard patellofemoral fashion, directly to the skin starting from outside of the patella and with a little tension secure to the inside of the knee. The knee taping applications were performed by a single physician (H.R.P). Patients in both groups also received similar rehabilitative exercise, as prescribed by the Department of Physical Medicine and Rehabilitation, Hasan Sadikin General Hospital, which included the hip- and knee- targeted exercises. Knee-targeted exercise includes either weight-bearing (resisted squats) or non-weight-bearing (resisted knee extension) exercise.


FIGURE 1. Application of (A) knee bracing; (B) knee taping

The minimum sample required for the study was calculated using the Gay and Diehl formula; the minimum sample size of 30 samples (each group consisted of 15 samples) were required to obtain a study with 80% power. Descriptive and analytical statistics were used for data analyses in this study. Descriptive statistics were used to describe both groups' numerical and categorical variables (baseline and after intervention). Mean, standard deviation, median, and range were used to describe numerical data. A Shapiro-Wilk test was used to determine data normality. Comparison between both groups would be analysed using a Mann-Whitney test in non-normally distributed data; an unpaired t-test was used if the data were normally distributed. Comparisons between both sets of categorical data were analysed using the chi-square test. A p-value of $<0.05$ was deemed statistically significant.

This study was approved in advance by the Hasan Sadikin Hospital - Research Ethical Committee, Bandung, Indonesia (Registration No. LB.02.01/X.6.5/190/2020). Each participant voluntarily provided written informed consent before participating.

## Results

Twenty-five subjects were included in this study, comprised of twelve patients in the taping group and thirteen patients in the bracing group. Baseline characteristics of both groups (Table 2) showed an insignificant difference in terms of age, affected side, and baseline Kujala score ($p>0.05$).

In both groups, significantly increased Kujala scores were found throughout the duration of the follow-up in the 1st, 2nd, and 4th weeks after treatment ($p<0.05$). Comparisons be-

**Table 2.** Baseline characteristics

| Variables | Taping | Bracing | p-value |
|---|---|---|---|
| Age (years) | 28.83±2.125 | 27.23±2.385 | 0.090 |
| Affected side (N) | | | 0.543 |
| Left | 7 (58.3%) | 6 (46.2%) | |
| Right | 5 (41.7%) | 7 (53.8%) | |
| Kujala score (baseline) | 68.67±3.985 | 68.85±3.484 | 0.781 |

tween both groups were performed in terms of Kujala score throughout the aforementioned follow-up period; taping and bracing did not differ significantly in terms of Kujala score after one week of intervention (p=0.142); the bracing group had a higher score compared to the taping group. On the 2nd (p=0.013) and 4th weeks (p=0.002), significantly higher Kujala scores were found in the bracing group compared to the taping group (Table 3).

**Table 3.** Functional outcomes

| Kujala score (follow-up) | Taping | Bracing | p-value |
|---|---|---|---|
| 1$^{st}$ week | 71.75±3.980 | 74.31±4.385 | 0.142 |
| 2$^{nd}$ week | 74.50±5.161 | 80.46±3.971 | 0.013 |
| 4$^{th}$ week | 79.00±5.510 | 86.69±3.815 | 0.002 |

## Discussion

Muscle strength imbalances, particularly of the lower extremities, may contribute to the development of PFPS by causing instability of patellar bone towards the femur, specifically during lateral movement, due to the weakness of vastus medialis oblique muscle (Lankhorst, Bierma-Zeinstra, & van Middelkoop, 2013). Associated with the relatively benign prognosis of the syndrome, treatment is mostly composed of conservative therapies. Knee taping or bracing are treatment modalities used in combination with rehabilitative exercises as the first-line, non-pharmacological treatment (Crossley et al., 2016; Willy et al., 2019).

Taping is an option to improve patellar tracking within the patellofemoral groove for PFPS management, as introduced by McConnell (1986). Quadriceps muscle weakness had been known to result in malposition of the patella and subsequently affect the muscle's ability to produce force (Kaya, Doral, & Callaghan, 2012). Lu, Li, Chen, and Guo (2018) proposed kinesio-taping as an effective rehabilitation modality used in musculoskeletal system. Thus, knee taping was associated with higher functional scores after intervention for patients with PFPS in terms of pain severity, muscle strength, joint position sense, static and dynamic balance compared to the functional scores before usage and compared with a placebo group (Aytar et al., 2011; Bicici, Karatas, & Baltaci, 2012). However, taping is not without weakness. The effectiveness of the taping procedure depends on many variables. Many years ago, Rarick, Bigley, Karst, and Malina (1962) raised the concern that athletic tape would lose 40% of its initial support after 10 minutes of exercise. The relative motion of the superficial skin layer in relation to the subcutaneous tissue can limit the tape effectiveness, as can sweating.

Knee bracing provides support to the knee joint by increasing the compression force of the knee joint and aids in the redistribution of the force to the knee joint. Knee bracing functions in preventing excessive lateral movement and aids in patellar realignment. Patellar alignment of the knees may also be repaired in patients using knee braces. An external compression force provided by the knee brace may prevent further maltracking of the patella, which may require surgical intervention to repair (Petersen et al., 2017; Willy et al., 2019). Braces are designed to overcome many of the problems related to conventional taping. The fabric used in the brace is stronger than the athletic tape, as reported by Hall, Simon, and Docherty (2016).

In this study, both methods were equally efficacious in increasing the functional score of patients with PFPS; both groups had significantly higher functional score starting from one week of use up to four weeks of use; in all follow-up time points (1st, 2nd, and 4th weeks), functional scores were significantly higher compared to the baseline Kujala score. This study noted that the difference in efficacy in alleviating pain related to PFPS was higher in the knee-bracing group than the knee-taping group on the 2nd and 4th weeks. A previous study concluded that patellofemoral knee orthoses did not have a meaningful effect on pain in the short term (Smith, Drew, Meek, & Clark, 2015). However, the same review had also noted the very low quality of evidence and heterogeneity of the braces' types. This study attempted to give an additional perspective on a focused comparison between certain type of braces and tapings, using a clinical scoring tool.

The study is a prospective study; as such, it can be inferred that the clinical efficacy of each method can be followed longitudinally at different time points. Despite its advantage as a prospective study, the study design had several limitations. First, this study was performed with a relatively small sample size, which risks type II statistical errors and may have resulted in some variations failing to reach statistical significance. Second, the underlying comorbidities, complications, and satisfactions were not explored sufficiently to be included in the assessments. Third, the study could not be blinded to the authors because the physicians had to treat the patients directly. Additionally, the follow-up duration of four weeks was relatively short. Despite its limitations, this study had provided information to be utilized in improving functional outcomes in a specific subset of locally based basketball athletes. Further studies should include longer follow-up to identify the mid-term and long-term effects of both methods.

Exercise and knee support usage are effective in achieving satisfactory outcomes by PFPS treatment indicated by Kujala scores. During exercise, knee bracing is found to be more effective compared to knee taping in improving functional outcomes in basketball athletes with PFPS. This result was attributable to a more stable and durable construct of knee bracing in comparison with taping, which was conducive to rehabilitative exercise. Further studies with larger sample sizes and longer follow-up durations may be required to ascertain whether the effects can be persistent until the condition fully heals.

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**Conflict of Interest**
The authors declare that there is no conflict of interest.

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ORIGINAL SCIENTIFIC PAPER

# Evaluation of the Dynamics of the Pressure Applied to the Trigger When Shooting In Biathlon

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**Abstract**

The presented study is associated with assessing the dynamics of the pressure applied to the trigger when making a shot in biathlon competition. The experiment involved five qualified athletes. The educational work and training sessions were completed with them to improve the trigger handling technique before the experiment. The pressure was recorded using a thin-film elastic sensor located in the contact zone of the biathlete's finger with the rifle trigger. The test task included shooting series from a standing and lying position both before and after loading. Three different trigger manipulation types were identified. The data indicate the feasibility of developing modern systems designed to improve the athlete's shooting profile in terms of the efforts applied to the trigger.

***Keywords:*** *biomechanical analysis, trigger manipulation type, shot phase composition, direct feedback*

## Introduction

The speed of overcoming the competitive distance and high-quality shooting at the firing line are the key factors that ensure successful competitiom in biathlon. Moreover, according to current trends, in which the difference in the speed of movement over the distance between athletes is steadily decreasing, the second component has a significant impact on the final result.

The shooting accuracy of biathletes increased, on average, by 3% from 2004 to 2016 (Romanova, Zagurskij, & Gushcha, 2016), and the time spent on firing lines decreased, on average, by 8.8%. Simultaneously, the number of athletes whose accuracy is in the range of 81–85%, on average, increased by 3.9% (males) and (1.7%) females (Romanova et al., 2016; Bolotin & Bakayev, 2017). In this context, it can be argued that the improvement of results in biathlon depends on the degree of reduction in the time spent on firing lines, which can be ensured by increasing the rate of fire. At the same time, it is extremely important to maintain the highest possible level of accuracy (Bakayev, 2015; Romanova & Astaf'ev, 2014; Luchsinger, Kocbach, Ettema, & Sandbakk, 2018; Astaf'ev, 1994; Laaksonen, Finkenzeller, Holmberg, & Sattlecker, 2018; Zagurskij & Romanova, 2017).

A high level of the rate of fire and accuracy is the result of focused work, including all technical elements: preparation, breath-holding, aiming, trigger-handling, rhythm, and intensity. When shooting, these factors have a significant impact on each other. So, the preparation and strategy of holding one's breath determine the features of aiming, which, in turn, together with the trigger processing, determine the rhythm and intensity of shooting. Many trainers note that it is necessary to coordinate the aiming of the weapon and handling the trigger not in the pulse mode of the finger but smoothly since this allows one to reduce the fluctuations of the weapon to a minimum and significantly facilitate aiming (Bakayev, Bolotin, & You, 2018).

In this case, the word "smoothly" is proposed to mean the following: the maximum effort with which the athlete pulls the trigger for one or half a second before the shot should be at least 70% of the maximum possible required for its failure. It

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is argued that compliance with this condition, as a rule, allows one to increase the effectiveness of shooting (Sattlecker, Buchecker, Gressenbauer, & Müller, 2017; Ihalainen, Laaksonen, Kuitunen, & Leppävuori, 2018).

The present research was carried out in close cooperation with biathlon coaches. Its purpose is to evaluate the dynamics of pressure applied by athletes to the trigger after a series of training sessions, during which focused work was carried out to improve the handling of the descent.

## Methods

At the coaches' request, the following conditions had to be met when shooting: individual rifles and cartridges; the distance to targets on the firing line was 50 m. To assess the individual dynamics of applied pressure, the "Grip" system (Tekscan, Inc., USA) was used. It enables measuring the contact pressure using a thin-film elastic sensor located in the area of contact of the phalanx of the index finger of the athlete with the trigger of the rifle. The touch element was attached using double-sided tape. Its connector was connected to the data receiver, located on the athlete's forearm using a Velcro cuff. The data recorded during the study was transmitted wirelessly to a computer. The study involved five athletes with experience in biathlon competitions (age 15.8±1.4).

Athletes performed four shooting series of five shots in a multi-purpose universal indoor shooting range from standing and lying positions. The subjects performed simulation exercises on the "SkyErg" simulator before the third and fourth series. The goal is to simulate shooting against the background of an increased heart rate in order to ensure compliance with natural (competitive) conditions better.

MS Excel was used for statistical processing and data visualization. The information obtained that characterizes the individual dynamics of the pressure applied by athletes to the trigger is presented in tabular and graphical form. The pressure values are averaged under conditions of firing before loading, as well as after loading.

The average pressure (P) is normalized to 0–100%, where 100% is the trigger pull. The time moments "$T_1$", "$T_{0,5}$", "$T_{0,2}$", "$T_{0,02}$" (Tables 1, 2) correspond to 1; 0,5; 0.2 and 0.02 seconds before the shot, and "TP" characterizes the maximum pressure after the trigger is released.

The average pressure profiles are presented in the form of graphs, each with dotted lines indicating the range of its changes, and the following phases are highlighted: phase I, initial pressure build-up; phase II – intermediate; phase III-trigger booster.

## Results

The individual dynamics of the pressure applied to the trigger data when firing before and after the load from the lying and standing positions are presented in Tables 1 and 2.

**Table 1.** Values of the Pressure Applied to the Trigger when Firing from a Prone Position

| Athlete number | Time point | Before loading | | After loading | |
|---|---|---|---|---|---|
| | | P±σ,% | t±σ, sec | P±σ,% | t±σ, sec |
| 4 | $T_1$ | 60.12±12.15 | 0.94±0.24 | 52.79±8.76 | 0.89±0.22 |
| | $T_{0,5}$ | 67.05±15.51 | 2.73±0.99 | 56.59±7.70 | 1.98±0.48 |
| | $T_{0,2}$ | 69.43±16.63 | 3.23±0.99 | 58.38±7.96 | 2.48±0.48 |
| | $T_{0,02}$ | 71.56±17.10 | 3.58±0.98 | 60.00±8.48 | 2.84±0.48 |
| | $T_n$ | 118.72±12.35 | 3.73±0.99 | 105.61±5.09 | 2.98±0.48 |
| 2 | $T_1$ | 51.06±11.42 | 1.63±1.21 | 56.04±22.29 | 2.15±1.44 |
| | $T_{0,5}$ | 69.45±12.09 | 3.58±1.03 | 61.77±18.11 | 3.47±1.51 |
| | $T_{0,2}$ | 75.75±7.82 | 4.08±1.03 | 72.01±14.77 | 3.97±1.51 |
| | $T_{0,02}$ | 86.68±9.12 | 4.45±1.03 | 85.71±10.37 | 4.35±1.51 |
| | $T_n$ | 108.36±6.47 | 4.58±1.03 | 103.49±6.53 | 4.47±1.51 |
| 5 | $T_1$ | 78.65±19.49 | 2.01±2.10 | 58.47±23.12 | 2.15±1.44 |
| | $T_{0,5}$ | 101.29±22.33 | 3.89±1.66 | 64.47±18.72 | 3.47±1.51 |
| | $T_{0,2}$ | 111.45±17.54 | 4.39±1.66 | 75.19±15.38 | 3.97±1.51 |
| | $T_{0,02}$ | 125.34±22.53 | 4.76±1.67 | 89.49±10.8 | 4.35±1.50 |
| | $T_n$ | 153.85±28.07 | 4.89±1.66 | 139.54±32.92 | 4.47±1.51 |
| 3 | $T_1$ | 45.53±9.86 | 1.28±0.63 | 56.25±14.62 | 1.99±0.77 |
| | $T_{0,5}$ | 67.69±9.71 | 2.77±1.01 | 67.18±16.99 | 2.83±0.85 |
| | $T_{0,2}$ | 76.31±9.09 | 3.27±1.01 | 79.29±11.69 | 3.33±0.85 |
| | $T_{0,02}$ | 90.60±9.47 | 3.58±1.01 | 86.51±9.96 | 3.60±0.85 |
| | $T_n$ | 111.49±7.10 | 3.77±1.01 | 106.21±6.32 | 3.83±0.85 |

Information concerning Athlete 1 has been excluded from Table 1, because there are artefacts on the initial recordings that significantly distort them and cannot be filtered. Also, there is no information in Table 2 concerning Athletes 2, 3, and 5 due to their low level of shooting preparedness, as they had recently switched from cross-country skiing to biathlon. Therefore, at this stage, their training is focused on shooting from a prone position.

**Table 2.** Values of the Pressure Applied to the Trigger when Firing from a Standing Position

| Athlete number | Time point | Before loading | | After loading | |
|---|---|---|---|---|---|
| | | P±σ,% | t±σ, sec | P±σ,% | t±σ, sec |
| 1 | $T_1$ | 43.76±10.12 | 1.23±0.57 | 38.66±11.58 | 0.89±0.54 |
| | $T_{0,5}$ | 71.07±11.48 | 2.83±1.22 | 61.91±12.66 | 1.79±1.09 |
| | $T_{0,2}$ | 78.67±8.68 | 3.33±1.22 | 73.79±8.49 | 2.29±1.09 |
| | $T_{0,02}$ | 87.55±9.21 | 3.67±1.21 | 85.52±9.63 | 2.65±1.08 |
| | $T_п$ | 110.38±8.68 | 3.83±1.22 | 104.03±7.29 | 2.79±1.09 |
| 4 | $T_1$ | 81.45±12.71 | 1.64±1.09 | 71.97±9.12 | 1.31±1.11 |
| | $T_{0,5}$ | 86.61±11.79 | 2.37±1.34 | 78.21±7.02 | 2.11±1.68 |
| | $T_{0,2}$ | 89.76±7.73 | 2.87±1.34 | 82.98±4.92 | 2.61±1.68 |
| | $T_{0,02}$ | 90.72±6.37 | 3.25±1.32 | 85.12±5.91 | 2.98±1.66 |
| | $T_п$ | 111.01±8.86 | 3.37±1.34 | 105.27±4.54 | 3.11±1.68 |

With Athletes 1, 2, and 3, when shooting both before and after loading, when processing the trigger in Phase II, a smoothness change in pressure is observed (Figures 1–3). Biathletes demonstrate a shooting style in which the pressure from the moment the trigger is touched to the moment the shot is fired in Phase III increases linearly, without sharp jumps.

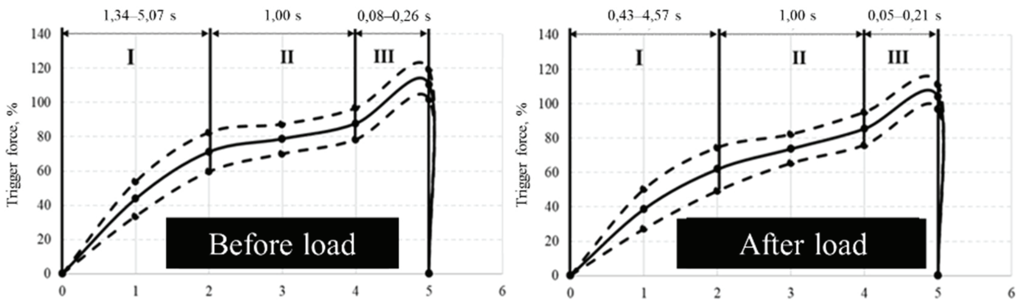


FIGURE 1. Athlete 1's trigger pressure when shooting from a standing position

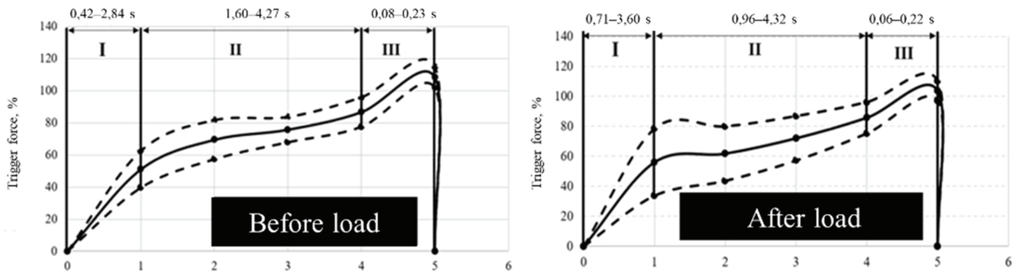


FIGURE 2. Athlete 2's trigger pressure when shooting from a prone position

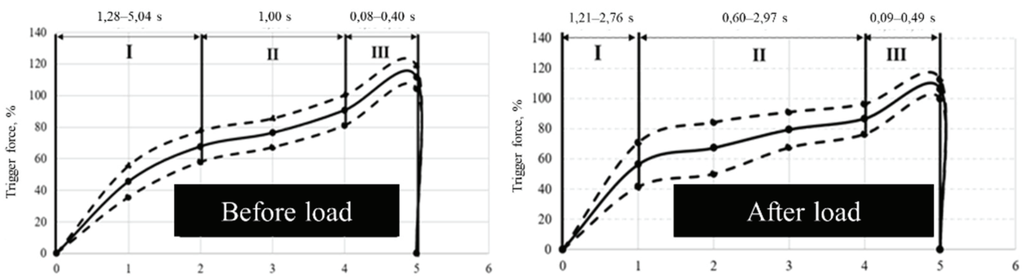


FIGURE 3. Athlete 3's trigger pressure when shooting from a prone position

Athlete 4 has a steady level of pressure when handling the trigger in Phase II (Figure 4). In Phase III, the pressure on the trigger increases evenly. It is noteworthy that when shooting from a standing position, the athlete presses the trigger in Phase III against the background of a high preliminary pressure level. the value of which is, on average, at the level of 90.72% before and 85.12% after loading.

Athlete 5 processes the trigger in pulse mode: only one phase is allocated, during which the pressure increases in a very short period (from 0.04 to 0.26s) to 100% or more (Figure 5).

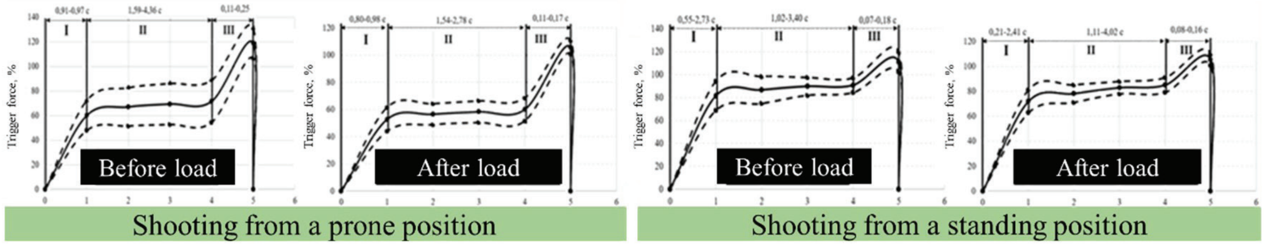


FIGURE 4. Pressure on the trigger by Athlete 4 when shooting before/after the load from the lying and standing positions

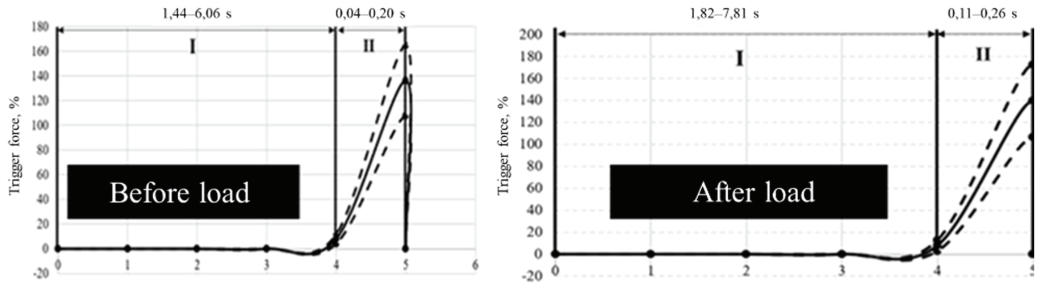


FIGURE 5. Athlete 5's trigger pressure when shooting from a prone position

The results of the study can be used to outline certain conclusions. The motor profile that all athletes demonstrated when handling the trigger can be defined as stable, as evidenced by the corresponding values of standard deviations of pressure. There are three classic types of processing:

- according to the first, the pressure on the trigger increases continuously and linearly. Sharp jumps are not observed throughout its processing, from the first touch of the trigger to the moment of firing (Phases I and III are clearly distinguished, Phase II can be determined by the change in the pressure build-up rate, which is expected to be less than in Phase I);
- the second type can be most fully characterized by the presence of a time interval in it, during which the pressure applied to the trigger can be designated as established, i.e., the athlete reaches a certain value and maintains it;
- in the third type, only one phase out of three can be determined, during which the pressure on the trigger increases abruptly to 100% or more in a very short period (0.3s or less).

There is no direct relationship between the quality of triggering and shooting success (Sattlecker, Buchecker, Rampl, Müller, & Lindinger, 2013). However, Žák, Struhár, Janoušek, and Ondráček (2020) found that higher pressure in the last 0.5–1.0 s contributes to significantly higher aiming stability. In other words, a large difference between the pressure required to trigger and observed during testing at these timestamps leads to greater destabilization of the rifle.

We can state that the first and second types of descent processing are preferable to the third, in which the athlete reacts to the appearance of a fly under the centre of the target with a sharp movement of the finger. This, in turn, can lead to sensorimotor discoordination, which will subsequently lead to a shift in the rifle's aiming devices relative to the target, and the result of which, in the worst case, will be a miss.

## Discussion

An increase in the smoothness in the muscular effort of the index finger from the beginning of aiming to the production of the shot, when processing the trigger, is observed in highly qualified biathletes, as well as in athletes specializing in shooting. Biathletes are less qualified; their efforts are distributed unevenly, which often causes different amplitudes of the weapon barrel vibrations, which results in poor shooting quality. In this regard, it is not recommended to use the third type of descent processing when shooting.

It is important to feel the movement and pressure of the finger on the trigger (differentiation of forces) with various changes in the state of the shooter caused by physical exertion and affecting the increase in vibrations of the weapon. For example, when shooting, use a trigger tension of 100 g can be used, which shows the best sensitivity and differentiation at a tension of 400 g. Therefore, it is necessary to select such a descent tension, in which the athlete shows the best indicators of sensations or differentiation of efforts, tested instrumentally. In our case, this is confirmed to some extent by the standard spread that can be observed in Figures 2 and 3 (represented by dotted lines). So, for example, in Athlete 2, when shooting after a load, it increased, on average, by 5.1%.

It is noteworthy that when athletes used the first two types of trigger handling, the pressure value at the time "TP" exceeded the required for the production of the shot, on average, by 31%. Simultaneously, the athlete who used the third type of shot exceeds it, on average, by 77%, which is also a rather negative factor, since it can potentially cause undesirably more significant fluctuations in the weapon after the shot. This, in turn, will require him to make additional efforts to repay them.

It should be noted that our findings are significantly different from those obtained by other researchers. This is confirmed by the results of several studies (Sattlecker, Müller, & Lindinger, 2009; Žák et al., 2020). In accordance with them, the level of pressure on the trigger for boys and girls for 1 s before the shot is about 75% or even more, and for juniors 85%, and then only continues to grow. In this regard, the question arises as to what this fact may be due. We suggest that it is connected with certain features of the organizational and methodological aspects of the training process.

Our experiment yielded a sufficiently informative picture of the triggering quality. It allows us to classify different triggering stereotypes and further analyse which of them can be most effective for athletes choosing a particular shooting style. It was found that even after targeted training sessions, the technique of processing the trigger in accordance with the key phases of athletes can differ significantly.

The composition of the phase structure of the shot is determined: the initial increase in force (I); the intermediate phase (II), in which the pressure can be constant or change; the trigger pull phase (III). In accordance with the phases selected, three types of processing descent: the first is characterized by a continuous, linear pressure increase; the second is determined by the presence of plateau pressure; a third pulse, wherein the pressure on the trigger increases significantly in a very short period.

In such conditions, there are methodological issues related to the selection of adequate training tools and methods aimed at improving the technique of handling the trigger. An important condition that must be met is the presence of a feedback system. However, although in the world of biathlon and shooting sports there are already tools that can provide it (for example, "SCATT"), we see the prospect of developing more advanced hardware and software systems and organizing their work not only in the laboratory but also in natural conditions (on the shooting range). This expansion of functionality will help solve problems related to improving proprioreceptive sensations associated with the differentiation of efforts applied by a biathlete to the trigger against the background of physical activity.

In our opinion, the most optimal way to organize feedback on the amount of pressure in this case is the glasses used by the athlete. This, in turn, imposes very serious requirements on the design features of the recording system: weight and overall dimensions. It is also important to ensure a sufficiently high level of measurement accuracy.

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**Conflict of Interest**
The authors declare that there is no conflict of interest.

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ORIGINAL SCIENTIFIC PAPER

# Effects of Delayed Cold Water Immersion after High-Intensity Intermittent Exercise on Subsequent Exercise Performance in Basketball Players

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**Abstract**

The purpose of this research is to compare the effects of passive recovery and delayed cold water immersion one and three hours after high-intensity intermittent exercise (HIIE) on exercise performance and muscle soreness on the subsequent day. Eleven male basketball players participated in the study. They followed the recovery methods after high-intensity intermittent exercise, including 15 minutes cold water (15°C) immersion one hour (CWI1) and three hours (CWI3) after HIIE and passive recovery (CON) in a randomized order on a weekly basis. The protocol for HIIE included progressive speed 20-metre shuttle sprint interrupted with repetitive jumping in order to induce fatigue. Twenty-four hours after HIIE, a 20-metre shuttle sprint and maximal vertical jump test were conducted to evaluate the effect of each recovery method. Maximal vertical jump height after one and three hours did not differ significantly compared to pre-test values. However, the maximal vertical jump height in the control group was significantly lower than their pre-test value. Also, 24 hours after HIIE, perceived muscle soreness in CWI1 and CWI3 groups was significantly lower than that of the control group. The total distance of the shuttle run did not differ depending on the recovery method used. Cold water immersions one and three hours after HIIE affected maximal vertical jump height and athletes' perception of pain. However, there were no significant differences in exercise performance between the cold water immersion at one and three hours after HIIE, which might be due to similar physiological responses during both immersion trials.

***Keywords:*** *cold water immersion, exercise recovery, high-intensity intermittent exercise, shuttle run test*

## Introduction

One factor limiting the performance in team sport athletes is insufficient time for recovery after matches, especially after high-intensity, long-duration competitions such as basketball, football, and volleyball tournaments. During competition, high-intensity exertion resulting in micro-injury activates inflammatory processes, thus increasing body temperature and fatigue in athletes. Inadequate recovery between competitions may affect muscular and cardiorespiratory functions, causing fatigue and reducing exercise performance in athletes (Barnett, 2006; Vaile, Halson, Gill, & Dawson, 2008). Adequate recovery from high-intensity exercise is essential to maintain performance throughout training and competitions (Brown et al., 2017). Therefore, techniques that facilitate recovery after competitions are essential for maintaining exercise performance in team athletes (Jackman, Macrae, & Eston, 2009).

At present, cold water immersion (CWI) is a recovery method used mostly by physical therapists, sport science researchers, and coaches to reduce fatigue and facilitate the recovery process (Calleja-González et al., 2016; Versey, Halson, & Dawson, 2013). Several physiological mechanisms to explain the effects of cold water immersion have been proposed. Cold induces vasoconstriction of blood vessels, muscle tissue cooling, and increases in hydrostatic pressure, leading to a reduction in blood

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flow, decreased oedema and inflammation, decreased cell permeability and a reduction in secondary oxidative metabolism (Higgins, Greene, & Baker, 2017; Leeder, Gissane, Someren, Gregson, & Howatson 2012; Wang & Siemens, 2015). Also, cold water immersion generates a series of physiological changes, including reductions in skin and core body temperatures (Peiffer, Abbiss, Nosaka, Peake, & Laursen, 2009; Yanagisawa, Homma, Okuwaki, Shimao, & Takahashi 2007), acute inflammation (Wilcock, Cronin, & Hing, 2006), muscle spasms and sensations of pain (Vaile, Gill, & Blazevich, 2007; Sánchez-Ureña et al., 2017). Several factors related to the effects of cold water immersion on physiological response and exercise recovery are germane, including variations in water temperature, duration, water level, and application techniques. Almeida et al. (2016) studied the effects of immediate cold-water immersion at different temperatures post-exercise. Their results show that cold water immersion for 15 minutes at 14±1 °C resulted in improvements in the autonomic nervous system compared to lower water temperatures (Almeida et al., 2016). The length of the period of cold water immersion after exercise may affect physiological response and subsequent physical performance. Brophy-Williams, Landers, and Wallman (2011) examined the effects of immediate and delayed cold water immersion after exercise and found that cold water immersion immediately and three hours post-exercise significantly improved exercise performance and reduced C-reactive protein levels compared to the control condition. However, there was no difference between the three conditions of immersion (Brophy-Williams et al., 2011).

Previous studies have attempted to determine the duration, water temperature, and level of water immersion on physiological changes in athletes. Most research has focused on the immediate effects of cold water immersion with different protocols. However, immediate cold water immersion is difficult to perform in real situations due to limitations of place and the preparation of cold water in the field or during competitions. In addition, recently, some studies have investigated the effects of cold water immersion on athletes' performance on subsequent days, which is the normal competition schedule in team sports, such as basketball, football, or volleyball. Such sports need both aerobic and anaerobic energy systems to function at a high level.

Therefore, this study aims to determine the effect of delayed cold water immersion one and three hours after high-intensity interval exercise (HIIE) on exercise performance. The exercises used were maximum vertical jump and a 20-metre progressive shuttle sprint in subsequent days in male basketball players.

## Methods

*Participants*

Eleven male basketball players in Walailak University, Thailand, were recruited into the study. The participants were selected based on the parameters in the study by Rowsell, Coutts, Reaburn, and Hill-Haas (2009). The inclusion criteria included 1) must have been regularly exercising at least two hours per day and three days per week for more than one year; 2) body mass index between 18.50–25.00 kg/m$^2$; 3) must have at least one year of experience in competitions in university games. Individuals with musculoskeletal problems within the six week study period, skin allergies, open wounds, abnormal skin sensations, and cardiopulmonary diseases were excluded. The details of this study were explained to the participants, and informed consent was given by each participant before starting the protocol. The present study was approved by the Ethics Committee of Human Research, Walailak University, Thailand.

*Measures and Procedures*

The present study used a cross-over design. Participants received three recovery techniques, including passive recovery (control), cold water immersion after one hour (CWI1) and three hours (CWI3) after HIIE. The order of the recovery technique applied was randomized using software with a wash-out period of at least seven days between interventions. On the first day, a twenty-metre shuttle sprint test and maximum vertical jump were performed prior to the study to determine baseline values. During the test, the heart rate at each speed of the 20-metre shuttle sprint was recorded and used to determine the appropriate speed for the high-intensity interval exercise. Seven days after the baseline test, participants received the first recovery techniques after the session of high-intensity interval exercise intended to induce physical fatigue. The protocol of HIIE comprised four rounds of the 20-metre shuttle sprint and repetitive vertical jump at different target heart rates with two minutes rest between rounds. Heart rate, muscle pain, and rating of perceived exertion (RPE) were recorded every two minutes of exercise. Immediately after HIIE, all parameters and blood pressure were repeated. After that, participants received an intervention randomly. Twenty hours after HIIE, the 20-metre shuttle sprint and maximal vertical jump were repeated as in the baseline measurement. All participants were instructed to avoid vigorous exercise, caffeine, and medicine for 24 hours before the test, as well as avoiding meals at least two hours before the test.

*Maximal vertical jump*

The maximal vertical jump was measured using a Vertec vertical jump® (USA) device, which had cells of 1.5 cm intervals longitudinally. Participants stood with legs at shoulder-width apart, one hand extended over the head to touch the Vertec slate, and the number was recorded. Then participants were asked to perform a maximal jump by doing as many hip and knee flexions as possible. They were assigned to perform the maximum jumps three times with a two-minute rest between each repetition, and the maximum value was recorded.

*Twenty-metre progressive shuttle sprint test*

The twenty-metre progressive shuttle sprint test consisted of one-minute stages of continuous, incremental speedrunning. The initial speed was 8.5 km/h and increased by 0.5 km/h each minute (Leger et al., 1988). Participants were required to run between two lines 20 metres apart while keeping pace with audio signals emitted from a pre-recorded compact disk. They were instructed to run in a straight line, pivot, then turn on completion and pace themselves in accordance with the audio signals. If the line was reached before the beep sounded, the subject had to wait until the beep sounded again before continuing. If the line was not reached before the beep, the subject was given a warning and had to continue to run to the line, then turn and try to catch up with the pace within two more beeps. The test ended when the individual failed to reach the end lines concurrent with the audio signals on two consecutive occasions. Each participant was encouraged to keep running for as long as possible. During the test, heart rate was continuously monitored using a pulse oximeter and RPE, and the fatigue scale was measured every minute.

*High-intensity interval exercise*

The protocol for HIIE comprised progressive speed 20-metre shuttle sprints at different percentages of maximum heart rate alternating with repetitive jumping in order to induce fatigue. Heart rate was recorded during the 20-metre progressive shuttle sprint at the end of each stage to calculate the exercise heart rate. Participants were required to perform four sets of sprints and vertical jump sets. The set of HIIE was composed of 1) the 20-metre shuttle sprint at 65–75% $HR_{max}$ for 5 rounds; 2) 2 jumps at 80% maximum jump height; 3) the 20-metre shuttle sprint at 75–85% $HR_{max}$ for 5 rounds; 4) 2 jumps at 100% maximum jump height; 5) the 20-metre shuttle sprint at 85–90% $HR_{max}$ for 5 rounds. Heart rate, muscle pain and RPE were recorded every two minutes of exercise.

*Three recovery techniques*

After completion of the HIIE session, participants moved to the lab and rested for five minutes. Resting heart rate, blood pressure, $SpO_2$, thermal sensation scale, and skin temperature were measured. Skin temperature was measured using a digital thermometer (TG-100 Rossmax) and infrared thermometer (AR 360 A+), respectively, at the axilla and the anterior thigh at the mid-line between hip joint and upper border of the patella. After that, participants sat in the long sitting position in a bath tank filled with 15 °C water. The level of the water was to the iliac crest, and the water temperature was monitored and controlled throughout the protocol with a thermostat. Every three minutes, all parameters were measured except thigh skin temperature, which was only repeated at the end of immersion. After immersion, participants were allowed to sit on a chair for five minutes, and all parameters were recorded. For the control intervention, subjects sat in the same room with no activity allowed. Room temperature was controlled at 25 °C, and humidity was recorded. During the test, only the researcher and the participants were in the lab. Participants received each recovery treatment at the same time of day to prevent a diurnal effect.

*Statistical analysis*

All data were presented as means±SD. One-way ANOVA was applied to determine the differences in the 20-metre progressive shuttle sprint, vertical jump height and muscle pain after 24 hours of the three interventions. The differences in heart rate, blood pressure, respiratory rate, RPE, muscle pain and body temperature were evaluated every three minutes during cold water immersion using a two-way repeated measurement ANOVA. $p<0.05$ was regarded as statistically significant. All analyses were performed using SPSS version 17 (SPSS Inc. USA)

## Results

All participants in the study were male basketball players at Walailak University. None had diseases that affected their ability to perform the tests, including musculoskeletal, nervous, cardiovascular, and respiratory disorders. All participants have an average duration of a basketball training period of five days per week for at least six continuous years. The mean and standard deviation for age, weight, height, and body mass index is shown in Table 1.

**Table 1** Subject characteristics including age, weight, height and body mass index of all participants (n=11)

| Characteristic | Mean±SD |
|---|---|
| Age (y) | 21.00±1.84 |
| Weight (kg) | 68.77±7.89 |
| Height (cm) | 175.00±6.15 |
| Body mass index (kg/m²) | 22.41±1.83 |

Prior to undergoing the recovery interventions, all participants performed high-intensity exercise for an average duration of about 24.04±1.12 minutes. Physiological responses to HIIE including exercise heart rate (HR), systolic/diastolic blood pressure (BP), respiratory rate (RR), rating of perceived exertion (RPE), percutaneous oxygen saturation ($SpO_2$), muscle soreness, and body temperature at axilla for each intervention were presented in Table 2. Results show that there was no significant difference between groups for all parameters. This indicates that the same intensity of exercise to induce fatigue prior to undergoing each intervention was achieved.

**Table 2** Physiological responses to HIIE before undergoing the recovery intervention in control, cold water immersion 1 and 3 hours after HIIE of all participants (n=11)

| Parameters | CON | CWI1 | CWI3 | p |
|---|---|---|---|---|
| | Mean±SD | Mean±SD | Mean±SD | |
| HR (beats per minute) | 187.20±7.93 | 186.45±5.57 | 184.00±7.06 | 0.539 |
| SBP/DBP (mmHg) | 144.20±21.24/ 69.70±11.74 | 148.45±15.58/ 75.09±10.20 | 146.73±24.92/ 73.09±11.55 | 0.897 0.545 |
| RR (times per minute) | 43.00±5.06 | 43.45±5.43 | 44.80±4.37 | 0.705 |
| RPE | 16.80±1.62 | 16.27±2.45 | 17.00±1.73 | 0.678 |
| $SpO_2$ (%) | 95.90±2.13 | 95.91±2.21 | 96.27±1.27 | 0.875 |
| Muscle soreness | 4.70±3.09 | 4.36±2.73 | 3.09±2.88 | 0.411 |
| Axillary temperature (°C) | 36.80±0.71 | 36.01±1.06 | 36.57±0.69 | 0.110 |

Legend: CON-control; CWI1-cold water immersion 1 h after HIIE; CWI3-cold water immersion 3 h after HIIE; HR-heart rate; SBP-systolic blood pressure; DBP-diastolic blood pressure; RR-respiratory rate; RPE-rate of perceived exertion; $SpO_2$-oxygen saturation

Twenty-four hours after HIIE, participants performed a 20-metre shuttle sprint and maximal vertical jump test to determine the effectiveness of passive recovery, compared with cold water immersion one and three hours after HIIE on subsequent physical performance. Pre-test values for the maximum vertical jump in all participants were 55.55±6.67 cm. Twenty-four hours after recovery by resting (control), the maximal vertical jump reduced to 50.60±5.50 cm, which is significantly lower than the pre-test value (p<0.05; Table 3). In contrast, there was no significant difference between subsequent maximum vertical jumps in CWI1 and CWI3 groups compared to pre-test values.

Moreover, the results showed a significantly higher maximum jump height in CWI1 and CWI3 than in the control group (p<0.05).

**Table 3** Maximum vertical jump height before HIIE (pre-test), and 24 hours after receiving recovery interventions including control, cold water immersion 1 and 3 hours after HIIE in 11 participants

| Maximum vertical jump (cm) | | | |
|---|---|---|---|
| Pre-test | 24 hours after intervention | | |
| Mean±SD | CON Mean±SD | CWI1 Mean±SD | CWI3 Mean±SD |
| 55.55±6.67 | 50.60±5.05* | 56.73±6.60† | 56.18±5.81† |

Legend: * - significantly different compared with pre-test value (p<0.05); † - significantly different compared with control (p<0.05)

Twenty- four hours after each intervention, a maximum 20-metre progressive shuttle sprint test in CON, CWI1, and CWI3 were not significantly different compared with the pre-test values between interventions. The physiological responses during the 20-metre progressive shuttle sprint test before and 24 hours after intervention are shown in Table 4. The results show that maximum heart rate, systolic/diastolic blood pressure, respiratory rate, and rating of perceived exertion scale were not different between groups (Table 4). This indicates that the effort taken to perform the test was of the same level after each intervention.

**Table 4.** Twenty-metre progressive shuttle sprint test before HIIE, 24 hours after receiving recovery interventions including control, cold water immersion 1 and 3 hours after HIIE in 11 participants (Mean±SD)

| Parameters | Pre-test | 24 hours after intervention | | |
|---|---|---|---|---|
| | | CON | CWI1 | CWI3 |
| | Mean±SD | Mean±SD | Mean±SD | Mean±SD |
| Shuttle sprint completed<br>- Absolute value (m)<br>- Δ change from pre-test (m) | 1004.27±297.09 | 1184.00±257.13<br>214.00±210.62 | 1196.36±284.65<br>229.10±366.20 | 1238.18±224.05<br>290.90±280.60 |
| HR (beats per minute) | 192.91±7.94 | 187.90±6.74 | 186.36±7.53 | 185.82±6.32 |
| SBP/DBP (mmHg) | 150.73±14.23/<br>80.73±5.95 | 163.70±21.45/<br>74.70±8.35 | 166.27±19.88/<br>70.82±11.72 | 151.91±16.22/<br>79.00±11.42 |
| RR (times per minute) | 44.71±3.68 | 43.80±4.18 | 44.90±5.47 | 43.36±4.74 |
| RPE | 16.45±1.04 | 16.20±1.55 | 15.82±2.18 | 17.18±1.08 |

Muscle pain was evaluated after the HIIE based on the pre-test value and values 24-hours after HIIE. In the control group, 24-hour post-HIIE muscle pain was not significantly different compared with pre-intervention values, whereas groups that underwent cold water immersion one and three hours after HIIE showed significantly lower muscle pain compared to their pre-test value and the control group (p<0.05), as shown in Table 5.

**Table 5.** Muscle pain scores after HIIE (pre-test) and 24 hours after intervention including control, cold water immersion 1 and 3 hours after HIIE in 11 participants

| Muscle soreness | | | |
|---|---|---|---|
| Pre-test | CON | CWI1 | CWI3 |
| Mean±SD | Mean±SD | Mean±SD | Mean±SD |
| 5.12±2.23 | 2.60±3.27 | 0.91±1.87*,† | 0.73±1.68*,† |

Skin temperature changes at the axilla and anterior thigh during cold water immersion in CWI1 and CWI3 were recorded every three minutes and five minutes after the immersion was completed, as well as heart rate, systolic/diastolic blood pressure and a thermal sensation scale as shown in Table 6. Results show that heart rate before, during, and five minutes after recovery after immersion in CWI3 were significantly lower than CWI1 (p<0.05). Systolic and diastolic blood pressure did not show a significant difference except for the systolic blood pressure at three min in the CWI3 condition was significantly higher than their resting condition (p<0.05). The temperature at the anterior thigh was significantly lower than before immersion in both groups (p<0.05).

**Table 6.** Physiological responses to 15-minute cold water immersion in CWI1 and CWI3 before (0), during 3, 6, 9, 12, and 15 minutes and after immersion for 5 minutes (20) (Mean±SD)

| | Minute | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 3 | 6 | 9 | 12 | 15 | 20 |
| | Mean±SD | Mean±SD | Mean±SD | Mean±SD | Mean±SD | Mean±SD | Mean±SD |
| **HR (beats per minute)** | | | | | | | |
| CWI1 | 79.73±8.75 | 75.91±8.46 | 75.82±6.65 | 76.00±6.48 | 76.36±7.90 | 74.00±7.58 | 72.36±10.45 |
| CWI3 | 68.55±7.98‡ | 69.09±6.92‡ | 68.91±7.45‡ | 67.73±4.84‡ | 69.64±7.68‡ | 69.36±7.15 | 63.09±6.17‡ |
| **SBP (mmHg)** | | | | | | | |
| CWI1 | 121.82±8.95 | 129.27±11.62 | 122.18±7.03 | 119.64±7.58 | 121.27±10.47 | 122.18±8.00 | 116.36±10.57 |
| CWI3 | 121.09±7.83 | 130.45±10.74# | 122.18±6.48 | 120.18±9.39 | 122.55±9.80 | 120.91±8.04 | 116.82±10.46 |
| **DBP (mmHg)** | | | | | | | |
| CWI1 | 70.00±5.12 | 75.91±8.63 | 73.36±3.91 | 71.55±5.99 | 71.09±6.46 | 70.64±7.27 | 71.09±6.43 |
| CWI3 | 75.45±9.50 | 79.82±9.45 | 75.91±6.50 | 72.82±4.87 | 73.27±9.02 | 77.00±7.63b | 71.64±8.29 |
| **Thermal sensation scale** | | | | | | | |
| CWI1 | -0.59±0.77 | -1.27±0.96 | -0.59±0.77 | -0.45±0.61 | -0.45±0.42 | -0.45±0.35 | 0.10±0.70 |
| CWI3 | -0.41±0.63 | -1.18±1.15 | -0.73±0.96 | -0.64±0.98 | -0.59±0.92 | -0.59±1.02 | -0.05±0.47 |
| **Temperature (℃)** | | | | | | | |
| CWI1 | 35.56±0.85 | 35.53±0.92 | 35.63±1.06 | 35.57±1.09 | 34.87±3.50 | 35.85±1.12 | 35.77±1.08 |
| CWI3 | 35.59±0.62 | 35.45±0.59 | 35.47±0.69 | 35.69±0.58 | 35.88± 0.55 | 35.83±0.66 | 35.87±0.51 |
| **Anterior thigh** | | | | | | | |
| CWI1 | 32.16±0.95 | | | | | 17.36±1.02# | 22.79±1.04# |
| CWI3 | 31.25±1.02 | | | | | 16.99±0.86# | 23.01±1.15# |

Legend: ‡ - significant difference compared to CWI1 ($p<0.05$); # - significant difference compared to minute 0 ($p< 0.05$)

## Discussion

This research aimed to compare the effects of delayed cold water immersions one and three hours after HIIE with passive recovery on exercise performance in male basketball players. Important findings show that the anaerobic performance measured from a maximal vertical jump height one and three hours after delayed cold water immersion can restore strength to pre-test values, whereas the decline in this parameter was demonstrated in the control recovery group. However, there was no significant difference between the two intervals of cold water immersions. In contrast to maximal vertical jump height, a 20-metre shuttle sprint test 24-hours after three recovery interventions showed no significant differences between groups. However, pain sensations were considerably reduced compared with passive recovery (control) in both cold water immersion treatments.

Thus, in this study, it was demonstrated that both cold water immersion conditions were able to restore 24-hour maximum vertical jump capacity, which is a mark of the anaerobic capacity of the muscles involved. This result is consistent with the findings of Ascensao et al. (2011), according to which participants who were immersed in 10 °C water up to the iliac crest for 10 minutes after a match showed a significantly greater maximal isometric voluntary contraction of the quadriceps muscle than control groups. Ascensao et al. (2011) also found that intermediate cooling can reduce perceived soreness and attenuate the biochemical signs of muscle damage demonstrated by the reduction in creatinine kinase (CK), myoglobin (Mb), and C-reactive protein (CRP). Another study done to determine the effect of immediate cold water immersion on anaerobic power is that of Taher, Fsharnezhad, Faghihi, Hazrati, and Bahrami (2017). A significant decrease in the anaerobic performance measured with a 30-second Wingate test after a competition was observed, and CWI were effective in enhancing the anaerobic performance after competition compared with the control group.

The physiological effects of cold water immersion have been studied. The hydrostatic pressure of the water may result in both muscular and vascular compression, which may decrease inflammatory responses as shown by a reduction in C-reactive protein level 24 hours after high-intensity exercise in normal people who undergo a 10-hour delay immersion in cold water (Goodall & Howatson, 2008; Lum, Landers, & Peeling, 2010; Williams, Landers, & Wallmen, 2011). In addition, cold water immersion is proposed to reduce inflammation by evoking vasoconstriction and decreasing peripheral blood flow (Wilcock, 2005). Cold-water immersion may also help to maintain power after exhaustion competition through direct and indirect mechanisms. For instance, cold water immersion inhibits the activity of group III and IV afferents in skeletal muscle and decreases the reduction of lactic acid during muscle activities, resulting in a decrease in the perception of fatigue and pain (Roberts et al., 2015; Yanagisawa, Niitsu, Takahashi, Goto, & Itai, 2003). Another study found that stroke volume and cardiac output increased during cooling, which assisted in decreasing core temperature (Gabrielsen et al., 2002).

However, the exercise performance restoration effects of cold water immersion one and three hours after HIIE were not different in a recent study, which is quite similar to the study of Williams et al. (2011). That previous study aimed at investigating the effects of immediate and three-hour CWI after exercise on subsequent performance. The results demonstrated that shuttle run completed as an intermittent yoyo test was only significantly higher than the control recovery group in CWI0. However, the study did not show a significant difference between CWI0 and CWI3. This could be explained by the similar reduction of CRP level in CWI0 and CWI3 that helped to decrease the inflammatory process to the same degree. In addition, the physiological responses during cold water immersion, including heart rate, systolic/diastolic blood pressure, body temperature and thermal sensation in CWI1 and CWI3, did not differ significantly in all parameters. Therefore, the restoration effects of cold water immersion on exercise performance demonstrate no significant difference between the two immersions.

This study is the first research done to determine the practical effect of delayed cold-water immersion at one and three hours for clinical use instead of applying it immediately, which is practically difficult to do. Our results demonstrate that both delayed cold-water immersion at one and three hours after HIIE resulted in the restoration of the ability to perform a maximal vertical jump and decreased the perception of pain compared to passive recovery, but it did not improve the subsequent 20-metre progressive shuttle sprint performance in basketball players.

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**Conflict of interest**

The authors declare that there are no conflicts of interest.

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ORIGINAL SCIENTIFIC PAPER

# Sedentary Living, Screen Time, and Physical Activities in Medical Students during the Coronavirus (Covid-19) Pandemic

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**Abstract**

The Ministry of Health of Indonesia has established large-scale social restrictions (LSSR) to limit the transmission of Covid-19, which inherently causes an increase in screen time levels and the physical activity level of students. This study aims to compare the level of screen time and physical activity before and during LSSR. This cross-sectional study was involved 206 medical students of the Atma Jaya School of Medicine and Health Sciences. Data were collected using a questionnaire and the International Physical Activity Questionnaire (IPAQ) – long form. A paired t-test, Wilcoxon signed-rank test, and McNemar test were used to compare the level of screen time and physical activity before and during LSSR. The mean screen time, sedentary time on weekday and weekend were significantly increased (Δ0.6, Δ1.7, Δ1.3 hours, respectively, all p<0.001), while total calorie of physical activity reduced (Δ-435, p<0.001). The number of students with higher screen time and sedentary time was also raised (Δ12.1%, Δ19.4%, Δ14.6%, respectively, all p<0.001), while the number of students with sufficient physical activity was significantly diminished (Δ-13.6%, p<0.001). There was a shift in the use of application types. The most significant change was Line usage, which had decreased by almost half (from 80 to 43). The pandemic situation greatly affected the students' physical activity behaviour to be more sedentary and changed the use of application type.

***Keywords:*** *Covid-19 pandemic, large-scale social restriction, online-based learning, screen time, physical activity*

## Introduction

In December 2019, the first report of Coronavirus Disease 2019 (Covid-19) came from Wuhan, People's Republic of China (PRC), and since then has spread worldwide. By September 6, 2020, the data showed that at least 213 countries reported 27,095,634 confirmed cases and 884,304 deaths. Along with its devastating impacts, WHO has declared Covid-19 as a global pandemic that must be handled urgently. In Indonesia, the first case of Covid-19 was confirmed on March 2, 2020 (Hermesauto, 2020). Since then, the number of cases has rapidly multiplied to 678,125 per December 2020 (Covid-19, n.d.).

The Indonesian Ministry of Health acknowledged the stagnancy of Covid-19 improvements in the nation and decided to limit various community activities and establish large-scale social restrictions to reduce its transmission (Covid-19, 2020). Crowded places such as shopping centres, offices, and educational facilities were shut down, thus forcing various community activities to be operated online. This large-scale social restriction (LSSR) also affects medical students' learn-

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ing methods, which shifted from face-to-face learning to small group discussions through online platforms (Rose, 2020), which also negatively affects the physical activity level of the students. Thus, it will further increase sedentary and the amount of screen time (Nagata, Magid, & Gabriel, 2020).

In a report by We Are Social and Hootsuite, in January 2019, Indonesia was ranked fifth based on the amount of time per day spent using the internet, with an average of 8 hours 36 minutes per day (Coconuts Jakarta, 2019). The current intense use of electronic media certainly contributes to numerous life aspects, including physical activity. Research suggests an inverse relationship between the use of electronic media and the level of physical activity. The higher the use of electronic media, the lower the level of physical activity (Sandercock, Ogunleye, & Voss, 2012; Spengler, Mess, & Woll, 2015).

With the precautions set by the government to combat Covid-19, screen time will undeniably increase at an alarming rate, and along with that, it will affect the rates of physical activity. There have been no studies to evaluate sedentary screen time and medical students' physical activities during online-based learning to the best of our knowledge. Therefore, this study aimed to evaluate whether LSSR affected screen time and physical activity in medical students.

## Methods

*Study design*

This cross-sectional study was conducted at the School of Medicine and Health Sciences, the Atma Jaya Catholic University of Indonesia, in February and June 2020. Preclinical students of the School of Medicine and Health Sciences, the Atma Jaya Catholic University of Indonesia, were recruited. Participants gave their informed consent. The exclusion criteria were set as follows: 1) unable to do physical activity optimally because of health problems or physical limitations; 2) have a mobile phone that did not work correctly or was not compatible with applications required for this study. Ethical approval had been obtained from the Ethical Review Committee of the School of Medicine and Health Sciences - Atma Jaya Catholic University of Indonesia (No: 28/01/KEP-FKUAJ/2020) before this study was carried out.

*Subjects & Sampling Methods*

This study's minimum sample size was calculated using the formula for population proportion with 95% CI, 5% margin of error, and the predicted prevalence of people using internet-connected devices ≥7 hours a day was 50% (Charan & Biswas, 2013). After calculating the possibility of a sample dropout of 10% and design errors, a sample size of 215 students was needed. Two hundred fifteen students filled out a questionnaire in the first survey. In the second survey, one student was absent, and eight students were excluded because they had limitations that made it difficult for them to perform physical activities. Thus, the number of eligible subjects for analysis was 206 students.

Data collection was done twice with an interval of three months. The first data collection was carried out in February 2020, just before LSSR. The second data collection was conducted in May 2020, 2 months after LSSR. Information sheets containing research objectives and procedures were distributed online to students. The students were then asked to sign an online informed consent form and fill in a self-administered questionnaire containing data on screen time and physical activity.

*Measurements*

Data measurement was performed using a questionnaire consisting of three sections: 1) demographics, 2) screen time questionnaire, and 3) an international physical activity questionnaire (IPAQ) (long form). The demographic questionnaire records the student's name, student/campus ID, age, gender, year of study, ethnicity, religion, and telephone numbers that can be contacted.

The screen time questionnaire includes several questions that must be filled in based on the results displayed from the built-in screen time application for iOS (Apple) users or the screen time application "Restrain yourself & parental control version 2.2.1 (Iridium Dust Limited)" for non-iOS phone users. The questions in the screen time questionnaire include 1) How long (in hours and/or minutes) has your screen time been during the last seven days, and 2) What are the five applications (with the usage duration) that you used most during the last seven days? The daily usage duration will be calculated and divided based on the screen time into ≥7 hours and <7 hours (Trinh, Wong, & Faulkner, 2015; Ngantcha et al., 2018).

The IPAQ was used to assess a person's metabolic equivalent (MET) from performing various physical activities in the past seven days (International Physical Activity Questionnaire, 2005). This questionnaire is in the English language and consists of five sections, including job-related physical activity; physical transportation activity; housework, house maintenance, caring for the family; recreation, sport, leisure-time physical activity; and time spent sitting; with a total of 27 questions. Students were asked to fill in each question based on the length of time they did an activity in a day and how many days a week they did the activity. Total MET – minutes/week is obtained from multiplying the length of time doing an activity by the number of days doing physical activity and the MET value. MET value for walking is 3.3; for moderate activity is 4.0; for cycling is 6.0, and for vigorous activity is 8.0. However, there are exceptions to the MET value of vigorous yard chores, which is 5.5, and moderate inside chores were 3.0 days (International Physical Activity Questionnaire, 2005). After calculation, the total physical activity MET in minutes/week is obtained and categorized as <600 MET for insufficient physical activity, and ≥600 MET for sufficient physical activity (Wu, Fisher-Hoch, Reininger, & McCormick, 2016; Poggio et al., 2016). Based on the IPAQ questionnaire, data on sedentary time were also obtained, which were further categorized into ≥7 hours/day or <7 hours/day (Ku, Steptoe, Liao, Hsueh, & Chen, 2018).

*Statistical Analysis*

Numerical data were presented as mean ± standard deviation, while categorical data as frequency (percentage). The comparison of numeric data between February and May was assessed using the dependent sample T-test or Wilcoxon signed-rank test based on the data distribution normality. The change of subject number in categorical data was evaluated using the McNemar test. The results are considered statistically significant if $p<0.05$. Data analysis was performed with Stata Statistical Software: Release 12.

## Results

The characteristics of the subjects were presented in Table 1. The average age was 19.2 years old. There were more females than males (69.4 vs 30.6%). The mean screen time was above the recommended maximal screen time (7.3 hours/day). The mean calorie for physical activity was 1235 calories. The sedentary time between weekday and weekend were almost similar (8.3 vs 8.4). Most subjects spent seven hours or more in screen time and being sedentary during weekdays and weekends. However, most subjects had sufficient physical activity (54.9%)

**Table 1.** Subjects characteristics

| Variables | | Mean (SD) or frequency (%) |
|---|---|---|
| Age | | 19.2±1.0 |
| Gender | female | 143 (69.4%) |
| | male | 63 (30.6%) |
| Screen time (hours/day) | | 7.3±2.5 |
| Physical activity (calorie/day) | | 1235.9±162.1 |
| Sedentary time (hours/day) | weekday | 8.3±3.4 |
| | weekend | 8.4±4.1 |
| Screen time | ≥7 hours/day | 106 (51.5%) |
| | <7 hours/day | 100 (48.5%) |
| Physical activity | Insufficient | 93 (45.1%) |
| | Sufficient | 113 (54.9%) |
| Sedentary (weekday) | ≥7 hours/day | 130 (63.1%) |
| | <7 hours/day | 76 (36.9%) |
| Sedentary (weekend) | ≥7 hours/day | 124 (60.2%) |
| | <7 hours/day | 82 (39.8) |

Table 2 describes the change of screen time, physical activity, and sedentary time after three months. The paired t-test showed the mean screen time, sedentary time on a weekday, and the weekend was significantly increased (Δ0.6, Δ1.7, Δ1.3 hours, respectively, all p<0.001). The Wilcoxon test showed that the total calorie of physical activity was significantly reduced (Δ-435, p<0.001).

**Table 2.** The change of mean value of the variables within 3 months

| | 1st survey (February 2020) | 2nd survey (May 2020) | p |
|---|---|---|---|
| Screen time (hours/day) | 7.3±2.5 | 7.9±2.9 | <0.001 |
| Physical activity (calorie) | 1235.9±162.1 | 800.0±159.9 | <0.001 |
| Sedentary time weekday (hours/day) | 8.3±3.4 | 10.0±3.3 | <0.001 |
| Sedentary time weekend (hours/day) | 8.4±4.1 | 9.7±3.6 | <0.001 |

Table 3 shows the change of subject number in categorical variables. The McNemar test results showed the number of subjects that had 7 hours or more screen time, sedentary time on weekdays and weekends was significantly increased (Δ12.1%, Δ19.4%, Δ14.6%, respectively, all p<0.001) within three months. The number of students with sufficient physical activity within three months was significantly diminished (Δ-13.6%, p<0.001).

**Table 3.** The change of subject number in categorical variables.

| | | 1st survey (February 2020) | 2nd survey (May 2020) | p |
|---|---|---|---|---|
| Screen time | ≥7 hours/day | 106 | 131 | <0.001 |
| | <7 hours/day | 100 | 75 | |
| Physical activity | ≥600 METs | 113 | 85 | <0.001 |
| | <600 METs | 93 | 121 | |
| Sedentary time weekday | ≥7 hours/day | 130 | 170 | <0.001 |
| | <7 hours/day | 76 | 36 | |
| Sedentary time weekend | ≥7 hours/day | 124 | 154 | <0.001 |
| | <7 hours/day | 82 | 52 | |

Legend: METs - metabolic equivalents

Figure 1 describes the most used subjects before (A) and during the pandemic (B). The Line was the most popular application before the pandemic, but the users dropped to almost half (Δ-37). Other applications (YouTube, Instagram, Twitter, etc.) were more consistent and tended to be changed slightly.

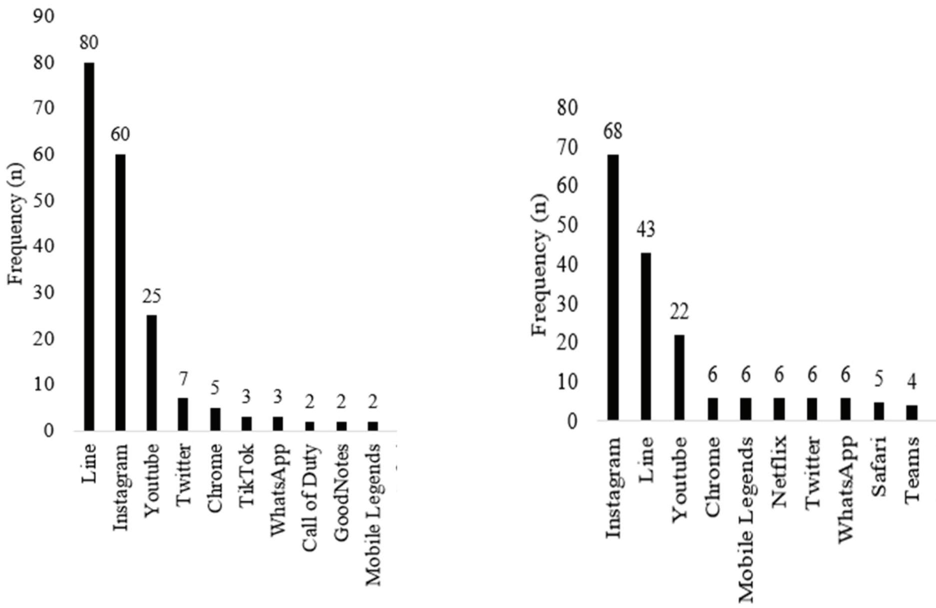


FIGURE 1. The top 10 most used application in February (A) and in May (B)

## Discussion

This study might be one of the very few that evaluated the change of activity behaviour during the Covid-19 pandemic. The change towards more screen time, sedentary time, and sufficient physical activity will develop health problems in the future. Obesity, type 2 diabetes, hypertension, and other physical inactivity-related diseases will increase. Our study showed that daily screen time, which is sedentary time, increased significantly after three months during a pandemic while physical activity was reduced. Also, the number of subjects with higher screen time and sedentary time, and insufficient physical activity dramatically increased.

A previous study also examined the impact of the pandemic on physical activity and sedentary behaviour. A study by Dunton et al. (2018) also reported decreased physical activity and increased sedentary behaviour in children. That study did not report how much increase in sedentary time and decreased physical activity between early and during the pandemic. They considered that reduced space to play might cause reduced physical activity and increased sedentary behaviour. The lack of available space to play or other activities might also be one of the causes, in addition to adherence to LSSR policy and self-limitation to avoid contact with others.

It is indeed a paradox for people to reduce their physical activity during the Covid-19 pandemic, whereas exercise has been recommended to continue. Exercise has been recognized to impact cardiovascular function, coagulation and fibrinolytic balance, cellular oxidative stress, and immune system (Pinckard, Baskin, & Stanford, 2019; Lippi & Maffulli, 2009; Narasimhan & Rajasekaran, 2016; Dorneles, Dos Passos, Romão, & Peres, 2020). This beneficial effect of exercise, of course, can enhance the immunity to viral infection, relieve symptoms, and accelerate the recovery from Covid-19 infection.

Reduced physical activity and high sedentary time during the Covid-19 pandemic will lead to increased risk of some diseases such as diabetes, coronary heart disease, and even mortality (Huang et al., 2020; Patterson et al., 2018; Stamatakis et al., 2019). Moreover, Covid-19 is also associated with a detrimental effect on lung damage, coagulation imbalance, cardiac and kidney injury (Liu et al., 2020; Tang, Li, Wang, & Sun, 2020; Chen et al., 2020). Insufficient physical activity also increases obesity and puts obesity at higher risk of hospitalization due to Covid-19 (Dietz & Santos-Burgoa, 2020). Thus, diminishing physical activity must be avoided during the pandemic.

With a lack of available space for being physically active, WHO's recommendation for sufficient physical activity is still achievable, especially for young college students. They can use their internet-connected devices to participate in exercise through an available application, internet-delivered exercise, or online exercise class (Tate, Lyons, & Valle, 2015). Using their internet-connected devices, students can monitor and motivate themselves to stay healthy by doing appropriate physical activity.

This study indicated that most students use mobile phones for social applications, followed by entertainment applications. Also, there was a shift of most used applications, but the applications used were slightly changed in general. This indicated that the use of internet-connected devices to improve their physical activity was still lacking. Therefore, a more intensive action to encourage students to use their internet-connected devices to maintain their healthy physical activity is required.

Some advantages of this study were noted. It was held at the right time, at which the situation in the two surveys was different, although not following the initial purpose. As subjects, college students could ensure that the information provided was more valid and reliable.

Nevertheless, some limitations existed. First, the study should involve a larger sample of varied ages and work background. This fact can confirm whether different ages and jobs will have a different response in the pandemic situation. Second, the anthropometric change, such as weight and body mass index, could not be measured due to social distancing. The anthropometric change will affirm the effect of LSSR on the increased obesity prevalence.

The large-scale-social restriction (LSSR) does impact sedentary behaviour and physical activity in medical students college. Screen time and sedentary time sharply increased while physical activity dramatically decreased. Students with higher screen time and sedentary time also increased, whereas students with sufficient physical activity significantly decreased. The LSSR puts medical college students at higher risk of inactivity-related diseases.

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**Conflict of Interest**
The authors declare that there are no conflicts of interest.

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ORIGINAL SCIENTIFIC PAPER

# The Effects of Functional Exercise Training on Obesity with Impaired Glucose Tolerance

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**Abstract**

Obese individuals with impaired glucose tolerance (IGT) are at risk for developing overt diabetes and cardiovascular diseases (CVD). This study aimed to examine the effects of 12 weeks of a functional exercise training (FET) programme in obese individuals with IGT. Sixteen males and females university staff, aged 50.4±1.3 years (43 to 59 yrs) with mean BMI ≥25 kg/m$^2$ (WHO Asian Guidelines) and IGT were randomly divided into the functional exercise training (FET) group or the control (CON) group. Both groups underwent the baseline assessments, including anthropometric measurements, exercise capacity, oral glucose tolerance test (OGTT), and blood chemistry analysis. All testing was repeated at 12 weeks post-intervention. The FET groups engaged in the FET programme, and the CON group carried out normal daily physical activity, including walking. After the intervention, the FET group showed significant changes in exercise capacity, body weight (BW), BMI, waist circumference, triglycerides, fasting plasma insulin (FPI), 2 hrs glucose, and glucose AUC ($p<0.05$) while the CON group only exhibited an improvement in HDL-C ($p<0.05$). The study showed that the FET programme improves exercise capacity and alters cardiometabolic parameters. It can be an alternative form of exercise for managing obesity and improves glycaemic control in those at risk.

***Keywords:*** *cardiorespiratory fitness, functional exercise, impair glucose tolerance, obesity*

## Introduction

Impaired glucose tolerance (IGT) is a major predictor of type 2 diabetes (Alberti, 2007) and is a cardinal sign of insulin resistance (DeFronzo, & Abdul-Ghani, 2011). Those with impaired glucose tolerance (IGT) are at increased risk for developing overt type 2 diabetes and cardiovascular disease (CVD) (DeFronzo, & Abdul-Ghani, 2011). Additionally, epidemiological studies have shown an association between physical inactivity and IGT (Tapp et al., 2006). Physical inactivity alters functional capacity and normal metabolic action of insulin, including glucose transport, glycogen synthesis, and glucose oxidation (Venables, & Jeukendrup, 2009). Previous data have shown that most individuals with IGT are overweight, and up to 80% are obese (Hawley, 2004). Thus, being obese with IGT can further accelerate the risk of frank diabetes (Rai, Wadhwani, Sharma, & Dubey, 2019). The American Diabetes Association (ADA, 2002) recommends that overweight individuals with IGT undergo some kinds of lifestyle intervention to prevent the onset of type 2 diabetes.

Exercise training is often prescribed for blood glucose management (ADA, 2002; Diabetes Prevention Program, 2002). Swindell et al. (2018) showed that exercise training improves glucose transporter 4 (GLUT 4) translocation to the cell membrane, facilitating glucose transport into the cell. Regular exercise training lowers blood glucose and produces other benefits, such as increased fitness, weight reduction, improve physical function, and reduced risk for developing non-communicable diseases (NCD) (Rehn, Winett, Wisløff, & Rognmo, 2013). The investigators in the Diabetes Prevention Program (DPP) found that lifestyle intervention that included regular physical activity reduced the incidence of diabetes by 58% compared to the use of metformin in those with IGT (Sigal, Kenny, Wasserman, Castaneda-Sceppa, &

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White, 2006). The DPP study reinforced the importance of achieving ≥150 min/wk of physical activity at moderate intensity (e.g. walking) for preventing the onset of diabetes (DPP, 2002; Sigal et al., 2006). General aerobic activity such as walking can be monotonous for some people, leading to dropping out of activity participation (ACSM, 2018). Thus, adding a variety of exercise into the daily routine can add fun and promote social interaction that can make exercise more enjoyable.

We intended to investigate the effects of functional exercise training on exercise capacity, glucose metabolism, and metabolic profiles in obese individuals with IGT. The functional exercise is simple, economical, and can be carried out at a gym or at home without utilizing many pieces of equipment and can be an alternative form of exercise that complements general aerobic activity. This type of exercise trains the muscles to work together and prepares them for daily living activities (Silva-Grigoletto, Brito, & Heredia, 2014). Additionally, it strengthens the body's core and improves stability, which can result in better posture and balance (Lagally, Cordero, Good, Brown, & McCaw, 2009). This type of exercise simulates common movements that can be done at home or at work while using the upper and lower body simultaneously. Previous studies have shown that functional exercise training improved mobility in older adults (Whitehurst, Johnson, Parker, Brown, & Ford, 2005), and it significantly improved physical fitness components in male college students (Shaikh, & Mondal, 2012). However, little is known about its effects on the metabolic profiles in obese individuals.

This study aimed to investigate the effects of functional exercise training on exercise capacity, glucose metabolism, and metabolic profiles in obese individuals with IGT. We hypothesize that FET will produce favourable changes in exercise capacity, glucose metabolism, and metabolic profiles.

## Methods

*Participants*

Sixteen obese males and females supporting staff from Nakhon Ratchasima Rajabhat University age 50.4±1.3 years (43 to 59 yrs) with impaired glucose tolerance (IGT) were recruited to participate in the study; they were randomly classified into experimental (n=8) or control (n=8) groups. The obesity classification was in accordance with WHO Asian guidelines: ≥25 kg/m² is considered obese (WHO, 2000) and IGT as classified by the American Diabetes Association (ADA, 2018) as having 2-hrs glucose ≥140 mg/dL$^{-1}$ and ≤199 mg/dL$^{-1}$. The participants were contacted by the primary investigator and were invited to the orientation session where they signed informed consent, filled out the health questionnaire, underwent the screening process, performed oral glucose tolerance test (OGTT), exercise testing, and blood chemistry analysis. To be eligible for the study, the participants had to have impaired glucose tolerance, had not participated in any formal exercise for the previous six months, and be free from heart disease, hypertension, diabetes, orthopaedic, and neuromuscular problems. All the testing was performed at baseline and at 12 weeks which was similar to the previous studies by Whitehurst et al. (2005) and McNeilly et al. (2012). The study protocols and procedures were approved by the Research Ethics Review Committee for Research Involving Research Participants, Health Science Group (COA No. 230/2019), Chulalongkorn University, Thailand.

*Anthropometric measurement*

Bodyweight (kg) was assessed using the standard digital (Nagata BW-110, Taiwan). Height (cm) was measured using the standard stadiometer (Nagata BW-110, Taiwan). Bodyweight and height were measured to the nearest 0.01 kg and 0.01 cm, respectively. Body mass index (BMI) was calculated by dividing body weight in kilogram (kg) by height in metre-squared (m²). Waist circumference (cm) was measured at the horizontal plane at the iliac crest.

*Exercise capacity*

The participants underwent the Astrand maximal cycle test (ACSM, 2018) to assess their exercise capacity (Cateye-EC1600 Bicycle Ergometers, Japan). Each participant was briefed on the testing procedure, adjusted seat height, fitted with a wireless heart rate monitor (Polar model H7, Finland), and was allowed time to warm up on the cycle ergometer for three minutes with a resistance of zero watts. Following the warm up, the subject was instructed to pedal the cycle ergometer at 50 rpm for two minutes in the initial stage with a load of 100 watts (men) or 50 watts (women). After the initial stage, the workload of 50 watts (men) or 25 watts (women) was incrementally increased every three minutes until the participant reached volitional fatigue or was unable to maintain the instructed cadence. Testing was terminated in accordance with the standard guidelines (ACSM, 2018). The exercise capacity was calculated for maximal oxygen uptake ($VO^2$ max) and metabolic equivalent (MET) value.

*OGTT and Blood chemistry analysis*

After an overnight fast, a 75-g OGTT was performed on the participants, and blood samples were obtained at baseline plasma glucose and insulin and every 30 min interval for 120 min after an oral glucose load (Slentz et al., 2016). Glucose areas under the curve (AUC) was calculated using the trapezoidal principle. Early and total phase glucose tolerances were calculated as total area under the curve (tAUC) using the trapezoidal model (Matthews et al., 1985). The homeostasis model assessment of insulin resistance (HOMA) was calculated as described previously (Matthews et al., 1985; Vogeser et al., 2007). Blood samples taken at baseline were also analysed for HbA1C, total cholesterol (TC), triglycerides (TG), LDL-Cholesterol (LDL-C), HDL-Cholesterol (HDL-C). Insulin resistance was estimated by the homeostatic model assessment (HOMA-IR). Blood samples were analysed for glucose, HbA1C; the lipid profile was determined using hexokinase method was measured using a cobas6000 (c501) clinical chemistry analyser system and insulin was determined using electrochemiluminescence immunoassay; the ECLIA method was measured using a cobase411 insulin analyser. Blood samples were measured by the clinical laboratory (Lab Plus Professional Laboratory Ultimate Service, Theptarin Hospital, Thailand).

*Exercise Programme*

For the 12-week study, the participants were randomly assigned into two groups: functional exercise training (FET) and control (CON). The FET group engaged in the functional exercise training in a circuit manner; they had to complete three circuits of exercises in a session (Whitehurst et al., 2005). A circuit consisted of 12 exercises that had to be performed consecutively with 60 seconds of rest in between each exercise; the functional exercise programme details are described in Table 1 and Figure 1. Each exercise session consisted of a 10 minute warm up followed by 30 minutes of exercise session and concluded with a cool down (10 min). The participants engaged in supervised exercise sessions three times per week and performed the same exercise routine at home two times per week. All group exercise sessions were monitored and supervised by the primary investigator to ensure safety and proper technique. The task difficulty was increased by having participants balance on one leg, perform a choreographed movement, and add external hands weights. At every three-week increment, from week 4 to week 12, 2 water bottles filled with sand weighing 335 g, 500 g, and 750 g each, respectively, were added as an external weight to increase resistance while performing these exercises (illustrated in Figure 1). The participants were instructed to perform a warm up, cool down, and stretching for every exercise session.

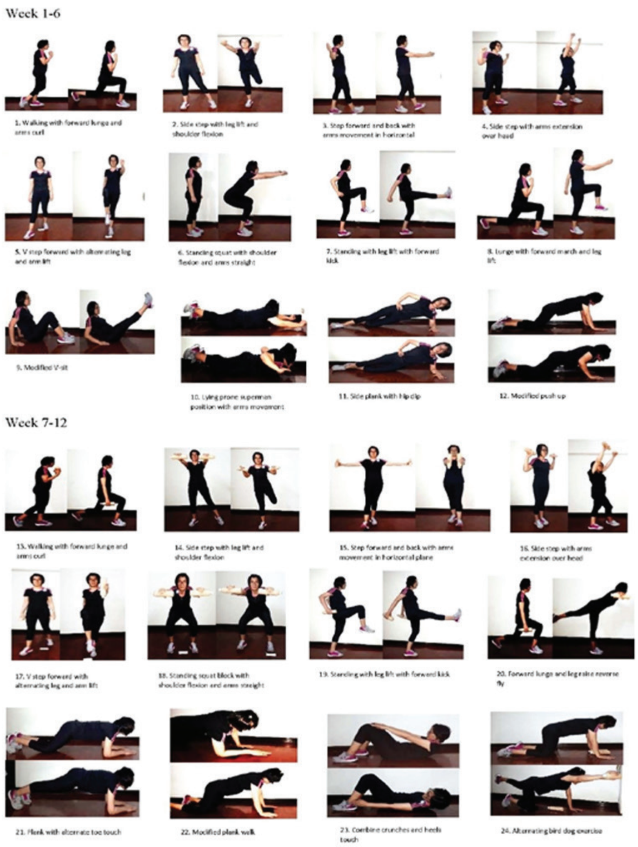

FIGURE 1. Description of Functional Exercise Training Programme

The participants in the CON group were instructed to continue their normal daily activity and were encouraged to engage in a walking routine on their own. All participants in both groups were educated on healthy diet. A text messaging group was set up for two-way communication to provide assistance and answer any questions.

**Table 1.** Description of Functional Exercise Training Programme

| Warm up/Cool down | Week 1-6 | Week 7-12 | Remarks |
|---|---|---|---|
| Dynamic movement and stretching such as marching place, walking, shoulders and arms movement | 1. Walking with forward lunge and arms curl | 13. Walking with forward lunge and arms curl | • The participants were instructed to perform the movement in a controlled manner. |
| Static stretching of the upper and lower extremities | 2. Sidestep with leg lift and shoulder flexion | 14. Sidestep with leg lift and shoulder flexion | • A metronome was used to control the movement, and the pace was set at 100-110 beats/min. |
| | 3. Step forward and back with arm movement in a horizontal plane | 15. Step forward and back with arm movement in a horizontal plane | |
| | 4. Sidestep with arm extension over head | 16. Sidestep with arm extension over head | • Week 1-3: exercise with bodyweight alone. |
| | 5. V step forward with alternating leg and arm lift | 17. V step forward with alternating leg and arm lift | |

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| Warm up/Cool down | Week 1-6 | Week 7-12 | Remarks |
|---|---|---|---|
| | 6. Standing squat with shoulder flexion and arms straight | 18. Standing squat block with shoulder flexion and arms straight | • Week 4-6: exercise with 2 water bottles filled with sand weighing 335 g each. |
| | 7. Standing with leg lift with forward kick | 19. Standing with leg lift with forward kick | |
| | 8. Lunge with forward march and leg lift | 20. Forward lunge and leg raise reverse fly | • Week 7-9: exercise with 2 water bottles filled with sand weighing 500 g each. |
| | 9. Modified V-sit | 21. Plank with alternate toe touch | |
| | 10. Lying prone superman position with arms movement | 22. Modified plank walk | • Week 10-12: exercise with 2 water bottles filled with sand weighing 750 g each. |
| | 11. Side plank with hip dip | 23. Combine crunches and heels touch | |
| | 12. Modified push up | 24. Alternating bird dog exercise | |

Legend: The participants performed 12 exercises per circuit and completed 3 circuits of exercises (12 exercises equal 1 circuit). Each exercise was performed at 3 sets of 10 repetitions.

*Final Testing*

All testing was repeated after 12 weeks of intervention. Due to the quick change in glucose metabolism after the cessation of exercise, OGTT and blood sampling were conducted within 36 hours of the final exercise bout.

*Statistical Analysis*

Both groups baseline characteristics were analysed, and variables are presented as the mean ± SD. The dependent t-test was used to detect the intragroup differences over time for each variable. The extent of the change in variables was calculated by subtracting the baseline data with post-12 weeks of intervention. The differences in variables between the two groups (FET and CON) were compared using the independent t-test. Statistical significance was set at $P<0.05$. All statistical analyses were performed using SPSS statistical software version 23 (IBM SPSS Inc., Chicago, USA).

## Results

*Baseline measurements*

Participants' characteristics in the FET and CON groups are presented in Table 2. The participants were similar in most variables at baseline. The FET group exhibited significantly higher FPG and glucose AUC at baseline than the CON group ($p<0.05$).

**Table 2.** Baseline characteristics of FET and CON groups

| Variables | Total (n=16) Mean±SD | FET (n=8) Mean±SD | CON (n=8) Mean±SD |
|---|---|---|---|
| Age (yrs) | 50.4±1.3 | 50.4±1.6 | 50.4±2.3 |
| BW (kg) | 70.5±2.3 | 68.4±2.5 | 72.7±3.9 |
| Ht (cm) | 159.3±1.8 | 156.9±2.2 | 161.7±2.7 |
| BMI (kg.m$^{-2}$) | 27.7±0.5 | 27.7±0.5 | 27.7±0.8 |
| Waist circumference (cm) | 89.7±1.9 | 88.9±2.0 | 90.5±3.3 |
| $VO_2$max (ml·kg·min$^{-1}$) | 29.3±1.3 | 29.8±1.5 | 28.8±2.2 |
| $VO_2$max (MET) | 8.7±0.4 | 8.5±0.4 | 9.0±0.8 |
| Total cholesterol (mg.dL$^{-1}$) | 206.9±7.4 | 209.3±13.5 | 204.6±7.1 |
| Triglycerides (mg.dL$^{-1}$) | 130.7±14.8 | 135.4±18.8 | 126.0±24.1 |
| HDL-C (mg.dL$^{-1}$) | 51.9±3.0 | 50.9±5.2 | 52.9±3.4 |
| LDL-C (mg.dL$^{-1}$) | 147.8±6.8 | 149.5±11.5 | 146.0±8.1 |
| FPG (mg.dL$^{-1}$) | 91.3±2.5 | 97.3±3.6* | 85.3±1.7 |
| HbA1c (%) | 5.6±0.1 | 5.6±0.2 | 5.5 ±0.2 |
| FPI (pmol/L) | 79.3±12.2 | 88.6±22.3 | 70.1±10.6 |
| 2-hrs glucose (mg.dL$^{-1}$) | 163.4±4.9 | 171.1±6.0 | 155.8±7.1 |
| Glucose AUC | 20935.3±651.9 | 22254.4±884.3* | 19616.3±736.4 |
| HOMA-IR | 2.6±0.5 | 3.1±0.9 | 2.1±0.3 |

Legend: * Statistically significant between-group baseline training (p<.05); BW-Body weight; Ht-Height; FPG-fasting plasma glucose; glucose AUC-glucose area under the curve; HbA1c-Glycosylate haemoglobin; FPI-fasting plasma insulin and HOMA-IR-homeostasis model assessment of insulin resistance

*Anthropometric variable and exercise capacity*

After 12 weeks of intervention, the FET group showed a significant decrease in BW ($p<0.05$), BMI ($p<0.05$), and waist circumference ($p<0.05$). A significant improvement in functional capacity, as shown by the increase in VO2max and MET ($p<0.05$) were observed in this group. Conversely, no changes were observed in the previously mentioned variables in the CON group (Table 3).

**Table 3.** Changes in body weight, body mass index; BMI, waist circumference, $VO_2$max and lipid profiles at baseline and after 12 weeks of training in FET and CON groups

| Variables | Within-group comparisons | | |
|---|---|---|---|
| | Baseline (Mean±SD) | 12 weeks (Mean±SD) | p-value |
| BW (kg) | | | |
| FET (n=8) | 68.35±2.55 | 65.55±2.59* | 0.008 |
| CON (n=8) | 72.69±3.92 | 72.50±3.94 | 0.780 |
| BMI (kg.m-$^{2}$) | | | |
| FET (n=8) | 27.73±0.52 | 26.55±0.54* | 0.005 |
| CON (n=8) | 27.65±0.80 | 27.60±0.82 | 0.847 |
| Waist circumference (cm) | | | |
| FET (n=8) | 88.88±2.02 | 84.31±2.53* | 0.003 |
| CON (n=8) | 90.50±3.30 | 90.00±3.33 | 0.419 |
| VO2max (ml/kg/min) | | | |
| FET (n=8) | 29.83±1.51 | 33.55±1.28* | 0.036 |
| CON (n=8) | 28.79±2.20 | 31.40±2.83 | 0.227 |
| VO2max (MET) | | | |
| FET (n=8) | 8.52±0.43 | 9.59±0.37* | 0.036 |
| CON (n=8) | 8.97±0.81 | 9.48±6.11 | 0.931 |
| Total cholesterol (mg.dL$^{-1}$) | | | |
| FET (n=8) | 209.25±13.50 | 204.25±12.50 | 0.515 |
| CON (n=8) | 204.63±7.10 | 218.50±8.66 | 0.093 |
| Triglycerides (mg.dL$^{-1}$) | | | |
| FET (n=8) | 135.38±18.82 | 123.63±20.65* | 0.046 |
| CON (n=8) | 126.00±24.11 | 115.88±26.89 | 0.190 |
| HDL-C (mg.dL$^{-1}$) | | | |
| FET (n=8) | 50.88±5.17 | 53.45±5.46 | 0.096 |
| CON (n=8) | 52.88±3.42 | 59.00±3.60* | 0.008 |
| LDL-C (mg.dL$^{-1}$) | | | |
| FET (n=8) | 149.50±11.54 | 137.38±10.27 | 0.165 |
| CON (n=8) | 146.00±8.09 | 147.75±8.43 | 0.800 |

Legend: * Statistically significant within-group change after 12 weeks training ($p<.05$)

*Blood chemistry*

The FET group showed a significant decrease in triglycerides ($p<0.05$), FPI ($p<0.05$), 2-hrs glucose ($p<0.05$), and glucose AUC ($p<0.05$). The CON group showed a significant improvement in HDL-C ($p<0.05$) and 2-hrs glucose ($p<0.05$) at post-intervention (Table 3, 4).

**Table 4.** Changes in metabolic and glycaemic at baseline and after 12 weeks of training in FET and CON groups

| Variables | Within-group comparisons | | p-value |
|---|---|---|---|
| | Baseline (Mean±SD) | 12 weeks (Mean±SD) | |
| FPG (mg.dL$^{-1}$) | | | |
| FET (n=8) | 97.25±3.61 | 95.63±2.12 | 0.509 |
| CON (n=8) | 85.25±1.73 | 90.13±2.97 | 0.070 |
| HbA1c (%) | | | |
| FET (n=8) | 5.61±0.15 | 5.53±0.16 | 0.613 |
| CON (n=8) | 5.51 ±0.17 | 5.49±0.12 | 0.722 |

*(Continued on next page)*

*(continued from previous page)*

| Variables | Within-group comparisons | | p-value |
|---|---|---|---|
| | Baseline (Mean±SD) | 12 weeks (Mean±SD) | |
| FPI (pmol/L) | | | |
| FET (n=8) | 88.63±22.27 | 50.31±8.62* | 0.048 |
| CON (n=8) | 70.06±10.62 | 61.04±10.15 | 0.231 |
| 2-hrs glucose (mg.dL$^{-1}$) | | | |
| FET (n=8) | 171.13±5.99 | 112.38±9.96* | 0.000 |
| CON (n=8) | 155.75±7.12 | 125.13±9.27* | 0.007 |
| Glucose AUC | | | |
| FET (n=8) | 22254.38±884.28 | 18528.75±932.48* | 0.003 |
| CON (n=8) | 19616.25±736.40 | 18442.50±1063.63 | 0.131 |
| HOMA-IR | | | |
| FET (n=8) | 3.13±0.86 | 1.72±0.32 | 0.060 |
| CON (n=8) | 2.13±0.35 | 1.97±0.33 | 0.387 |

*Absolute changes*

The FET group exhibited significant absolute changes in BW ($p<0.05$), BMI ($p<0.05$), waist circumference ($p<0.05$), 2-hrs glucose ($p<0.05$), and glucose AUC ($p<0.05$) when compared to the CON group (Table 5).

The Glucose AUC was significantly decreased with training at 12 weeks in the FET group ($p<0.05$) Figure 2.

**Table 5.** Absolute changes in body weight, body mass index; BMI, waist circumference, $VO_2$max, lipid profiles, metabolic and glycaemic after 12 weeks training between FET and CON groups

| Variables | FET (n=8) (Mean±SD) | CON (n=8) (Mean±SD) | p-value |
|---|---|---|---|
| BW (kg) | -2.80±0.77* | -0.19±0.65 | 0.021 |
| BMI (kg.m-$^{2}$) | -1.18±0.30* | -0.05±0.25 | 0.011 |
| Waist circumference (cm) | -4.56±1.05* | -0.50±0.58 | 0.005 |
| VO2max (ml/kg/min) | 3.73±1.44 | 2.62±1.98 | 0.657 |
| VO2max (MET) | 1.07±0.41 | 0.75±0.56 | 0.658 |
| Total cholesterol (mg.dL$^{-1}$) | -5.00±7.30 | 13.88±7.13 | 0.085 |
| Triglycerides (mg.dL$^{-1}$) | -11.75±4.85 | -10.13±6.97 | 0.851 |
| HDL-C (mg.dL$^{-1}$) | 2.88±1.49 | 6.13±1.66 | 0.168 |
| LDL-C (mg.dL$^{-1}$) | -12.13±7.82 | 1.75±6.65 | 0.198 |
| FPG (mg.dL$^{-1}$) | -1.63±2.34 | 4.88±2.29 | 0.067 |
| HbA1c (%) | -0.09±0.17 | 0.09±0.15 | 0.440 |
| FPI (pmol/L) | -38.28±16.02 | -9.03±6.88 | 0.126 |
| 2-hrs glucose (mg.dL$^{-1}$) | -58.75±7.33* | -30.63±8.12 | 0.022 |
| Glucose AUC | -3725.63±856.78* | -1173.75±686.53 | 0.036 |
| HOMA-IR | -1.42±0.63 | -0.16±0.17 | 0.091 |

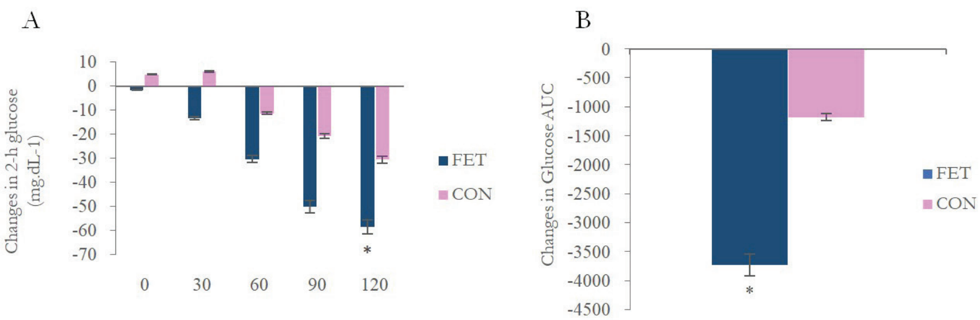


FIGURE 2. A. Training-induced changes in glucose values at each time point during OGTT; B. Change in glucose AUC following 12 weeks of training and glucose AUC. *Statistically significant (p<.05).

## Discussion

This study shows that functional exercise training (FET) performed in a circuit manner resulted in improved exercise capacity, expressed in VO2 max and MET. The participants in the FET group significantly increased their exercise capacity by 1 MET from baseline ($p<0.05$); on the other hand, the CON group did not show a significant improvement in this parameter. It is conceivable that this change occurred as a result of repetitive physical training that induced physiological response in favour of cardiorespiratory endurance. Our findings are inconsistent with those of Whitehurst et al. (2005) that looked at the benefits of functional exercise training in older adults. Their findings showed that functional exercise performed in a circuit manner improved the timed walk test by 7.4% from baseline, indicating cardiorespiratory fitness improvement. The FET programme utilized large muscle groups for movement and was done continuously for a certain amount of time which elevated exercise heart rate and stimulated hemodynamic changes. When performed on a regular basis for 12 weeks, it caused physiological adaptation and improved fitness for this group.

Improvement in exercise capacity translates into a better quality of life in those with risk factors (e.g. impaired glucose tolerance) and/or chronic medical conditions such as heart disease, diabetes, hypertension, or obesity (E. Teixeira-Lemos, Nunes, F. Teixeira, & Reis, 2011). A previous study by Myers et al. (2002) showed that an improvement in fitness over time yielded a better prognosis and a marked reduction in the risk of death from all causes. The result of this 12 weeks study provides evidence that the FET programme can result in fitness gain when compared to the CON group that carried out the usual walking routine. The absolute change of 1 MET may not appear substantial, but the benefit is clinically significant. A meta-analysis conducted by Lee et al. (2011) shows that for each MET increase in exercise capacity is associated with a 15% reduction in risk of all-cause mortality and a 13% reduction in the future risk of CVD and CHD events. Fit individuals have lower all-cause and CVD mortality risk than unfit counterparts, regardless of adiposity classification and medical conditions. Thus, the improvement in exercise capacity showed in our FET group will result in a better prognosis for these individuals.

While the FET group's triglycerides concentration significantly reduced ($p<0.05$) at post-training, no significant change was observed in total cholesterol, HDL-C, and LDL-C. It is speculated that the change in triglycerides concentration may have been attributed to high energy expenditure during the exercise training. The FET group performed exercise in a circuit manner that requires major muscle groups to work in a coordinated fashion, which yielded high energy expenditure and higher fatty acid oxidation. Similarly, a study by Westcott (2012) showed that the reduction in triglyceride concentration is related to sufficient energy expenditure and previous level of physical activity, which is inconsistent with our findings. The participants in the FET group were sedentary upon entering the study; thus, engaging in a prescribed functional exercise training would have increased their activity level from sedentary to active, which may explain the observed reduction in triglycerides concentration.

In contrast, the CON group exhibited significant changes in HDL-C ($p<0.05$) at the end of the 12 weeks. It is widely accepted that HDL-C is inversely correlated with heart disease, and the improvement of HDL-C is related to the volume of physical activity and exercise (Durstine, Grandjean, Cox, & Thompson, 2002). The participants in the CON group were instructed to carry out their usual walking routine daily. It is possible that these individuals were walking in greater quantities, which resulted in the HDL-C change during the study. Our finding agrees with that of Koba et al. (2011), who showed that HDL-C change has a positive correlation with the amount of walking distance per week, and it increases in a dose-dependent manner.

In the current study, the body weight, BMI, waist circumference, fasting plasma insulin, 2-hrs glucose, and glucose AUC of the FET group were significantly decreased ($p<0.05$) at 12 weeks. However, when the absolute changes in these parameters were compared between the two groups, the FET group shows significant reductions in body weight, BMI, waist circumference, 2-hrs glucose, and glucose AUC ($p<0.05$). The reduction in 2-hrs glucose and glucose AUC (Figure 2) is postulated to be related to the body weight reduction and the decrease in waist circumference. Our result is consistent with that of McNeilly et al. (2012), in which the research group discovered that weight loss through moderate exercise training resulted in a reduction in blood biomarkers for cardiovascular risks. In our study, weight loss induces changes in many cardiometabolic parameters and improved insulin sensitivity which helps to lower the glucose appearance in the blood. The Diabetes Prevention Programme (DPP) (2002) showed that a 7% reduction in body weight from baseline has a significant impact on the glucose metabolism in prediabetes. The data from O'Gorman et al. (2006) showed that acute exercise training improves GLUT-4 response, which facilitates the glucose transport into the cell, which lowers blood glucose. Our participants in the FET group performed exercise for 12 weeks, which could have improved the GLUT-4 effectiveness that would result in lower 2-hrs glucose and glucose AUC ($p<0.05$).

Additionally, the fasting plasma insulin in the FET group significantly changed ($p<0.05$) at the end of the study, but the magnitude of change was not statistically significant compared to the CON group. It is speculated that functional exercise training exerted a certain effect on plasma insulin response. Our finding is supported by the study conducted by Rice, Janssen, Hudson, and Ross (1999), which concluded that physical training exerts a lowering effect on insulin concentrations in the plasma in obesity. Decreased plasma insulin concentration after physical training could be due to either decreased insulin secretion or an increase in peripheral clearance of insulin rate, or both (Eriksson et al., 1998; Pratley et al., 2000).

### *Limitation*

The authors understand that the small sample size is a limitation of this study. It is difficult to find and recruit obese individuals with IGT that are not taking any medications or have other comorbidities. Despite the small sample size, the study was able to show the effects of 12 weeks of functional exercise training.

## Conclusion

This study illustrates that 12 weeks of functional exercise training performed in a circuit manner is an effective means of inducing body weight change, increasing exercise capacity, and alters the cardiometabolic variables such as triglycerides HDL-C, 2-hrs glucose, and glucose AUC. It appears that the functional exercise training programme can be utilized as a cost-effective therapeutic means to help manage obesity and impaired glucose metabolism. Exercise training remains a cornerstone intervention for blood glucose management. The functional exercise training programme can be an alternative form of exercise for obese individuals.

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**Conflict of Interest**
The authors declare the absence of conflict of interest.

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SportMont

ORIGINAL SCIENTIFIC PAPER

# The Effect of Transactional and Transformational Leadership Behaviours on Factors Establishing Teams' Cultural Aspects to Promote Organizational Effectiveness

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**Abstract**

This study aimed to analyse the relationships between transactional leadership, transformational leadership, and organizational culture in university soccer teams. First, the study focused on the transactional and transformational leadership behaviours of soccer coaches in university soccer teams using Multifactor Leadership Questionnaire 5X (MLQ 5X) by Bass and Avolio (1990) as an instrument. Second, the cultural factors of the university soccer teams were measured using the Organizational Culture Assessment Questionnaire (OCAQ, Sashkin, 2001). Using random cluster sampling, 316 players in university soccer teams participated in the study. The study results showed that both transactional and transformational leadership had a positive effect on organizational team culture, but the effect of transactional leadership behaviour appeared more extensive than transformational leadership behaviour did in the present study. In a Korean context, it remains undeniable that strong transactional leadership behaviours exist, and they exert significant influence on university soccer team culture, but the effect of transformation leadership behaviours was also obvious on team culture. It could be concluded that the combination of transactional and transformational leadership is likely to be a key factor in the successful development of organizational effectiveness.

***Keywords:*** *transactional leadership, transformational leadership, organizational culture, MLQ 5X, OCAQ, university soccer teams*

## Introduction

*Needs and purpose of the study*

As the popularity of soccer grows, interests in it become more detailed. Fans have come to be concerned about not only what is seen superficially but also what is happening behind the games, such as personal interest stories about soccer players, game style, game strategies, coaches, and similar. Since Guus Hiddink, the head coach of South Korea's national team in the 2002 World Cup, gained huge popularity nationwide, interest in leadership and team culture fostered by the leader drew increased attention (Jung & You, 2020). Previously, Korean soccer fans' major interest was in who the competent players on the team are and in which region of the country the team is based. With the appearance of Hiddink, soccer fans came to consider the role of a coach in the soccer game and realized the entertaining factors that a coach can make. In other words, the concept of "leadership" manifested itself in Korean soccer fans' perception. Leaders can help shape and maintain the desired or ideal organizational culture, according to Weese (1995), and organization culture is

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one of the most important factors that may bring success to the team. This study examines what leadership behaviours of a coach predict team culture. Specifically, 1) how the transactional coach leadership behaviours predict the team culture and 2) how the transformational coach leadership behaviours predict the team culture.

*Transactional leadership*

According to Bass (2008), transactional leadership has been described as an exchange of requests or needs to be satisfied between the leader and the followers. This kind of leader works to clarify the roles and task requirements of followers recognizes the needs and desires of subordinates and make it clear that if they work to fulfil their job requirements, then those needs and desires will be met. Bass (2008) stated that a transactional leader operates within the existing system or culture, has a preference for risk avoidance, pays attention to time constraints and efficiency, and generally prefers process over substance as a means for maintaining control.

*Transformational leadership*

Many scholars contend that leadership cannot be simply explained as the notion of social exchange between leader and followers. Leadership must address the follower's sense of self-worth to have the follower truly committed and involved in the effort at hand (Bass & Riggio, 2006). Burns (1978) is often cited as the source of the concepts of this approach to leadership theory; he regarded transformational leadership as a contrast to transactional leadership. Cascio (1995) noted that as today's multicultural organizations are interrelated with each other, transformational leadership is even more necessary. Yukl (2006) reported that leaders with transformational leadership have a clear vision and communicate it to followers, act confidently and are optimistic, articulate confidence to followers, lead followers by example, use symbolic actions to emphasize key values, and take advantage of the empowerment of followers to achieve the vision. He also stated that transformational leaders communicate a clear vision of the potential and priority of an organization. The vision helps followers see what an organization can accomplish, helps followers understand their purpose in the organization, and helps guide followers' actions and decisions. Communicating the vision is not enough; the leader must also convince his followers of its feasibility and gain their agreement.

*Leadership and organizational culture*

Culture is a dynamic phenomenon and influenced by leader behaviour. Leaders are those who help shape the culture. Leadership and culture are two sides of the same coin. Cultural norms define how an organization will define leadership and leaders create and manage culture. Leadership and culture are conceptually intertwined with each other (Schein, 2004). MacIntosh and Doherty (2005) emphasized that organizational culture is a shared understanding and acceptance among staff members of what is valued and expected in an organization; thus, organizational culture cannot be determined from above; instead, it is directed. Therefore, cultural understanding is essential for all the organization members, especially for the leaders (Schein, 2004).

Many organizational cultures in sport researchers have acknowledged the valuable role of transformational leadership (Arthur, Wagstaff, & Hardy, 2017) and coaching (Turnnidge & Côté, 2018). You (2020) demonstrated the leadership of Park Hangseo coach in the Vietnamese National Soccer Team and emphasized that leaders with appropriate leadership help overcome difficulties that a sport team faces. This perspective concerns the management of meaning and emphasizes culture, and thus more attention to values and emotions. Organizational leaders actively cultivate the symbolic significance of shared meaning, a common history, a golden age, idiosyncratic leaders, and dramatic results. This is different from that of the transactional approaches, which focuses on behavioural typologies, coach-athlete relationships, and outcomes. Frontiera (2010) also uncovered leadership and organizational culture transformation in professional sport. He understood how leaders in professional sport changed culture, and leaders were aware of different elements of organizational culture.

## Methods

*Participants and data collection*

The population of this study was all of the 2600 players of 72 university soccer teams in the U-league in Korea. With the use of random sampling, a total of 350 questionnaires were distributed, of which 332 were collected. Among those collected, 16 had incomplete answers. After eliminating the 16 incomplete questionnaires, 316 questionnaires were retained for the study for subsequent analysis. As there were 32 items in MLQ and 24 in OCAQ, the sample size of 316 was adequate to meet the criteria. Therefore, responses of 316 players from 2600 players of university soccer teams were used in this research.

*Instrument*

To assess the leadership behaviour and organizational culture, MLQ and OCAQ were chosen for the study. Both were developed in English originally, so the researcher adapted Song's (2002) Korean version to administer appropriately to the Korean university setting for the present study.

The survey instrument used to identify leadership style is Multifactor Leadership Questionnaire 5X developed by Bass and Avolio (1990), and it came to be an industry standard in education and the private sector during the 1990s (Avolio, Bass, & Jung, 1999). It suggests the most validated and efficient measure of a full range of leadership behaviour in comparison to the original MLQ in 1985 with 90 items. MLQ 5X consists of 45 items, including the twelve Full Range Leadership styles, rater, and leader forms. The survey relies on Likert-scale responses ranging from frequently, if not always (5), fairly often (4), sometimes (3), once in a while (2), to not at all (1).

The questions of MLQ 5X measure four components: employees' perceptions of transformational leadership factors, transactional leadership factors, laissez-faire leadership factors and outcomes of leadership. Transformational leadership measures five components: idealized influence (attributed), idealized influence (behaviour), inspirational motivation, intellectual stimulation, and individualized consideration. Transactional leadership measures three components: contingent rewards, management by exception (active) and management by exception (passive). As this study focused on transactional and transformational leadership style, the researcher removed questions about the laissez-faire leadership and outcomes scale, so the total number of survey questions was reduced from 45 to 32.

Sashkin (2001) developed an instrument called the Organizational Culture Assessment Questionnaire (OCAQ) in order to identify and quantitatively measure the type and strength of the culture within an organization based on a framework and theory of action in social systems by Parsons (1960). OCAQ is composed of five factors with six items; each item is scored on a five-point Likert scale ranging from 5 "completely true", 4 "mostly true", 3 "partly true", 2 "slightly true", to 1 "not true." As was the same with MLQ 5X, questions in OCAQ decreased from 30 to 24, following the removal of six questions in the customer orientation factor because university students are not generally regarded as the customer of a coach in the Korean context.

*Data analysis*

The data were analysed using SPSS 23.0. Multiple regressions were used to analyse the research questions. Independent variables were transactional leadership behaviours and transformational leadership behaviours. The dependent variables were the five cultural factors. Exploratory factor analysis (EFA) was performed to determine how well the measured variables presented a unidimensional construct. Also, Cronbach's alpha was used to assess reliability. All the statistical significance tests were performed at an alpha level of .05.

## Results

*Exploratory factor analyses and the reliability of the survey instruments*

An EFA of the MLQ for preferred and actual leadership behaviour was also performed. Thirty-one items for each were chosen to be tested. Like an EFA of OCAQ, principal component analysis with VARIMAX rotation was conducted, and the results revealed seven factors for each MLQ, which supports the proposed model of the study. The Bartlett Test of Sphericity showed that the result of the EFA was statistically significant, indicating that the correlation matrix had significant correlations among variables. Additionally, the Kaiser-Meyer-Olkin score of MLQ for preferred leadership behaviour came out as .864, and for actual leadership behaviour, it was .887, which is considered valid. The construct seemed reliable as Cronbach's alpha for all factors were over .7. Table 1 summarizes the results of the EFA.

**Table 1.** Exploratory Factor Analysis of MLQ 5X for Leadership Behaviours

| Attributes | | Factor 1 | Factor 2 | Factor 3 | Factor 4 | Factor 5 | Factor 6 | Factor 7 |
|---|---|---|---|---|---|---|---|---|
| Factor 1: Charisma | Q19 | **.865** | .162 | .108 | .138 | -.015 | .142 | .052 |
| | Q3 | **.852** | .114 | .058 | .133 | -.042 | .170 | .083 |
| | Q21 | **.838** | .215 | .020 | .126 | .005 | .040 | .037 |
| | Q30 | **.836** | .164 | .085 | .117 | -.015 | .146 | .086 |
| | Q16 | **.828** | .166 | .145 | .075 | -.063 | .144 | .100 |
| | Q5 | **.826** | .158 | .141 | .133 | -.019 | .100 | .077 |
| | Q12 | **.523** | -.132 | .031 | .064 | .006 | .094 | .052 |
| Factor 2: Contingent Reward | Q14 | .181 | **.864** | .058 | .112 | -.075 | .278 | .062 |
| | Q9 | .110 | **.857** | .049 | .110 | -.052 | .156 | .056 |
| | Q1 | .186 | **.854** | .062 | .127 | -.046 | .146 | .063 |
| | Q31 | .160 | **.844** | .031 | .137 | -.035 | .239 | .046 |
| Factor 3: Inspirational Motivation | Q32 | .122 | .028 | **.906** | .024 | .054 | .085 | .043 |
| | Q7 | .127 | .048 | **.894** | .005 | .067 | .106 | .101 |
| | Q24 | .079 | .071 | **.889** | .073 | .053 | .069 | .079 |
| | Q11 | .121 | .035 | **.889** | .032 | .007 | .082 | .053 |
| Factor 4: Individualized Consideration | Q26 | .212 | .128 | .025 | **.903** | -.174 | .158 | .078 |
| | Q17 | .149 | .122 | .055 | **.877** | -.098 | .145 | .060 |
| | Q13 | .154 | .103 | -.009 | **.877** | -.077 | .114 | .077 |
| | Q28 | .186 | .138 | .084 | **.823** | -.188 | .160 | .036 |
| Factor 5: Management-by-Exception Passive | Q3 | -.027 | -.022 | .050 | -.145 | **.911** | -.018 | -.018 |
| | Q15 | -.018 | -.034 | .014 | -.111 | **.906** | -.086 | .044 |
| | Q10 | -.004 | -.034 | .036 | -.067 | **.883** | -.048 | .061 |
| | Q18 | -.046 | -.092 | .077 | -.130 | **.879** | -.001 | .009 |
| Factor 6: Intellectual Stimulation | Q29 | .202 | .188 | .115 | .171 | -.068 | **.849** | .087 |
| | Q2 | .187 | .238 | .146 | .122 | -.057 | **.826** | .156 |
| | Q27 | .168 | .225 | .073 | .148 | -.068 | **.812** | .067 |
| | Q6 | .215 | .189 | .074 | .154 | .007 | **.770** | -.020 |

*(Continued on next page)*

*(continued from previous page)*

| Attributes | | Factor 1 | Factor 2 | Factor 3 | Factor 4 | Factor 5 | Factor 6 | Factor 7 |
|---|---|---|---|---|---|---|---|---|
| Factor 7: Management-by-Exception Active | Q20 | .123 | .012 | .036 | .015 | .008 | .092 | **.886** |
| | Q22 | .036 | -.020 | .090 | .079 | .044 | .112 | **.857** |
| | Q4 | .101 | .077 | .036 | .083 | .085 | .107 | **.829** |
| | Q25 | .082 | .097 | .076 | .029 | -.031 | -.061 | **.599** |
| KMO | | | | | .887 | | | |
| Bartlett's Test of Sphericity | | | | | .000 (sig) | | | |
| Initial Eigen Value | | 4.985 | 3.381 | 3.358 | 3.350 | 3.335 | 3.110 | 2.695 |
| Variance (%) | | 16.081 | 10.905 | 10.834 | 10.808 | 10.757 | 10.031 | 8.694 |
| CumulativeVariance (%) | | 16.081 | 26.987 | 37.820 | 48.628 | 59.385 | 69.416 | 78.110 |
| Cronbach's Alpha | | .793 | .929 | .891 | .940 | .926 | .908 | .745 |

An EFA of OCAQ was performed to verify whether all measured variables were related to each factor-by-factor loading estimates as well as whether each measured variable was loaded highly on only one factor and had a smaller loading on the other factor. Twenty-four items were chosen to be tested. Principle component analysis with VARIMAX rotation was conducted, and the results revealed four factors that support OCAQ used for the study.

**Table 2.** Exploratory Factor Analysis of OCAQ

| Attributes | | Factor 1 | Factor 2 | Factor 3 | Factor 4 |
|---|---|---|---|---|---|
| Factor 1: Achieving Goals | Q18 | **.874** | .248 | .157 | -.020 |
| | Q2 | **.865** | .305 | .221 | .003 |
| | Q14 | **.851** | .170 | .081 | .014 |
| | Q22 | **.844** | .250 | .195 | -.037 |
| | Q10 | **.822** | .261 | .137 | -.005 |
| | Q6 | **.781** | .140 | .088 | .023 |
| Factor 2: Managing Change | Q21 | .275 | **.867** | .104 | .057 |
| | Q13 | .253 | **.863** | .090 | -.006 |
| | Q1 | .288 | **.854** | .222 | .016 |
| | Q9 | .238 | **.850** | .140 | .055 |
| | Q5 | .204 | **.783** | .135 | -.022 |
| | Q17 | .106 | **.781** | .180 | .016 |
| Factor 3: Cultural Strength | Q24 | .177 | .134 | **.857** | -.045 |
| | Q4 | .145 | .110 | **.827** | -.011 |
| | Q20 | .053 | .101 | **.825** | .008 |
| | Q8 | .196 | .188 | **.821** | -.003 |
| | Q12 | .089 | .140 | **.818** | .018 |
| | Q16 | .123 | .121 | **.763** | -.079 |
| Factor 4: Coordinated Teamwork | Q23 | -.008 | -.041 | -.005 | **.892** |
| | Q3 | .036 | .042 | .003 | **.877** |
| | Q19 | -.008 | .039 | -.024 | **.834** |
| | Q11 | -.057 | .065 | .004 | **.808** |
| | Q7 | .021 | -.021 | .072 | **.625** |
| | Q15 | .003 | .008 | -.140 | **.570** |
| KMO | | | .907 | | |
| Bartlett's Test of Sphericity | | | .000 (sig) | | |
| Initial Eigen Value | | 4.688 | 4.627 | 4.333 | 3.647 |
| Variance (%) | | 19.535 | 19.277 | 18.054 | 15.197 |
| Cumulative Variance (%) | | 19.535 | 38.812 | 56.866 | 72.063 |
| Cronbach's Alpha | | .943 | .938 | .917 | .858 |

To verify the degree of intercorrelations among the variables and the appropriateness of factor analysis, the Bartlett Test of Sphericity and the Kaiser-Meyer-Olkin were obtained. The Bartlett test of sphericity showed that the result of the EFA was statistically significant, indicating that the correlation matrix had significant correlations among variables. Additionally, the Kaiser-Meyer-Olkin (KMO) measured the degree to which each variable was predicted without error. A score of .80 or above is considered to be valid, and the result of KMO showed .907. Cronbach's alpha coefficients were used to assess the internal consistency of measurements for each construct. The construct seemed reliable as Cronbach's alpha for all factors were over .7. Table 2 summarizes the results of the EFA.

*Influence of leadership behaviours on team culture*

According to Table 3, all transactional leadership behaviours had statistically significant effects on Managing Change and Achieving Goals. Contingent Reward (ß=.139) and Active Management-by-Exception (ß=.111) had positive effects, but Passive Management-by-Exception (ß=-.154) had a negative effect on Managing Change, and 6.5% of the Managing Change team culture was explained by transactional leadership behaviours. Contingent Reward (ß=.180) and Active Management-by-Exception (ß=.113) had a positive effect, but Passive Management-by-Exception (ß=-.241) had a negative effect on Achieving Goals, and 11.9% of Achieving Goals team culture was explained by transactional leadership behaviours. Passive (ß=.218) and Active Management-by-Exception (ß=.119) had statistically significant on Coordinated Teamwork, and 6.4% of Coordinated Teamwork was explained by transactional leadership behaviours. Contingent reward had no statistically significant effect on Coordinated Teamwork. Transactional leadership had the least effect on Cultural Strength. Only Passive Management-by-Exception had a statistically significant effect on Cultural Strength (ß=-.119), and 1.7% of Cultural Strength was explained by transactional leadership behaviours.

**Table 3.** Influence of the Transactional Leadership Behaviours on Team Culture

| | Dependent Variable | | | |
|---|---|---|---|---|
| | **Managing Change** | **Achieving Goals** | **Coordinated Teamwork** | **Cultural Strength** |
| Contingent Reward | .139* | .180** | .034 | .039 |
| Passive Management-by-Exception | -.154** | -.241*** | .218*** | -.119* |
| Active Management-by-Exception | .111* | .113* | .119* | -.009 |
| $R^2$ | .065 | .119 | .064 | .017 |

Legend: *p<.05, **p<.01, ***p<.001

To determine the influence of the transformational coach leadership behaviours on the team members' perceptions of their team culture, a multiple regression procedure was also used for analysis. Four transformational leadership behaviours (Charisma, Inspirational Motivation, Intellectual Stimulation, and Individualized Consideration) were regarded as predictors (independent variables), and the dependent variables were Managing Change, Achieving Goals, Coordinated Teamwork and Cultural Strength. Significance is determined at the level of .05.

According to Table 4, only some of the transformational leadership behaviours had a statistically significant effect on cultural functions. Specifically, Individualized Consideration (ß=.305) positively affected Managing Change, and 10.7% of the Managing Change team culture was explained by transformational leadership behaviours. Inspirational Motivation (ß=.126) and Individualized Consideration (ß=.209) had a significant influence on Achieving Goals, and 9.5% of Achieving Goals team culture was explained by transformational leadership behaviours. Charisma (ß=-.135) had a negative effective on Coordinated Teamwork, and 2.6% of Charisma was explained by transformational leadership behaviours. Cultural Strength turned out not to be influenced by transformational leadership behaviours.

**Table 4.** Influence of the Transformational Leadership Behaviours on Team Culture

| **Independent Variable** | Dependent Variable | | | |
|---|---|---|---|---|
| | **Managing Change** | **Achieving Goals** | **Coordinated Teamwork** | **Cultural Strength** |
| Charisma | .049 | .013 | -.135* | .039 |
| Inspirational Motivation | .040 | .126* | .060 | .023 |
| Intellectual Stimulation | -.014 | .083 | .085 | .014 |
| Individualized Consideration | .305** | .209** | -.081 | .084 |
| $R^2$ | .107 | .095 | .026 | .014 |

## Discussion

In the present study, it turned out that not only transformational leadership behaviours but also transactional leadership behaviours influenced cultural functions in the university soccer teams in Korea. All transactional leadership behaviours, such as Contingent Reward, Passive Management-by-Exception, and Active Management-by-Exception, influenced Managing Change and Achieving Goals. Passive and Active Management-by-Exception influenced Coordinated Teamwork. Among transformational leadership behaviours, Individual Consideration had a significant influence on Managing Change and Achieving Goals, Inspirational Motivation on Achieving Goals, and Charisma on Coordinated Teamwork. The results indicated that transactional leadership behaviours were more effective on cultural functions than transformational leadership behaviours were.

Overall, both transactional and transformational leadership had a positive effect on organizational team culture, but the effect of transactional leadership behaviour appeared more extensive than transformational leadership behaviour in the present study. However, it was not obvious from the present study why transactional leadership behaviours were more influential on cultural functions in university soccer teams in Korea. This finding could be related to the fact that transactional leadership among coaches in Korea has been deeply rooted in both the societal and athletic cultures over the years. Consequently, because it can take a long time to change the culture in an organization and because leadership behaviours are not the only factors affecting cultural functions, it is premature to conclude that transactional leadership behaviours are better in building effective organizational culture in Korean university soccer. As was the case from Hiddink's leadership in 2002, transformational leadership behaviours gain more popularity and are favoured more in sport teams in Korea nowadays; therefore, examining the relationship between leadership behaviour and organizational culture in this context will require further quantitative and qualitative investigation.

## Conclusion

This study investigated how transactional and transformational coach leadership behaviours predicted the organizational cultural functions of the university soccer teams. Scott (2000) emphasized the significance of culture management to leadership, stating that this may be the most challenging yet critical component of sport organizational leadership. He added that among a variety of leadership styles, transformational leadership makes a strong impact in the development of a positive organizational culture. Additionally, Weese (1995) indicated that transformational leaders in recreational organizations influence a culture of "excellence and continual improvement."

In the Korean context, it remains undeniable that strong transactional leadership behaviours exist, and they exert significant influence on university soccer team culture. However, it is impressive that the effect of transformation leadership behaviours was obvious on team culture as well as those of transactional leadership behaviours. Leaders of university soccer teams need to consider how to modify their leadership behaviour effectively and appropriately, as was mentioned by Hersey and Blanchard (1998), asserting situational leadership that emphasizes interplay among task behaviour, relationship behaviour and followers' readiness.

Finally, it could be summarized that "the combination of transactional and transformational leadership is likely to be a key factor in the successful development of organizational effectiveness" (Bass & Avolio, 1990).

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**Conflict of Interest**
The authors declare that there is no conflict of interest.

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ORIGINAL SCIENTIFIC PAPER

# Analysis of the Behavioural and Emotional Profile of Adolescent Judo Practitioners

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**Abstract**

In recent decades, the number of social projects that use sports as a tool has been increasing dramatically, necessitating rigorous investigations into their immediate and long-term effects and the behavioural changes in children and adolescents who participate in these projects. This study aimed to assess the behavioural and emotional profile of adolescent judo practitioners. The participants of the Judo Social Project in São José do Rio Preto answered the Brazilian version of the "Youth Self-Report" (YSR/2001). In the analysis of scores, the borderline range was grouped with the clinical range to minimize the occurrence of false negatives, specifically, the number of adolescents with scores outside the clinical range on the YSR/11-18 scale (t scores ≥60 for the clinical range) who required psychological or psychiatric care. The scores on the anxiety and depression scale were significantly higher for female participants (p=0.0431). On the total scale of emotional and behavioural problems, 34.4% (N=106) of the study population had mean scores considered in the clinical range. Of these, the scores were found to be in the clinical range in 24.8% (N=31) of the female participants and 41% (N=75) of the male participants. The comparison between the sexes indicated that internalization symptoms (anxiety and depression) were more frequent in female participants, whereas externalization problems (rule-breaking and behavioural problems) were more frequent in male participants.

***Keywords:*** *adolescence, physical activity, health, judo*

## Introduction

Several studies have correlated physical activity and exercise with health benefits. A lack of physical activity, in turn, is associated with increased risks of cardiovascular disease, diabetes, obesity, hypertension, other causes of mortality (Centers for Disease Control and Prevention, 2010), and mental disorders (Rhodes & Mark, 2012). The association between mental disorders and physical inactivity (M.N. Baptista, A.S.D. Baptista, & Dias, 2001) is reinforced by studies on anxiety, depression, obsessive-compulsive disorder, and eating disorders, among others (Zschucke, Gaudlitz, & Ströhle, 2013), which are considered to be problems with significant personal, family, social, and economic impacts (Vianna & Lovisolo, 2009). In the search for efficient and low-cost treatments with long-term benefits (Zschucke et al., 2013), physical activity and exercise continue to gain the attention of researchers, even for aspects related to prevention.

Olsen, Myklebust, Engebretsen, Holme and Bahr (2005) reported that physical activity has become an attractive therapeutic option and perhaps a prevention strategy due to several reasons, including fewer side effects, adaptability to clinical comorbidities and functional status of the patient, increased self-esteem, less stigma than psychiatric and psychological treatment, reduced need for pharmacotherapy, and decreased risk of cardiac and metabolic diseases.

Several authors have indicated that the effects of physical

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activity in children and adolescents are similar to those observed in the adult population (Baptista et al., 2001). In this respect, primarily physiological approaches or methods originally developed for adults are used for young people, although the validity of these methods has not been established for adolescents and children (Fleitlich & Goodman, 2000). Therefore, these therapeutic strategies should consider the differences between the target populations (Eime, Young, Harvey, Charity, & Payne, 2013) and evaluate different scenarios using qualitative and quantitative approaches with scientifically grounded studies (Chaddock-Heyman, Hillman, Cohen, & Kramer, 2014).

However, few studies have evaluated the correlation between physical activity and mental health among young people. Most studies have focused on emotional problems, particularly depression and anxiety. Furthermore, few studies have evaluated behavioural and social problems, and even fewer have addressed the phenomenon in a broader sense, including aspects related to internalization and externalization (Fleitlich & Goodman, 2000). The presence of emotional and behavioural problems in this age group and the limited practice of physical activity from youth to adulthood underscore the need to address the possibility of an association between these variables (Fleitlich & Goodman, 2000). Systematic reviews and meta-analyses have reported the benefits of physical activity on depression, anxiety, and behavioural problems in children and adolescents (Ekeland, Heian, & Hagen, 2005). However, the effect of physical activity and exercise on the mental health of individuals in this age group has not been elucidated (Ekeland et al., 2005).

Moreover, studies on this topic that use physical exercises as the main tool can help strengthen the protective factors (e.g., environmental, quality of life, social support, coping) and reduce problematic behaviours (Piccinelli & Wilkinson, 2000). Martial arts, such as judo, require specific psychological readiness to perform tasks. Emotional and mental states are subject to extreme oscillations during the fight. For young judokas, it is a challenge in a state of extreme tension to compete, to attack, and defend simultaneously, hiding their intentions from the opponent (Ziv & Lidor, 2013). The practice of long-term judo positively influences the "psyche" of young judokas, improving their concentration level, regardless of gender (Janowska, Wojdat, Bugajska, Paradowska, & Stępniak, 2018). There are many common beliefs regarding the social-psychological results of martial arts practice, ranging from very positive to very negative (Vertonghen & Theeboom, 2010). To the best of the authors' knowledge, this is the first study to examine the behavioural and emotional profile of young judokas.

This study aimed to assess the behavioural and emotional profile of adolescents who participate in a judo social project in São José do Rio Preto, State of São Paulo, Brazil.

## Methods

The study comprised 308 adolescents (183 boys and 125 girls) aged between 11 and 18 years (12.4±1.54 years) who participated in the Judo Social Project "Sports for Children" developed in the city of São José do Rio Preto, Brazil. The project involved 16 centres located in different regions of the city and the provision of 60-minute judo classes two to three times per week. The study was approved by the Human Research Ethics Committee of the Medical School of São José do Rio Preto, Brazil (Decision No. 138/2011).

The inclusion criteria were informed consent by the participants or guardians, age between 11 and 18, and enrolled in elementary education and the judo project. All project participants in this age group were invited to participate in the study.

The questionnaire was completed in class, on the premises of the judo centre, in the presence of researchers and the instructor responsible for the judo centre. The researchers assisted those who had difficulty reading the questionnaire.

The behavioural profile of the participants was evaluated using the Brazilian version of the "Youth Self-Report" (YSR) (Bordin et al., 2013). This instrument is a self-reported questionnaire, where individuals aged between 11 and 18 provide an overall assessment of their behaviour. The YSR consists of 105 items that assess the behavioural problems of the participants, and these items are grouped into eight syndrome scales, including anxiety/depression, withdrawal/depression, somatic complaints, social problems, attention problems, thought problems, rule-breaking behaviour, and aggressive behaviour. The sum of the first three items forms the internalization scale; the sum of the last two items forms the externalization scale; the total sum of the behavioural problems forms the full scale of emotional and behavioural problems. The instrument also contains open questions that assess the overall social competence and participation in activities such as sports and entertainment.

The YSR enabled the formation of groups using the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV) (Achenbach & Rescorla, 2007). These groups included affective disorders, anxiety disorders, somatic problems, attention deficit hyperactivity disorder, oppositional defiant disorder, conduct disorder, obsessive-compulsive disorder, and post-traumatic stress disorder. The YSR scores, even in the clinical range of the DSM scales, were not automatically equivalent to a diagnosis (Rhodes & Mark, 2012). Rather, they suggested the occurrence of problems in specific areas, helped identify children eligible for a detailed assessment, and confirmed the need for psychiatric or psychological care.

In this study, we analysed eight syndrome scales and the six groups guided by the DSM-IV, in which the rules are similar to those used in the validation study for the Brazilian population (Rocha, 2012). In the analysis of scores, the borderline range was grouped with the clinical range to minimize the occurrence of false negatives, meaning the number of adolescents with scores outside the clinical range on the YSR/11-18 scale (t scores ≥60 for the clinical range) who required psychological or psychiatric care. The raw scores (mean and standard deviation) were also evaluated and compared with those of the Brazilian validation study (Rocha, 2012). The instrument was validated for the Brazilian population by Rocha (2012). The Brazilian version is suitable for research on adolescents from all socioeconomic status, even those with family members with low education living in vulnerable regions (Rocha, Pereira, Arantes, & Silvares, 2010). For analysis, the participants were placed into two groups: younger (11–14 years) and older (15–18 years); these groups were compared using the standards adopted in instrument validation for the Brazilian population.

The data were tabulated and analysed with descriptive statistics (mean, standard deviation, and relative frequency for all variables). Unpaired t-tests were used to compare the groups; p-values equal to or less than 0.05 were considered significant. The data were also presented as absolute and relative values.

## Results

Although all adolescents enrolled in the project were invited to participate in the study, the estimated rate of non-participation was 5%. The most common reasons for non-participation were absence from classes in which data were collected and personal reasons. The mean period of adherence to the project varied between four months and three years, with an average period of judo practice of one year. The ethnic and racial distribution of the participants was 46.10% Caucasians and 53.9% African descendants, and family income ranged between R$150.00 (ca USD 30) and R$1,920.00 (ca USD 350) per month.

The results of the total scale of emotional and behavioural problems indicated that the mean scores were in the non-clinical range (M=31.31±12.05) for 202 adolescents (65.6% of the total sample). A total of 106 adolescents (34.4% of the total sample) had mean scores in the clinical range (M=72.46±19.70).

The analysis of the mean T scores on the YSR scale was compared in both sexes, and Table 1 shows the scores for the types of emotional and behavioural problems using the YSR scale in both sexes. Among the eight syndrome scales evaluated, only two showed significant differences between the sexes: anxiety/depression and rule-breaking behaviour.

**Table 1.** Adolescent participants of the Judo Social Project: differences in the scores obtained on the YSR scales for emotional and behavioural problems in both sexes

| Scales | Male (N=183) | Female (N=125) | p |
|---|---|---|---|
| | Mean±SD | Mean±SD | |
| Anxiety/depression | 6.85±4.1 | 7.88±4.74 | 0.043* |
| Withdrawal/depression | 3.63±2.6 | 3.63±2.7 | 0.99 |
| Somatic complaints | 3.9±3.03 | 4.1±3.24 | 0.580 |
| Social problems | 4.32±3.1 | 4.45±3.51 | 0.732 |
| Thought problems | 3.68±3.19 | 3.29±3.34 | 0.302 |
| Attention problems | 4.97±3.18 | 4.78±3.38 | 0.616 |
| Rule-breaking behaviour | 4.43±3.47 | 3.18±3.45 | 0.002* |
| Aggressive behaviour | 8.9±5.83 | 7.98±5.89 | 0.176 |
| Internalization scale | 14.38±7.86 | 15.61±9.08 | 0.206 |
| Externalization scale | 13.33±8.69 | 11.16±8.60 | 0.031* |
| Total scale of emotional and behavioural problems | 46.16±23.79 | 44.46±26.09 | 0.554 |
| Affective disorders | 5.04±3.36 | 4.9±3.74 | 0.731 |
| Anxiety disorders | 3.33±2.23 | 4.22±2.47 | 0.001* |
| Somatic problems | 2.39±2.18 | 2.54±2.23 | 0.557 |
| Attention deficit and hyperactivity disorder | 4.59±2.78 | 4.58±2.97 | 0.976 |
| Oppositional defiant disorder | 3.44±2.18 | 3.14±2.38 | 0.254 |
| Conduct disorder | 4.87±4.32 | 3.59±3.92 | 0.008* |
| Obsessive-compulsive disorder | 4.37±2.72 | 4.26±2.92 | 0.735 |
| Post-traumatic stress disorder | 8.08±4.33 | 8.41±4.81 | 0.530 |

Legend: SD - standard deviation; * - p<0.05

For anxiety/depression, the mean score for boys and girls was in the non-clinical range, according to Brazilian norms. A comparison of the mean scores for anxiety/depression between the sexes indicated that boys (6.85±4.1) had lower scores than girls (7.88±4.74; p<0.043) did. On the scale of somatic complaints, only boys achieved scores within the clinical range.

Concerning rule-breaking behaviour, the scores of the study population were within the non-clinical range. Boys scored higher (4.43±3.47) than girls (3.18±3.45; p<0.002) did; however, the scores for both sexes were significantly lower (p<0.001) than those of the clinical range of the Brazilian norms and therefore were considered to be in the non-clinical range. The scores on the externalization scale were in the non-clinical range, and the mean scores for boys (13.33±8.69) were higher than those for girls (11.16±8.60; p<0.031).

For the syndrome scales, the mean scores of the study population were significantly lower (p<0.05) than those for the population within the clinical range of the Brazilian norms. Comparing to the non-clinical range of the Brazilian norms, the mean scores for attention problems and rule-breaking behaviour were lower for both sexes (p<0.05). The mean scores on the internalization scale were lower for boys, whereas the mean scores for thought problems, aggressive behaviour, and the externalization scale were lower for girls (p<0.05).

On the total scale of emotional and behavioural problems, the study population did not reach the scores of the clinical range, and only girls had significantly lower (p<0.05) mean scores than the population within the non-clinical range of the Brazilian norms. Regarding the scores for withdrawal/depression and social problems, the study sample obtained scores within the non-clinical range, and the mean scores were similar for both sexes.

According to the Brazilian norms, the analysis of the six groups guided by the DSM-IV indicated that the scores were in the non-clinical range in both sexes. Female participants had significantly lower (p<0.05) scores than the non-clinical population for affective disorders, anxiety disorders, somatic problems, attention deficit hyperactivity disorder, obsessive-compulsive disorder, and post-traumatic stress disorder. Male participants had significantly lower mean scores than the non-clinical population only for somatic problems. A comparison between the sexes indicated that girls achieved significantly higher mean scores for anxiety disorders (boys: 3.33±2.23; girls: 4.22±2.47; p<0.001), whereas boys achieved significantly higher mean scores for conduct disorders (boys: 4.87±4.32; girls: 3.59±3.92, p<0.008). Table 2 shows the differences in the groups for emotional and behavioural problems on the YSR scale by age group.

**Table 2.** Adolescent participants of the Judo Social Project: differences in the groups of emotional and behavioural problems on the YSR scale by age group

| Syndrome type | Younger (N=274) | Older (N=34) | p |
|---|---|---|---|
| | Mean±SD | Mean±SD | |
| Anxiety/depression | 7.33±4.49 | 6.74±3.51 | 0.412 |
| Withdrawal/depression | 3.67±2.63 | 3.35±2.70 | 0.505 |
| Somatic complaints | 4.12±3.15 | 2.85±2.52 | 0.024* |
| Social problems | 4.42±3.31 | 4.03±2.92 | 0.512 |
| Thought problems | 3.55±3.32 | 3.32±2.72 | 0.698 |
| Attention Problems | 4.91±3.33 | 4.74±2.6 | 0.774 |
| Rule-breaking behaviour | 3.93±3.56 | 3.91±3.18 | 0.975 |
| Aggressive behaviour | 8.51±5.59 | 8.62±5.67 | 0.914 |
| Internalization scale | 15.12±8.52 | 12.94±7.01 | 0.153 |
| Externalization scale | 12.44±8.79 | 12.53±8.14 | 0.954 |
| Total scale of emotional and behavioural problems | 45.81±25.19 | 42.70±20.68 | 0.489 |
| Affective disorders | 5.06±3.5 | 4.41±3.65 | 0.310 |
| Anxiety disorders | 3.75±2.41 | 3.21±1.95 | 0.210 |
| Somatic problems | 2.55±2.23 | 1.62±1.72 | 0.019* |
| Attention deficit and hyperactivity disorder | 4.62±2.85 | 4.32±2.57 | 0.559 |
| Oppositional defiant disorder | 3.28±2.25 | 3.65±2.44 | 0.371 |
| Conduct disorder | 4.42±4.26 | 3.76±3.69 | 0.388 |
| Obsessive-compulsive disorder | 4.34±2.88 | 4.21±2.35 | 0.800 |
| Post-traumatic stress disorder | 8.3±4.61 | 7.5±3.82 | 0.332 |

Legend: Younger - (11 to 14 years); Older - (15 to 18 years)

Among the eight syndrome scales evaluated, only somatic complaints showed a significant difference between the age groups. Younger adolescents had higher mean (4.12±3.15) scores than older adolescents (2.85±2.52; p<0.024) did. On the scale of somatic complaints, younger adolescents achieved scores in the clinical range, whereas the scores of older adolescents were within the non-clinical range in relation to the Brazilian norms.

For the remaining syndrome scales, the study population reached the non-clinical range and achieved significantly lower (p<0.05) scores for thought problems and attention problems than the Brazilian norms. Only older adolescents had lower mean scores (p<0.05) for rule-breaking behaviour and on the total scale of emotional and behavioural problems compared to the non-clinical range Brazilian norms.

The analysis of the six groups guided by the DSM-IV indicated a significant difference only for somatic problems, and the mean scores in younger adolescents were higher (2.55±2.23) than those in older adolescents (1.62±1.72; p<0.019). Compared to the Brazilian norms, younger adolescents reached the clinical range, whereas older adolescents reached the non-clinical range. For the remaining groups, the study population obtained scores within the non-clinical range with significantly lower (p<0.05) mean scores for anxiety disorders, hyperactivity attention deficit disorder, and post-traumatic stress disorder. Concerning conduct disorders, the mean scores of younger adolescents were significantly lower (p<0.05) than those of the population that achieved the non-clinical range for the Brazilian norms.

In the qualitative section of the YSR scale, adolescents reported having positive relationships with their peers and engaging in sports and hobbies, particularly games. Most adolescents engaged in some activity at home (housework), and a few participants worked.

In the open answers section of the instrument regarding concerns or problems related to school, the participants recurrently reported concerns about failure in school. Furthermore, motivation and performance in the practice of judo also appeared regularly.

## Discussion

Social projects that include sports activities have increased significantly in Brazil (Vianna & Lovisolo, 2009). These projects, which have a socio-educational nature, aim to meet the needs not covered by government-based health and leisure activities, particularly in socially disadvantaged areas. These projects improve mental health, eating behaviours, physical activity, self-concept, self-esteem, self-confidence, coping mechanisms, and networking opportunities and decrease drug abuse levels (McLean & Anderson, 2009).

The greater participation of men in the Judo Social Project of São José do Rio Preto is understandable due to the form of sport offered and the traditional male hegemony in sports (Anderson, 2009a). Martial arts, in general, attracts men primarily for cultural reasons, although women have excelled in high-performance judo in recent years (Anderson, 2009b).

A predominance of participants of African descent was noted, although the population of São José do Rio Preto is predominantly Caucasian (Souza & Mourão, 2011).

Most participants achieved non-clinical scores for emotional and behavioural problems on the YSR scale. As low-income populations, both adults and children (Fleitlich & Goodman, 2000; Instituto Brasileiro de Geografia e Estatística, 2010) are considered most vulnerable to mental disorders; however, it is of note that this problem was not observed in our study population. Despite the absence of a control group in this study, the extensive literature on regular physical exercise and mental health (Chaddock-Heyman et al., 2014; Piccinelli & Wilkinson, 2000; Hinkley et al., 2014) allows us to infer that the low number of adolescents in the clinical range is associated with the protective role of physical exercise, in this case, the practise of judo. However, longitudinal studies are needed to corroborate this assumption.

A comparison of emotional and behavioural problems between the sexes indicated the prevalence of anxiety and depression in female participants and rule-breaking behaviour in male participants.

McLean and Anderson (2009) reported that girls are more likely than boys to develop anxiety disorders, with greater vulnerability in infancy and an increased likelihood of being currently diagnosed or having a lifelong diagnosis. By the age of six years, girls have a two-fold higher probability of developing anxiety disorders than boys, and this difference seems to persist during adolescence. Female adolescents reported a greater number of concerns and greater anxiety about divorce; female adolescents also have a six-fold increased likelihood of developing generalized anxiety disorder compared to boys (McLean & Anderson, 2009).

In the study population, the prevalence of depressive disorders among girls was consistent with epidemiological results, which indicated a higher prevalence, incidence, and risk of morbidity from depressive disorders in women (Piccinelli & Wilkinson, 2000). Studies also show a higher prevalence of depression and anxiety symptoms in young female athletes when compared to men (Junge & Feddermann-Demont, 2016). It should also be noted that the prevalence of depression and anxiety disorders in young athletes is similar to the female population in general (Junge & Prinz, 2018).

The predominance of behaviours that involve rule-breaking among male participants was similar to the results of previous studies. Evidence indicates that specific characteristics of male participants are associated with overt aggression and disruptive behaviour disorders and a higher incidence of disciplinary and behavioural problems in school. Low socioeconomic status and family and school characteristics are relevant variables associated with the early onset of conduct disorders in vulnerable children (Baptista et al., 2001; Strauss, Rodzilsky, Burack, & Colin, 2001). Mallia, Lucidi, Zelli, Chirico, and Hagger (2019), when researching the relationships between socio-contextual, motivational factors, attitudes of young male athletes, concerning prosocial and antisocial behaviours and their real rules violations, from team modalities during the matches, concluded that the promotion of autonomous motivation and the satisfaction of needs through support for autonomy could promote attitudes towards prosocial behaviours and minimize rule violations in young athletes.

The somatic problems identified in the study population, with higher frequency in younger children than in older children, were also reported in the DSM-IV. In the case of depression, children may display an irritable mood rather than a depressed mood. In addition, younger children are more likely than older children to express somatic complaints, irritability, and social withdrawal (IBGE, 2010).

Social projects are usually offered in communities with greater vulnerability to behavioural problems due to economic disadvantages and other characteristics, including the presence of single-parent families (Baptista et al., 2001; Fleitlich & Goodman, 2000). In this context, physical exercise and inclusion in social programmes can improve social support, strengthen protective factors, and reduce stress and risk factors (Masi et al., 2008).

The limitations of this study include the need to longitudinally collect data from project participants (participants, family, and teachers) and to collect data from several informants about the overall status of children who participated in the evaluated judo programme.

The difference between the language of the instrument and the capacity of the participants to understand and interpret this tool made the application more arduous.

The validation of the instrument for the Brazilian population does not specify differences between practitioners and non-practitioners of physical exercises or differences in the characteristics of sports in their multiple contexts. Therefore, in this study, we could not infer whether the differences in the scores between the study population and the Brazilian norms were correlated with the practice of physical exercises.

Identifying behavioural problems such as anxiety disorders, depressive symptoms, conduct disorders, rule-breaking behaviour, and somatic complaints are critical areas of clinical research. The early identification of these problems and their manifestations in both sexes can improve diagnosis and prognosis and promote the development of preventive interventions to improve the outcomes in vulnerable populations during their transition to adulthood (Strauss et al., 2001).

Therefore, the services offered in social projects that are focused on sports should be organized in such a manner as to allow easier access of vulnerable social groups to these preventive and therapeutic programmes (Strauss et al., 2001).

The percentage of study participants with scores within the clinical range was lower than that found for the Brazilian population. A comparison between the sexes indicated that internalization symptoms (anxiety and depression) were more frequent among female participants, whereas externalization symptoms (rule-breaking behaviour and conduct problems) were more prevalent among male participants. Furthermore, younger children had more somatic problems and complaints than older children did.

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**Conflict of Interest**
The authors declare that there are no conflicts of interest.

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ORIGINAL SCIENTIFIC PAPERS

# The Difficulty of Standardizing the Tester in the Physical Fitness Test in the Indonesian Air Force

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**Abstract**

The physical fitness test is a method to determine physical abilities whose results are also very much determined in the measurement process carried out by the tester. This study aimed to determine the difficulty the tester has in meeting certain standards in measuring physical fitness in the Indonesian Air Force. This research method uses a qualitative method with a phenomenological approach through interviews with 15 testers. This qualitative data were analysed by referring to the phenomenological qualitative research steps of Moustakas and Cresswell. This study indicates difficulties in standardizing the tester in carrying out physical fitness tests in the Indonesian Air Force due to educational backgrounds, both in general education and military education, as well as corps, rank, and experience of different testers. Moreover, it was also found that there was also a lack of understanding of procedural mastery both in administration, measurement process procedures, and procedures for assessment and reporting of physical fitness test results. Continuous training of the tester is required to improve and monitor the tester's ability.

***Keywords:*** *difficulty, standardization, tester, physical fitness test*

## Introduction

Physical fitness is a primary asset for a member of the military and has a linear correlation with the success of the task, so there is a need for regular and continuous improvement and maintenance of physical fitness. The importance and magnitude of the influence of physical fitness on the results of one's work result in many governments and private institutions requiring a certain level of physical fitness as an aspect of work performance assessment, certification, and professional licensing. This also occurs in many military and service education institutions that require a certain level of physical fitness as one of the selection requirements to be accepted as a student or to attend education (Castelli, Hillman, Buck, & Erwin, 2007; TNI AU, 2019) In connection with the assessment of the physical fitness of military personnel, of course, accurate data is needed that is obtained through valid and reliable measurements.

The process of measuring physical fitness quantifies the quality of a person's physical fitness. According to D'Isanto, D'Elia, Raiola and Altavilla (2019), the assessment produced through measurements on a physical fitness test determines a person's anthropometric and psychomotor profiles used to help determine the objectives required in the training programme. Furthermore, measurements on a physical fitness test are needed to produce data, to monitor the physical development of coaching and in the context of the selection, to indicate risk factors, to evaluate physical exercise, and to determine the type and dose practice.

According to Bompa, Tudor and Haff (2009), the aspects that must be measured in physical health include strength, endurance, speed, flexibility, and coordination. There are two measurement methods in a test to obtain data: by using measuring instruments and without measuring instruments, which in the measurement process is carried out purely through observation by the tester, including the interpretation of the results. While

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the form of physical fitness tests that are often used, according to Fox (1988), Piscopo and Baley (1981), and the Indonesian Air Force (2019), consists of a 2.4 km running test for 12 minutes for general endurance, pull up tests, push-ups, sit-ups, to determine the endurance and muscle strength and the shuttle run test is used to measure speed and agility. Based on the types and forms of the various tests, there is a need for guidelines that become the basis for conducting physical fitness tests, using equipment, and more technically in the measurement process.

In organizing a physical fitness test, a tester must always refer to the established standard procedure (SOP). In the use of equipment, testers must master the equipment to be used both in terms of its function and how to operate it. Meanwhile, other measurements do not use the equipment and only use the results of the tester's observations to provide a right and wrong decision, which directly affects the measurement result score. Based on the form of the test and the equipment used in the physical fitness test, it shows that the tester's ability is very influential in carrying out measurements and assessments.

The difference in the quality of the testers makes it possible to have differences in the physical fitness test result data. The ability of testers is influenced by many factors, including physical fitness testers in military institutions. In military institutions that apply a hierarchy of ranks, seniority, corps, and others, of course, that ability can be one of the factors that determine the quality of the tester to be different. Research conducted by Arifin, Retnawati and Putranta (2020) regarding the value of the agreement between physical fitness testers in the Indonesian Air Force in making measurements shows that the agreement between testers is still not good and produces different data in measuring the same testee. The same research conducted by Mathews (2013) and Fielitz, Coelho, Horne and Brechue (2016) shows that the coefficient between testers on the measurement of the push-up test remains inadequate. The difficulty of the testers on the physical fitness test using observations when compared to the test with the aid of measuring equipment is not the same. This is also supported by the research results of Baumgartner, Oh, Chung and Hales (2002) and Baumgartner and Ghaunt (2005), which states that the difficulty in a skills test is interpreting the results of the testers' observations into a decision appraisal. Based on the problems in the field related to differences in measurement results that often arise, it is necessary to conduct research that can show what aspects affect the quality of the tester and why there are difficulties in standardizing the physical fitness tester.

## Method

This study uses a qualitative phenomenological approach. A qualitative approach is used to determine the difficulties in standardizing the tester's activities. In this study, participants consisted of 15 testers who were male with an age range of 25–50 years who were still active in the physical fitness test. The qualitative research procedure was carried out by interviewing testers selected to be respondents with open-ended questions with interview protocol guidelines. Data analysis from interviews in qualitative research were analysed by referring to the steps of Moustakas (1994) and Creswell (2018), which include organizing data; describing, clarifying and interpreting data into codes and themes; interpreting data; presenting and visualizing data.

## Results

The study results used a qualitative approach to obtain data on the educational background that directly or indirectly affected the tester's ability to carry out physical fitness tests. The data obtained from the respondents were grouped into two parts: the background of the testers and the mastery of procedures in carrying out physical fitness tests.

### *Educational Background and Experience of Tester*

The results of the tester's educational background and experience (seniority) to be a tester can be shown in Table 1.

**Table 1.** Background of the Tester

| Description | Indicator |
|---|---|
| Tester skills education (profession) | Not all testers have attended skills education, courses, and upgrades related to the profession as a tester |
| General education | The formal education of the tester varies from junior high, high school, and college |
| Experience as a Tester | Experience being a variation tester (junior to senior tester) |

The data generated in Table 1 shows that the testers have various backgrounds, both on expertise and general backgrounds. Skills education, which is intended to provide knowledge and skills regarding the implementation of physical fitness tests, also varies where some obtain formal training through training, upgrading, and some testers have not or even did not get provisioning. Moreover, some testers study independently to gain knowledge and skills. Meanwhile, concerning tester experience, some testers have experience from junior to senior.

### *Mastery of Procedures*

Based on the results of interviews with respondents about mastery of administrative procedures, the data can be summarized in Table 2.

**Table 2.** Mastery of Administrative Procedures

| Description | Indicator |
|---|---|
| Mastery of test administration | The use of forms is not the same |
| | The input of data by the tester varies |
| Mastery in giving instructions/ directions before the test | The ability to direct/explain procedures for implementing tests is not systematic and unequal |
| Teste arrangement in the test group | The understanding of the tester about setting the number of testes in one group varies |

Table 2 shows a very diverse mastery of the procedure by the testers, including those who have not mastered the procedure for implementing the physical fitness test. The procedure for the physical fitness test includes three stages: the procedure at the preparation stage, the implementation stage, and the assessment or evaluation stage. The preparation stage includes knowledge and skills, such as organizing participants into test groups, preparing assessment forms, explaining the test to participants, and warming up. The implementation stage includes the use of test equipment, correct interpretation of movements, and other aspects during implementation. The assessment stage includes the tester's ability to manage field data into the final physical fitness test data for each participant and their categories.

The results of interviews with testers regarding mastery of measurement procedures are summarized in Table 3.

**Table 3.** Mastery of Measurement Procedures

| Description | Indicator |
|---|---|
| Understanding and implementing warming up | Understanding the adequacy of warming up is not yet understood |
| Mastery of using tools | Mastery of different testers in using the split facility on the stopwatch |
| | The difference in reaction speed in the operation of the stopwatch |
| The tester's measuring ability | Different understandings and interpretations of the movement |
| | The tester's different understanding of rest requirements during movement and between test items |
| | Different testers' understanding of correct place in measurement/assessment |
| | There is a tester subjectivity in measuring and assessing |

The results of other interviews with testers regarding mastery of assessment and reporting procedures obtained data, which are summarized in Table 4.

**Table 4.** Mastery of Assessment and Reporting Procedures

| Description | Indicator |
|---|---|
| Mastery in calculating physical fitness values | Not all testers understand the formula for calculating the value of physical fitness. |
| | Not all testers can process data using a computer. |
| | Different tester knowledge about the physical fitness value category. |

## Discussion

*Educational Background and Experience of Tester*

Status testers with different formal backgrounds have the ability to understand the knowledge and mastery of the concept of a different physical fitness test. The higher the level of education of a person, the more likely there is a tendency to master the concept of knowledge about his job, and this mastery cannot be separated from the mastery of the material and skills that soldiers must have (Mareike et al., 2013).

Likewise, the tester's experience will affect foresight, accuracy, and speed in deciding an assessment. Supriadi (1998) states that the longer a person is in the profession, the higher the level of professionalism. The impact of experience will be seen in completing work and someone who already has significant experience or is more able to master and have a strategy in completing the task. However, if these conditions are not developed and do not try something new, the experience will decrease (Rice, 2010). According to Sawastha and Sukotjo (1998), the indicators of experience are education, training, and years of service. In this study, testers had different backgrounds of experience from three years and more than 25 years. Foster (2001) states that the indicator for determining a person's ability to complete his job is the length of the work period. These different conditions of experience certainly impact different abilities, such as accuracy and speed in making decisions related to the development of knowledge and technology. Another condition related to the background of the testers is the existence of a hierarchy of ranks and positions, which can directly or indirectly affect the objectivity of the tester in making decisions on measurement results.

*Mastery of Procedures*

Mastery of procedures is imperative for testers to understand and use procedures as guidelines for preparation, planning, implementation, and evaluation. Arifin, Zamroni and Subali (2020) state that in a physical fitness test, to produce a valid and reliable test begins with the fulfilment of procedures starting from the planning stage, the implementation stage, and the termination stage (sometimes consisting of assessment and evaluation). In the control of administrative procedures, it can be seen that the tester has a variety of understandings about how to organize large numbers of participants, to determine which individuals are not eligible to take the test, to prepare assessment forms, and to explain test procedures to testees. In the mastery of measurement procedures carried out at the implementation stage, obstacles were found in the form of how the tester positioned himself appropriately to be able to see the testee's movement, the provision of time breaks between test items, provisions for rest during movement, use of test kits, and interpretation in determining the correct movement. Another obstacle was the assessment and reporting procedures to determine the final result of the physical fitness test, namely that some testers were unable to explain the assessment formulas and data processing either manually or using data processing programmes.

Foster (2001) argues that what can describe a person's ability to complete work is the level of knowledge that refers to concepts, principles, procedures, other required information, levels of knowledge, and skills. One of the functions required of a procedure is to provide facts or useful ways to act and to achieve predetermined goals. Testers who understand and master procedures appear to be more proficient in completing work than those who do not understand procedures or even do not use procedures (Park, 2009). According to Winnick and Short (2014), the responsibility of a tester in a physical fitness test is to measure the physical fitness level of a person by managing the test items that are selected appropriately, providing recommendations for test administration, including the necessary equipment, assessment, testing/training, test modifications, and safety guidelines and precautions. Another responsibility is to evaluate the level of physical fitness associated with comparing their results on the recommended or optional test items with the standard and referenced fitness zone criteria suitable for them.

Furthermore, Wursanto (2005) and Moekijat (1989) state that procedures are guidelines for the right way to carry out activities. One of the reasons for the failure of a job is the loss of certain information due to the eliminated stages of the procedure so that they cannot make the right decision (Vanlehn, 1990). The tester must understand and master what is being prepared and done, both before and after the test.

## Conclusion

In a physical fitness test, the role of a tester is indispensable for smooth implementation and obtaining reliable and accurate data. In a physical fitness test involving many testers, the difficulty that arises is to standardize the testers involved. These difficulties can be caused due to the tester's background and mastery of different test procedures. It is necessary to develop a measuring instrument to assist testers in observing movement on physical fitness tests and the need for alternative tests to measure physical fitness, especially muscle strength and endurance. Continuous tester training is required to improve the ability of testers and minimize non-standard tester quality.

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**Conflict of Interest**

The authors declare that there are no conflicts of interest.

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ORIGINAL SCIENTIFIC PAPER

# Prediction of Knee Injury in Professional Soccer Players Using Core Endurance and Strength: A Cross-sectional Study

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**Abstract**

Although relationships between lower limb injury and core strength and endurance have been reported, limited research on the risk of knee injury specifically among soccer players exists. This study aimed to compare preseason trunk muscle endurance as well as trunk and hip muscle strength between soccer players who experienced knee injury during their season and those who did not. Dependent variables were also used to predict the risk for injury. This prospective cross-sectional study involved thirty-nine male soccer players (age 19.64±2.84 years, weight 73.94±15.66 kg and height 175.67±9.92 cm). By the end of the season, twelve (30.77%) reported knee injuries. Accordingly, two groups were identified and compared: injured and non-injured. Prone-bridge, side-bridge, trunk flexion and horizontal back extension hold times were used as trunk endurance measures, while peak isokinetic trunk flexor and extensor torques, as well as hip abductor and external rotator torques, were recorded as strength measures. MANOVA showed that only prone-bridge hold time was significantly higher in the non-injured players ($p<0.05$). Logistic regression showed that prone-bridge hold time and peak isokinetic hip abductor torque were significant predictors of injury (OR=0.97&0.03, respectively). Thus, soccer players with knee injuries have lesser core endurance. Reduced prone-bridge hold time and abductor torque, specifically, are associated with an increased risk of injury.

***Keywords:*** *core endurance, trunk strength, hip strength, soccer, knee injury*

## Introduction

Soccer is the most popular sport with more than 265 million players worldwide (FIFA, 2007). The game involves continuous running, jumping, cutting, acceleration, deceleration, and contact with other players. Thus, there is a massive technical, physiological, and structural demand, growing interest primarily on the lower limbs, making players more susceptible to injury (Dellal et al., 2011). Lower limb injuries account for 61-82% of soccer injuries (Emery & Meeuwisse, 2010). Ramathesele (1998) reported that knee injuries account for 12-26% of injuries in youth soccer players. Recently, Gebert et al. (2020) reported that knee injuries account for 24.8% of all injuries and 53.2% of the cost of injury in Swiss amateur soccer players. In addition to the monetary cost, knee injuries are most severe, resulting in the greatest time away from play compared to other injuries (Stubbe et al., 2015). There is also an emotional and psychological cost to injured players. Thus, reducing injury should be a top priority for everyone involved (Dellal et al., 2013).

There has been growing interest in the proximal control of the knee (Zazulak, Hewett, Reeves, Goldberg, & Cholewicki, 2007), particularly that from the core (lumbopelvic-hip complex). Reduced core control would result in increased displacement of the centre of mass. Since the knee is the articulation at the distal end of the femur, the uncontrolled centre of mass displacements would result in excessive torques experienced at the knee (Zazulak et al., 2007). These excessive torques can

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strain different knee structures, causing injury (Zazulak et al., 2007). Weak hip abductors and external rotators specifically can lead to excessive knee valgus. Knee valgus has been termed the "position of no return" (Ireland, 2002) and is linked to many injuries, including those of the anterior cruciate ligament (ACL). Stickler, Finley and Gulgin (2015) reported that a 1% increase in hip abductor strength reduced knee valgus by 0.216º. Since soccer involves repetitive unilateral limb support situations, in our opinion, players with reduced core strength or endurance can be susceptible to experiencing dynamic knee valgus.

Few researchers have studied the influence of core related variables on lower limb injury in a limited number of sports. In these studies, the focus was on lower limb injury in general and not specifically the knee. For example, suboptimal core muscle endurance predicted lower limb sprain and strain injury in collegiate American football players (Wilkerson & Colston, 2015; Wilkerson, Giles, & Seibel, 2012), while reduced hip external rotator strength predicted lower limb injuries in collegiate basketball and track athletes (Leetun, Ireland, Willson, Ballantyne, & Davis, 2004). In addition, a recent study (Abdallah, Mohamed, & Hegazy, 2019) examined the relationship between reduced core endurance and lower limb sprain and strain injury in professional male soccer players. Specifically, players with reduced side-bridge hold times experienced more injuries throughout the season.

Although relationships between lower limb injury and core strength and endurance have been reported, to our knowledge, none of these studies was specific to knee injuries. In addition, only one study (Abdallah et al., 2019) established this relationship in soccer players; however, trunk muscle strength was not included as part of the assessment. Thus, the purpose of this study was to compare trunk muscle endurance as well as trunk and hip muscle strength between soccer players who experienced knee injuries during their season and those who did not. In addition, trunk muscle endurance, as well as trunk and hip muscle strength, were also used to predict the risk for injury. We hypothesized that players with lesser endurance and strength would experience more injuries. Furthermore, we would be able to predict injury from these reduced endurance and strength variables.

## Methods

### *Design & participants*

Eighty-two professional male soccer players from four clubs volunteered to participate in this prospective cross-sectional study. However, only 39 met the inclusion criteria. Inclusion criteria comprised age between 16 and 27 years, BMI between 18 and 30 kg/m², having no history of pain, injuries, or surgeries for at least one year. In addition, exclusion criteria included a manual muscle test score of less than five for trunk flexors and extensors, tightness of hamstrings or iliopsoas, and experiencing injury during the season in a non-practice or game setting.

### *Instrumentation*

McGill core endurance tests were used for endurance assessment (McGill, Childs, & Liebenson, 1999), specifically, the prone-bridge, side-bridge, trunk flexion and horizontal back extension tests. Time (measured in seconds) recorded while holding a specific position was the variable of interest. McGill endurance tests have moderate to very high reliability (intraclass correlation coefficient (ICC)=0.66-0.96; Waldhelm & Li, 2012).

The Biodex System 3 Pro multi-joint testing and rehabilitation system (Biodex Medical System, Shirley, NY, USA) was used to assess trunk and hip muscle strengths. Peak trunk flexor and extensor, as well as hip abductor and external rotator isokinetic torques, were the variables of interest. The Biodex system is a safe, objective, and reliable assessment tool having an ICC of 0.99 (Alvares et al., 2015). All torque values were corrected for the effect of gravity using the Biodex Advantages Software v.3.33

### *Procedures*

Prior to data collection, all procedures were approved by the Faculty of Physical Therapy, Cairo University Institutional Review Board. All procedures were carried out at an isokinetic laboratory. Players were then given a detailed orientation session on the purpose of the study and its procedures. All players or their legal guardians read and signed an informed consent form. All minors also provided verbal assent. Personal data were collected, and study inclusion and exclusion criteria were verified by the same examiner (a physical therapist with 10 years of experience). Each player's dominant foot (the preferred foot for kicking a ball) was specified.

Core endurance tests were performed first, followed by isokinetic hip and trunk muscle strength assessment. The prone-bridge test assesses anterior and posterior core muscle endurance. To perform this test, players supported their weight on their forearms and toes while keeping their pelvis in a neutral position. The total time they were able to do so before falling into hyper-lordosis was recorded. The side-bridge test assesses lateral core muscle endurance. To perform this test, players assumed a side-lying position and lifted their right


FIGURE 1. Core endurance tests; Side-bridge (a), Prone-bridge (b), Flexor endurance (c), and Horizontal extensor endurance (d)


FIGURE 2. Isokinetic strength assessment of hip abductors (a), hip external rotators (b), trunk flexors (c), and trunk extensors (d)

hip off the supporting table, thus, supporting their weight on both feet and right elbow. The left foot was placed in front of the right, and the left hand was placed on the right shoulder. The total time they were able to maintain this position without their pelvis dropping towards the supporting table was recorded. McGill et al. (1999) reported similar times for both sides; thus, the test was performed on the right side only. The flexor endurance test assesses anterior core muscle endurance. In this test, players sat on the supporting table while keeping their trunks flexed 60° and hips flexed 90°. The total time they were able to maintain these exact angles against gravity was recorded. Lastly, the horizontal back extension test was used to assess posterior core muscle endurance. In this test, players lied prone with their trunks off of the supporting table. Their pelvis and knees were stabilized by the examiner. The total time they were able to keep their trunk in a horizontal position without falling was recorded.

Hip muscle strength assessment was carried out through a 0–30° range of motion at a 60°/sec (Boling et al., 2009) while that of the trunk through a 70° (20° extension-50° flexion) range of motion at a 60°/sec (Shirado, Ito, Kaneda, & Strax, 1995). All torque data were normalized to body mass (Nm/kg). Players performed five consecutive maximal muscle contractions for familiarization, followed by a one-minute break, followed by five recorded trials. Both endurance and strength assessments (Figures 1a-d and 2a-d) were conducted before the season.

Players were instructed to avoid any sports activity (including team practice) for 24 hours before testing. All knee injuries experienced by players during the season in game and practice settings were recorded. Players were excluded from the study if they experienced injuries in other settings. Team doctors were responsible for diagnosing and reporting injuries. Injury details, including mechanism, site, and whether it was contact or non-contact, were recorded. Injuries were operationally defined as those that led to time loss from games or practice (Leetun et al., 2004). Therefore, all injuries should have occurred during organized practices and/or games during the season.

*Statistical analysis*

Following the end of the season, players were subdivided into two groups; injured and non-injured. Initially, data exploration was conducted in which outliers and extreme scores were removed. Once assumptions for parametric testing were verified (normality and homogeneity of variance assumptions), MANOVA analysis was conducted to compare endurance times of the four tests, as well as the peak isokinetic torques of the four muscle groups between both groups. MANOVA was conducted with subsequent multiple pairwise comparison tests using Bonferroni adjustment of a 0.05-alpha level. To predict the risk of knee injury, each of the endurance and strength variables was used with logistic regression analysis. Hold times of the four endurance tests were used together as independent variables with injury occurrence as the dependent variable (injury presence=1, and injury absence=0).

Similarly, peak isokinetic torques of trunk flexors and extensors, as well as hip external rotators and abductors, were used together as predictors with injury occurrence as the dependent variable. Backward stepwise regression was conducted. SPSS version 17 (IBM, Inc, Armonk, NY) was used for statistical analysis.

## Results

Descriptive statistics for player demographic data showed that the mean age was 17.92±1.93 vs 20.41±2.87 years, weight 77.83±19.52 vs 72.2±13.67 kg, height 1.76±0.1 vs 1.76±0.1 m, and BMI 24.83±3.75 vs 23.23±2.93 kg/m² for the injured vs non-injured groups, respectively. Injured players were significantly younger (p=0.01). No other demographic variables were significantly different (p>0.05).

Frequency distribution analysis revealed that twelve (30.77%) of the 39 players had at least one knee injury. A total of 25 knee injuries were recorded; 11 (44% of the total number of injuries) patellofemoral pain syndrome, 5 (20%) quadriceps strain, 3 (12%) knee lateral collateral ligament sprain, 2 (8%) iliotibial tract syndrome, 1 (4%) hamstrings strain, 1 (4%) hip adductors strain, 1 (4%) calf strain, and 1 (4%) knee medial collateral ligament sprain (Figure 3).

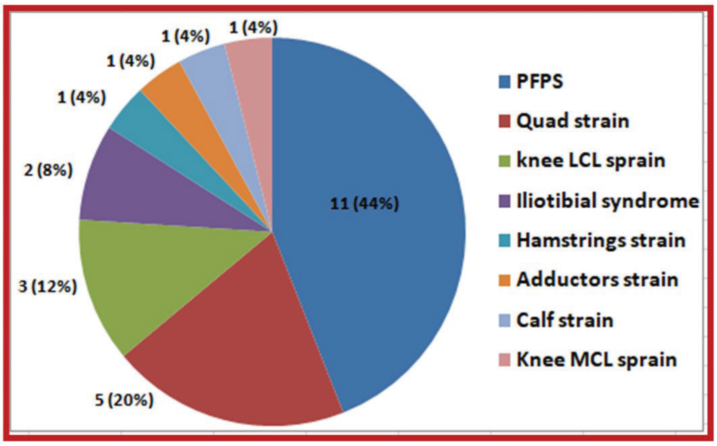


FIGURE 3. Knee injury distribution among injured soccer players

MANOVA analysis showed that prone-bridge hold time was significantly higher in non-injured players compared to injured (p=0.01), with no other significant differences for all other variables (Table 1).

**Table 1.** Descriptive statistics and multiple pairwise comparison tests for the core muscle hold time and peak hip and trunk muscle isokinetic torques between injured and non-injured soccer players

| | | Injured M±SD | Non-injured M±SD | p |
|---|---|---|---|---|
| Core muscle hold time (sec) | Prone- bridge | 74.27±30.99 | 107.68±37.03 | 0.013* |
| | Side- bridge | 64.36±31.23 | 73.28±29.86 | 0.42 |
| | Trunk flexion | 95±42.11 | 83.88±32.19 | 0.39 |
| | Horizontal trunk extension | 144.45±64.49 | 133.12±35.63 | 0.51 |
| Normalized hip and trunk muscle isokinetic torque (Nm/kg) | Hip abductors | 0.82±0.28 | 1.02±0.33 | 0.09 |
| | Hip external rotators | 0.63±0.2 | 0.61±0.22 | 0.85 |
| | Trunk flexors | 1.78±0.63 | 2.02±0.75 | 0.35 |
| | Trunk extensors | 2.73±1 | 3.3±1.1 | 0.15 |

Legend: * - Significant at p<0.05

Logistic regression revealed that prone-bridge hold time was the only significant predictor of knee injury (OR=0.97, p=0.02). The odds ratio indicated that with every unit (second) increase in the prone-bridge hold time, the odds of injury decreases to 0.97 times (i.e. decreases by 0.03 times (3%)). When only the constant was included in the model, the model correctly classified 70.3% of players into injured and non-injured categories. Adding prone-bridge hold time increased this percentage to 73% (Table 2).

**Table 2.** Knee injury logistic regression using core muscle hold times as predictors

| | | B | Wald | Sig. | Exp (B) |
|---|---|---|---|---|---|
| Step 1[a] | Prone-bridge | -0.04 | 4.856 | 0.028* | 0.961 |
| | Side-bridge | 0.00 | 0.001 | 0.980 | 1.000 |
| | Flexion Endurance test | 0.009 | 0.588 | 0.443 | 1.009 |
| | Extension Endurance test | 0.011 | 0.973 | 0.324 | 1.011 |
| | Constant | 0.287 | 0.029 | 0.866 | 1.333 |
| Step 2[a] | Prone-bridge | -0.040 | 5.607 | 0.018* | 0.961 |
| | Flexion Endurance test | 0.009 | 0.591 | 0.442 | 1.009 |
| | Extension Endurance test | 0.012 | 1.266 | 0.260 | 1.012 |
| | Constant | 0.289 | 0.029 | 0.865 | 1.335 |
| Step 3[a] | Prone-bridge | -0.039 | 5.776 | 0.016* | 0.962 |
| | Extension Endurance test | 0.013 | 1.513 | 0.219 | 1.013 |
| | Constant | 0.823 | 0.285 | 0.593 | 2.277 |
| Step 4[a] | Prone-bridge | -0.032 | 5.423 | 0.020* | 0.968 |
| | Constant | 2.030 | 2.805 | 0.094 | 7.615 |

Legend:a - Variables entered in the corresponding step; B-coefficient of the predictor (slope values); Constant-value of the criterion when the predictor equals zero; *-Significant at p<0.05; Cox & Snell $R^2$=0.186; Nagelkerke $R^2$=0.264; Hosmer & Lemeshow test= $\chi^2(7)$=3.759; p=0.807 for step 4

When peak trunk and hip muscle isokinetic torques were used for prediction, hip abductor torque was the only significant predictor of knee injury (OR=0.03, p=0.03). The odds ratio indicated that with every unit (Nm/kg) increase in the abductor torque, the odds of injury decreases to 0.03 times (i.e. decreases by 0.97 times (97%)). When only the constant was included in the model, the model correctly classified 68.4% of players into injured and non-injured. Adding abductor torque increased this percentage to 78.9% (Table 3).

**Table 3.** Knee injury logistic regression using the peak hip and trunk muscle isokinetic torques as predictors

| | | B | Wald | Sig. | Exp (B) |
|---|---|---|---|---|---|
| Step 1[a] | Trunk flexors | -0.459 | 0.202 | 0.653 | 0.632 |
| | Trunk Extensors | -0.205 | 0.105 | 0.746 | 0.815 |
| | Hip Abductors | -2.906 | 2.865 | 0.091 | 0.055 |
| | Hip External Rotators | 3.413 | 1.964 | 0.161 | 30.341 |
| | Constant | 1.218 | 0.639 | 0.424 | 3.379 |
| Step 2[a] | Trunk flexors | -0.667 | 0.716 | 0.397 | 0.513 |
| | Hip Abductors | -3.016 | 3.190 | 0.074 | 0.049 |
| | Hip External Rotators | 3.505 | 2.124 | 0.145 | 33.296 |
| | Constant | 1.039 | 0.548 | 0.459 | 2.826 |
| Step 3[a] | Hip Abductors | -3.500 | 4.502 | 0.034* | 0.030 |
| | Hip External Rotators | 2.674 | 1.546 | 0.214 | 14.502 |
| | Constant | 0.741 | 0.311 | 0.577 | 2.097 |
| Step 4[a] | Hip Abductors | -2.513 | 3.443 | 0.064 | 0.081 |
| | Constant | 1.515 | 1.518 | 0.218 | 4.551 |

Legend: Cox & Snell $R^2$=0.138; Nagelkerke R2=0.193; Hosmer & Lemeshow test= $\chi^2(8)$=8.058; p=0.428 for step 3

## Discussion

The purpose of this study was to compare trunk muscle endurance as well as trunk and hip muscle strength in soccer players that experience knee injury to those who did not throughout a season. The ability to predict knee injury from these variables was also assessed.

Prone-bridge hold time was the only variable that was significantly longer in players who did not experience knee injury than those who did. Therefore, it is likely that muscles active during the prone-bridge are of sufficient strength in all players. However, as games progress, muscles with less endurance are not able to sustain their force production. This reduction in force production reduces the body's ability to control centre of mass motion, thus, increasing the need for the lower limbs to compensate (Wilkerson et al., 2012). Considering that the knee lies between the two longest levers in the body, any minor centre of mass perturbations can lead to a huge amount of force experienced at the knee (Del Bel, Fairfax, Jones, Steele, & Landry, 2017). A reduction in core proprioception has also been shown to reduce lower limb neuromuscular control. Hart et al. (2006) reported a reduction in quadriceps activation following paraspinal fatigue when the quadriceps itself was not fatigued. Similarly, Park et al. (2008) reported a reduction in lower limb coordination following paraspinal muscle fatigue. Thus, it is reasonable to argue that core fatigue contributes to knee injury in soccer players directly by increasing the demand on lower limb muscles and indirectly by altering lower limb neuromuscular control.

The prone-bridge primarily assesses trunk flexor endurance as well as rectus femoris endurance (Escamilla, Lewis, Pecson, Imamura, & Andrews, 2016). The activation of both trunk flexor and rectus femoris is of key importance in reducing the load on the knee. During different tasks, such as walking and jump landing, the ground reaction force vector will pass in front of the hip and behind the knee, creating a flexion moment at both joints. How much flexion torque is experienced at each joint will depend on the distance between the force and joint centre. As trunk flexors become active, trunk flexion increases along with hip flexion, which leads the ground reaction force vector to pass close to the knee joint reducing the flexion moment at the knee, thus, reducing the level of quadriceps activation needed (Powers, 2010). In situations in which trunk flexors are not as active, the trunk will be more upright, causing the ground reaction force vector to be further away from the knee, resulting in greater knee flexion moment and a need for the quadriceps to increase its activation to control knee flexion. Similarly, a fatigued rectus femoris cannot control normal knee flexion moments sustained, even when the moment arm of the ground reaction force vector is close to the knee. Both situations can result in excessive loads on the quadriceps during its eccentric action, which is a common mechanism for quadriceps strain (Kary, 2010), which made up 20% of injuries suffered in our study.

Perhaps the reduced trunk flexor and rectus abdominis endurance combination differentiated the prone-bridge from both the side-bridge and trunk flexion tests. Our previous study (Abdallah et al., 2019) reported that both prone-bridge and side-bridge correlated with lower limb strain and strain injuries, with the side-bridge being the only predictor. We expected to have similar results in the present study; however, the side-bridge did not correlate or predict knee injury. Compared to the prone-bridge, the side-bridge requires greater activation of the gluteus medius (74% and 27% of MVC for the side-bridge and prone-bridge, respectively ;Ekstrom, Donatelli, & Carp, 2007). Our results suggest that knee injuries were more related to gluteus medius strength rather than its endurance.

In contrast, the prone-bridge requires greater trunk flexor activation (21% and 40% of MVC for the side-bridge and prone-bridge, respectively ;Escamilla et al., 2016). Although other mechanisms may be involved, the effect of lower trunk flexor endurance is described above. Similar to the prone-bridge, the trunk flexion test assesses trunk flexor endurance; however, the prone-bridge requires greater rectus femoris activation (6% and 20% of MVC for the trunk flexion and prone-bridge, respectively; Escamilla et al., 2016). Thus, it is likely that a combined reduction in both rectus abdominis and rectus femoris endurance is related to injury and not just one muscle on its own.

Hip abductor strength was the other significant knee injury predictor. Although it was not statistically different between groups, it did approach significance (p=0.09). Weaker hip abductors are unable to resist knee valgus tendency. Specifically, hip abductor weakness leads to femoral adduction, resulting in the knee joint centre moving medially as the tibia moves to a more abducted position relative to the femur (Powers, 2010). This pattern is linked to different knee injuries, including ACL, patellofemoral pain syndrome, and iliotibial band syndrome (Fredericson et al., 2000; Powers, 2010). Although there were no ACL injuries in the current study, the most prevalent injury experienced was patellofemoral pain syndrome, with 11 (44%) injuries occurring throughout the season. Patellofemoral pain syndrome has been consistently linked to decreased hip abduction and external rotation (Bolgla, Malone, Umberger, & Uhl, 2008). Although we measured hip abductor group strength, our data suggest patellofemoral pain syndrome is most likely linked to weakness of the gluteus medius rather than tensor fasciae latae considering the gluteus medius is an external rotator whereas the tensor fasciae latae is an internal rotator. In addition, one participant (4%) experienced iliotibial band syndrome. Weaker hip abductors and greater hip adduction have been observed in runners with the iliotibial band syndrome (Fredericson et al., 2000). The hip adduction position stretches the iliotibial band, thus, leading to its strain.

Weak hip abductors have also been linked to lateral collateral ligament (LCL) strain, which was experienced by three players accounting for 12% of knee injuries. During single-limb support situations, such as running, the ground reaction force vector passes medial to the knee, thus increasing varus stress, which is resisted by the LCL. Weak hip abductors can result in the trunk falling away from the support leg, thus increasing the moment arm of the ground reaction force vector, and increasing the strain on the LCL (Powers, 2010). This force can be greatly increased in situations, such as cutting and changing direction, commonly seen in soccer (Besier, Lloyd, Cochrane, & Ackland, 2001).

Our previous study (Abdallah et al., 2019) found no relationship between hip abduction strength and lower limb sprain and strain injuries. However, that study was not specific to the knee, and 56% of injuries were ankle sprains. Thus, a knee-specific analysis for our previous study data could have revealed hip abductor strength involvement in knee injury; however, it was not conducted.

The current study findings support that lower core endurance and hip muscle strength are related to and can be used to predict knee injuries. Specifically, reduced prone-bridge time and reduced hip abductor strength increase the probability of injuries. Our first hypothesis was partially supported, as prone-bridge hold time (a trunk endurance variable) was the only variable that differentiated between injured and uninjured players. Our second hypothesis was supported as both prone-bridge hold time (a trunk endurance variable) and hip abductor strength (a hip strength variable) predicted injury. Thus, core training can be an effective injury prevention strategy for soccer players (Vasileiadis, 2020), particularly those identified as susceptible to injury by preseason screening.

The findings of the current study should be considered in light of few limitations. First, our findings are limited to professional male soccer players. Thus, our findings cannot be generalized to female soccer players or athletes involved in different sports. In addition, training load (hours of exposure) was not considered in our study, which may have impacted injury incidences. Furthermore, despite isokinetic trunk extensor and hip abductor torques showing moderate effect size, there was no significant difference between groups. We attribute this to our small sample size; however, we were limited to players who volunteered from the four clubs that met our inclusion criteria.

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**Conflict of Interest**

The authors declare that there are no conflicts of interest.

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SportMont

ORIGINAL SCIENTIFIC PAPER

# Effects of Two Types of Warm-Up Exercises on Vital Capacity and Forced Vital Capacity Values

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**Abstract**

Valuable information can be obtained about the respiratory system when performing lung function tests. These tests show differences in pulmonary functional quantities, which can be attributed to many factors. Some factors that may significantly affect the optimal pre-test values for pulmonary function may appear, including the subject's physical condition before testing. This study aims to analyse the physiological effects of various types of warm-ups exercises and their effect on pre-test results of respiratory variables of Vital Capacity (VC) and Forced Vital Capacity (FVC). Sixteen healthy males participants ages (19–21) years (20.08±1.55 years) were intentionally selected. The homogeneity of age, height, mass, Vital Capacity (VC), and Forced Vital Capacity (FVC) was verified. The results of VC and FVC tests were taken before and after field and laboratory warm-ups; the laboratory warm-up was performed on a treadmill. The study revealed significant differences in the VC results between non-warm-ups compared with the VC predicted values. No significant differences between field and laboratory warm-ups compared with VC predicted value were found. Significant differences in the VC results after the field and laboratory warm-ups compared to non-warm-up results were recorded. The study showed significant differences in the FVC results between non-warm-ups compared with FVC predicted value. No significant differences between field and laboratory warm-ups compared with FVC predicted value were found. Significant differences in the FVC results after the field and laboratory warm-ups compared to non-warm-up results. We observed that warm-up exercises had a positive effect on variable-related results for VC and FVC, especially when the warm-up was in the lab.

***Keywords:*** *laboratory warm-up, field warm-up, respiratory muscles, pulmonary function*

## Introduction

Valuable information can be obtained on the strength of the respiratory muscles, the mechanical properties of the lungs, the movement of the rib cage, and the efficiency of gas exchange processes when performing pulmonary function tests. In the area of sports, the effects of training on pulmonary functions are the primary aim, so a pulmonary test should utilise the best method to obtain the best value at pre-test, which should be close or similar to the predictable results shown by the device. In addition, this value should be adopted as a correct baseline for the post-test of the sports training programme. These tests show differences in pulmonary function quantities values that may be attributed to factors associated with instrumentation, measurement-based experience, temperature, and a subject's response to following the instructions. It was observed that all of the factors mentioned above make the actual values differ from their corresponding predicted ones. For instance, these factors could be controlled by the calibration of testing instruments, laboratory settings, and training on the optimal test performance. However, we show some other factors that may significantly affect the optimal test values of the pulmonary functions, including the physical condition of the subject before the test.

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Gradation and preparation are important and necessary in all human activities, both mentally and physically. Prior to any physical activities, warm-ups must be sufficiently performed in order to prepare the body to be active and ready for the assigned activities. It is known that warm-up exercises are very important and highly recommended by physical fitness experts. These exercises are considered indispensable to facilitate the movement of muscles in all directions and increase muscular activity. Performing warm-up exercises results in physiological and chemical changes in the muscular structure, which in turn increases elasticity and power (Alanazi, 2016; Morrin & Redding, 2013).

"It is important that warming ups should be specific to the exercise that will follow, which means that exercises (of warming up) should prepare the muscles to be used and to activate the energy systems that are required for that particular activity" (Kar & Banerjee, 2013).

It is noted that most studies in this field of research focus primarily on the effects of exercise and training on respiratory functions, but not on the importance of lung function pre-test values and the best way to conduct the pre-test. The researchers also noted, through many functional tests of the respiratory system (because they are responsible for exercise physiology laboratories in their colleges), that the actual values do not match or come close to much of the expected values that the device gives after entering the data subject's (length, weight, gender, smoker or not, etc.). Therefore, the researchers suggested preparing respiratory muscles before beginning respiratory tests by warming up and determining the effects of warm-ups on the results of some respiratory variables (Flesch & Dine, 2012). Moreover, determining the best way to warm-up in such functional tests should aid in obtaining actual pulmonary values near to their predicted ones, to be a baseline for the pre-post of the sports training programme.

The current research addresses the following questions: 1) Do warm-ups affect the values of the results of Vital Capacity (VC) and Forced Vital Capacity (FVC); 2) What type of warm-ups are appropriate and which have the greatest effects on the outcome of VC and FVC

## Methods

*Subjects*

The subjects of this study were a purposeful sample chosen from 58 students from the third academic class at the Faculty of Physical Education at KOYA University. After excluding females, athletes, and obese students, the subjects were 24 students homogeneous in age, height, and body mass but not in VC and FVC. Therefore, the outliers values above and below the VC and FVC results were omitted. The final and main subjects were 16 students at age 19–21 years and homogeneous in the variables shown in Table 1.

**Table 1.** Homogeneity statistics of Subjects

| Variables | Statistical parameters | |
|---|---|---|
| | **Mean±SD**<br>**SD ±** | **Skewness** |
| Age (year) | 20.08±1.55 | 0.29 |
| Height (cm) | 172.3±5.59 | 0.79 |
| Body Mass (kg) | 69.5±4.65 | 0.74 |
| VC (L) | 4.05±0.43 | 0.60 |
| FVC (L. s-1) | 3.72±0.36 | 0.35 |

Legend: VC - vital capacity; FVC- Forced vital capacity

*Anthropometric Measurements*

Two anthropometric measurements were taken: height and weight. They were measured in triplicate with the median value used as the criterion. The height was recorded during inspiration using a stadiometer (Charder Electronic, Taichung, Taiwan) to the nearest 0.1 cm. The subject was asked to stand upright on the stadiometer barefoot, the metal plate of the stadiometer was placed on the top of the subjects' head, and the results were recorded. Weight was measured by digital standing scales (Detecto solo Digital Physician Scale, Brooklyn, NY, USA) to the nearest 0.1 kg with the subjects barefoot and in shorts (Eston & Reilly, 2009; Koley, 2011)

*Spirometry*

The VC test is the total volume of air that can be exhaled after maximum inhaling by using a spirometer for measuring lung function type (CHESTGRAPH HI-301, Tokyo, Japan). VC testing begins by guiding the subject in performing the appropriate technique. The subjects need to understand that they have to fill and empty their lungs as much as possible. The VC testing was performed with a subject using a mouthpiece and wearing a nose clip. The VC was performed conveniently but not inappropriately slow, except for near inspiration and expiration. All subjects maximumly exhale, then maximally inhale, and finally maximally exhale again. Technicians should carefully monitor this subject to ensure that his lips are closed and there are no leaks or obstructions to the mouthpiece (Miller, Hankinson, Brusasco, Burgos, & Others, 2005).

The FVC is the amount of air exhaled forcefully and quickly after inhaling as much as possible. The subject takes a deep breath in, as large as possible, and blows out as hard and fast as possible and keeps going until there is no air left using a mouthpiece and wearing a nose clip (Moore, 2012).

*Independent variables*

Laboratory warm-ups were carried out according to the modified Bruce protocol test on an institutional treadmill (Vacuumed, California, USA), and the warm-up period was 6 minutes. Compared to the standard Bruce protocol, the modified Bruce protocol has two warm-up stages, each lasting 3 minutes. The first stage is at 1.7 mph and a 0% grade, and the second stage is at 1.7 mph and a 5% grade. Therefore, this protocol is convenient for the aim of this study; it simulates or parallels the field warm-ups (Harris & White, 2009). The field warm-ups were carried out outside the laboratory for 6 minutes, where the subjects were given a light jog for 2-3 minutes; after that, they were assigned leg, hip, arm, and chest exercises (Lee, 2014).

*Final experiment*

The final experiment included three tests on three separate days for each subject. For tests warm-up, the subjects were divided into four groups with four subjects for each group to ensure no significant time lags when waiting for the test. On the first day, the test of VC and FVC was performed without a warm-up. On the second day, the test of VC was performed after a 6-minute warm-up on the treadmill under laboratory control followed by rest for 3 minutes before the test, then repeated after a two-hour interval but after a 6-minute field warm-up, also followed by rest for 3 minutes before the test. On the third day, the test of FVC performed after a 6-minute warm-up on the treadmill under laboratory control, then repeated after the two-hour interval but after a 6-minute field warm-up, either way, followed by a rest for 3 minutes before the tests; this is shown in Table 2.

**Table 2.** Steps to perform the final experiment

| Day | Groups | Subject number for each group | Warm-up type | Duration of warm-up | Rest | Test type |
|---|---|---|---|---|---|---|
| Day 1 | Group 1 | 16 | Non | Non | 2 hours between VC and FVC test | VC |
| | | | | | | FVC |
| Day 2 | Group 1 | 4 | field warm-up | 6 minutes | 3 minutes | VC |
| | Group 2 | | | | | |
| | Group 3 | | | | | |
| | Group 4 | | | | | |
| | 2 hours interval between field warm-up and Laboratory warm-up in VC test | | | | | |
| | Group 1 | 4 | Laboratory warm-up | 6 minutes | 3 minutes | VC |
| | Group 2 | | | | | |
| | Group 3 | | | | | |
| | Group 4 | | | | | |
| Day 3 | Group 1 | 4 | field warm-up | 6 minutes | 3 minutes | FVC |
| | Group 2 | | | | | |
| | Group 3 | | | | | |
| | Group 4 | | | | | |
| | 2 hours interval between field warm-up and Laboratory warm-up in FVC test | | | | | |
| | Group 1 | 4 | Laboratory warm-up | 6 minutes | 3 minutes | FVC |
| | Group 2 | | | | | |
| | Group 3 | | | | | |
| | Group 4 | | | | | |

*Statistical analysis*

Paired t-test statistical analysis was used to find the differences between the means of three independent VC and FVC tests, Non-warm-up, Laboratory warm-up and Field warm-up and to compare them with predicted values for both variables. The one-way analysis of variance (ANOVA) is used to determine any statistically significant differences between the means of three independent VC and FVC tests, Non-warm-up, Laboratory warm-up and Field warm-up. A post-hoc test of less significant difference (LSD) was used for situations in which the findings have already obtained a significant F-test and for adding exploration of the differences among means to provide specific information on which means are significantly different from each other. Descriptive statistics of mean, standard deviation, and skewness coefficient were utilized to describe the basic features of the data in this study and to provide simple summaries about the sample and the measures. SPSS version 18.0 was used for all analyses (SPSS Inc., Chicago, IL, USA).

## Results

Table 3 shows that the mean VC values are 4.05 for non-warm-up, 4.52 for laboratory warm-up, and 4.46 for field warm-up. Additionally, it explains that the mean FVC values are 3.72 for non-warm-up, 4.11 for laboratory warm-up, and 4.05 for field warm-up.

In Table 4, a statistical comparison is made using a t-test to compare non-warm-up and warm-ups values with the predicted values. The predicted or optimal values are obtained via the spirometer based on the input data (height, weight, gender, etc.); we did obtain the predicted values of VC and FVC from Knudson's reference values, which are the closest fit to the lung function of subjects. Knudson's reference values are included in the settings of the utilized spirometer; we choose these values to be a predicted reference. Table 4 shows that a statistically significant difference is found in the VC variable when non-warm-up results are compared with the predicted value ($t=-4.92$, $p=0.001$). Relatedly, no significant difference between the field

**Table 3.** Descriptive statistics of VC and FVC at various warm-ups

| Warm-up type | Functional variable | |
|---|---|---|
| | VC | FVC |
| | SD±Mean | SD±Mean |
| Non-warm-up | 0.43±4.05 | 0.36±3.72 |
| Laboratory warm-up | 0.40±4.52 | 0.44±4.11 |
| Field warm-up | 0.52±4.46 | 4.05±0.32 |
| predicted value | 0.32±4.78 | 0.33±4.28 |

Legend: VC - vital capacity; FVC- Forced vital capacity

warm-up and the predicted value is noted (t=- 1.74, p=0.102).

Additionally, no significant difference is found between the laboratory warm-up and the predicted value (t=-1.63, p=0.123) in the VC variable. The same table shows a statistically significant difference in the FVC variable when non-warm-up results are compared with the predicted value (t=-4.54, p=0.001) and that there is no significant difference between the field warm-up and the predicted value (t=-1.54, p=0.138). No significant difference between the laboratory warm-up and the predicted value (t=-1.43, p=0.171) in the FVC variable is found.

**Table 4.** VC & FVC results compare with predicted value by Paired t- test

| | Mean±SD | t | p |
|---|---|---|---|
| Vital Capacity (VC) | | | |
| N warmup- predicted value | -0.73±0.59 | -4.92 | 0.001* |
| F warmup – predicted value | -0.31±0.71 | -1.74 | 0.102 |
| L warmup- predicted value | -0.25±0.62 | -1.63 | 0.123 |
| Forced Vital Capacity (FVC) | | | |
| N warmup- predicted value | -0.57±0.50 | -4.54 | 0.001* |
| F warmup - predicted value | -0.24±0.63 | -1.56 | 0.138 |
| L warmup- predicted value | -0.18±0.51 | -1.43 | 0.171 |

Legend: F warm-up – Field warm-up; L warm-up – Laboratory warm-up; N warm-up – non-warm-up; * - p<05

Table 5 shows that a statistically significant difference was found among the three levels of VC's test on the types of warm-up (F=5.208, p=0.009). A statistically significant difference was found among the three levels of FVC tests on types of warm-up (F=4.703, p=0.014).

LSD post-hoc tests in the table indicate that there were significant mean differences of VC testing between the Non-warm-up group and both the Field warm-up group (p<0.012) and the Laboratory warm-up group (p<0.005); this is shown in Table 6. LSD Post hoc tests in the table indicate that there were significant mean differences in the FVC testing between the Non-warm-up group and both the Field warm-up (p<0.021) and the Laboratory warm-up (p<0.006)groups; this is shown in Table 6.

**Table 5.** One-way ANOVA of VC and FVC at various warm-ups

| Variables | Statistical treatments | Sum of squares | Mean square | F | p |
|---|---|---|---|---|---|
| VC / L | Between group | 2.23 | 1.105 | 5.238 | 0.009* |
| | Within group | 9.51 | 0.211 | | |
| | Total | 11.72 | | | |
| FVC / L.s | Between group | 1.37 | 0.688 | 4.703 | 0.014* |
| | Within group | 6.58 | 0.146 | | |
| | Total | 7.96 | | | |

**Table 6.** LSD of VC and FVC among various warm-ups

| Variables | Group | Comparison group | Mean differences | p |
|---|---|---|---|---|
| VC | Non-warm-up | Field warm-up | -0.42 | 0.012* |
| | Non-warm-up | Laboratory warm-up | -0.48 | 0.005** |
| | Field warm-up | Laboratory warm-up | 0. 51 | 0.731 |
| FVC | Non-warm-up | Field warm-up | -0.32 | 0.021* |
| | Non-warm-up | Laboratory warm-up | -0.38 | 0.006* |
| | Field warm-up | Laboratory warm-up | -0.063 | 0.65 |

## Discussion

This study aims to determine the effects of the warm-up type on VC and FVC for health practitioners of sports activity but not athletes. Moreover, it aims to examine the most beneficial warm-up type that increases the VC and FVC values and attempts to match them with the predicted values. VC test differences were found between warm-ups and both field warm-up and laboratory warm-up.

We know that the results of the respiratory tests depend on the efficiency of the respiratory system. One factor that negatively affect the efficiency of the respiratory system are respiratory diseases. Another factor is the extent to which respiratory muscles participate in the test, which is a group of muscles that can reach 16 muscles between primary and secondary or the supporting muscles (Kraemer, Fleck, & Deschenes, 2014). Excluding the fact that the participants suffer from respiratory diseases because the initial results were presented to the respiratory physician who confirmed their safety, we still have the effect of the respiratory muscles on the results of the VC test, which was affected by warm-ups, whether in the laboratory or field.

The researchers attribute the significant differences between the results of field warm-up and laboratory warm-up when compared with the results of no warm-up in the VC test to the effectiveness of warm-up in the preparation and adaptation of the respiratory muscles in the implementation of the VC test technique. McGuff and Little mention that no one argues that athlete's connective muscles and connective tissue should be warm and that viscosity should be reduced before engaging in any activity (Kraemer et al., 2014). Warming up, as well as injury prevention, includes other benefits, such as increased speed and efficiency muscle contraction, tissue compliance, enhanced utilized oxygen delivery, and facilitating the transmission of nerve impulses (V. L. Katch, McArdle, & F. I. Katch, 2011). This was achieved by the increase in the VC values after the warm-ups.

In the VC equation (VC=IRV+Vt+ERV), we see that a VC variable that depends on three elements. The most important aspects in this equation variable is the inspiratory reserve volume (IRV), the maximum amount of air that can be taken by the inspiration, and the expiratory reserve volume (ERV), the maximum amount of air can be expelled by exhalation. These are two forced operations that require the insertion of extra muscles into action (Guyton & Hall, 2006). The Vt variable is excluded because the tests are taken at rest. We notice that the IRV and ERV variables influence the value of VC. These variables depend on the extent of the respiratory muscles involved in this action; like other skeletal muscles, they are all affected by warm-ups. When referring to the comparison of probability levels between no warm-up with field warm-up and no warm-up with laboratory warm-up, we note that the greatest significant differences go to laboratory warm-up. The researchers believe that the continuity of work on the treadmill has placed a greater burden on the respiratory muscles than field warm-up. The degree of respiratory muscle mobilization in laboratory warm-up was more than an intermittent exercise in the field warm-up. According to Nicholas Ratamess 2012, an important component of aerobic exercise is the level of continuity and the size of skeletal muscles involved in the work (Ratamess, 2012).

Aerobic exercises on a treadmill requires the use of large groups of body muscles and thus an uptake in the amount of oxygen. High-intensity aerobic exercises improve airflow in the respiratory system. When a large lung volume is required, the lung is enlarged substantially and thus has significant contraction force, and the diameter of the respiratory passages is expanded to reduce airflow resistance (Park & Han, 2017). All of this requires an increasingly effective contribution from the respiratory muscles, and thus reflects positively on the VC test.

Warming up increases the elasticity of the skeletal muscles, as well as increasing the breathing rate and in the air entering the lungs to obtain oxygen. Hayes and Karman indicate that FVC is not only limited to the exhalation muscles' effort but also by the elasticity of the lungs (Hayes & Kraman, 2009). That happened in both warm-ups to the FVC variable; because the respiratory muscles are skeletal muscles, they were positively affected by the warm-up; also, the increase in the respiratory rate increases the movement of the lungs in the entry and exit of the air, which led to increasing elasticity for lungs.

From another perspective, there were significant differences in the results of VC, in both laboratory and field warm-ups when compared to non-warm-up. Researchers believe that the subjects that were able to make a significant difference in the VC test can make the same differences in the FVC test in favour of the warm-up. Yuan, He, Xu, Wang and Casaburi (2014) point out that in normal or healthy people, there is a slight difference between the results of VC and FVC, and sometimes that difference may be absent.

When comparing the calculated mean for the FVC test in laboratory warm-up with their results in field warm-up, we observe that the preference goes to laboratory warm-up. Rawashdeh and Alnawaiseh (2018) indicate that high-intensity exercises on the treadmill have a positive effect on the FVC in healthy people.

According to the results of this research, we noted that the warm-up exercises had a positive effect on the results related to the variable VC, especially when warm-up was in the laboratory and on the treadmill. In addition, warming up had a significant effect on the results of the variable FVC and in both warm-ups, but it was more effective when in the laboratory and on the treadmill. Researchers recommend that it is more helpful to have a warm-up before starting a VC or FVC test. Thus, the study recommends warming-up on the treadmill to improve the pulmonary function of the VC and FVC before performing lung function tests. Researchers also recommend researching other respiratory variables after introducing warm-up exercises.

### *Perspectives*

Several studies were conducted on the number of attempts that should be given to the topics to achieve credibility in results VC and FVC. In addition to studies on the effect of exercises on two variables VC and FVC. However, no study on preparing the subject physically before performing the tests. The current study showed that the warm-up before the test has a significant effect on the initial results of the tests VC and FVC and nearer to the expected values that the device gives when entering the initial information of the subject in it. There is still an urgent need for more studies on other respiratory variables to understand the effect of warming up before testing.

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SportMont

ORIGINAL SCIENTIFIC PAPER

# Association of Laboratory and Field Balance Test

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**Abstract**

Balance can be defined as keeping the center of gravity of the body within the surface of the support and has crucial role in sport. However, there are insufficient knowledge regarding balance field testing. The main aim of this study was to determine association between Biodex laboratory balance test and Y balance field test. The participants in this study were 12 students (6 males, 6 females) of Faculty of Kinesiology in Split, Croatia. The set of variables included anthropometric measures (body height, body weight, body mass index), two laboratory balance tests conducted on Biodex (Postural stability test, Limits of stability test) and field balance test (Y balance test). The correlations between observed variables were calculated by Pearson's product moment correlation. No significant correlations were found between Y balance test and both Postural stability test (r=-0.06 and 0.02 respectively for left and right leg) and Limits of stability test (r=-0.06 and 0.02). The results of this study indicate that Y balance test is not a precise measure of balance ability in well-trained individuals. Authors hypothesize that Y balance test performance is greatly influenced by lower extremity strength and mobility. There is an obvious need for the construction and validation of new field tests to assess the level of balance in amateur and professional athletes.

***Keywords:*** *dynamic balance, Y balance test, limits of stability, postural stability, Biodex*

## Introduction

When performing daily physical activities, from the simplest such as walking to extremely complex motor skills, a person constantly goes out and returns to a state of balance. As ability, balance is defined differently within different professions, since it has a different meaning in practice. In biomechanics, balance is defined as the ability to maintain individual's center of gravity within base of support, with minimal postural sway. As such we view it from the angle of sporting performance (Hrysomallis, 2007; Ndayisenga, 2019; Shumway-Cook, Anson, & Haller, 1988). Researchers have found that good balance plays a crucial role in many physical activities and directly contributes to the success of sports performance (Ghram, Damak, & Costa, 2017). In addition to allowing other motor abilities and skills to be optimally utilized, adequate balance has the effect of reducing the risk of injury (Ghram et al., 2020).

The general classification of balance is on: static and dynamic. Static balance represents the ability of sustaining the body position within its base of support (Goldie, Bach, & Evans, 1989; Olmsted, Carcia, Hertel, & Shultz, 2002). Dynamic balance, which is much more common in sport activities, involves maintaining a balanced position when performing dynamic movements (Bressel, Yonker, Kras, & Heath, 2007; Winter, Patla, & Frank, 1990). Both manifestations of balance are dependent on sensorimotor information collected through the somatosensory, visual and vestibular system and motor responses to these information (Amiri-Khorasani & Gulick, 2015; Grigg, 1994; Palmieri et al., 2003).

Testing the state of balance depends on the goals within the particular profession. In general, all tests in sports science, including those related to balance, can be divided into laboratory and field. Most commonly used laboratory balance test is the Biodex Balance System SDTM (Biodex medical Systems, NY, USA). Among other standardized tests, the Limits of Stability Test (LST) and the Postural Stability Test (PST) are most popular Biodex tests for balance monitoring (Cachupe, Shifflett, Kahanov, & Wughalter, 2001). PST is used to assess static balance. During PST performance, the subject stands with one or two legs on an unstable platform, and his task is to minimize the movement of the platform with timely and precise muscle contraction (Aydoğ,

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Aydoğ, Cakci, & Doral, 2006). LST assess dynamic balance. During test performance subject controls his body's' center of gravity and manipulates/moves the platform in a desired direction (Glave, Didier, Weatherwax, Browning, & Fiaud, 2016).

On the other hand, field tests are much simpler and cheaper to use, and the Star Excursion Balance Test (SEBT) and the Y Balance test (YBT) are mostly used in balance testing (Gribble, Hertel, & Plisky, 2012; Plisky et al., 2009). YBT is derived from SEBT and is used to asses the asymmetries of lower limb movements and the level of balance. It is assessed through single-leg standing with movements in the anterior (ANT), posteromedial (PM) and posterolateral (PL) direction (Smith, Chimera, & Warren, 2015). Previous researches have repeatedly confirmed the reliability and validity of both PST and LST on the Biodex System and YBT (Arnold & Schmitz, 1998; Cachupe et al., 2001; Gribble et al., 2012; Plisky et al., 2009).

In the review study of Sibley, Beauchamp, Van Ooteghem, Straus and Jaglal (2015), authors indicated that both LST and YBT assessed underlying motor systems, functional stability limits, and anticipatory postural control (Sibley, Beauchamp, Van Ooteghem, Straus, & Jaglal, 2015). Since there is a lack of research that compared outcomes of laboratory and field tests, aim of this study was to investigate association of Biodex platform and YBT test in context of measuring same or similar aspects of balance. We hypothesize that results will be positively correlated, specifically between LST and YBT as both tests supposed to measure dynamic balance capacity.

## Methods

Participants in this study were 12 students (6 male and 6 female, 21 years old on average) of third-year undergraduate study of Kinesiology. All participants are active athletes and in the time of testing were clinically healthy and without any locomotor injuries. The testing was held during the Strength and conditioning of athlete's course and was part of the courses' exam. This cause an additional motivating factor for subjects' test performance.

Variables included in this study were (i) anthropometric measures - body height (BH), body weight (BW) and body mass index (BMI), (ii) laboratory balance tests including Limits of Stability Test (LST) and the Postural Stability Test (PST) and (iii) field balance test Y balance test (YBT).

In the PST, participants needed to maintain static balance position for 30 seconds while standing on two feet in the center of the platform. Before the test the position of the subjects' feet is recorded. The result on the test shows a deviation from the center. Smaller results values are and presented with Balance index (BI). In the LST, participants had to move the body to bring the cursor on the screen to the blinking targets and return the cursor to the center as soon as possible with as less deflection possible. This was repeated randomly with 9 targets position in circle around the center target. LST BI is calculated with Biodex software. Higher BI indicates better dynamic stability result.

YBT was assessed with a YBT kit (Perform Better, FMS). Before testing participants conducted five minutes warm up and were allowed to have one trial attempt on each leg in each of the three directions before official testing. Participant task was to stand on one leg in the center of the platform and reach three times with the free leg in the anterior, posteromedial and posterolateral direction. While reaching, participants were forbidden to kick indicator. Farthest point reached by the foot at the proximal edge of the indicator was noted as the result. If the participant lost his balance during the test, raised the heel of the foot in the center, leaned on the moving foot or moved indicator unproperly, the trial was annulled and had to be repeated (Kokinda et al., 2018). Normalization of results is calculated by the ratio of average results (absolute distance) of each movement and leg length of the subject. The total result on the test is the sum of all three absolute distances divided by three times leg length and multiplied with 100. All tests were measured three times and the best score was taken as final.

Statistical analyses included the calculation of descriptive statistical parameters (arithmetic means and standard deviations, minimum and maximum measurement values and the Kolmogorov-Smirnov test for testing normality of distribution) and correlation analysis (Pearson's product-moment) to determine the relationship between the observed variables. For all analyses, Statistica 13.0 (TIBCO Software Inc, USA) was used, and a p-level of 95% was applied.

## Results

In Table 1 descriptive statistic parameters are shown.

Table 2 represents association between YBT and LST and PST on Biodex. Results show no statistically significant correlation between YBT and LST (r=-0.06 and r=0.02 for left and right leg respectively) and PST (r=-0.02 and r=0.05 for left and right leg respectively).

**Table 1.** Descriptive parameters

| Variable | Mean±St.Dev. | Minimum | Maximum |
|---|---|---|---|
| body height | 179.50±6.053 | 168.00 | 186.00 |
| body weight | 75.83±12.209 | 60.00 | 96.00 |
| body mass index | 23.44±2.817 | 20.05 | 29.00 |
| PST – Postural stability test | 1.47±0.543 | 0.80 | 2.50 |
| LST – Limits of stability | 19.33±9.326 | 5.00 | 38.00 |
| YBT (L) – Y balance test left leg | 98.22±8.251 | 76.00 | 106.10 |
| YBT (D) – Y balance test right leg | 100.35±7.734 | 80.00 | 107.70 |

**Table 2.** Correlation matrix (Pearson's product-moment correlation)

| Variables | YBT (L) – Y balance test left leg | YBT (D) – Y balance test right leg |
|---|---|---|
| PST–Postural stability test | -0.06 | 0.02 |
| LST–Limits of stability | -0.02 | 0.05 |

## Discussion

This study aimed to evaluate the association of the YBT with the LST and PST on the Biodex Balance System. Regarding to this, main finding is that there are no significant correlations between Biodex tests and YTB. Lack of correlations implies that: (i) the conducted test protocols measure different aspects of balance, or (ii) other factor could influence results (e.g. flexibility, strength, stability).

As previously mentioned, YBT is used to estimate dynamic balance as well as LST on Biodex, while PST is a measure of static balance. If a somewhat smaller association of PST and YTB could be expected to some extent, it was assumed that the two tests that measured dynamic balance would have a significant association. These results are most likely conditioned by different factors that influenced the assessment of balance in each test and nature of particular test. In particular, in PST the participant stands still and resists platform movements in anteroposterior and mediolateral directions simultaneously (Almeida, Monteiro, Marizeiro, Maia, & de Paula Lima, 2017). In LST, the participant needs to move center of pressure as a representation of body center of mass. On the other side, YBT is much more dynamic and includes maintaining center of mass over base of support through performing a dynamic movement with the other leg (Glave et al., 2016).

Also, in both tests on Biodex, movements in the hip and knee joints are limited, and the movement takes place almost exclusively in the ankle of the standing leg, while in YBT hip and knee flexion is one of the more important parameters that affect performance (Kang et al., 2015; Robinson & Gribble, 2008). Researches confirmed that YBT requires lower limb strength, stability, range of motion, and coordination while in tests on Biodex that dimension of motor space will be less pronounced (Coughlan, Fullam, Delahunt, Gissane, & Caulfield, 2012; Plisky, Rauh, Kaminski, & Underwood, 2006). It is obvious, that mobility and strength of the lower extremities will play a major role in the performance of YBT. Especially in well-trained individuals as is was the case in our study. Although there are no many studies that have dealt with this issue, the results of this study are in accordance with some previous researches (Almeida et al., 2017; Glave et al., 2016). In a study conducted on 40 recreational individuals, no statistically significant correlation was found between YBT and PST (Almeida et al., 2017). Moreover, a study of 31 students from a university in Texas found a negative association between the Star Excursion Balance Test (SEBT) and the LST test at Biodex (Glave et al., 2016). These findings suggest that YTB and LST and PST on Biodex measure different aspects of balance and therefore comparation and consistency of the results is limited.

## Conclusion

This was one of the first studies exploring associations between laboratory and field balance tests. Main limitation of this study is relatively small sample of participants and fact that both males and females were included. However, given that such a practice was also in other researches related to balance, the authors believe that this was methodologically appropriate couldn't produce suppressors' effect.

The results of this study confirm the conclusions of previous studies that say that there is no "gold standard" in the field of balance diagnostics and that different tests should be used for different subtypes of balance. Also, in assessment selection, gender and characteristics and level of training status should be taken into consideration. This study induced an issue in exploring athletes' balance capacities, specifically in specific conditions. Clearly, future studies should be focused on construction and validation sport (activity)-specific field balance tests.

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**Conflict of interest**
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ORIGINAL SCIENTIFIC PAPER

# Movement Mechanism Differences of Badminton Overhead Forehand and Backhand Smash Stroke Techniques during Teaching Learning in Human Movement Science

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**Abstract**

This study aims to analyze the movement of backhand and forehand smash stroke techniques in three dimensions using a kinematics approach in badminton. The results were analyzed using a descriptive and quantitative approach. Furthermore, 24 male badminton players from the University Student Activity Unit with an average age of 19.4±1.6 years, a height of 1.73±0.12m, and a weight of 62.8±3.7kg were used. The study was conducted using 3 Panasonic Handycams, a calibration set, 3D Frame DIAZ IV motion analysis software, and a speed radar gun. The data normalization from the kinematics values of the shoulder, elbow, and wrist joint motion was calculated using the inverse dynamics method. Also, the one-way Anova test was used to determine the differences in the kinematics of motion in the two different groups. The results showed that the speed of the shuttlecock during the forehand smash was greater than the backhand. In the maximal shoulder external rotation phase, two variables were found with the best results during the forehand smash, namely the velocity of shoulder external rotation and wrist palmar flexion. The velocity of shoulder internal rotation, elbow extension, and forearm supination in the maximum angular velocity phase showed greater results when making a forehand smash.

***Keywords:*** *badminton, overhead smash, biomechanics, kinematics, three dimensions*

## Introduction

According to Kuntze, Mansfield and Sellers (2010), stroke techniques are categorized into three types considering the position of the racket. They include underarm, sidearm, and overhead strokes. The attack technique often used is the overhead smash stroke technique (Chow, Seifert, Hérault, Chia, & Lee, 2014). Similarly, there are two types of smash technique skills, namely forehand and backhand smash. These are powerful attack weapons to kill opponents and get as many points as possible by contributing 39.8% (Barreira, Chiminazzo, & Fernandes, 2016). Furthermore, a smash is a fast stroke that relies on the strength, velocity, and flexion of the wrist with the shuttlecock swooping down towards the opponent's field area (Lam, Wong, & Lee, 2020).

The world record for smash speed is held by Fu Haifeng, a Chinese doubles player. This medalist paired with Cai Yun with a shuttlecock speed of 332 km/h at the June 2005 Sudirman Cup championship (Martin et al., 2020). The speed of the shuttlecock exceeded those of other racket sports by reaching 493 km/h. This was played by a Chinese player Tan Boon Heong while testing a new racket product (Yonex ArcSaber Z-Slash) in 2017 (Rusdiana et al., 2020). Meanwhile, the fastest backhand smash was conducted by Taufik Hidayat, an Indonesian player with a gold medal at the 2004 Athens Olympics with a shuttlecock speed of 206 km/hour (McErlain-Naylor et al., 2020).

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The backhand smash is an overhead stroke using the rear racket head. When making this, the body's position needs to back to the net by prioritizing the wrist joint flexion motion which is directed to swoop backward (Sakurai & Ohtsuki, 2010). This is because the transfer of body weight to the pedestal is the same as the position of the hand while holding the racket. The upper extremity rotates rapidly when the shuttlecock moves to the front of the player. Sequentially, it continues with the rotation of the hip, shoulder, and elbow joints (Li, Zhang, Wan, Wilde, & Shan, 2016). Same with a forehand smash, the shuttlecock needs to be hit at the highest possible position. Furthermore, the flexible and strong wrist flexion motion is a major factor in producing a hard and targeted stroke (Miller, Felton, Mcerlain-Naylor, Towler, & King, 2013). The reason for applying the motion mechanics principles is the key to producing a smash that provides maximum strength, speed, and accuracy to kill the opponent's movements and generate points (Ooi et al., 2009).

Due to the lack of backhand smashes, different studies tried to connect with almost the same motion patterns to add broader insights on tennis sports such as serve, smash, backhand, and forehand drive techniques. According to Abian-Vicen, Castanedo, Abian, & Sampedro (2013), a one-handed backhand drive is not only supported by the velocity of the trunk rotation. However, it is determined by the amount of momentum and force movement generated from the shoulder and wrist joints. This drive involves the motion of body segments such as the legs, hips, trunk, upper arms, forearms, and hands (Alexandros, Christina, Nikolaos, & Konstantinos, 2013).

The velocity of maximal shoulder external rotation and the backswing of the upper arm are the main factors in generating a greater force when making a backhand drive (Kolman, Kramer, Elferink-Gemser, Huijgen, & Visscher, 2019).

Genevois, Reid, Rogowski and Crespo (2014) reported that in the advanced player group, the maximum speed of the racket is obtained from the strength of the upper arm force. Meanwhile, in the novice group, the maximum speed is obtained from the motion of the wrist and elbow. During the one-handed backhand drive, the velocity of hip rotation makes a significant contribution to that of the other upper limb joints (Wu, Gross, Prentice, & Yu, 2001). Meanwhile, the forehand smash requires harmonious coordination of body motions from the strength generated by the trunk, shoulders, arms, and wrists (Mavvidis, Metaxas, Riganas, & Koronas, 2005). To produce an effective smash, the biomechanics principles should be implemented in the phase of motion sequences. These include the preparation phase, backswing, forward swing, racket impact with the shuttlecock, and follow-through motion phase (Phomsoupha & Laffaye, 2014). Nesbit, Elzinga, Herchenroder and Serrano (2006) stated that the importance of wrist flexion, forearm pronation, and upper arm rotation. In addition, the "kinetic chain movement" principle will produce an effective and efficient smash. The study of Taha, Hassan, Yap and Yeo (2016) reported that these joints and segments have an effect on one another during movement. When one is in motion, it creates a chain of events that affects the movement of neighboring joints and segments. Furthermore, the optimal performance in conducting a forehand smash depends on the motion of the body segments that work in a harmonious motion chain sequence (Abian-Vicen et al., 2013).

Based on the background explanation, this study aims to analyze the movement of backhand and forehand smash techniques in three dimensions with the motion kinematics approach in badminton.

## Method

*Method and Design*

The method used is descriptive and a quantitative approach. Descriptive is a method that aims to systematically describe facts accurately about certain symptoms that are the center of attention.

*Participants*

The sample used was 24 male badminton players that joined the University Student Activity Unit with high skills with an average age of 19.4±1.6 years, a height of 1.73±0.12m, and a weight of 62.8±3.7kg. Furthermore, purposive sampling was used, and all participants gave their consent on the form that had been given previously and were confirmed not to be injured. Before the test, they received technical explanations related to the implementation procedures in a comprehensive manner. The data collection test was conducted in the badminton field sports hall building, Faculty of Sports and Health Education, Indonesia University of Education.

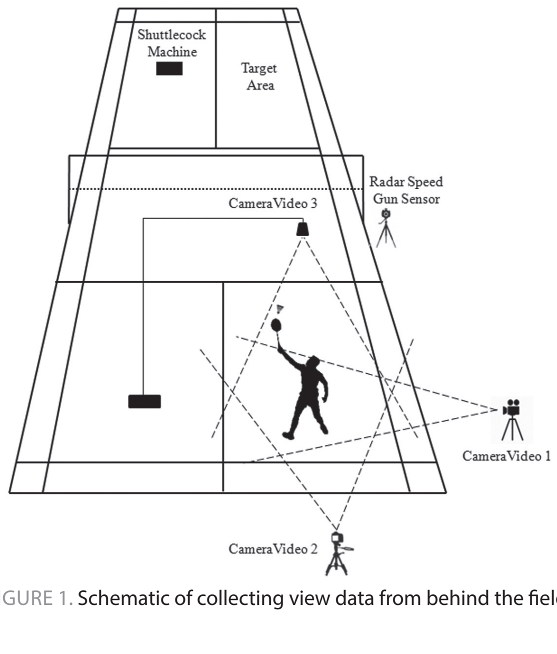


FIGURE 1. Schematic of collecting view data from behind the field

*Instrument*

The instrument used three video cameras (Panasonic Handycam HC-V100 Full HD, Japan), a three-dimensional calibration, a 3D motion analysis software (Frame DIAZ IV, Japan), one set manual marker, and a radar speed gun (Bushnell Speed gun 101911, Italy).

*Procedure*

Before the test, the participants engaged in a warming up for about 15 minutes. This was followed by performing overhead backhand and forehand smashes using their racket to be more comfortable and adapt fast. Figure 2 describes the scheme for field data collection, where ball speed is measured using a radar speed gun with a shutter speed of 100 Hz. It was placed near the net with a distance of 45 cm outside the field line. In addition, video camera 1 was placed on the right side of the field with a distance of 2.5 m perpendicular to the position of the subject standing. Video camera 2 was positioned behind the field line parallel to the subject area with a distance of 3m from the player's position. Video camera 3 was placed above the subject standing in a perpendicular position parallel to the subject area. The three video cameras were set by users according to the needs of the study characteristics. This includes a frame rate of 100 Hz, a shuttle speed of 250 s, and an exposure time of 1/1200 s. Meanwhile, calibration and data processing analyzed in three dimensions were conducted using the direct linear transformation structure method developed by Aziz Abdel (Hong, Wang, Lam, & Cheung, 2014).

*Data Analysi*

This study uses the SPSS version 22.0 application. (SPSS Inc., Chicago, IL), where the average and standard deviation were calculated as initial data for further calculations of normality, homogeneity, and hypothesis tests. To test the hypothesis, a one-way analysis of variance approach was used. This analysis helped to calculate the level of difference between the backhand and forehand overhead smash with an alpha confidence level of 0.05. The three-dimensional coordinate data of the signs affixed to each part of the player's joints were adjusted using the Butterworth low-pass filter method approach. This was carried out with a cut-off frequency of 15 Hz and determined by the residual analysis technique (Iino & Kojima, 2011).

*Kinematics Parameters*

To obtain the kinematic parameters of an overhead smash motion, a model is made following the anatomical principles of the body in Figure 2.

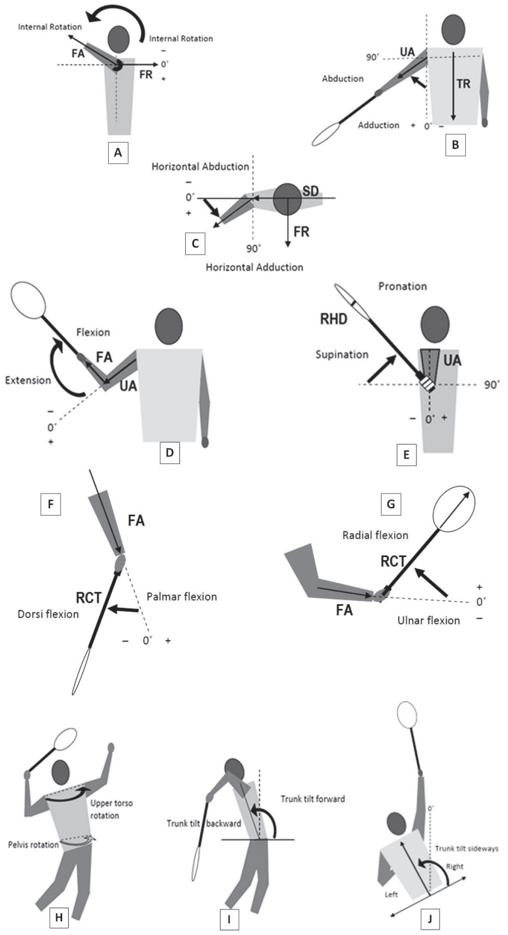


FIGURE 2. Kinematic parameters of motion in the upper limbs joint (source: Rusdiana et al., 2020)

Initially, the shoulder joint consists of three movements, namely internal-external rotation (A), abduction-adduction (B), and horizontal abduction-adduction (C). Furthermore, the elbow joint consists of two movement characteristics, namely flexion-extension (D) and forearm pronation-supination (E). The wrist joint consists of two movements, namely the palmar-dorsiflexion (F) and the radial-ulnar flexion (G). The next movements are upper torso rotation and pelvis rotation (H), trunk tilt forward and trunk tilt backward (I), as well as trunk tilt left and right sideways (

## Result

Table 1 showed the data on the difference in ball speed and changes in the kinematics of motion during backhand and forehand smashes.

**Table 1.** Kinematic parameters during maximal shoulder external rotation

| Kinematic Parameter Analysis | Backhand | Forehand |
|---|---|---|
| | Means±SD | Means±SD |
| Shuttlecock velocity (km/h)* | 112±5.7 | 158±3.5 |
| Shoulder external rotation (deg)* | -122±3.5 | -169±4.2 |
| Shoulder abduction (deg) | 101±1.2 | 106±1.4 |
| Shoulder horizontal adduction (deg) | 7±0.83 | 9±0.96 |
| Elbow flexion (deg) | 94±1.1 | 102±1.3 |
| Radio-ulnar Pronation (deg) | 1±1.1 | 12±1.3 |
| Wrist palmar flexion (deg)* | -23±2.1 | -47±2.4 |
| Trunk tilt backward (deg) | 21±3.5 | 24±3.1 |
| Trunk tilt sideways left (deg) | 19±1.4 | 21±1.6 |

Legend: * - Significance difference at the 0.05 level

Table 1 showed the significant differences in three variables of the nine kinematic parameters analyzed in the maximal shoulder external rotation phase. These include shuttlecock velocity ($p=0.035$), shoulder external rotation ($p=0.048$), and wrist palmar flexion ($p=0.037$). From these results, the three variables at the forehand smash have a greater value than the backhand.

**Table 2.** Kinematic analysis parameters in the maximum angular velocity phase

| Kinematic Parameter Analysis | Backhand | Forehand |
|---|---|---|
| | Means±SD | Means±SD |
| Shoulder internal rotation (deg/s)* | 1623±3.5 | 2111±4.2 |
| Upper torso rotation (deg/s) | 761±1.2 | 782±1.4 |
| Pelvis rotation (deg/s) | 421±0.8 | 429±0.9 |
| Elbow extension (deg/s)* | 523±1.1 | 995±1.3 |
| Supination (deg/s)* | 642±1.1 | 494±1.3 |
| Wrist dorsi flexion (deg/s) | 763±2.1 | 855±2.4 |
| Trunk tilt forward (deg/s) | 185±3.5 | 199±3.1 |

Table 2 showed the significant differences in three variables of the seven kinematic parameters analyzed in the maximum angular velocity phase during the forehand smash. These include the speed of the shoulder internal rotation ($p=0.042$), elbow extension ($p=0.035$), and forearm supination ($p=0.024$). From these results, the three variables at the forehand smash have a greater value than the backhand.

## Discussion

The results showed a significant difference in the maximum speed of the shuttlecock produced during the forehand smash compared to the backhand. Others showed a positive contribution between shuttlecock speed and wrist angular velocity when making backhand and forehand smashes. Meanwhile, the sequence pattern of upper limb joint rotation at the beginning of the backswing phase up to the moment of impact has similarities in the two smash techniques. The shoulder joint rotation velocity showed a greater result than the elbow joint. The wrist flexion angular velocity showed a smaller result than the elbow angular velocity. This is consistent with Creveaux, Dumas, Hautier and Rogowski (2013), where the upper limb motion sequence starts from the rotation of the shoulder, elbow, and wrist joints during backhand drives in tennis. According to Rota, Morel, Saboul, Rogowski and Hautier (2014), one major contribution of racket speed is obtained from the forearm supination rotation motion. Rogowski, Creveaux, Chèze, Macé and Dumas (2014) stated that the combination of shoulder internal rotation and forearm supination provides approximately 53% support for the shuttlecock speed during an overhead forehand smash. The result is related to the backhand smash technique. This shows that the forearm supination and upper arm lateral rotation provide the maximum bearing capacity to the speed of the racket swing before impact occurs (Fu, Ren, & Baker, 2017).

The series of motion patterns from the overhead forehand and backhand smashes require linear and circular velocity as well as an acceleration of the body movement, shuttlecock, and racket swing. There is very little study on badminton that explains the movements of forehand and backhand overhead smash stroke techniques. However, the study by Gordon and Dapena (2006) analyzed the contribution of upper limb joint rotation velocity during the tennis serve. It was stated that the backward maximal shoulder external rotation is the initial momentum to produce a larger forward shoulder internal rotation force. This results in a greater racket speed as represented in figure 3.

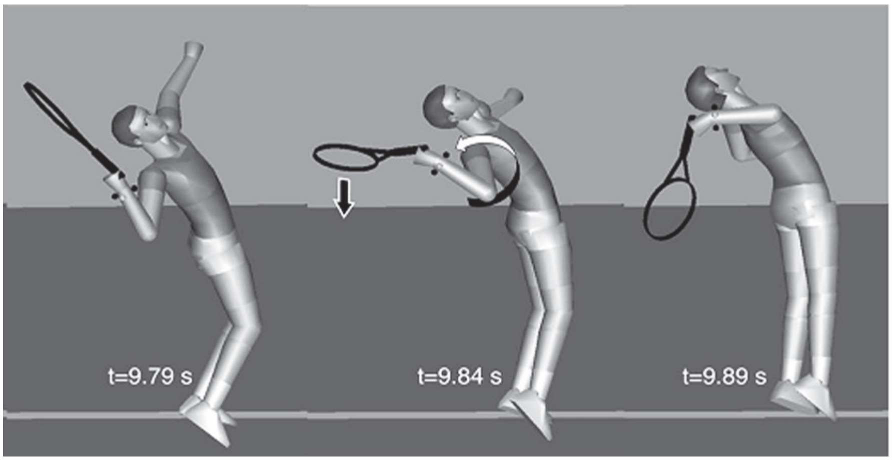


FIGURE 3. Contribution of shoulder maximal external rotation when the racket is swinging backward (Gordon, & Dapena, 2006).

During maximal shoulder external rotation, the racket head position needs to be close to the hip joint. This helps to minimize the moment of inertia by a large amount depending on the distance to the axle of the shoulder rotary axis. The smaller the resulting moment of inertia, the greater the rotation speed. Therefore, it creates an impact on the forward racket swing to be faster until the ball impact occurs (Maeda et al., 2017).

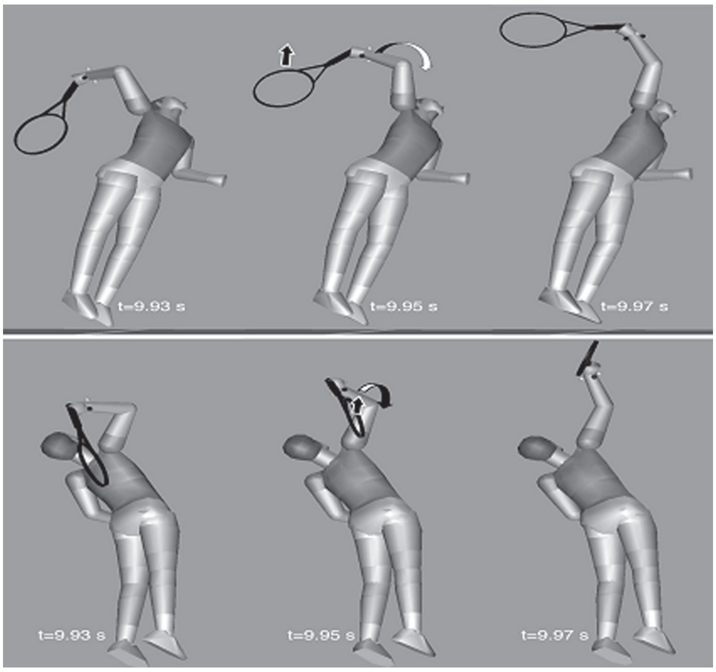


FIGURE 4. Elbow flexion-extension movement (Gordon, & Dapena, 2006).

Furthermore, the joint velocity in elbow extension shows a significantly greater result, especially during the forehand smash. This is consistent with the study conducted by Reid, Elliott, & Crespo (2013) on the tennis serve. It was reported that the elbow joint provides positive support for racket speed. In the elbow extension motion, the faster it rotates, the more the production of a large force on the motion of the upper arm and racket. This happens before the occurrence of its impact on the shuttlecock as shown in Figure 4. Furthermore, the elbow extension motion contributes about 30% to the racket speed (Martin et al., 2021).

Another joint rotation that has an important role in racket speed is the arm velocity in the radio-ulnar pronation motion (Gordon, & Dapena, 2006). This motion shows the movement pattern, especially in the group of players with high technical skills. Meanwhile, for the novice, this motion is usually almost non-existent. Therefore, it is not surprising that professional players produce shuttlecock speeds, which are much greater than amateurs.

## Conclusion

From the results, it is concluded that the speed of the shuttlecock during the forehand smash is greater than the backhand smash. During maximal shoulder external rotation, the forehand smash has a significant difference in three variables, including shuttlecock velocity, shoulder external rotation, and wrist palmar flexion. Furthermore, shoulder internal rotation, elbow extension, and forearm supination at maximum angular velocity showed greater results when performing a forehand smash. The shoulder internal rotation and elbow joint velocity as well as forearm supination make a very significant contribution to the shuttlecock speed when performing the two-stroke techniques.

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**Conflict of interest**

The authors declare that there are no conflicts of interest.

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ORIGINAL SCIENTIFIC PAPER

# Determinants of Sports Performance in Young National Level Swimmers: A Correlational Study between Anthropometric Variables, Muscle Strength, and Performance

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**Abstract**

This study aimed to verify how the anthropometric characteristics and muscle strength levels of young swimmers of both sexes can influence sport performance on 50 m and 400 m freestyle events; 184 swimmers, aged between 13 and 16 years (mean±standard deviation: 14.64±0.80 years, 1.69±0.08 m height, 58.71±7.87 kg in body weight) participated in the study. The evaluation took place over two days. On Day 1, each subject was assessed with regard to anthropometric measures (i.e., body mass, height, wingspan); subsequently, the wingspan/height index and the body mass index, in addition to that, the strength of the lower and upper limbs were measured. On Day 2, swimming performances in 50m and 400m were evaluated, in the morning and afternoon, respectively. For the analysis of the results, the swimmers were divided into two groups, according to the competitive level (i.e., Group A and B). No anthropometric differences were found between male swimmers in the A and B Groups. However, female swimmers in Group A showed significant differences ($p<0.05$) in height and weight that positively affected performance. With regard to muscle strength, male Group A swimmers have a tendency towards higher values, with statistically significant differences in medicine ball throw. Differences in sports performance seem to be related to the biomechanical parameters of swimming, with higher values of the swimming index in male swimmers and gestural frequency in female swimmers. The performance level of young swimmers seems to be determined by anthropometric and muscle strength variables.

***Keywords:*** *freestyles events, anthropometric measures, muscle strength, biomechanical parameters*

## Introduction

Swimming is characterized as a cyclical modality in which the performance can be represented by the time that the swimmer takes to complete the predicted distance under the established rules (Mujika & Padilla, 2000). Previous research has linked swimming performance to biomechanical (Alberty, Sidney, Pelayo, & Toussaint, 2009; Zamparo et al., 2012) and physiological parameters (Holfelder, Brown, & Bubeck, 2013; Palayo, Alberty, Sidney, Potdevin, & Dekerle, 2007). In addition, other investigations (Barbosa et al., 2010; Figueiredo, Pendergast, Vilas-Boas, & Fernandes, 2013) have indicated that these parameters are likely interconnected and provided answers that could help explain performance in different swimming events. The anthropo-

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metric characteristics of the swimmers, due to the recognized relationship with drag and propulsion, also seem to be determinants of performance (Morais et al., 2012).

A study conducted with young male swimmers (Lätt et al., 2009) found a significant relationship between body height and arm span with time in 400 m freestyle events with young male swimmers. Another investigation (Morais et al., 2012) found a strong correlation between arm span, height, chest circumference, hand surface area, foot surface area, trunk cross area, and the results of 100 m freestyle in young swimmers of both sexes. Furthermore, the association between anthropometric characteristics and sports performance was also considered a relevant indicator for identifying talents in the athletes' long-term development process (Sammoud et al., 2018). A previous study suggested that anthropometric characteristics are among the critical factors used as early predictors of talented athletes (Morais, Silva, Marinho, Lopes, & Barbosa, 2017). In addition, young male swimmers are characterized as taller and heavier, with greater wingspans in comparison to young female swimmers, and these characteristics play a major role in the differences observed in performance between genders (Schneider & Meyer, 2005). Correlations between anthropometric characteristics and swimming speed in young male and female swimmers have also been previously reported (Geladas, Nassis, & Pavlicevic, 2005).

However, particularly over short distances (i.e., 50 m ), performance was strongly correlated to muscle strength and power, with the ability to apply force in the aquatic environment a crucial factor for success during competition (Crowley, Harrison, & Lyons, 2017). In this regard, a previous study inferred that the characteristics of strength and power of the lower limbs were characterized as predictors of performance in swimming (West, Owen, Cunningham, Cook, & Kilduff, 2011), distinguishing swimmers with different levels of performance (Jones, Pyne, Greg Haff, & Newton, 2018). In addition, positive correlations between muscle strength and upper limb power with swimming performance have been shown in the literature (Garrido et al., 2010a), and this topic still needs further investigation, especially regarding young people. Young athletes of a highly competitive level also present higher values of gestural frequency (GF) (Craig & Pendeegast, 1979), cycle distance (CD), and swimming index (SI) (Lätt et al., 2009; Morais et al., 2013), which also represent excellent predictors of performance (Jürimäe et al., 2007; Lätt et al., 2009).

The literature has reported a strong association between anthropometric characteristics, strength, power, and performance in pure sports swimming; however, to the best of our knowledge, there is a gap in the literature on the impact of these characteristics on the performance of young swimmers. Although several studies (Geladas et al., 2005; Jürimäe et al., 2007; Sammoud et al., 2018) have investigated the importance of anthropometric characteristics in swimming performance in different age groups, knowledge about the effects of some variables on performance remains unclear. In addition, few studies have made specific comparisons between swimmers of different sexes and similar chronological ages who belong to different competitive levels. In this sense, the present study aimed to verify how the anthropometric characteristics and strength levels of young swimmers of different sexes can influence their sports performance in 50m and 400m freestyle events at different levels.

## Methods

*Study Design*

The present investigation consisted of a cross-sectional study that aimed to verify the impact of anthropometric characteristics and strength levels on sports performance in young swimmers (14–16 years) at a national level, in the 50 m and 400 m freestyle swimming events. Thus, all participants were analysed with regard to their anthropometric characteristics (height, body mass, body mass index, and wingspan), 50m and 400m freestyle swimming performance, and biomechanical variables.

*Participants*

One-hundred-and-eighty-four (184) swimmers, aged between 13 and 16 years (mean±standard deviation: 14.64±0.80 years, 1.69±0.08 m height, 58.71±7.87 kg in body weight) participated in the study. These swimmers belonged to the U-16 and U-15 levels, 92 of whom were female (14.08±0.56 years; 1.64±0.06 m height; 53.37±4.97 kg weight) and 92 of whom were male (15.21±0.60 years; 1.75±0.07 m in height; 64.06±6.49 kg weight). The sample was composed of members familiar with the practice of the competitive sport of swimming and the methodologies used for evaluation. After being selected, all swimmers and guardians were informed of the procedures, and only those who agreed to sign the informed consent form participated in the study. In addition, the swimmers were informed that they could withdraw from the study at any time. All procedures were carried out following the Helsinki Declaration.

The participants in the study were selected because they were a regular presence at internships carried out by the Portuguese Swimming Federation at the beginning of the season between 2014 and 2018, where the highest scorers in the national championships held at the end of the previous season were present. The swimmers were divided into two groups for the analysis of the results, according to the International Swimming Federation (FINA) score obtained in the 400 m freestyle. Therefore, all swimmers with a time shorter than that corresponding to 500 FINA points (296 s for female swimmers and 268 s for male swimmers) were considered to belong to Group A (n=82), while the remainder of the swimmers were considered to belong to Group B (n=102).

*Procedures*

During the internship period, the evaluations were performed, which took two days and comprised four training and evaluation sessions. All individuals were assessed during the sports season (October). The tests were carried out with sufficient rest between sessions to avoid energy expenditure and accumulate fatigue before the strength and specific performance tests, which could negatively influence performance.

On the day of the assessment, after arriving at the site and five minutes of rest, each subject was assessed with regard to anthropometric measures such as body mass, height, wingspan and, subsequently, the wingspan/height index (WHI) and the body mass index (BMI). Then the subjects performed the evaluation of the strength of the lower limbs through the horizontal jump. In the afternoon session, the subjects performed the assessment of the strength of the upper limbs by throwing a medicine ball. On the following day, they performed the performance evaluation, with the 50 m freestyle in the morning and the 400 m freestyle in the afternoon. With these results, the critical swimming speeds were later calculated.

*Anthropometric Measures*

All measures were assessed according to international standards for anthropometric assessment (Marfell-Jones, Olds, Stewart, & Lindsay Carter, 2006) and were obtained before any physical performance test. Participants were barefoot and dressed in underwear or as little clothing as possible during the assessment. To measure body height (in m), a precision stadiometer with a scale of 0.001 m was used. BMI was obtained by dividing the body mass value by the square of height. Wingspan was determined by measuring the athletes with a tape measure placed on a precision wall with a scale of 0.001 m.

*Strength Assessment*

To assess the strength of the lower limbs, each swimmer performed three horizontal jumps, with a three-minute pause between each jump. The swimmers stood with their legs shoulder-width apart and, with the help of their arms, they pushed their body forward, trying to move as far as possible. For analysis, there was an average between the three jumps performed and the best jump performed. The responsible investigator relied on the collaboration of the national technical director of the pre-junior classes to verify the correct position of the swimmers in the execution of each jump. The reliability of the performance of the horizontal jump was determined by the intraclass correlation coefficient (ICC), with an average value of 0.9 and a coefficient of variation (CV) of 3.6%.

The medical ball launch (BM) was measured through the horizontal distance reached after launching a 3 kg ball. To perform the evaluation, each subject sat on the floor with their backs against a rectilinear structure (wall). Each individual held the ball in front of them with both hands (close to the chest) to achieve the greatest amplitude, speed, and distance possible and without rotating the torso and hips during the execution of movements. Two experienced evaluators assisted in the correct verification of the launch and in the obtained range. Three attempts were counted with a 3kg medicine ball, with a one-minute rest period between each throw. The distance from the starting position to where the ball touched the ground was measured (Castro-Piñero et al., 2009). Overall, the launch of the medicine ball showed an average ICC of 0.9 and a CV of 2.8%.

Both the assessment of the horizontal jump and the launch of the medical ball were also recorded on camera, and the confirmation of the observed values was obtained by the subsequent analysis of the footage using Kinovea® software (version 0.8.15).

*Swimming Performance Evaluation*

The evaluation of specific swimming performance was performed by simulating the 50 m freestyle and 400 m freestyle swim. The 50 m freestyle swim was performed in the morning, while the 400 m freestyle was performed in the late afternoon to provide sufficient time for the participants to recover. After performing a 1000 m warm-up using the usual structure based on the protocols described by Neiva, Marques, Barbosa, Izquierdo and Marinho (2014), each swimmer performed a simulated race (50 or 400 m). The evaluation protocols were applied in a 25 m covered swimming pool at an average temperature of 28º C and an average humidity below 70%, with departure from the block and official voices. The timing was recorded using a stopwatch (Finis 3x100 Stopwatch, Livermore, California). The swims were also filmed and subsequently analysed using Kinovea® software (version 0.8.15). Biomechanical variables were evaluated for both simulations. Thus, the evaluation of gestural frequency (GF) was performed using a chronometer in three stroke cycles and later converted to units of measurement in the international system (Hz). Cycle distance (CD) was measured by estimation using the following equation (Craig & Pendeegast, 1979):

$$CD = v/GF \quad (1)$$

Where CD is the cycle distance (m.c-1), v is the average speed of the swimmer (m.s-1), and GF is the gestural frequency of swimming. The swimming index (SI) was then estimated using the following equation (Costill et al., 1985):

$$SI = CD \times v \quad (2)$$

Where SI represents the swimming index ($m^2$ c-1 s-1), CD is the cycle distance (m.c-1), and v is the average swimming speed (m.s-1). The speed variables (GF, CD, and SI) were evaluated in the second 25 m of each 50 m (either in the 50 m event or 400 m event) and used to determine the average measure in the 400 m freestyle swim based on analysis in the Kinovea® software (version 0.8.15).

*Statistical Analysis*

Data analysis was performed using the IBM SPSS statistical software (Statistical Package for Social Sciences), version 22.0, for Microsoft Windows (Armonk, NY, EU: IBM Corp.). The level of significance was set at 5%. The calculation of means, standard deviations, differences, and confidence intervals (95% CI) were performed using standardized statistical methods. Reliability was measured by CV and ICC in the three tests performed for the launch of the medicine ball and for the horizontal jump. The Kolmogorov-Smirnov test (n>30) was used to verify that the data had a normal distribution. Thus, parametric tests were used for data analysis. To compare the results obtained among the juveniles of the best sports level with the rest, the t-test for independent samples was used. For the bivariate correlations, we used Pearson's coefficient, and the determination coefficient ($r^2$) was also calculated. The ratio was considered very high for values between 0.90 and 1.00, high for values between 0.70 and 0.90, moderate between 0.50 and 0.70, low for values between 0.30 and 0.50 and small for values between 0.10 and 0.30. The effect size was also calculated using Cohen's d, for comparison between the groups analysed (Cohen, 2013). The magnitude of the effect was considered trivial (<0.2), small (0.2-0.59), moderate (0.60-1.19), high (1.2-1.99) or very high (>2.00) (Hopkins, Marshall, Batterham, & Hanin, 2009).

## Results

Table 1 shows the values of the anthropometric characteristics assessed in male swimmers in Group A and Group B. No statistically significant anthropometric differenc-

**Table 1.** Comparison between the mean values±standard deviation of the anthropometric variables of male and female swimmers belonging to Group A and Group B

| Variables | Male Swimmers | | | | | | Female Swimmers | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A (n=28) M±SD | B (n=64) M±SD | Difference (CI 95%) | | p-value | Effect size M±SD | A (n=54) M±SD | B (n=38) M±SD | Difference (CI 95%) | | p-value | Effect size |
| | | | Higher | Lower | | | | | Higher | Lower | | |
| Height (m) | 1.75 ± 0.08 | 1.75 ± 0.06 | -0.03 | 0.02 | 0.85 | 1.75 ± 0.08 | 1.65 ± 0.05 | 1.62 ± 0.06 | 0.01 | 0.06 | 0.01** | 0.53 |
| Weight (kg) | 64.73 ± 6.98 | 63.76 ± 6.30 | -1.61 | 3.54 | 0.46 | 64.73 ± 6.98 | 54.28 ± 4.74 | 52.08 ± 5.07 | -0.20 | 4.61 | 0.07 | 0.45 |
| BMI (kg/ m2) | 21.15 ± 1.26 | 20.80 ± 1.41 | -0.29 | 0.99 | 0.28 | 21.15 ± 1.26 | 19.93 ± 1.50 | 19.91 ± 1.50 | -0.59 | 0.61 | 0.98 | 0.01 |
| Wingspan (m) | 1.80 ± 0.10 | 1.81 ± 0.07 | -0.04 | 0.02 | 0.57 | 1.80 ± 0.10 | 1.66 ± 0.06 | 1.65 ± 0.08 | -0.15 | 0.05 | 0.32 | 0.14 |
| Wingspan/ Height | 1.03 ± 0.02 | 1.03 ± 0.02 | -0.02 | 0.01 | 0.61 | 1.03 ± 0.02 | 1.01 ± 0.03 | 1.02 ± 0.03 | -0.02 | <0.01 | 0.06 | 0.34 |

Legend: BMI - body mass index; CI - Confidence interval

es were detected between male swimmers. Furthermore, Table 1 shows the values of the anthropometric characteristics assessed in female swimmers in Group A and Group B. The values showed a small magnitude difference in height, with Group A registering higher values than Group B.

Table 2 shows the muscular strength values of the upper and lower limbs in young male and female swimmers, respectively. There was a tendency toward higher values in the horizontal jump and in the throw of the medicine ball in the case of male swimmers, with moderate effects in the throw of the medicine ball. No statistically significant differences were observed for the female swimmers.

**Table 2.** Comparison between the mean values (± standard deviation) of the muscle strength variables of male and female swimmers belonging to Group A and Group B

| Variables | Male Swimmers | | | | | | Female Swimmers | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A (n=28) M±SD | B (n=64) M±SD | Difference (CI 95%) | | p-value | Effect size | A (n=54) M±SD | B (n=38) M±SD | Difference (CI 95%) | | p-value | Effect size |
| | | | Higher | Lower | | | | | Higher | Lower | | |
| Horizontal jump - average (m) | 2.22 ± 0.16 | 2.14 ± 0.22 | -0.01 | 0.16 | 0.09 | 0.40 | 1.70 ± 0.18 | 1.71 ± 0.18 | -0.10 | 0.07 | 0.74 | 0.06 |
| Horizontal jump - maximum (m) | 2.27 ± 0.16 | 2.19 ± 0.23 | -0.01 | 0.17 | 0.08 | 0.38 | 1.75 ± 0.19 | 1.77 ± 0.20 | -0.11 | 0.06 | 0.62 | 0.20 |
| Medical ball throw - average (m) | 4.81 ± 0.39 | 4.50 ± 0.56 | 0.11 | 0.52 | <0.01** | 0.61 | 3.20 ± 0.43 | 3.17 ± 0.37 | -0.16 | 0.23 | 0.72 | 0.08 |
| Medical ball throw - maximum (m) | 5.02 ± 0.39 | 4.67 ± 0.59 | 0.13 | 0.57 | <0.01** | 0.66 | 3.38 ± 0.45 | 3.31 ± 0.39 | -0.14 | 0.27 | 0.52 | 0.17 |

With regard to swimming performance, Table 3 shows that male swimmers in Group A registered better performance in the 50 m and 400 m freestyle than male swimmers in Group B, with a significantly higher SI, even without significant differences in GF and CD. The critical speed was also significantly higher for individuals in Group A

**Table 3.** Comparison between the mean values (± standard deviation) of the swimming performance variables in the 50m freestyle and 400m freestyle, as well as the gestural frequency (GF), cycle distance (CD), swimming index (SI) and critical speed of male and female swimmers belonging to Group A and Group B

| Variables | Male Swimmers | | | | | | Female Swimmers | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A (n=28) M±SD | B (n=64) M±SD | Difference (CI 95%) | | p-value | Effect size | A (n=54) M±SD | B (n=38) M±SD | Difference (CI 95%) | | p-value | Effect size |
| | | | Higher | Lower | | | | | Higher | Lower | | |
| 50m freestyle (s) | 27.15 ± 0.65 | 28.01 ± 0.82 | -1.28 | -0.42 | <0.01** | 1.12 | 30.88 ± 0.82 | 31.58 ± 1.48 | -1.11 | -0.29 | <0.01** | 0.54 |
| 50m GF (5-20m) (Hz) | 52.40 ± 5.15 | 52.08 ± 4.45 | -1.74 | 2.39 | 0.76 | 0.07 | 50.04 ± 4.45 | 50.09 ± 4.70 | -1.99 | 1.89 | 0.96 | 0.01 |
| 50m CD (m.c-1) | 2.10 ± 0.29 | 2.02 ± 0.18 | -0.01 | 0.18 | 0.08 | 0.37 | 1.92 ± 0.19 | 1.87 ± 0.20 | -0.04 | 0.13 | 0.28 | 0.26 |

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| Variables | Male Swimmers | | | | | | Female Swimmers | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A (n=28) M±SD | B (n=64) M±SD | Difference (CI 95%) | | p-value | Effect size | A (n=54) M±SD | B (n=38) M±SD | Difference (CI 95%) | | p-value | Effect size |
| | | | Higher | Lower | | | | | Higher | Lower | | |
| 50m SI (m2 c-1 s-1) | 3.85 ± 0.88 | 3.51 ± 0.33 | 0.12 | 0.54 | <0.01** | 0.62 | 3.05 ± 0.36 | 2.90 ± 0.38 | -0.05 | 0.35 | 0.13 | 0.41 |
| 400m freestyle (s) | 262.10 ± 3.46 | 277.49 ± 7.97 | -18.38 | -12.40 | <0.01** | 2.24 | 290.87 ± 4.17 | 308.45 ± 8.83 | -20.45 | -14.72 | <0.01** | 2.30 |
| 400m GF (Hz) | 36.04 ± 3.09 | 35.01 ± 3.91 | -0.63 | 2.70 | 0.22 | 0.28 | 38.23 ± 3.50 | 35.41 ± 4.11 | 1.22 | 4.41 | <0.01** | 0.72 |
| 400m CD (m.c-1) | 2.58 ± 0.20 | 2.50 ± 0.26 | -0.03 | 0.18 | 0.19 | 0.33 | 2.19 ± 0.21 | 2.23 ± 0.27 | -0.15 | 0.06 | 0.41 | 0.16 |
| 400m SI (m2 c-1 s-1) | 3.91 ± 0.30 | 3.62 ± 0.38 | 0.14 | 0.45 | <0.01** | 0.82 | 3.00 ± 0.29 | 2.90 ± 0.36 | -0.04 | 0.25 | 0.17 | 0.30 |
| Critical speed (m.s-1) | 1.42 ± 0.07 | 1.36 ± 0.07 | 0.04 | 0.09 | <0.01** | 0.87 | 1.35 ± 0.02 | 1.27 ± 0.04 | 0.06 | 0.10 | <0.01** | 2.30 |

Legend: *p<0.05; **p<0.01

than Group B. For female swimmers, the swimming performance proved to be higher in the 50 m and 400 m freestyle for Group A than Group B, as shown in Table 3. Swimmers in Group A were able to swim with a higher GF compared to Group B in the 400 m freestyle. The critical speed was also significantly higher for swimmers in Group A than Group B.

In order to understand the influence of anthropometric and strength variables on the 50 m and 400m performance, the correlations between variables were analysed for all of the swimmers. There was a moderate negative linear correlation between height (r = -0.64 and r = -0.60, p<0.01), body mass (r = -0.67 and r = -0.60, p<0.01), wingspan (r = -0.66 and r = -0.58, p<0.01) with the 50 m freestyle and 400 m freestyle time, as can be seen in Figures 1a. 1b, 1c, 1d, 1e, 1f respectively.

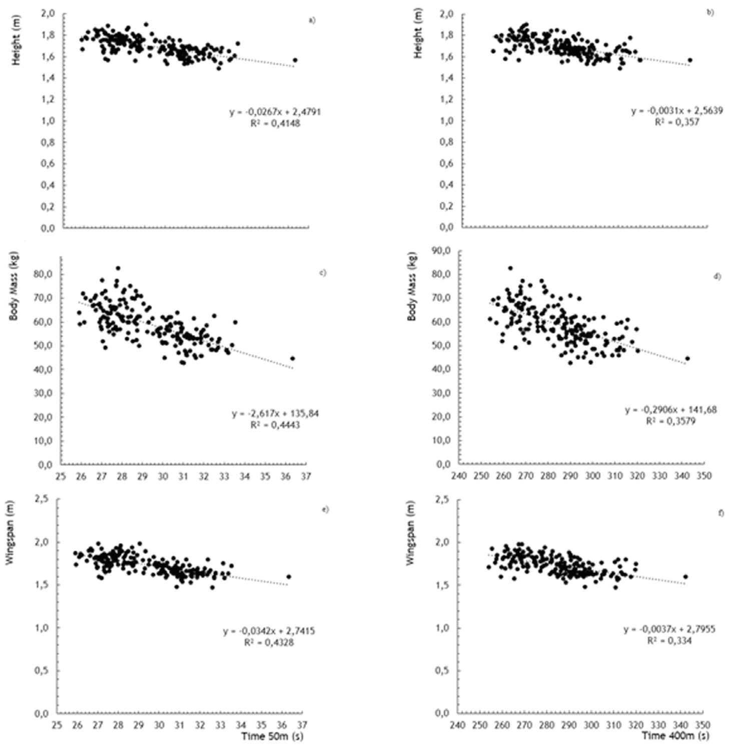


FIGURE 1. Graphical representation of the relationship between the height, body mass and wingspan with the time of the 50 m free and the time of the 400 m free

With regard to muscle strength, there was a strong negative linear correlation between the launch of the medicine ball and the 50m freestyle time (r = -0.80, p<0.01) and the 400m freestyle time (r = -0.70, p<0.01) (Figure 2a and Figure 2b). The horizontal jump was also negatively correlated with the 50m freestyle time (r = -0.78, p <0.01) and the 400m freestyle time (r = -0.61, p<0.01) (Figure 2c and Figure 2d).

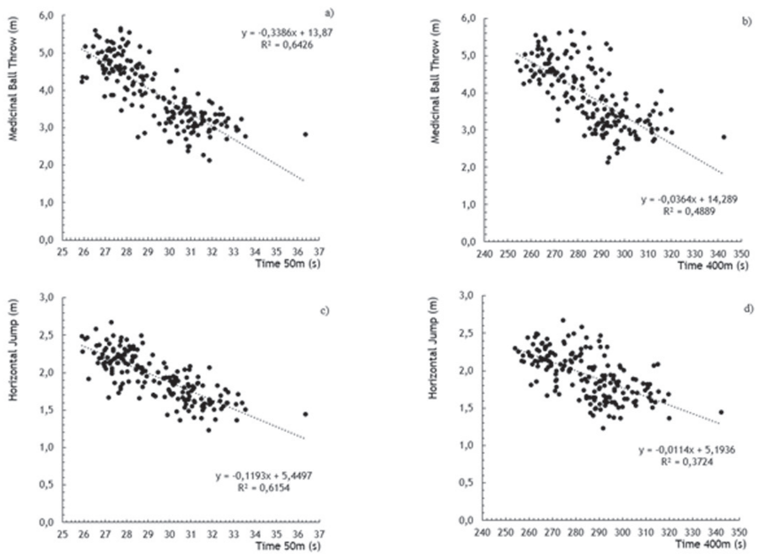

FIGURE 2. Graphical representation of the relationship between the average value of the medical ball throw (BM) and horizontal jump with the 50 m freestyle time and the 400 m freestyle time

## Discussion

The present study aimed to verify how the anthropometric characteristics and strength levels of young swimmers of different sexes can influence their sports performance in 50 m and 400 m freestyle events at different levels. In addition, we sought to understand how these characteristics can be decisive in sports performance for U-16 and U-15 swimmers with the 50 m and 400 m freestyles. Regarding anthropometric characteristics, it was found that male swimmers of a higher competitive level (Group A) did not show significant differences compared to male swimmers of a lower level (Group B). However, female swimmers at a higher competitive level tend to be taller and heavier than those at a lower level, which is in line with a study by Malina, Bouchard and Bar-Or (2004) that emphasized that body composition is a determinant in swimmers' performance. Male swimmers in Group A showed a tendency towards higher muscle strength values compared to male swimmers in Group B, with a clear difference in the throw of the medicine ball, supporting findings from a previous study (Garrido et al., 2010b). No significant differences were found in female swimmers regarding muscle strength. These data highlight the potential importance of strength for swimming performance, taking into account that differences were not observed in relation to anthropometric characteristics among male swimmers. Thus, it is likely important that swimmers perform strength training that allows them to increase their ability to move and propel their upper limbs in the aquatic environment (Marques et al., 2020), thereby increasing their performance. In addition, strength training combined with swimming training shows better results for swimmers than swimming training alone (Amaro, Marinho, Marques, Batalha, & Morouço, 2017).

As expected, the performance of Group A male and female was superior to that of Group B, both in the 50 m and 400 m freestyle. This difference may be the result of higher SI values in the 50 and 400 m freestyle for male swimmers and higher GF values in female swimmers during the 400 m freestyle. Furthermore, these results may be related to the fact that swimmers in Group A of both sexes are more advanced in maturational terms compared to Group B. According to Malina et al. (2004), maturation progress is directly associated with improved motor performance and is based on the skeletal and sexual maturation of individuals. When analysing the entire sample, a significant relationship was found between all of the variables analysed. However, the correlation values between performance and muscle strength should be emphasized: the upper limbs showed higher values than the lower limbs. Thus, it was found that the level of performance seems to be determined mainly by anthropometric variables in young female swimmers and by strength in young male swimmers. However, through the correlations found, it can be observed that the fastest swimmers in the 50 and 400 m freestyle seem to be influenced by both anthropometric and muscle strength variables, which contradicts what was reported in a previous study (Zampagni et al., 2008).

With regard to the horizontal jump, there was less discrepancy in values found in the 50 m freestyle than in the 400 m freestyle. This observation may explain the correlation values between the explosive strength of the lower limbs and the swimming performance, which showed a lower correlation in the 400 m freestyle race. Therefore, the explosive strength of the lower limbs seems to be a major factor in the performance of young swimmers, especially in shorter events (i.e., 50 m freestyle). These data show that strength training allows for better specific performance in short swimming events, as previously reported in the literature (Crowley et al., 2017; Lopes, Neiva, Gonçalves, Nunes, & Marinho, 2020). Considering the importance of planning in strength training, it is necessary to reflect on the training load quantification. After setting the objectives, the next step in developing a plan is determining the quality and quantity of load needed to produce the desired effect. The training load can be manipulated through its components, such as, volume, intensity, density, and complexity (Mujika et al., 1995). Another important factor to mention is the critical speed, which presented statistically significant variations in both groups analysed and for both sexes. In fact, critical speed is related to aerobic capacity and aerobic power, and it seems to be an important determinant to distinguish performance levels, which contradicts what was previously reported in the literature (Toubekis & Tokmakidis, 2013).

In addition, it is important to note that the biomechanical variables were different between performance levels. In a previous investigation, Strass (1988) observed an increase in CD and possible improvement in sports performance when applying muscle strength training program. The importance of speed depends on the swimming technique and the distance of the race, which is linked to technical coordination and the nature of the effort in terms of intensity and duration. Even in longer events, speed is important, especially in changes of pace and at the end of the race (Navarro, Castañón, & Gaia, 2003).

This study shows that the strength of upper limbs is likely related to the speed of the swim, which is consistent with a previous study (Garrido et al., 2010b), which also found that the muscular strength of the upper limbs seems to increase performance more in swimming events of short distance (50 m) in comparison with long-distance swimming events (100 m).

## Conclusion

This study aimed to verify how the anthropometric characteristics and strength levels of young swimmers of different sexes can influence their sports performance in the 50 m and 400 m freestyle events at different competitive levels. Male swimmers with a higher competitive level (Group A) did not show differences in anthropometric characteristics in relation to male swimmers with a lower competitive level (Group B). However, in the case of female swimmers, those of higher competitive level (group A) demonstrated differences in height and weight that positively influenced their performance.

Regarding muscle strength, the higher-level male swimmers (Group A) showed a tendency towards higher values in relation to the lower-level male swimmers (Group B), with a clear difference in the launch of the medicine ball. The differences in sports performance in the 50 m and 400 m freestyle seem to be related to biomechanical parameters of swimming, with higher values of SI in male swimmers and GF in female swimmers. Furthermore, the level of performance seems to be determined by anthropometric and muscle strength variables, with the launch of the medicine ball and the horizontal jump determining the performance. Future studies could complement the present results and analyses with an accurate assessment of the maturational state of the sample under study.

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**Conflict of interest**

The authors declare that there are no conflicts of interest.

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ORIGINAL SCIENTIFIC PAPER

# The Effect of Physical Exercises and Ball Games on the Static Balance of Students with Musculoskeletal Disorders

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**Abstract**

This research aims to detect the effect of using exercises and ball games in physical education on the static balance of students with musculoskeletal disorders. The research involved 40 secondary school students aged 16-19, who were divided into two groups. Students have disabilities with mild and average forms of illness. The level of static balance was determined by the indicators of a modified Romberg test, which was carried out at the beginning and the end of the training lesson. The research was carried out for 18 months. It was established that the indicators of students of two groups, both at the beginning and at the end of the physical education lesson, improved. At the beginning of the lesson, a reliable change is traced only in the group of students with congenital defects of the musculoskeletal system ($p<0.05$); at the end of the lesson, balance indicators significantly improved in both groups ($p<0.05$). It was found that the developed system of exercises and ball games in which it was necessary to keep a set initial position, not due to different actions with the ball, is an effective means of improving balance. Exercising and playing with the ball reliably (at the level of significance $\alpha=0.05$) increases the chance of students to improve static balance indicators, which can improve the quality of motor actions in everyday life. The inclusion of specially selected exercises and ball games in physical education classes for students with musculoskeletal defects related to the success of meeting the requirements of Romberg's test is statistically confirmed.

***Keywords:*** *students, musculoskeletal system, physical education, balance, Romberg's test, exercises with the ball*

## Introduction

The process of physical education in special educational institutions for students with disabilities is one of the components of their social adaptation; this applies to students with impairment of the musculoskeletal system (Druz, Klimenko, & Pomeshchikova, 2010). Maintaining stable balance and normal support ability and preserving them in different situations is acute for this category of students. Doing so provides them with relative freedom of movement and a rational rhythm of motor actions, which are important for their better adaptation to life conditions (Pomeschikova & Terent'eva, 2010; Pomeshchikova et al., 2017).

The problem of physical and social adaptation of people with musculoskeletal disorders has been considered by many specialists in the following development areas: psychological adaptation (Razuvaieva et al., 2019), wellness programs

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(Araújo, Starling, Oliveira, Gontijo, & Mancini, 2020), and training athletes with musculoskeletal disorders (Mishyn et al., 2018). The authors raised the possibility of social rehabilitation and improving the level of comfort life of people with musculoskeletal disorders using physical exercises of different orientations.

Balance is one of the main motor coordination qualities, the level of development of which can fully serve as an indicator of motor abilities (Bretz, 1997). According to Davletiarova and Kapilevich (2012), a decrease in the persistence of the vertical pose (disruption of balance function) is one of the leading problems accompanying motor disorders of different aetiologies. Impaired balance function significantly increases the possibility of falls, both when standing and walking, and increases the risk of injuries. Therefore, the formation of balance in persons with disorders of the musculoskeletal system is an important element for their better adaptation to life conditions (Pomeshchikova & Terentieva, 2010; Bretz, 1997). Researchers have used different means of physical education to improve coordination abilities: exercises on specially designed gym devices (Hagberg, Hermansson, Fredriksson, & Pettersson, 2015), equine therapy (Silkwood-Sherer et al., 2012), among others. However, exercises and ball games have yet to find wide application in the physical education of students with musculoskeletal disorders. At the same time, significant interest of children and adolescents in ball sports can be noted (Ashanin et al., 2018; Bykova et al., 2017). Students' diverse motor activity during the ball game is accompanied by positive emotions and increases interest in exercising.

The contribution of this research is to increase the efficiency of physical education classes with students who have musculoskeletal disorders in order to restore their balance function.

## Methods

The research involved 40 students with musculoskeletal disorders (16–19 years old, girls and boys) who studied at Accounting and Economic College-Boarding School in Kharkiv. The students with mild and average levels of disability. All students were under the supervision of a doctor and did not have contraindications to physical education. Agreements were obtained from all participants to participate in the pedagogical experiment.

Students were divided into two groups to determine the effectiveness of using exercises and ball games in physical education classes. The first group included students who have congenital diseases that led to musculoskeletal disorders. The second group – students at which musculoskeletal disorders arose as a result of injuries and diseases throughout their lives. Among them 60% (24 students) have congenital defects, 40% (16 students) acquired. The information about diseases and pathologies of students was obtained due to the analysis of doctors' remarks in medical records.

Students of both groups were engaged in the adjusted program of physical education of special educational institutions during three semesters. The lesson lasted 90 minutes and were of average intensity. Classes were held twice a week. The content of physical education classes (simultaneously with the programme's educational material) included exercises and ball games, aimed at developing static resistance. These exercises were performed in the initial position, standing with legs together; standing on the heel of one foot and on the toe of the other. When they were carried out, the tasks were performed on one position and, as a more difficult option, with closed eyes. These include exercises such as placing the ball from hand to hand around the neck and torso; raising the ball over oneself and catching it; dribbling balls on the floor. Basketballs, volleyballs, and tennis balls were used. Exercises were performed either for a time from 6 to 10 s, or with a dosage from 1-2 to 3-4 times, using from 1 to 3 series, rest pauses lasted 20-40 s. The exercises took into account individual features of students' health. Examples of exercises with balls aimed at the development of static balance have been presented previously (Pomeshchikova et al., 2017; Table 1).

Exercises with balls were included in the content of moving games such as "Duel", "Gentle Ball", "Running on bumps", relay races with balls, dribbling in space limited by the conditions of the assignment, but others. At the same time, the conditions of the game constantly changed (Pomeschikova, 2010).

The research was carried out in compliance with the basic bioethical provisions of the Council of Europe Convention on Human Rights and Biomedicine (dated 04.04.1997).

The level of students' static balance was determined by the indicators of modified Romberg's test. The student putting his feet on one line (the toe of the right leg is near the heel of the left leg) stood, holding his balance. Standing in the position of the hand along the torso less than 15 s, the tested person received 1 point, standing in this position 15 s, received 2 points. Extending his hands forward and standing another 15 s – 3 points, closing his eyes and standing another 15 s – 4 points, raising his head with his eyes closed up and standing another 15 s in the same position – 5 points (Ilyin, 1981). With 3-5 points – the score was "passed", with 1-2 points – "didn't pass". The assessment of static balance was carried out at the beginning and the end of the physical education lesson of medium intensity.

The statistical data were analysed using STATISTICA version 10 and Excel 2016 spreadsheets. The test of statistical hypotheses about the belonging of the studied sample of students of the general population and the validity of differences in indicators at the beginning and the end of the pedagogical experiment was performed using Student's t-test was considered to be reliable at $p<0.05$.

In the research, the qualitative performance indicators of Romberg's test were studied to establish the presence ($X_1$) of static balance at the studied, which have a deviation of a congenital ($Y_0$) character and acquired during life ($Y_1$). To establish relationships between qualitative features at study factors X and Y, the contingent coefficient was calculated ($K_k=\varphi$):

$$\varphi = \frac{ad - bc}{\sqrt{(a+b)(c+d)(a+c)(b+d)}}$$

and associations ($K_a=\zeta$):

$$\zeta = \frac{ad - bc}{ad + bc}$$

If the contingent coefficient ($K_k=\varphi$) is less than the association coefficient ($K_a=\zeta$), this indicates the presence of a relationship between the two factors studied: static balance (X) and deviation in physical health (Y).

Pearson criterion $\chi^2$ was applied to test the hypothesis that there was a relationship between the studied factors:

$$\chi^2 = \varphi^2 \cdot n.$$

Pearson's estimated value was compared to Pearson's table

**Table 1.** Ball exercises aimed at developing static balance

| | Exercise content | Dosage |
|---|---|---|
| 1. | in the initial position, standing feet together, shifting a basketball (volleyball) ball from hand to hand around you:<br>- at the neck level;<br>- at the waist level;<br>- at the knee level ;<br>(one and then the other) | 6-8 times, 1-2 repetitions, rest between 10-20 s series |
| | also, in the initial position, standing, heel of one leg - toe of the other | 4-6 times, 1-2 repetition, rest between series 10-20 s |
| | also with closed eyes | 2-4 times, 1-2 repetitions, rest between 10-20 s series |
| 2. | - in the initial position, standing legs together, tossing a basketball (volleyball) ball with two (one) hands up and catching it without leaving the place | 4-6 times, 2-3 repetitions, rest between 20-30 s series |
| | also, in the initial position, standing heel of one leg - toe of the other | 3-4 times, 1-2 repetitions, rest between 20-30 s series |
| | also with closed eyes | 2-3 times, 1-2 repetitions, rest between series 30-40 s |
| 3. | - in the initial position, standing feet together dribbling a basketball ball in front of oneself, alternately with left - right hand (from hand to hand), putting a hand on a ball from the side outside and hitting the ball on the floor in front of oneself in the same place | 8-10 s, 1-2 repetitions, rest between 20-30 s series |
| | also with closed eyes | 6-8 s, 1-2 repetitions, rest between series 30-40 s |
| 4. | - in the initial position, standing heel of one leg - toe of the other, dribbling the basketball ball with one hand forward - backward (putting a hand on a ball in turn in front - behind) and hitting the ball on the floor in one and the same | 8-10 s, 1-2 repetitions, rest between 20-30 s series |
| | also with closed eyes | 6-8 s, 1-2 repetitions, rest between series 30-40 s |
| 5. | - in the initial position, standing feet together, a tennis ball is in one hand, tube for storing tennis balls is in the second; lobbing a tennis ball and catching it in a tube without moving out of place | 3-4 times, 2-3 series, rest between repetitions 20-30 s |
| | also, in the initial position, standing heel of one leg - toe of the other | 2-3 times, 1-2 repetitions, rest between series 30-40 s |
| | - in the initial position, standing feet together, a tennis ball is in one hand, tube for storing tennis balls is in the second; hitting the ball in the floor and after bouncing the ball catching it in a tube without going out of place | 3-4 times, 2-3 series, rest between repetitions 20-30 s |
| | also, in the initial position, standing heel of one leg - toe of the other | 2-3 times, 1-2 repetitions, rest between series 30-40 s |

$\chi^2_\alpha$ with the number of degrees of freedom ν=1. There is a lack of dependence between the studied indicators for conditions $\chi^2<\chi^2_\alpha$. If $\chi^2>\chi^2_\alpha$, this indicates the presence of a statistical relationship between the qualitative studied indicators. The research applied a two-sided criterion, which is determined by the number of degrees of freedom ν=1 as $\chi^2_{0.05}$=3,84; $\chi^2_{0.01}$ = 6,63 and $\chi^2_{0.001}$=10,83 (Lupandin, 2009).

The study objects were classified according to several nominal characteristics: Romberg's test before physical education classes and after it, at the beginning of the research, and during re-examination after the introduction of the corrective technique.

## Results

An analysis of the obtained indicators of Romberg's test before the pedagogical experiment noted the highest indicators of static balance, both at the beginning and at the end of the lesson in the first group of students (who have diseases and disorders of the musculoskeletal system acquired during life), but the differences were not reliable (p>0.05; Table 2).

It should be noted that the results of testing students

**Table 2.** The analysis of Romberg's test at the beginning and at the end of the research

| Studied | Romberg's test at the beginning of classes | | t | p | Romberg's test at the end of the classes | | t | p |
|---|---|---|---|---|---|---|---|---|
| | Before the experiment | After the experiment | | | Before the experiment | After the experiment | | |
| Group 1 | 2.88±0.38 | 3.75±0.25 | 1.94 | >0.05 | 2.56±0.36 | 3.88±0.26 | 2.94 | <0.05 |
| Group 2 | 3.00±0,28 | 4.04±0.20 | 2.99 | <0.05 | 2.96±0.30 | 4.29±0.15 | 3.91 | <0.05 |
| t | 0.25 | 0.91 | | | 0.85 | 1.37 | | |
| p | >0.05 | >0.05 | | | >0.05 | >0.05 | | |

Legend: Group 1 - Students with lifetime acquired diseases ($Y_1$) (n=16); Group 2 - Students with congenital diseases ($Y_0$) (n=24) with musculoskeletal disorders are much lower than those of healthy people.

When studying data obtained after the use of specially directed exercises and ball games that affect the ability to maintain static balance, it was found that indicators of the students of two groups improved, both at the beginning and at the end of the physical education lesson, but these changes were not always reliable (Figure 1). For example, at the beginning of the lesson, a reliable change is traced only in the group of students with congenital defects of the musculoskeletal system ($p<0.05$), while at the end of the lesson, balance indicators significantly improved in both groups ($p<0.05$).

Between the selected groups, indicators are slightly better noted, both at the beginning and end of the physical education lesson, among students with congenital musculoskeletal system defects, although there are no reliable differences ($p>0.05$).

The improvement in Romberg's test at the beginning of the lesson in the group of students with congenital musculoskeletal defects amounted to 1.04 points; in the group with acquired musculoskeletal disorders, 0.87 points; at the end of the lesson, 1.33 and 1.32 points, respectively, according to Table 3.

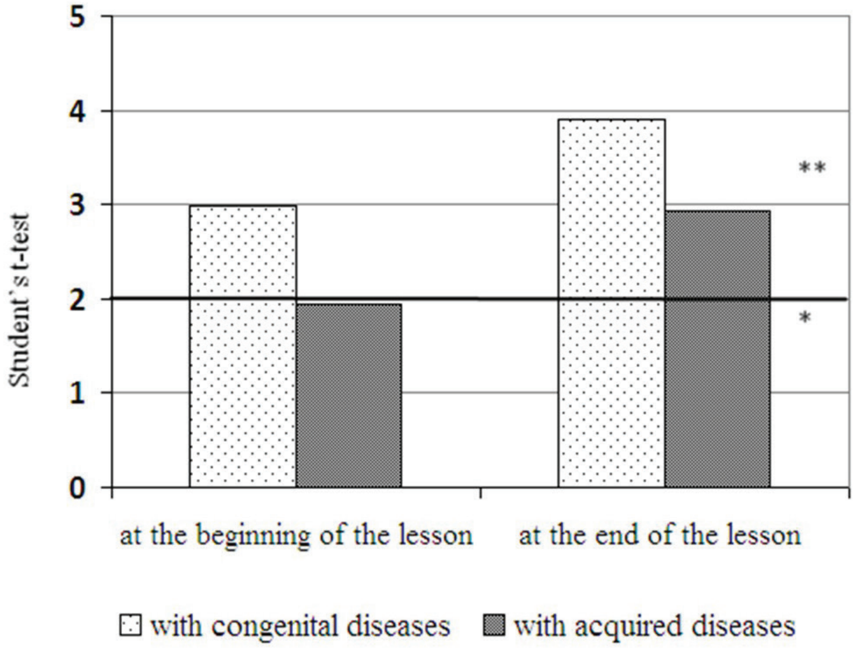


FIGURE 1. The validity of changes in statistical balance indicators on the student's criterion at the beginning and at the end of the physical education lesson (Student's t-test limit for n=40 is $t_{limit}$=2.01 (Lupandin, 2009), **– reliable differences ($p<0.05$); *– lack of reliable differences ($p>0.05$)

The research results on the qualitative level of balance development are presented in the form of tables of ratios. In Table 4, the lines indicate the disease group ($Y_1$ – acquired during life and $Y_0$ – congenital), and the columns indicate the result of Romberg's test (the presence of static balance – $X_1$ and its absence – $X_0$). In response to the presented table, we highlight two factors of one phenomenon.

**Table 3.** Changes in performance in Romberg's test under the influence of ball exercises and games

| Studied | Romberg's test at the beginning of classes | | Romberg's test at the end of the classes | |
|---|---|---|---|---|
| | points | % | points | % |
| Group 1 | 0.87 | 17.4 | 1.32 | 26.4 |
| Group 2 | 1.04 | 20.8 | 1.33 | 26.6 |

Calculation of the contingent coefficient ($K_k$=φ=0.33) and the association coefficient ($K_a$=ζ=0.60) and their comparison indicates the presence of dependence between the two balance factors (X) and a deviation in the physical health of the studied students (Y), both before the lesson and after the lesson

**Table 4.** Dichotomous table for finding balance (X) ratio in students with musculoskeletal disorders (Y) at the beginning of the research

| Group of diseases | The result of Romberg's test before the lesson | | Total Σ= | The result of Romberg's test after the lesson | |
|---|---|---|---|---|---|
| | passed ($X_1$) | didn't pass ($X_0$) | | passed ($X_1$) | didn't pass ($X_0$) |
| Acquired during life ($Y_1$) | a=17 | b=7 | 24 | a=16 | b=8 |
| Congenital ($Y_0$) | c=6 | d=10 | 16 | c=5 | d=11 |
| Total Σ= | 23 | 17 | | 21 | 19 |

($K_k$=φ=0.35 and $K_a$=ζ=0.63).

Pearson's value $\chi^2$ both before the lesson =6.55; and after the lesson =7.24 indicates the presence of a relationship with validity p=0.95, at the significance level α=0.05. The criterion value φ=0.33 and φ=0.35 with the number of studied n=40 (according to Lupandina, 2009) is interpreted as a relatively strong relationship between nominal variables at the significance level α=0.05.

Under the influence of the developed method of the structure of educational classes on physical education, students with health defects improved balance indicators (Table 5), both students with acquired defects of the musculoskeletal system during life and adolescents with congenital defects of the musculoskeletal system. The score "didn't pass" disappeared from the two examined groups.

At the end of the physical education lesson, the balance indicator "passed" appeared in almost all students. The score "didn't pass" was observed only in one student with acquired defects of the musculoskeletal system during life in four students with congenital defects of the musculoskeletal system.

The obtained results of the analysis of the indicators of the ratio of the examined factors X and Y and the calculation of the contingent coefficients (before the lesson $K_k$=φ=0.31 and after the lesson $K_k$=φ=0.31) and association (before the lesson $K_a$=ζ=0.58 and after the lesson $K_a$=ζ=0.77) indicate the presence of a close dependence, the contingent coefficient is less than the association coefficient ($K_k$=φ<$K_a$=ζ before the physical education lesson and after it). Pearson's calculation figure $\chi^2$, both before the class ($\chi^2$=5.58) and after the class ($\chi^2$=5.71) exceeds the critical value with the number of freedom degrees ν=1 $\chi^2_{0.05}$=3.84.

**Table 5.** Dichotomous table for finding balance (X) ratio in students with musculoskeletal disorders (Y) at the end of the research

| Group of diseases | The result of Romberg's test before the lesson | | Total Σ= | The result of Romberg's test after the lesson | |
|---|---|---|---|---|---|
| | passed ($X_1$) | didn't pass ($X_0$) | | passed ($X_1$) | didn't pass ($X_0$) |
| Acquired during life ($Y_1$) | a=19 | b=5 | 24 | a=23 | b=1 |
| Congenital ($Y_0$) | c=8 | d=8 | 16 | c=12 | d=4 |
| Total Σ= | 27 | 13 | | 35 | 5 |

The use of non-standard methods of mathematical statistics in the research of qualitative and nominal balance indicators in students with defects in the musculoskeletal system contributed to the improvement of methods for the structure of educational classes.

By calculating Pearson's test $\chi^2$ and its alternatives, it was statistically confirmed that the choice of physical exercises and ball games to develop balance correlates and is associated with musculoskeletal disorders of students. From a practical point of view, there must be a relationship between the analysed qualitative indicators and when estimating the degree of connection between them at the level of significance α=0.05.

## Discussion

For the results of Student's t-test, Pearson's criterion $\chi^2$, the contingent coefficient and association obtained in the research, the effectiveness of the influence of motor activity using ball exercises in physical education classes on the static balance of students with musculoskeletal disorders can be argued. The level of 17.4–26.6% showed that we established the influence of exercises and outdoor games with balls on improving balance indicators in students with disabilities. Our research supports the results of other authors (Gutierrez & García-López, 2012; Hastie & André, 2012), which point to the positive impact of gaming actions on students' physical fitness indicators. Thus, it is possible to recommend ball exercises and games to improve the process of physical education of students with musculoskeletal disorders. It should be noted that ball exercises and games increase the psycho-emotional background of the class, are attractive for students and are performed with satisfaction, as evidenced by the work of Fink, Stagnitti, and Galvin (2012) and Hastie and André (2012).

Using the statistical analysis of the research of qualitative indicators of each student individually provided an opportunity to take into account the physical state depending on the defect of the musculoskeletal system, which also contributed to a more accurate selection of the initial position of the exercises, the conditions for their performance, and dosing. The results of our research continue and correlate with the work of Aurora (2014) in improving the physical education of people with disabilities. This is consistent with the data of Kashuba and Zharova (2006), which noted the improvement in vertical resistance parameters in patients with orthopaedic pathology after the use of special physical exercises.

In summation, the balance state of students with musculoskeletal disorders is improved under the influence of the proposed means, namely ball exercises and games. When applying the proposed technique, it is possible to reproduce the individual trajectory of exercise, which allows students to be active in the lesson. Increasing balance indicators will improve people's quality of life with defects in the musculoskeletal system. The same conclusions are reached in the research of Martino et al. (2019), Pomeshchikova et al., (2016), and Salter (1999).

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**Conclusions**

Exercising and playing with balls reliably increases (at the level of significance α=0.05) the possibility of students to improve static balance indicators in a modified Romberg's test.

Using the calculation of criterion χ2, we statistically confirmed that the inclusion of specially selected exercises and ball games in physical education lessons for students with musculoskeletal disorders related to the performance of meeting the requirements of test exercises aimed at assessing the balance indicator.

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REVIEW PAPER

# Effects of Aerobic Exercise on Children and Young Peoples' Body Composition

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**Abstract**

This study aimed to collect relevant data from current studies on the effects of aerobic exercise on Children and Young Peoples' body composition. The following databases were reviewed: Google Scholar, Mendeley, SCIndeks, and KOBSON. The criteria for the analysis of the papers were as follows: the period of publication of papers from 2008 to 2020, longitudinal studies conducted in English, a sample of respondents aged 7 to 20 and the type of results for the purposes of a systematic review. The final analysis included 15 studies, which were analysed and presented, and the analysis of the obtained results shows that the effects of aerobic exercise have a positive effect on the body composition of children and young people. The results of the research can be used by future research in order to find adequate literature on the effects of aerobic exercise on children and young peoples' body composition.

***Keywords:*** *aerobic training, body composition, children and young people*

## Introduction

The physical inactivity of young people and its increased relationship with diseases such as obesity and diabetes have become a leading health concerns at the global level (Garland et al., 2011). This has led to increased concern for children's health, their daily habits, and physical activity. How children spend their free time seems to be a factor that contributes to their increasing obesity (Stellino, Sinclair, Partridge, & King, 2010). Based on this fact, some authors believe that children spend most of their free time sitting in front of a television or computer (Bener et al., 2011; Hills, Obkely, & Baur, 2010). We have arrived at an absurd situation: new inventions and discoveries certainly help a person perform various tasks faster and easier, while energy consumption decreases. The "danger" can become greater if nothing is done during childhood.

Physically active people can maintain or reduce their body weight for a longer period much more easily than people who only rely on a reduced diet. However, maintaining body composition also depends on proper nutrition. Physical activity affects weight reduction by correcting body composition; in combination with a programmed diet, it can present an ideal formula in correcting body composition (D. C. Nieman, Brock, Butterworth, Utter, & C. C. Nieman, 2002). Excessive amounts of fat tissue pose a risk for various diseases: if the waist size increases by 1 cm, the risk of cardiovascular diseases increases by 10% (Milanović, Sporiš, Pantelić, Trajković, & Aleksandrović, 2012). Strategies for treating long-term obesity are largely ineffective in adults. Given the alarming increase in physical inactivity in children, primary measures to reduce obesity should be taken in early childhood, so that there would be no consequences later in life (Malina, 2007).

Children and adolescents can find a solution in a variety of aerobic activity programmes and their benefits (Centers for Disease Control. Prevention, 2007; Danaei et al., 2009; Klijn, van der Baan-Slootweg, & van Stel, 2007; Reed, Maslow, Long, & Hughey, 2013; US Department of

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Health and Human Services, 2008). Participating in aerobic exercise not only reduces cardiovascular risk, but risk reduction is also minimized over time (Brown, Naples, & Booth, 2012; Li, 2012; Scully, Kremer, Meade, Graham, & Dudgeon, 1998). Existing models of obesity intervention include increased physical activity, as well as correction and diet modification. Some of the structural programmes of aerobic exercise are walking, jogging, dancing and cycling, which are usually performed three to five times a week, from moderate to submaximal intensity, and according to G. A. Kelley and K. S. Kelley (2008) these are quite satisfactory exercise opportunities. According to Kostić (2009), changes in the structure of children and young peoples' body composition, which result in obesity, are considered one of the most significant public health problems of modern times, which is why constant monitoring of physical activities and energy consumption is important.

The author of the present study believes that there is a need to summarize the relevant literature on the effects of aerobic exercise on children and young peoples' body composition.

## Methods

To collect relevant literature suitable for research of this type, the following databases were searched: Google Scholar, MEDLINE, Web of Science, SCOPUS, SCIndeks, and KOBSON. Searched papers (abstracts or whole papers) were analysed. For the works to be included in the final analysis, they had to meet the following criteria:

1. Works that were published in the period from 2008 to 2020;
2. Longitudinal studies conducted in English;
3. Sample of respondents: males and females, 7–20 years old;
4. Type of results obtained: the primary result obtained for the purposes of systematic examination were the effects of aerobic exercise on the body composition of children and young people.

A descriptive method was used to analyse the obtained data. All titles and abstracts are reviewed for potential papers to be included in the systematic review. The keywords used in the database search were: "aerobic training", "body composition", "children and young people", or a combination of these keywords in English: "aerobic training", "body composition", "children", "youth".

Also, the lists of references of previous reviews and original research studies were reviewed. Relevant studies were obtained after a detailed review if they met the inclusion criteria. The exclusion criteria were:

1. Studies written in a language other than English;
2. Duplicates;
3. Studies with respondents older than 20 years.

The search strategy was modified and adapted to each database and search, where possible, in order to increase search sensitivity.

## Results

After a general search of the database, 152 studies were identified. After eliminating papers that did not meet the title, abstract, 102 studies did not meet the criteria. Another 20 studies were eliminated due to the language of writing, as well as an additional 15 studies based on the inappropriate age of the respondents. The remaining papers are reviewed in detail. A total of 15 studies met all the set criteria and have been systematically reviewed.

A detailed overview of the process of collecting appropriate works based on the pre-defined criteria can be found in Figure 1.

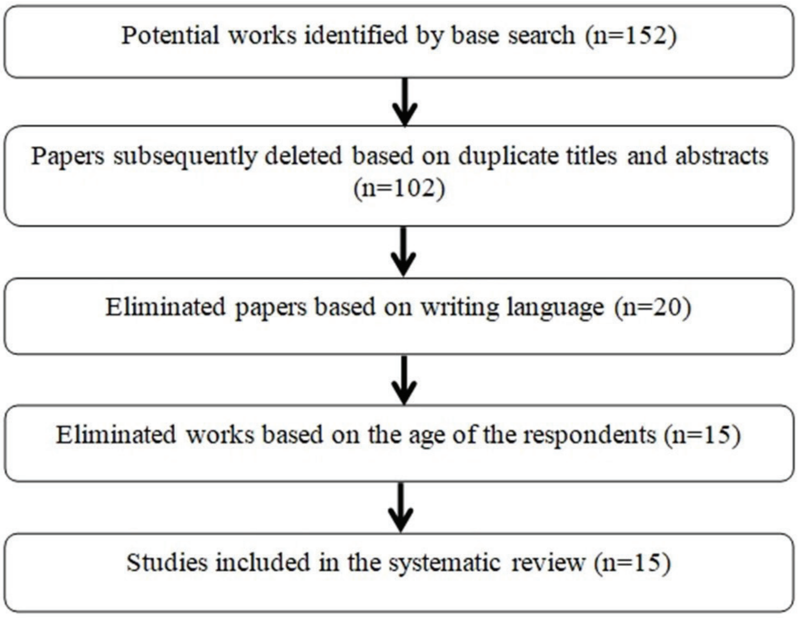


FIGURE 1. Overview of the process of collecting adequate works based on pre-defined criteria

In the final analysis, 15 relevant studies were included in the systematic review, based on early defined parameters and criteria, studies that were published in the period from 2008 to 2020, longitudinal studies conducted in English, the sample of participants had to be both sexes, 7–20 years old, and the primary result obtained for the purposes of systematic examinations were the effects of aerobic exercise on the body composition of children and young people. Table 1 shows the review of the studies.

**Table 1.** Review of studies

| First author and year | The aim of the research | Sample of respondents | | Exercise programme | Variables | Results |
|---|---|---|---|---|---|---|
| | | Number | Years | | | |
| Knöpfli et al., (2008) | Effects of an 8-week programme on BC, aerobic fitness, and quality of life | N-130 M-78 F-52 | 12.1-15 | 7 days, 60-90 min. | AV, VO2max, Sp, BE, Q | Significantly corrected BMI and absolute body fat, VO2max and quality of life |
| Wong et al., (2008) | Effects of 12-week aerobic exercise and endurance training on aerobic fitness BC and BV | M-24 E-12 K-12 | E-13.8±1.1 K-14.3±1.5 | 2x per week, 40-60 min. | AV, BC, BV, BE, T, Ct, Sp | BC E group significantly improved, K group decreased body weight |
| McGuigan et al., (2009) | Effects of 8 weeks of endurance training | T-48 M-22 F-26 | 7-12 | 3x per week | D, AV, BC, CMJ, SJ, PF | Absolute body weight decreased significantly |
| Dorgo et al., (2009) | Effects of an 18-week manual endurance training programme on PF | N-222 E1-63 E2-30 K-129 | E1-16±1.2 E2-15.9±1.2 K-15.8±1.1 | 3x per week, 80 min. | MEt, MRt+Et, BMI, SF, PF | Muscle fitness and cardiovascular endurance significantly improved, the programme did not affect BC |
| Zorba et al., (2011) | Effects of 12-week aerobic training on BC, BV, and insulin levels | N-40 E-20 K-20 | 11±1 | 3x per week, 20-45 min. | AV, BV | Group E significantly reduced body weight, BMI and AV |
| Martins et al., (2011) | Effects of an 8-week physical activity programme on BC and PF | F-16 E-8 K-8 | E-12.3±0.9 K-13.2±1.1 | 3x per week, 30 & 45 min. | FG, AV, BC, PF, BE, T, Ks | The programme gives positive effects |
| Sijie et al., (2012) | Effects of 12-week HIIT on BC, cardiac and aerobic function | F-60 | 19-20 | 5x per week, 30-40 min. | HIIT, MICT, VO2max | The high- and medium-intensity group reduced BC, with a significant improvement in VO2max |
| Reed et al., (2013) | Effects of 12-week physical activity on CA, motor skills and BC | N-470 E-165 K-305 | E-10.2±2.3 K-11.2±1.9 | 5x per week, 45-50 min. | CA, FG, BC | The programme gives positive effects of group E, the girls showed significant results in all variables |
| Regaieg et al., (2013) | Effects of a 16-week physical activity programme on BC and aerobic capacity | N-28 M-16 F-12 | 12-14 | 16 weeks, 4x per week, 60 min. | AV, BC, BE, Ct, Ks | The E group corrected BMI, waist circumference, fat and non-fat fats |
| Barker et al., (2014) | The effect of 2-week HIIT on aerobic fitness, fat oxidation, blood pressure and BMI | M-10 | 14-16 | 6x +per week. | HIIT, AV, BC, VO2max, BE | The programme did not significantly affect body weight and BMI |
| Silva et al., (2014) | Effects of a 12-week aerobic exercise programme on BC and BV | N-14 E-9 K-7 | 13-17 | 3x per week, 30-40 min. | AV, BMI, SF, BC, BV, BE | Significant improvement of SF, reduction of % M and fat fats of group E. |
| Lee et al., (2014) | Effects of a 22-week swimming programme on BC and pulmonary flow | N -20 E-10 K-10 | E-11.4±2.87 K-11.1±1.69 | 3x per week, 60 min. | BC, AV, PF | The programme had a positive effect on the reduction of BC and % M |
| Sigal et al., (2014) | Effects of 22-week aerobic exercise and endurance training, as well as combined training on body weight percentage | N-304 E1-75 E2-78 E3-75 K-76 | 14-18 | 4x per week | BC, AV, VO2peak,T, PF | All types of training significantly corrected % M and waist circumference |
| Arazi et al., (2016) | Comparison of 2 aerobic training methods of 8 weeks each | N-33 E1-12 E2-11 K-10 | 11.2±0.64 | 3x per week, 30-60 min. | BC, SF, PF VO2max | Screw training significantly affected TK correction and aerobic strength |
| Yoon et al., (2017) | Effects of 16-week cycling on BC, PF i BV | F-24 E1-12 E2-12 | E1-13.3±0.4 E2-13.4±0.3 | 3x per week, 60 min. | BE, BC, BV, PF | Achieved positive effects on BC and PF |

Legend: N- total number of respondents, M- male, F- female, E- experimental group, K- control group, BC- body composition, AV- anthropometric variables, CMJ-vertical jump, SJ-squat jump, MEt- manual endurance training, MRt + Et- manual resistance training + endurance training, BMI- body mass index, SF- skin folds, HIIT- high-intensity interval training, MICT- moderate training intensity, CA- cognitive abilities, VO2max- maximum oxygen consumption, BV- blood variables, VO2peak- oxygen volume during active work, BE- bicycle ergometer, T- treadmill, Q- questionnaire, D- diet, Sp- sports programme, PF- physical fitness, Ks- collective sports, FG- Fitnessgram, Ct- circuit training, %M- percentage of fat; The age values of the respondents are shown as Mean ± SD

## Discussion

This study aimed to summarize the relevant literature on the effects of aerobic exercise on children and young peoples' body composition. A total of 1439 subjects participated in the study; the largest number of subjects was in the study by Reed et al. (2013), with 470 subjects, while the smallest number of subjects was in the study by Barker, Day, Smith, Bond and Williams (2014), with ten respondents. The youngest respondent was seven years old, in a study by McGuigan, Tatasciore, Newton and Pettigrew (2009), while the oldest respondent was 20 years old, in a study by Sijie, Hainai, Fengying and Jianxiong (2012).

The duration of the experimental programme should be adequate and adjusted to the student population. Specifically, the study of Barker et al. (2014) lasted only two weeks and, in the end, there were no significant effects. The obvious and noticeable improvement in physical fitness was not enough to cause positive changes in body composition, and an adjusted duration of the experimental programme is needed, a minimum of 12 weeks in adolescents, if a positive effect on body composition is to be achieved (Kessler, Sisson, & Short, 2012).

Only three studies monitored caloric intake (Knöpfli et al., 2008; McGuigan et al., 2009; Sigal et al., 2014). Although these studies differ according to the type of training they applied, all the mentioned studies showed positive effects on body composition.

The selection of the sample of respondents is a key characteristic, specifically a healthy population, as well as the promotion of studies of that type and their quality. Only five studies had a healthy population for the sample of respondents (Dorgo et al., 2009; Barker et al., 2014; Reed et al., 2013; Arazi, Jalali-Fard, & Abdinejad, 2016; Yoon, Kim, & Rhyu, 2017). It is a very important fact that both the overweight and especially the obese population need to be exposed to physical activities and active lifestyle, physical education classes, various school games and exercises for skills development, as well as many recreational and fitness activities, all in order to improve their health status (Dorgo et al., 2009).

A large number of studies have applied aerobic exercise (Knöpfli et al., 2008; Wong et al., 2008; Zorba, Cengiz, & Karacabey, 2011; Barker et al., 2014; Silva et al., 2014; Arazi et al., 2016; Yoon et al., 2017). Insufficient aerobic capacity can be a predictor of mortality, so long-term improvements in this ability should be a goal, which would significantly change body fat (Watts, Jones, Davis, & Green, 2005). Also, the aerobic type of exercise enables positive changes in body composition, reduction of BMI and fat percentage (Ounis et al., 2008), and also strengthening muscles, increasing bone mass, maintaining oxygen intake, reducing the risk of cardiovascular disease, reducing stress, but also a positive impact on self-esteem (Ekeland, Heian, & Hagen, 2005; Mota-Pereiraet et al., 2011). Cattuzzo et al. (2016) noted particularly important parameters for the development of physique and physical fitness of children and young people, because poor health outcomes at this age can be reflected in later life.

Four studies applied a combination of aerobic training and resistance training (Martins, Marialva, Afonso, Gameiro, & Costa, 2011; Regaieg et al., 2013; Reed et al., 2014; Sigal et al., 2014). The combination of these two types of training provides several benefits, such as improved metabolic capacity and cardiorespiratory fitness (McArdle, Katch, & Katch, 2001) but also quantitative changes in skeletal muscle and increased muscle strength (Kraus & Levine, 2007).

The limitations of this study can be attributed to the fact that the authors did not have absolute access to all databases, so the number of studies that entered the systematic review research is relatively small. Also, some studies monitored the caloric intake, and others did not, which is why the authors decided to summarize all studies under the same set of analyses.

The results of this research can be used in future studies in order to find suitable literature on the effects of aerobic exercise on children and young peoples' body composition and to use them properly in other new qualitative analysis in the future.

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REVIEW PAPER

# Active Commuting and Sustainable Mobility in Spanish Cities: Systematic Review

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**Abstract**

The General Assembly of the United Nations established 17 sustainable development goals in its 2030 agenda, and urban mobility is in the sights of political authorities to empower sustainable cities and communities. This work consists of a review of the literature published within the Spanish context concerning public bicycle systems and urban mobility. To select studies, a search was carried out with different descriptors in the main Spanish and international databases, namely Scopus (Elsevier), Web of Science (WoS), and Dialnet. Some of the analysed works examine the efficacy of public bicycle systems as an efficient and sustainable alternative in cities; other works study the impact on individual and public health of shared bicycle schemes via increased physical activity engagement. Likewise, infrastructure and facilities for cyclists are also analysed as they favour perceptions amongst the population of greater road safety within their environment. Bicycle-share systems can help to maintain healthy habits amongst the population. Better infrastructure, technology and appropriate policies can favour the use of these systems.

***Keywords:*** *Urban transport, public health, public transport, bike-sharing systems, physical activity*

## Introduction

Healthy lifestyles have emerged as an important topic in contemporary society. Given this circumstance, governments and institutions promote the revitalization of public spaces, which encourages engagement in physical activity and the development of human interrelationships (Braçe, 2016; Curto et al., 2016). Thus, an active lifestyle, including walking or cycling, has become a key factor in reducing the impact of chronic diseases, obesity and/or coronary problems linked to human behaviour, such as those produced by a lack of physical exercise. In the same way, when such activities are used as a means of transport, they favour a less-congested urban environment and reduce greenhouse gas emissions, which cause climate change. All of this has a positive effect on human health (Anaya & Castro, 2012; Curto et al., 2016; Sanmiguel-Rodríguez, 2015, 2019, 2020; Seguí, Mateu, Ruiz, & Martínez, 2016). The field of study relating to urban mobility and active transport in cities has emerged as a relevant research area. The growing interest in environmental care has produced a socio-logical change in large sectors of society, which now prefer to walk or use non-polluting means of transport, such as bicycles (Herranz, 2015; Zozaya, 2016, 2017). Similarly, the increasing rise of fuel use makes the bicycle an ideal means of transport with regards to the sustainability of the urban environment (Pellicer-Chenoll et al., 2020). Given the enormous fuel consumption in Spain, where there is a high external dependence on oil, encouraging cleaner cities is crucial (Herranz, 2015).

At the international level, the 2030 Agenda of the United Nations (UN) opted to establish objectives for sustainable development, addressing the need to establish changes in urban mobility (UN, 2015).

In a review (Anaya & Castro, 2012) on bike-sharing systems in Spain, a detailed analysis of the different systems existing in 2011 was presented. In Spain, 196 systems had been implemented. According to the city profile, 51% of the systems are located in urban centres of less than 50,000 inhabitants; 21% are found in cities of 50,000 to 100,000 inhabitants, 24% in cities of between 100,000 and 500,000 inhabitants, and 4% in

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centres made up of more than 500,000 inhabitants. However, most of the Spanish cities that have bike-sharing systems are poorly equipped with bicycle infrastructure. According to Castillo-Manzano, López-Valpuesta, and Sánchez-Braza (2016), a strategy that has started to achieve good results in the promotion of bicycle use, along with the construction of bicycle lanes and availability of bicycle parking, is the implementation of public shared bikes systems that coexist with the private use of bicycles; Their findings showed that the average duration of trips on private bicycles was higher than those made using public bicycles; however, there is a complementary relationship between the two modes of transport in regards to distance. Following on from this research, the results of another study (Braun et al., 2016; Curto et al., 2016) showed that the modal competition between cycling and public transport, through the presence of more public transport stops and better cycling infrastructure and stations for bicycles, is associated with greater active displacement within the urban environment.

Other international studies (Eren & Uz, 2020) have addressed the need for a comprehensive review of the factors affecting bike-sharing demand to bridge the gaps by deepening the knowledge on weather, built environment and land use, public transportation, station level, socio-demographic effects, temporal factors, and safety.

Bike-sharing systems have recently become a key issue in urban mobility and in related research activity. Due to their relative novelty, most scholars focus on the characteristics of the supply side without taking demand into account. Data on this subject has not yet been analysed in detail as most of the systems have only recently been introduced (Munkácsy & Monzón, 2017). Ferrando, Anaya and González (2010) pointed out that the approach to implementation of bicycle systems in Spain is currently under development. The data obtained have shown a series of trends that characterize Spanish public bicycle systems. For example, it is noted that there are many types of systems and that the evolution of those that are perceived as successful is usually towards automation. It has also been noted that these systems are successfully implemented not only in medium and large cities but that small cities can also implement systems adapted to their context, which are capable of producing good results. In a survey carried out by Curto et al. (2016) in Barcelona, travellers' favourable perceptions towards public bicycles were reported. Further, the most important facilitators for using bicycle-sharing systems were reported as follows: avoiding bicycle theft and vandalism, and maintaining the low cost of the system. According to Braçe (2016), public bicycle programmes have begun to receive increasing attention in recent years due to the great interest of urban planners in developing and improving active transport systems in the urban environment. These measures would help reduce dependence on private vehicles and encourage non-motorized journeys, thus maintaining the three pillars of sustainable development: environmental, economic, and social (Braçe, 2016; Castillo-Manzano et al., 2016; Morales, 2011; Norveto, 2010). As a result, bike-sharing systems have experienced relevance and popularity in European countries and around the world (Castillo-Manzano et al., 2015; Faghih-Imani, Hampshire, Marla, & Eluru, 2017). Furthermore, bicycle infrastructure has also been shown to be an extremely important element in sustainable mobility strategies in the urban sphere (Ballester & Peiró, 2008; Braun et al., 2016; Luque, 2016; Morales, 2010, 2011; Munkácsy & Monzón, 2017; Norveto, 2010; Seguí et al., 2016; Zozaya, 2016, 2017) and as part of strategies targeting less polluted environments. It fits in with research into the design of urban spaces and how this influences health, improving understanding of the physical and social elements that condition people's lives (Anaya & Castro, 2012; Ballester & Peiró, 2008; Braun et al., 2016; Curto et al., 2016; Herranz, 2015; Munkácsy & Monzón 2017).

Thus, it was decided to review bicycle systems found in the Spanish context, given that the climatic characteristics of this country favour the practice of physical activity and outdoor cycling. Also, many planning policies are being developed in Spain within the urban environment to promote less congested traffic environments whilst also favouring public health. Simultaneously, these active means of transport (walking or cycling) favour a less congested urban environment, reducing greenhouse gas emissions. This also has a positive effect on human health (Anaya & Castro, 2012; Curto et al., 2016). The choice of this environment for the study of urban mobility relating to bicycle use is because Spain enjoys situational, climatic, and topographic characteristics that favour outdoor sports throughout the year.

This work aims to review the literature published in recent years concerning Spanish bike-sharing systems. Specifically, the objectives that our article aims to address are as follows:

a) Compile research studies conducted on public bicycle systems and better understand the status of issues relevant to this research field within the Spanish context.

b) Classify the main lines of research developed around the subject.

c) Document the background of investigations relating to current public bicycle systems for future investigations.

## Methods

This article's development was based on the realization of a bibliographic review based on the search and analysis of information relating to bike-sharing systems within the Spanish context. This type of review is called an "overview" (Grant & Booth, 2009), through which an update of all the macro information published on a specific topic is established. Its main advantage is the ability to analyse a large amount of information published in recent years and clarify different subtopics related to researchers' main topic. To carry out this review, the parameters and recommendations set by the PRISMA Declaration were used, complying with the analysis of that declaration's 27 items (Moher, Liberati, Tetzlaff, & Altman, 2009). Different search descriptors were used, among which the following keywords are highlighted: shared bicycles, public bicycles, bicycle systems, physical activity and bicycles, active transport and public health and bicycles. Works published up until 2020 were included. The inclusion criteria used were as follows:

a) Scientific articles published within the Spanish context up until December 20, 2020;

b) Addressing any type of research related to bicycle systems and urban mobility in the Spanish context incorporating quantitative, non-experimental, descriptive, prospective, longitudinal, cross-sectional and/or case studies;

c) Published in English or Spanish.

After the application of these criteria, a total of 181 documents on the subject, published in English and/or Spanish up until December 2020, were included. The work schedule for the information search consisted of four distinct phases:

- 1st Phase: Search and selection of the aforementioned descriptors using the UNESCO Thesaurus.
- 2nd Phase: Search carried out using general search engines and in the following databases using the inclusion criteria described above: Scopus, Web of Science, and Dialnet.
- 3rd Phase: Analysis of the content of articles and classification according to themes.
- 4th Phase: Categorization of the articles and preparation of the manuscript. It should be noted that, in general, attempts were made to use the article itself as a reference. However, in some cases, due to the difficulty accessing the content of some articles, the corresponding abstracts were analysed and evaluated.

The work schedule for the information search consisted of five differentiated stages. These are described next and can also be observed in the flow diagram, which provides a graphical representation of the process in Figure 1.

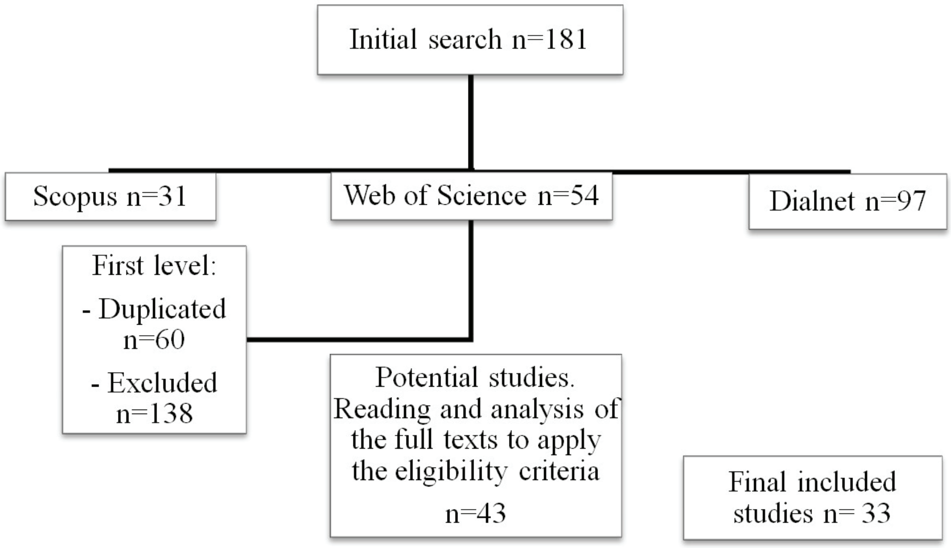


FIGURE 1. Flow diagram of the systematic search process

The research was carried out by dividing it into five large blocks of content to try to answer the different issues that we believe to be most important. The first section will deal with the current state of Spanish bicycle systems. In the second section, we will analyse the importance of cycling infrastructure, accessibility and facilities within bicycle sharing systems in the urban environment as a means of favouring active policies within the Spanish population. In the third, studies addressing the importance of road safety and new technologies within the Spanish system of public bicycles will be addressed and the social impact that it has on its population. The fourth point relates to the benefits of bicycle-sharing systems as a means of promoting healthy habits within urban environments, as well as the educational vision that different professionals and students have about cycling as an active means of transport. Finally, in the fifth section, we will attempt to explore whether correct political planning within the urban environment can favour healthy practices and the use of public bicycle schemes, with reference being made to the sustainable mobility and ecology offered by these systems.

## Results

Once the flow chart of the systematic review of Bike-sharing systems and urban mobility in Spain was made, the result was 33 publications. All of them were included in the process of categorization by subject, which produced five categories of analysis of the scientific literature. The results of the systematic review carried out are detailed below, specifying the publications that belong to each of the five categories analysed (Table 1).

**Table 1.** Synthesis of the studies found on Bike-sharing systems and urban mobility in the Spanish context

| Authors | Article title | The purpose of the study | Results and conclusions |
|---|---|---|---|
| | | Research on urban mobility and public bicycle systems | |
| Álvarez-Valdés et al., 2016 | Optimizing the level of service quality of a bike-sharing system | Distribution of bicycles among stations | Computational results using real data from the bike-sharing system in Palma de Mallorca are reported |
| Brey et al., 2017 | "I want to ride my bicycle": delimiting cyclist typologies | The aim of determining whether different typologies of cyclists exist depending on the type of bicycle for urban commuting (public bicycle/private bicycle) | This study showed that users of public bicycles are predominantly male, young and use the public bicycle for subsistence trips due to its easy intermodality; while private bicycle riders are mainly females who regularly make "non-subsistence" trips and prefer a more flexible bicycle for their daily needs |

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| Authors | Article title | The purpose of the study | Results and conclusions |
|---|---|---|---|
| | | Research on urban mobility and public bicycle systems | |
| Castillo-Manzano & Sánchez-Braza, 2013 | Managing a smart bicycle system when demand outstrips supply: the case of the university community in Seville | This paper analyses this experience in the university community, which represents one-third of system users | The people who are most satisfied with the system are those who use it for leisure and recreation activities, non-residents of the city, more environmentally aware people and those who have no alternative mode of transportation |
| Munkácsy & Monzón*, 2017 | Potential User Profiles of Innovative Bike-Sharing Systems: The Case of BiciMAD (Madrid, Spain)* | The aim of this paper is the analysis of the evolution of bike-sharing and the exploration of how innovative technologies have changed bike-sharing systems for users and the identification of user (and non-user) profiles of the latest generation of bike-sharing based on an ex-ante case study on the BiciMAD | These authors showed that parking and inter-modality were the most relevant factors for BiciMAD users |
| Pellicer-Chenoll et al., 2020 | Gender differences in bicycle sharing system usage in the city of Valencia | This study analysed the movements of men and women who use the BSS in the city of Valencia during weekdays | These authors showed that women use the BSS less than men in all the tested time slots. They also observed different network density and centrality for men and women. Finally, They found that women do not use the peripheral areas of the city at night |
| Rojas-Rueda et al., 2011 | The health risks and benefits of cycling in urban environments compared with car use: health impact assessment study | To estimate the risks and benefits to health of travel by bicycle, using a bicycle-sharing scheme, compared with travel by car in an urban environment. | Public bicycle sharing initiatives, such as Bicing in Barcelona, have greater benefits than risks to health |
| Sanmiguel-Rodríguez*, 2019 | Analysis of the ages, routes and minutes of use in the use of a shared bicycle system: the case of VaiBike in Vilagarcía de Arousa (Spain)* | This study is intended to categorize the ages of users of this system, as well as their frequency of use, the route characteristics, and average minutes of use of bicycles | Users' average age was 46 (men 49; women 38.7). The highest frequency of use begins and ends in the city centre. Men between 50 and 69 years old and women between 30 and 49 years old use bicycles the most. Coastal routes are the most popular in women. The average minutes of use in public bicycle trips were 36,1 (men 38,1; women 31,4). |
| Sanmiguel-Rodríguez*, 2020 | Compliance with the recommendations for physical activity set by the WHO by public bicycle users in a Spanish municipality | To know if the users of the public bicycle sharing system of Vilagarcía de Arousa (Spain) comply with the recommendations of physical activity for health established by the WHO. | The results indicate that users of the Vaibike bicycle sharing system of Vilagarcía de Arousa comply with the minimum recommendations of physical activity given that the average number of minutes of use of bicycles is greater than 30 minutes. |
| Sanmiguel-Rodríguez & Arufe Giráldez, 2019 | Impact of climate on a bike-sharing system. Minutes of use depending on the day of the week, month and season of the year | The objectives of this article are, firstly, to determine if the impact of climate, temperature and average rainfall on the use of shared bicycles; and, secondly, to analyse if the use of these bicycles is affected by the day of the week, month or season of the year | These authors found no significant differences in use concerning the day of the week. With respect to month, the data reveal a progressive increase in use from April to July, reaching a peak of 15.8% in September |
| Seguí et al.*, 2016 | Bike-Sharing schemes and sustainable urban mobility. An analysis in the city of Palma (Mallorca, Balearic Islands)* | The article analyses public bicycle systems as an instrument to encourage bicycle trips within the framework of sustainable mobility policies | The analysis shows a low acceptance of the system, despite the more-than-notable increase in the number of cyclists in the city |

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| Authors | Article title | The purpose of the study | Results and conclusions |
|---|---|---|---|
| | | Research on urban mobility and public bicycle systems | |
| | | Accessibility, public spaces and infrastructure of bicycle systems and public facilities in the urban environment | |
| Braçe*, 2016 | Study of the Effects of Urban Morphology on Physical Activity* | This article explores the association between urban design variables and physical activity, showing as the results obtained in a European Mediterranean area are consistent with the scientific literature | This author affirmed that in this environment, there is a relationship between urban sprawl, physical activity and use of transport-related physical activity (walking and cycling) |
| De Manuel, 2016 | Sustainable urban mobility networks and the reactivation of the public space: Alcosa | This author has made a diagnosis about the relationship between a mobility model and public space occupancy. | There is a direct relationship between the use of public space and mobility model |
| Orzanco et al., 2018 | Perception of psychosocial and environmental factors related to active displacement | The purpose of the present study was to determine the perception of individual factors and of the nearby environment, related in a special way to each of the two modalities of active transport, in a population sample of the adults living in the metropolitan area of Pamplona | People who spend less time walking to go from one place to another indicate lack of time as the reason that prevents them from carrying out some physical activity, while the group that uses the bicycle less for transport indicates a lack of enjoyment |
| Zozaya, 2016 | La nueva infraestructura de la bicicleta en París y Barcelona: retos de su implantación e influencia de la trama urbana | This study showed that cycling infrastructure is an element of growing importance in the development of sustainable mobility strategies in urban areas | The hybrid nature of the bicycle as a means of transport, halfway between the pedestrian and the motorized vehicle, induces a rethink of the current configuration of urban roads and public spaces |
| Zozaya, 2017 | Retos de la expansión de los sistemas de bicicletas públicas en las aglomeraciones urbanas metropolitanas | The creation of specific regulations and standards that would guarantee the compatibility of key elements among the different providers of these schemes is essential to ensure their success during the process of metropolitan integration | This study showed that bicycle systems can become a key element in the sustainable mobility strategy of cities |
| | | *Potential User Profiles of Innovative Bike-Sharing Systems: The Case of BiciMAD (Madrid, Spain); Munkácsy and Monzón<br>Social factors, installation of bicycle systems, new technologies and road safety | |
| López & Monzó, 2014 | Sistemas de bicicleta pública: vehículos inteligentes para ciudades sostenibles. | The article is part of the search for transport solutions | The article forms part of the search for transport solutions within what has been termed intelligent mobility and incorporates some type of communication and information technology |
| Morales, 2011 | El Fomento del uso de la bicicleta en entornos educativos | The object of study of this work is to carry out a review bibliography of the evolution of the bicycle from its appearance to the culmination in different educational settings | This study showed the benefits of using this means of transport, both at an energy and environmental level |
| Osorio-Arjona & García-Palomares, 2017 | New sources and challenges for urban mobility studies | In this article, the state of the art in these new data sources use for urban mobility analysis is implemented | To promote actions towards sustainable mobility, it is necessary to use dynamic information sources with high spatial and temporal detail that allow for efficient diagnoses of the mobility situation in our cities. Information and Communication Technologies and Big Data appear as new interactive sources that respond to these needs |

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| Authors | Article title | The purpose of the study | Results and conclusions |
|---|---|---|---|
| | Research on urban mobility and public bicycle systems | | |
| Reboreda et al., 2016 | Cyclope: sistema tecnológico para mejorar la seguridad vial de bicicletas y ciclomotores | These authors have created a system aimed at the prevention of traffic accidents amongst cyclists and motorcyclists | The number of injuries sustained on the road in Spain has been maintained over time |
| Tironi, 2015 | Éticas en el cuidado de los recursos urbanos: mantención y reparación en un sistema de bicicletas públicas | This study demonstrated the essential work that takes place behind the scenes by those who maintain and repair urban resources, such as bike sharing systems | |
| | *Potential User Profiles of Innovative Bike-Sharing Systems: The Case of BiciMAD (Madrid, Spain); Munkácsy and Monzón<br>*Perception of psychosocial and environmental factors related to active displacement; Orzanco et al.<br>Planning policies in the urban environment and studies of sustainable mobility, environment and ecology | | |
| Ballester & Peiró, 2008 | Transport, environment and health | These authors review the negative impact of current transport forms on health in terms of traffic injuries, climate change, atmospheric contamination, noise, and interference with daily activities and exercise, such as impediments to walking or cycling. | Recommendations are made on the need to reduce the use of private cars and to develop segmented routes and areas of quiet traffic connected in the cities and among nearby towns to promote walking are cycling |
| Herranz, 2015 | Un nuevo concepto para la ordenación del territorio | This study showed that public authorities often proceed in a contradictory manner when promoting active means of displacement | |
| Rojas, 2013 | Transportation, Air Pollution And Physical Activities; an integrated health risk assessment programme of climate change and urban policies (TAPAS) | Active transport (walking, cycling or public transport) may have the capacity to reduce greenhouse gas emissions and climate change and may bring with them benefits for the environment and health | |
| | *Study of the Effects of Urban Morphology on Physical Activity; Braçe<br>*Potential User Profiles of Innovative Bike-Sharing Systems: The Case of BiciMAD (Madrid, Spain); Munkácsy and Monzón<br>*Bike-Sharing schemes and sustainable urban mobility. An analysis in the city of Palma (Mallorca, Balearic Islands); Seguí et al.<br>Healthy habits, benefits of the practice of physical activity and educational vision | | |
| Chillón et al., 2017 | Active commuting to school, positive health and stress in Spanish children | The objective was to analyse the association between active travel to school and variables of positive health and stress in Spanish children | Measures are necessary to encourage active travel to school due to the positive benefits it has on physical and emotional health, seen as a possibility of adequately channelling stress in Spanish children |
| Luque, 2016 | La movilidad urbana sostenible una nueva razón para fomentar el uso de la bicicleta en el ámbito educativo | Encourage the use of bicycles, not only in our sessions but also as an excellent means of promoting "transportation to school" | |
| Mallada, 2012 | El cicloturismo en el currículo de Educación Secundaria de Cantabria | This article is a review of the possibilities of the use of the bicycle and the realization of cycling activities within the framework of the educational curriculum of Cantabria (Spain) | |
| Mira & Tortosa, 2009 | The bicycle as a means of sport and transport | Cycling can be the way for all of them to do the advisable daily sport and to reach a healthy and sustainable life, according to the basic competences of the Organic Law of Education (OLE) and the principles of the World Health Organization of Health (WHO) | |
| Moreno & Bernal 2016 | Transporte activo y ciudad: propuesta interdisciplinaria para la educación física | This article showed an educational proposal focused on active transport (use of the bicycle to get to the school) and on the generation of critical awareness based on the experience of the city as an educational space-time | |

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| Authors | Article title | The purpose of the study | Results and conclusions |
|---|---|---|---|
| Research on urban mobility and public bicycle systems | | | |
| Rodríguez-López et al., 2013 | Family factors influence active commuting to school in Spanish children | The objective was to analyse the association between parents' occupational activity and parents' mode of commuting to work with the mode of commuting of their children | Children whose parents did not work used to engage in higher levels of active commuting to school than those whose parents worked. Children whose parents used to commute actively to work used to engage in higher levels of active commuting to school than those whose parents used both passive modes of commuting to work. |
| Ruíz-Ariza et al., 2017 | Active commuting to school influences on academic performance of Spanish adolescent girls | Active commuting has been associated with better health and cognitive performance | |
| Sanmiguel-Rodríguez, 2015 | Ambiente urbano y bicicletas compartidas: efectos sobre la actividad física | The objective of the study was to analyse the uses of a public bike system according to user characteristics, as well as the time of use of bicycles, months, seasons and weather | Users of the bicycle sharing system are middle-aged. If we take into consideration gender, the service is more used by men than by women. Women show an earlier usage of the service compared to men |
| Villa-González, Ruíz & Chillón, 2016 | Recommendations to implement quality interventions to promote active commuting to school | The objective of the current study is to propose different practical recommendations to increase the quality of the intervention programmes focused on promoting active commuting to school, based on previous intervention experiences with Spanish schoolchildren | These authors recommended increasing the dose of the interventions, provide proper guidance about the content of the intervention, and conducted several assessments across the intervention, in order to improve the quality of the interventions |
| Villescas et al., 2016 | Towards a city in penny-farthing: The role of children as essential changemakers | The purpose of this study is to approach the essential role of children as changemakers in the city of Murcia (Spain) | |
| *Analysis of the ages, routes and minutes of use in the use of a shared bicycle system: the case of VaiBike in Vilagarcía de Arousa (Spain); Sanmiguel-Rodríguez | | | |
| *Compliance with the recommendations for physical activity set by the WHO by public bicycle users in a Spanish municipality; Sanmiguel-Rodríguez | | | |

Legend: * - Repeated studies in the different categories

## Discussion

We present below a synthesis of the main lines of research reviewed. After reading and analysing each of them, different degrees of development and evolution are indicated.

*Research on urban mobility and public bicycle systems*

Concerning this first theme, several articles that analysed various aspects relating to bicycle systems in Spain are cited. Rojas-Rueda, Nazelle, Tainio, & Nieuwenhuijsen (2011) evidence a large degree of success in terms of the number of subscribers and the frequency of travel on shared bikes in Barcelona. Castillo-Manzano and Sánchez-Braza (2013) analysed the Sevici bicycle sharing system in the city of Seville. Surveys analysing the weather were administrated to students, professors, and administrative staff. They showed that the low levels of rainfall in Seville make it a favourable place for bicycle use as a sustainable mean of transport, although two factors could alter this aspect. The findings of Brey, Castillo-Manzano, and Castro-Nuño (2017) show that users of public bicycles in Seville are predominantly young men with a high level of education who use public bicycles to a great extent due to their greater inter-modality.

In contrast, women used the private bicycle as a means of regular transport and preferred it for their daily needs. The results of Pellicer-Chenoll et al. (2020) showed that women use public bicycles in the city of Valencia less than men do, and women do not use them in the peripheral areas of the city at night. Munkácsy and Monzón (2017) surveyed BiciMAD in Madrid, analysing the system`s uses (leisure, sport, tourism, work or school), topography, infrastructure and the challenges posed to the Madrid government when attempting to promote cycling. In another investigation (Seguí et al., 2016) carried out in Palma de Mallorca, the sustainability of the city's bicycle mobility over recent years was examined, together with increases in bike lanes and specific parking. According to Álvarez-Valdés et al. (2016), the quality of service is drastically affected by imbalances in the distribution of bicycles between stations. BiciPalma has made it possible to improve the image of the bicycle in the city and to expand its use to other user groups who previously did not opt for this means of transport, for instance, to work. Sanmiguel-Rodríguez and Arufe Giráldez (2019) examined outcomes of the Vaibike system in Vilagarcía de Arousa in relation to age, gender, route taken, hours, weeks, and climatic variables, while another study (Sanmiguel-Rodríguez, 2019) indicated that women preferred journeys along the coast in this city. Further, its effect on meeting WHO's physical activity recommendations was identified (Sanmiguel-Rodríguez, 2020).

*Accessibility, public spaces and infrastructure of bicycle systems and public facilities in the urban environment*

According to the framework developed for this theme, many programmes exist to implement or promote increased citizen participation related to cycling in cities. However, each of these initiatives has the same essential purpose: to create a network of efficient and useful cycling paths that will enable bicycles to be used safely on main roads, incorporating the bicycle into the model of inter-modality of urban transport. There has been a progressive introduction of bike lanes, and many people have begun to take advantage of them to move around the city. Despite this, all structural modifications require a period of adaptation and, in reality, the network of cycling lanes is full of obstacles to the cyclist. Along these lines, Munkácsy and Monzón (2017) also showed that parking and inter-modality were the most relevant factors for BiciMAD users. Indeed, the designation of shared lanes on busy roads in the centre of Madrid was highly criticized by participants. To make the service qualitatively and quantitatively more attractive, the development of appropriate infrastructure must be encouraged by the local government. However, many people are more concerned about the flexible, economic, and ecological nature of cycling.

In another investigation (Zozaya, 2016), it has been shown that cycling infrastructure is an element of growing importance in the development of sustainable mobility strategies in urban areas. An increasing number of cities are encouraging the use of bicycles through various initiatives, including municipal bicycle rental systems. The hybrid nature of the bicycle as a means of transport, halfway between the pedestrian and the motorized vehicle, induces a rethink of the current configuration of urban roads and public spaces. Another study by Zozaya (2017) showed that bicycle systems can become a key element in the sustainable mobility strategy of cities. Also, the visibility of public bicycles and stations serves to publicize the commitment to sustainable mobility in the municipality, generating interest in the public regarding this means of transport, with the system even becoming incorporated into the "brand" and the attractiveness of the municipality. However, the decision to incorporate a public bicycle system in the city must take into account the difficulties involved in the implementation project, such as achieving the acceptance of citizens and demonstrated economic sustainability, which will depend on maintenance and replacement costs, obtaining significant revenues, and a commitment to the system of future administrations, amongst others. Although a public bike system will probably not become linked at a state and international level in the same way that the modern railway network has been, its scope for potential action within urban groups often exceeds the municipal perimeter in which many current initiatives operate. Thus, the creation of a standard is a necessary step if we want to guarantee the maximum utility of public bicycle systems in the metropolitan environment. Standardization would allow greater investment in bicycle systems based on initiatives at a local level with the certainty of being able to integrate them later on within a metropolitan network. It would also force different types of stations and vehicles to work together to find solutions, facilitating competition and innovation.

Orzanco, Guillén, Sainz, Redín, and Aguinaga (2018) show that the development of infrastructure that facilitate the mobility of pedestrians is associated with greater bicycle use for commuting. Following these conclusions, the results of another investigation (Braçe, 2016) have shown low-density urban areas, a lack of local services, a scarcity of public transport, and low-quality public spaces, reduce the likelihood of displacement through physical activity (walking and cycling) and increase dependence on private vehicles. In contrast, De Manuel, González and Donadei (2016) pointed out that there is a direct relationship between the use of public spaces and the mobility model in the Alcosa neighbourhood in Seville. To reactivate public spaces at the level of urban neighbourhoods, it is necessary to adapt the model of metropolitan mobility so that it favours alliances between public transport and active mobility. Doing so will encourage the reduction of public spaces for motor vehicles and improve pedestrian and bicycle accessibility, thereby activating the use of public spaces.

*Social factors, installation of bicycle systems, new technologies and road safety*

Regarding this theme, Osorio-Arjona and García-Palomares (2017) highlight that increasing demand for mobility in cities has led to an unsustainable dynamic both socially and environmentally. To promote actions towards sustainable mobility, it is necessary to use dynamic information sources with high spatial and temporal detail that allow for efficient diagnoses of the mobility situation in our cities. Information and Communication Technologies and Big Data appear as new interactive sources that respond to these needs. This article reviews the state of the art in using these new data sources for the analysis of urban mobility, comparing its usefulness with respect to traditional sources, classifying them, presenting the research topics they offer, and identifying challenges for the future. Other authors (López & Monzón 2014) point out the need to introduce greater inter-modality within public transport in the urban environment. Their article forms part of the search for transport solutions within what has been termed intelligent mobility, incorporating some type of communication and information technology. Bicycles as a means of transport was analysed and, in particular, how ICTs have enabled the development of public rental systems, which, in effect, have been equipped with some form of technological innovation. According to Munkácsy and Monzón (2017), smart technologies make it easy to use shared bike systems, since they allow location tracking, intelligent access, and the development of online applications. They enable the integration of bicycle-sharing systems within the urban transport system both from the user's (route planning, rates, etc.) and the operator's points of view. Other researchers (Reboreda et al., 2016) have created a system aimed at the prevention of traffic accidents amongst cyclists and motorcyclists. According to their study, the number of injuries sustained on the road in Spain has remained steady over time. To address this, they have tried to introduce a technological system that helps improve road safety for cyclists.

In contrast, Orzanco et al. (2018) has revealed that perceptions of heavy traffic are more prevalent within populations that spend less time walking to move from one place to another. However, the development of infrastructure that facilitates the mobility of pedestrians is associated with greater bicycle use for travel. Another study (Tironi, 2015) demonstrates the essential work that takes place behind the scenes by those who maintain and repair urban resources, such as bike-sharing systems. This research makes us aware of those almost artisanal practices that, without much marketing, allow us to enjoy smart cities or sustainable transport systems. In contrast, Morales (2011) highlights the considerable social acceptance of the population to the use of bicycles as a means of ecological transport, showing the benefits of using this means of transport, both at an energy and environmental level.

*Planning policies in the urban environment and studies of sustainable mobility, environment and ecology*

The purpose of this theme is to analyse studies on policy and spaces, identifying predictive factors in the urban environment. Ballester and Peiró (2008) propose the development and maintenance of a public transport system that is faster, safer, cheaper and less polluting than private transport, which should be an important goal in current public policies. According to Rojas (2013), active transport policies can produce great benefits for the health of the population. These benefits are mainly associated with the increase in levels of physical activity. Munkácsy and Monzón (2017) point out that the European Union's transport policies, campaigns, and awareness-raising events are factors that influence the use of a non-polluting means of transport by members of society. According to these researchers, the BiciMAD system was not popular when it was inaugurated in July 2014 because there was no relevant public participation in the planning of the project, and it was not directly advertised before being presented, with only a few press releases being published. Although BiciMAD is considered a mobility management tool that is designed to be attractive to urban travellers, the local government or service provider did not directly approach the issue of public acceptance of the bicycle sharing system when developing it. According to Seguí et al. (2016), sustainable urban transport planning and the political decisions for its implementation are the result of a set of measures and interventions (dissuasive parking, traffic calming, car sharing, improvement of pedestrian areas and public transport or parking management) that can change and improve the habitability of cities.

Following these contributions, Herranz (2015) states that public authorities often proceed in a contradictory manner when promoting active means of displacement. Whilst communication is positive, the actions put into practice fail to offer an adequate response to social demands. Braçe (2016) states that there is also a relationship between urban morphology, physical activity, and the use of transport types that involve some physical activity, such as walking and cycling. These results should be useful for territorial and urban planners and managers when taking measures to avoid the increased dispersal of urban areas and the promotion of nuclei of centrality. These measures would help reduce dependence on private vehicles and encourage non-motorized journeys, thus maintaining the three pillars of sustainable development (environmental, economic, and social).

In recent years, growing interest in environmental care has produced a sociological change in large sectors of society, which prefer to walk or use non-polluting means of transport such as bicycles (Herranz, 2015). According to Rojas (2013), active transport (walking, cycling, or public transport) may have the capacity to reduce greenhouse gas emissions and climate change and may bring with them benefits for the environment and health. Influencing these ideas, the study of Ballester and Peiró (2008) shows the negative impact on health that the current type of transport has in terms of traffic injuries, climate change, air pollution, noise, and interfering with daily activities and physical activity, for instance by making walking or cycling more difficult. These actions will help achieve a change in societal transport habits, a healthier population and a more sustainable environment. However, to promote active displacement, it will be necessary to reduce the use of private cars and develop quiet traffic spaces that connect cities and nearby towns.

*Healthy habits, benefits of the practice of physical activity and educational vision*

This area of investigation deals with aspects that include the benefits of bike systems and engagement in physical activity. Previous research (Sanmiguel-Rodríguez, 2015, 2019, 2020) has shown that bicycle systems are an active and sustainable means of transport that could help individuals fulfil the 2010 World Health Organization (WHO) recommendations for physical activity. According to Rodríguez-López et al. (2013), active transport between home and school can improve the health of school children and represent a significant percentage of their daily physical activity. Moreover, this practice has been associated with a better cardio-metabolic profile and improved general physical condition. In corroboration, Chillón, Villén, Pulido, and Ruíz (2017) indicate that the promotion of daily physical activity in young people, such as active displacement to school (walking or cycling), can have important health benefits. The results of this study showed that active displacement to school was inversely associated with stress. Likewise, in another study (Ruíz-Ariza, de la Torre, Suárez, & Martínez, 2017), it is shown that active displacement is defined as the act of going to the educational centre by means of transports that involve metabolic expenditure, such as walking or using a bike. The average daily time of active displacement in adolescents is 18 minutes, and it could increase total daily physical activity by 13%. Active displacement has been associated with better health and cognitive performance in Spanish girls in Secondary Education. Research by Villa-González, Ruíz and Chillón (2016) came to the same conclusions, in that it was observed that regular engagement in physical activity (walking or cycling) had numerous health benefits in young students, and that long-term engagement generated mental, academic, cognitive, psychological and social benefits for them.

Moreno and Bernal (2016) proposed that education should be focused on active transport and on generating critical awareness based on the characteristics of the city pertaining to space or time. They considered a community-focused pedagogical procedure that attends to interdisciplinary relationships and the collaborative generation of knowledge between all the parts to be indispensable. Luque (2016) reports that Spain is falling behind other European countries in the use of this means of sustainable transport and states that schools should encourage the use of bicycles, not only in physical education classes but also as an excellent means to promote transportation to school. Teachers in general and physical education teachers, in particular, have one more reason to invite students and the rest of the educational community to use bicycles to promote sustainable mobility. Other authors (Mira & Tortosa 2009) highlight that professionals in physical education and sports have an ethical and moral obligation to promote bicycles as a means of physical activity, transportation, education, and health. Children travelling to school, teenagers travelling to college and adults travelling to work will find a means to meet recommended daily physical activity levels and achieve a healthy and sustainable lifestyle in accordance with the basic competences of the Organic Law of Education (LOE) and the principles of the WHO. Mallada (2012) found significant associations between the contents of physical education at secondary school, especially in the modules undertaken in nature, and the acquisition of basic competences. At the same time, bicycle use is promoted as a means of ecological transport and as a way to develop one's physical condition through play. Villescas et al. (2016) declare that children adapt easily to the reality presented to them and that education plays a decisive role in generating a transport model via the new streams of sustainable mobility and in accordance with a balanced lifestyle.

From the review of previous research, the following conclusions can be drawn:

1. The studies reviewed highlight a clear predominance of the sustainability of active transport, healthy mobility habits, and the benefits of engaging in physical activity.

2. Many studies indicate the great potential of bicycle systems, with studies on bicycle sharing systems and urban mobility in general gaining increased attention from international researchers due to its innovative nature. In addition, given the favourable climatic conditions, Spain is one of the countries with the most potential to encourage engagement in outdoor physical activity. This includes the use of bicycles or bicycle-sharing systems as an active means of transport throughout the entire year.

3. Active transportation to school is presented as a healthy habit and promotes improvements in students at academic, cognitive, social, and psychological levels. However, studies show that many young people do not practice physical activity on a regular basis and do not actively travel to their school or place of study.

4. The proper use of new technologies and advice from experts on the subject can help public bicycle systems to undergo major developments and be integrated successfully within the urban environment.

5. Regarding spaces and policies in the urban environment, several studies show a clear positive correlation between the creation of infrastructure designed to favour the sustainability of the environment and perceived safety, with higher levels of physical activity. In addition, given the great benefits to public health, policies should focus on creating active means of transport (such as bicycle-sharing systems) in order to reduce the rates of obesity and engagement in sedentary behaviour amongst the Spanish population.

6. In general, we have detected few publications on urban mobility and bicycle-sharing systems in the Spanish context. This may be because public bicycle systems have begun to emerge during recent years. The present study intends to create more knowledge about bicycle systems and their application within the urban environment in order to favour less congested traffic and pollution environments.

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**Conflict of Interest**
The authors declare that there are no conflicts of interest.

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REVIEW PAPER

# Injuries in High-Performance Football: A Systematic Review

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**Abstract**

The large number of sports injuries, especially in football, is becoming a major problem for professionals who work with athletes, making it one of the team sports with the highest injury incidence rates. The objective of this review is to offer an overview of the most recent scientific publications in relation to injuries in high-performance football. For this, a systematic review was carried out from 2015 to 2020, searching with the terms of the UNESCO Thesaurus: "injuries", "football", "elite", "professional football" and "high performance" in the international databases Scopus and Web of Science and the Spanish database Dialnet, allowing the selection of original articles (experimental, descriptive, quasi-experimental studies and/or case studies), which included information on this line of research. A total of 833 articles were found, although this was reduced to 67 articles after applying the review's inclusion criteria. These publications were divided into three main categories: A) Research related to characteristics and types of injuries, B) Research related to game conditions and training loads and C) Other topics studied. In conclusion, this systematic review allows us to quickly and easily analyse information about injuries in high-performance football in recent years. These results are interesting for the researchers and different professionals who comprise coaching staff in football clubs.

***Keywords:*** *injuries, football, soccer, elite, high performance*

## Introduction

Football is the most popular team sport in the world; it is estimated that around 4% of the world's population plays it; thee activity involves running, kicking, jumping, stopping, and changing direction at high and medium speeds (Echavarria-Calderon & Galvis-Rincon, 2020; Fernández et al., 2020). The dynamic character is a determining factor in the face of injuries that occur. Although most injuries are caused by contacts or impacts, many are caused by catches after jumping and by the sudden changes of direction characteristic of this sport (Fernández et al., 2020).

Thus, due to the specific characteristics of football, according to which high high-intensity action such as jumps and changes of direction can become determining factors in achieving sporting success, including strength training in football training plans is essential. Depending on the variables to be influenced and the time of the season, a specific strength training method should be chosen, so that knowledge of the effects of each one of them seems essential for the success of the training, not only concerning physical-sports performance but also injury prevention (Raya González & Sánchez, 2018). At a professional level, the combination of these high physical demands coupled with the stress and anxiety generated by the intense competitive calendar can place players at a high risk of injury (Carling, McCall, Le Gall, & Dupont, 2016; López Valenciano, 2018; Wollin, Pizzari, Spagnolo, Welvaert, & Thorborg, 2018).

The internal workload of training and games is considered one of the most important risk factors for injury in elite football; however, there is little published evidence to support this belief (McCall, Dupont, & Ekstrand, 2018). Injuries have a great impact on high-performance football during practice in training and especially in competition, due to their significant influence on team performance and the considerable rehabilitation costs for players (Carlos-Vivas, Martín-Martínez, Chavarrias, &

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Pérez-Gómez, 2017; Chena, Rodríguez, & Bores, 2017; Mears, Osei-Owusu, Harland, Owen, & Roberts, 2018; Raya González, 2017a; Rossi et al., 2018; Windt, Ekstrand, Khan, McCall, & Zumbo, 2018); therefore, many efforts are made to reduce the incidence of injuries in football, and preventive programmes based on strength training appear to show positive results (Chena et al., 2017; Martín-Moya & Ruiz-Montero, 2017; Raya González, 2017a). Existing studies in the literature provide only a preliminary understanding of which factors primarily affect injury risk (Coppalle et al., 2019; Rossi et al., 2018).

The large number of sports injuries, especially in football, is becoming a major problem for professionals who work with athletes and make it one of the team sports with the highest incidence rates of injuries (Eckerman, Svensson, Edman, & Alricsson, 2019; López Valenciano, 2018; Martín-Moya & Ruiz-Montero, 2017; Palmi, Planas, & Sole, 2018). The study of the epidemiology of sports injuries and the complexity of the variables present in the athlete's recovery process prompt the incorporation of new intervention techniques (Palmi et al., 2018). Injuries to the knee joint have a high incidence among football players. One of the most frequent traumas is an injury to the anterior cruciate ligament, which involves a high social, psychological and economic cost for footballers and their teams (Bertomeu et al., 2019; Gómez-Piqueras et al., 2017). Unfortunately, many players do not regain the level they maintained before the injury due to the loss of functional aspects such as knee stability in rotational movements (Bertomeu et al., 2019). Different studies have shown that a poor psychological and kinematic predisposition of the injured athlete could make it difficult for them to return to training and competition (Gómez-Piqueras et al., 2020; Oriol, Leyton, Pascual, & Batista, 2018). However, the COVID-19 pandemic has changed the conditions for competing in football around the world. Thus, several competitions and leagues have been cancelled or postponed, and players have been forced to train alone and in small groups with strict contact restrictions, and return to competitive play may occur after only a few weeks of normal group training preparation; these special circumstances are likely to affect return to competition performance and injuries (Mohr et al., 2020).

For all the aforementioned, the objective of this work is to review the scientific literature from 2015 to 2020 that addresses the field of high-performance football, selecting only articles related to injuries for content analysis.

## Methods

The bibliographic review is a type of scientific article that, while not original, collects the most relevant information on a specific topic. Thus, for this review, a bibliographic search was carried out in the two most relevant international databases in this line of study. The first one, the Scopus database (Elsevier), selected as it is a review in social sciences (texts in different languages); the second database was Web of Science (WoS). In addition, the Spanish Dialnet database was used as a complement. As keywords, the following terms taken from the UNESCO Thesaurus (injuries, football, elite, high performance) were chosen. The inclusion criteria used in the review were the following:

1) Articles published from January 1, 2015 to August 1, 2020;

2) Articles that address any type of research related to football in the international context, incorporating experimental, descriptive, quasi-experimental studies and/or case studies;

3) Articles that are published in English or Spanish;

4) That the study be carried out with a sample of high-performance players, or else, analyse some variable related to this area.

## Results

A total of 833 articles were found, but after removing the duplicates, the search brought together a total of 798 documents for analysis. After the initial review of these 798 documents, those articles that did not directly address or were not related to high-performance sports and injuries were discarded. After applying the selection and categorization criteria, a total of 67 articles that provided a scientific method and fulfilled the inclusion criteria mentioned above were compiled. Likewise, the work schedule for the search for information had four different phases, as can be seen below and in the flow diagram represented graphically in Figure 1: 1st Phase: Search and selection of descriptors through the UNESCO Thesaurus; 2nd Phase: Detailed search in the scientific databases Scopus, Web of Science (WoS) and Dialnet, using the inclusion criteria described above; 3rd Phase: Analysis of the content of the articles and classification by subject; 4th Phase: Categorization of articles and preparation of the manuscript (i.e., a systematic review).

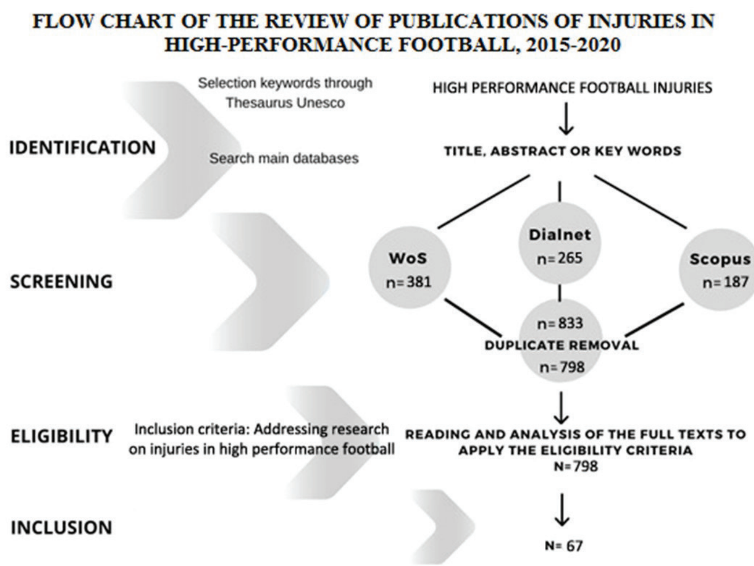


FIGURE 1. Flow diagram of the systematic search process

Once the 67 definitive articles had been selected, a detailed reading of all the articles was carried out individually, and a first categorization was made. The second phase was the analysis of the different articles and the specification of the three definitive categories. As a result of this deductive procedure and triangulating the information, the final classification of the articles was carried out in the three mentioned categories.

Once the process described in the flowchart of the systematic review of publications on injuries in high-performance football was made, the result was 67 publications. All of them were included in a categorization process by subject, finally finding three categories of analysis of the scientific literature (Table 1).

**Table 1.** Synthesis of the studies found on injuries in high-performance football

| Categories (number of articles) | Authors and year |
|---|---|
| Research related to characteristics and types of injuries (27) | Ayala et al. (2019); Bernal et al. (2019); Bourne et al. (2020); Carlos-Vivas et al. (2017); Cruz-Ferreira et al. (2015); Esteve et al. (2018); Fransz et al. (2018); Gómez-Piqueras et al. (2017); Konopinski et al. (2016); Kudaş et al. (2016); Langhout et al. (2018); Larsson et al. (2016); López Valenciano (2018); Lundblad et al. (2019); Molano & Molano (2015); Moreno-Pérez et al. (2019); Oriol et al. (2018); Raya-González et al. (2018); Raya-González et al. (2018); Ribeiro et al. (2020); Rhodes et al. (2019); Sintes & Caparrós (2019); Stubbe et al. (2015); Svensson et al. (2018); van Dyk et al. (2018); Wong-On et al. (2017); Yanguas et al. (2017) |
| Research related to game conditions and training loads (17) | Abade et al. (2017); Abade et al. (2018); Coppalle et al. (2019); Ekstrand et al. (2020); García-Concepción et al. (2015); Jadczak et al. (2019); Krutsch et al. (2020); Lubberts et al. (2019); Martín-Moya & Ruiz-Montero (2017); Núñez et al. (2016); Pfirrmann et al. (2016); Raya González (2017b); Raya González et al. (2020); Raya-González et al. (2018); Suarez-Arrones et al. (2019); Torrontegui-Duarte et al. (2020); Zouita et al. (2016) |
| Other topics investigated (injuries and gender, types of surfaces and recovery times; 23) | Calloway et al. (2019); Castro et al. (2016); Ekstrand et al. (2019); Gómez-Espejo et al. (2017); Lai et al. (2018); Lai et al. (2019); Lanzetti et al. (2017); Larruskain et al. (2018); Leventer et al. (2016); Lundblad et al. (2020); Malone et al. (2018); Mears et al. (2018); Pellicer-Chenoll et al. (2017); Royán-González et al. (2017); Prieto (2015); Prieto (2016); Roberts et al. (2020); Shalaj et al. (2016); Smpokos et al. (2018); Stares et al. (2019); Valle et al. (2018); Waldén et al. (2018); Zurita et al. (2017) |

As shown in Table 1, from 2015 to 2020, the category of research related to characteristics and types of injuries has brought together a total of 27 studies. The category of research related to game conditioning factors and training loads has had a total of 17 studies, and the category of other topics has brought together a total of 23 studies on different topics on injuries in high-performance football.

## Discussion

*Research related to characteristics and types of injuries*

Carlos-Vivas et al. (2017) state that injuries are a major problem in high-performance football;  83.4% of them appeared in the lower extremities and specifically were the thigh (35.7%), ankle (23.8%), adductors (14.3%), knee (4.8%) and calves (48%). The number of lower extremity injuries was higher in the group that did not perform preventive work than in the group that did. Along these lines, another investigation (Stubbe et al., 2015) pointed out that the injuries were more likely to be located in the lower extremities (82.9%), as the most common injury in the muscles and tendons with a recovery time between 1 and 752 days. Gómez-Piqueras et al. (2017) indicated that the incidence of injuries during competition was higher than that obtained during training; specifically, the back of the thigh (19.6%), the knee (18.3%) and the groin (17.4%) were the most frequently injured areas. It was found that 14.4% of the injuries were relapses of injuries suffered previously. According to Larsson, Ekstrand, and Karlsson (2016), 45% of traumatic fractures and 86% of stress fractures affected the lower extremities. For van Dyk et al. (2018), the hamstring has been repeatedly identified as the most common non-contact injury in high-performance football at 12%. Likewise, the results of other authors (Molano & Molano, 2015) allowed identifying that the highest rate of injury occurred in the lower limbs, especially the ankle (56%), with the most frequent injury of a first-degree sprain (43.4%), and muscle tear (38%). Fransz et al. (2018) showed that after a landing with a jump and a fall with one leg, the probability of an ankle sprain increases. In contrast, Lundblad et al. (2019) indicated that knee injury is the most common in high-performance football, 75% of which occurred with a contact mechanism. These same authors (Lundblad et al. 2019) pointed out that devices such as knee braces should not be necessary in milder cases.

For Carlos-Vivas et al. (2017), including a preventive programme after warming up helps reduce the risk of lower limb injuries in football players. Following these contributions, López Valenciano (2018) indicated that the lower extremities have more injuries, with the thigh being the anatomical region where more injuries occur. The results of this study (López Valenciano, 2018) show the need to prescribe exercises aimed at improving the range of motion of hip flexion with extended knee and dorsiflexion of the ankle with knee flexed during training sessions. Additionally, and since bilateral range-of-motion imbalances are common, unilateral training should be implemented if necessary. However, Bourne et al. (2020) indicated that hip abduction imbalance was associated with a reduced likelihood of future injuries to the hip and groin.

Moreno-Pérez et al. (2019) pointed out that the majority of groin injuries occurred during competitive matches, in which lower adductor maximal isometric force values increase the probability of injury by 72%. According to Langhout et al. (2018), the point prevalence of serious groin injuries was 24%, and the incidence of injury within the season was 11%. For their part, Wong-On et al. (2017) collected injury data from four teams in the Spanish League in a total of four seasons, and the results indicated that a total of 16 players suffered injuries to the external and internal shutter during matches or training sessions. According to Raya-González, Gómez Piqueras, and Sánchez-Sánchez (2018), the application of an eccentric resistance training programme during the functional recovery process increases the power of the lower body and reduces the asymmetry caused by an injury, which is reflected in the decrease in the payback period. Esteve et al. (2018) indicated that hip adductor muscle weakness and a history of groin injuries have been identified as important risk factors for re-injury. Thus, male footballers with groin pain during the previous season are likely to start the next season with a high risk of groin injury. The results of Raya-González, Suárez-Arrones, Risquez, and Sáez (2018) suggest that the inclusion of an eccentric resistance training programme in the periodization of football training allows the optimization of the specific physical condition of football players.

Strain in the hamstring muscles, mainly in the biceps femoris, is the most common injury in football. Despite all the studies carried out on its prevention, the incidence is not reduced. Possible causes are the incorrect choice of exercises for strength development and the failure to consider the interrelationships between risk factors (Sintes & Caparrós, 2019). Similarly, other authors (Ribeiro, Oliveira, De Lima, & Baroni, 2020) demonstrated that players with a history of hamstring strain in the previous season present a reduction in the eccentric strength of the knee flexors in the injured limb. Following these contributions, Rhodes, McNaughton, and Greig (2019) indicated that eccentric strength of the hamstrings is a risk factor for injury, and these strength parameters would not be fully recovered until 96 hours after football-specific fatigue. Hamstring injuries are the most common in football, and they can present residual effects that change the pattern of a technical gesture (Oriol et al., 2018). Other studies (Ayala et al., 2019; Cruz-Ferreira, Marujo, Folgado, Gutierres, & Fernandes, 2015; Yanguas, Pruna, Puigdellívol, & Mechó, 2017) indicated that hamstring injuries are the most frequent in high football performance, and the long head of the biceps is the most affected muscle, with the proximal locations being the most common with important clinical characteristics, such as time off and the risk of re-injury (Yanguas et al., 2017). According to Svensson, Eckerman, Alricsson, Magounakis, and Werner (2018), in 53% of cases, there were more hamstring injuries in the dominant leg compared to the non-dominant leg.

Bernal, Morcillo, Santafé, and Santafé (2019) highlight the importance and added value provided by the podiatrist within the medical services of a high-performance football team in bone consolidation or cases of refracture in the fifth metatarsal, as well as the validity of conservative treatment for this type of injury based on medical considerations and the characteristics and location of the injury. For their part, Konopinski, Graham, Johnson, and Jones (2016) indicated that hypermobility showed a trend towards a higher risk of injury. According to Kudaş et al. (2016), non-surgical treatment modalities were effective in two thirds of the cases in posterior ankle impingement, with posterior ankle arthroscopy being a safe and effective treatment option if conservative treatment fails.

*Research related to game conditions and training loads*

Warm-up routines are normally used to optimize football performance and prevent injuries. Furthermore, official pre-match protocols may require players to rest passively for approximately 10 to 15 minutes between warm-up and the start of the match (Abade et al., 2017, 2018). The absence of re-warm up activities can be detrimental to the physical performance of the players. However, including a pre-game warm-up is a complex issue, as manipulating volume, intensity, and recovery can affect performance positively or negatively. Abade et al. (2018) demonstrated that eccentric exercise can be harmful to physical performance when performed before a football game; however, plyometrics and repeated directional exercises appear to be simple, fast, and effective activities for attenuating losses in vertical jump and sprinting ability after a warm-up. For Martín-Moya and Ruiz-Montero (2017), the key elements of an effective strengthening and injury prevention programme for football players must include cardiovascular exercises, functional strength (which includes eccentric work of the biceps femoris), stability of the trunk, neuromuscular balance, plyometrics and static or dynamic stretching depending on the time of the session.

The preseason training develops the physical capabilities of the players and prepares them for the demands of the competitive season. Teams that did the most preseason workouts had "healthier" season spells. Preseason training and football team planning and preparation could help reduce and prevent injuries during the season (Ekstrand et al., 2020). In contrast, Coppalle et al. (2019) showed that the training load during the preseason is not associated with the general performance of the team and that this is due to a multifactorial association, since other factors, such as the technical and tactical level of the team, the opponents, and the environment can play an important role for the collective performance of the team. For Suarez-Arrones et al. (2019), a combined football and eccentric resistance training programme promoted positive changes in body composition and physical factors relevant to both onfield performance and injury prevention in elite football players. According to Raya-González et al. (2018), the effect of a strength training programme with eccentric load based on the squat exercise and the application of a strength programme executed in a rotational inertia device during the process of functional recovery produces an increase in the muscular power of the lower body and decreases the asymmetry caused by the sports injury, which is reflected in the reduction of the recovery period.

The results obtained in other investigations (Raya González, 2017b; Raya González et al., 2020) show that football is an injury-prone sport that varies according to the category in the same club, that there are more incidences of injuries in matches than in training (López Valenciano, 2018; Lubberts et al., 2019; Pfirrmann et al., 2016; Raya González, 2017b; Raya González et al., 2020), that a preventive force programme is effective in reducing of the number of muscle injuries in a season, and that training with an inertial device with eccentric overload improves vertical jump and leg power (Raya González, 2017b). For other authors (Zouita et al., 2016), precisely and efficiently programmed strength training-induced performance improvements and reduced the injury rate in young football players. According to Krutsch et al. (2020), the key to the sustainability of prevention measures are programmes specifically adapted to the demands of the level of play and the preferences of the coaches. Following these contributions, Torrontegui-Duarte et al. (2020) pointed out that exposure to training was inversely related to the total number of injuries, which means that the higher the exposure to training, the lower the number of injuries.

The results indicate the importance of evaluating and monitoring the dynamic and static balance in both legs, which allows a complete comparison of the control of the body balance and the balance recovery strategy based on the sport level represented. The study indicates that the higher the sporting level of the players, the better their balance, which can indirectly contribute to the prevention of injuries and the more effective execution of actions directly related to the game (Jadczak et al., 2019). Núñez, Lancho, and Ramírez (2016) pointed out that, during the first stages of functional recovery, general exercises provoke adaptations between extremities and reduce the asymmetry caused by sports injury. In the physical recovery process, the excessive load caused by separately working the limb decreases and, consequently, so does the recovery period. Thus, according to García-Concepción, Peinado, Paredes, and Alvero-Cruz (2015), the performance of combined recovery protocols carried out after the training session tend to be more effective compared to the protocol that only included stretching.

*Other topics studied (injuries and gender, types of surfaces and recovery times)*

Fatigue is an element that brings with it a series of physiological changes and renders the motor response ineffective in the face of the diversity of stimuli and actions offered by a sport, such as football, which can lead to injury (Royán-González et al., 2017). Thus, for other authors (Malone et al., 2018), players with poor aerobic fitness had a higher risk of injury than players with better developed aerobic fitness, and exposing players to large and rapid increases in distances in high-speed running increased the odds of any type of injury. Larruskain et al. (2018) demonstrate that prevention strategies must be adapted to the needs of both male and female football players, with men more predisposed to hamstring strains and hip/groin injuries and women to quadriceps strains and severe knee and ankle ligament injuries. For Pellicer-Chenoll et al. (2017), both men and women showed lower rates of injury in the non-dominant leg compared to the dominant leg.

According to Shalaj et al. (2016), sprains, thigh muscle tears, knee ligament injuries, as well as meniscus or other cartilage tears, represented the most frequent differential diagnoses, although no significant differences were found between players of different positions. In contrast, another study (Leventer et al., 2016) indicated that midfielders had the highest incidence and injury rate during matches, while central defenders maintained the highest injury incidence rate during training. However, Torrontegui-Duarte et al. (2020) indicated that the forwards presented the highest rates in both the incidence and severity of the injury.

Shalaj et al. (2016) found that the injury rate in competitions in Kosovo had been slightly lower than the international average, surely related to less exposure to matches, but in contrast, the incidence of injury was 10-13%, higher in younger players, which may indicate a more aggressive and risky playing style in this age group. Following these lines, Pfirrmann, Herbst, Ingelfinger, Simon, and Tug (2016) pointed out that injury rates were higher during matches than in training sessions for both young and adult players, whereas younger players had a higher incidence of injuries during training sessions. Other research results (Prieto, 2015, 2016) indicated that a higher number of total injuries and a higher injury rate were associated with a lower age. According to Lai, Feller, and Webster (2019), players under the age of 25 were more likely to return to their pre-injury performance levels after ACL reconstruction. Following these contributions, another study (Lai, Feller, & Webster, 2018) indicated that the injury rate to the anterior cruciate ligament in any knee was 30% and was especially high among players under 21 years of age. Larsson et al. (2016) indicated that stress fractures produce longer absences than traumatic fractures and younger players have more stress fractures than older players do. In contrast, Valle et al. (2018) demonstrated that hamstring injuries among younger football players are less frequent than among older ones.

In contrast, the results of another study (Gómez-Espejo, Álvarez, Abenza, & Olmedilla, 2017) show that the group of uninjured football players had higher levels of social support compared to the group of injured players. According to the results of other authors (Zurita et al., 2017), the higher the level of professionalism, the greater the resilience capacity since the competitive level directly affects the ability to face injuries regardless of the levels of anxiety that football players have. Castro, Chacón, Zurita, and Espejo (2016) demonstrated that the competitive level directly affects the ability to face injuries, and footballers who have suffered more injuries are used to facing them. However, due to the few differences found, it is clear that the resilience capacity depends on individual factors.

According to Mears et al. (2018), 91% of players perceive that the type or condition of a surface such as artificial turf could increase the risk of injury. Following these contributions, Roberts, Osei-Owusu, Mears, and Harland (2020) indicated a greater preference of players for natural grass because they perceive a greater risk of injury on artificial grass. Calloway et al. (2019) found that ankle fracture had a statistically higher incidence in artificial grass, although the general injury rate in artificial grass was not lower than that of natural grass; artificial grass is licensed from FIFA as a viable alternative to natural grass. Following these contributions, Lanzetti et al. (2017) showed equivalence in the risk of injuries on natural grass and artificial grass in high-performance football during official matches.

For Ekstrand et al. (2020), most injuries are mild (42%), and these resulted in an average absence of 7 days or less; moderate injuries have a mean absence of 7 to 28 days in 56% of cases, while only 2% were severe with a mean absence of more than 28 days. Other authors (Lundblad et al., 2020), in contrast, indicated that the lateral collateral ligament and posterior cruciate ligament injuries lasted two and four weeks, respectively, and are associated with a contact injury mechanism. In contrast, Waldén et al. (2018) indicate that the injury rate is higher when players have a recovery time of five days or less between two games. In another study (Stares et al., 2019), the risk of injury was highest in the week of return to play and decreased with each week, indicating the need for injury prevention strategies. According to other authors (Ekstrand et al., 2019), teams without winter holidays (English clubs) had a higher incidence of injuries than other European clubs that did have their scheduled break. For Smpokos, Mourikis, and Linardakis (2018), the highest total distance travelled was registered in January and the lowest during the preparation phase, while in the February matches, higher average levels were found in high-speed running in relation to the ones of November.

## Conclusions

After the analysis of the 67 articles used for this review on injuries in high-performance football that have been published during the years 2015 to 2020, the researchers have concluded that the analysis of physical loads in football can be very useful to identify the characteristics and types of injuries and power, in this way, to carry out more individualized and specific training. Therefore, this review provides summary information on injuries in high-performance football and could be effective in managing the loads of players to avoid the risk of injuries since data is provided to different professionals, such as researchers in the field of physical activity and sports, coaches, physical trainers, sports doctors and physiotherapists, since all of them should work in a multidisciplinary way to improve the prevention and recovery of injuries in high-performance football.

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**Conflict of Interest**
The author declare that there are no conflicts of interest.

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SportMont

REVIEW PAPER

# Occurrence of Muscle Imbalance and Risk of Injuries in Athletes using Overhead Movements: A Systematic Review

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**Abstract**

The purpose of this study was to examine injuries attributed to muscle imbalance in sports with overhead movements. Available sources in the period between 2010 and 2020 that provide an overview of the occurrence of muscle imbalance and the risk of injuries in overhead sports were evaluated. A comprehensive search of relevant sources was conducted using Google Scholar, PubMed databases, and other databases, including Science Direct, Research Gate, Web of Science, and Psyc Info. Eleven articles met the criteria to be included in the systematic review. Muscle imbalance significantly impacted overhead athletes and was responsible for injuries of the shoulder, lower back, elbow, and wrist. Based on the findings of the review, further study on muscle imbalance should be carried out. More importantly, future research should investigate the muscle imbalance in the non-dominant side and identify relevant exercises that can reduce the imbalance and increase the stability and strength of the muscles on the non-dominant side. Researchers have identified muscle imbalance as a cause of the injuries, but detailed information on the prevalence of muscle imbalance and its impact on athletes remains lacking.

***Keywords:*** *dominant and non-dominant limbs, overhead sports, injuries, muscle imbalance*

## Introduction

Researchers have identified numerous overhead sports, including water polo (Lupo, Capranica, Cugliari, Gomez, & Tessitore, 2016), tennis (Correia, Oliveira, Vaz, Silva, & Pezarat-Correia, 2016; Trompeter, Fett, & Platen, 2017), rowing (Bahr et al., 2004), wrestling, and weightlifting (Baranto, Hellström, Cederlund, Nyman, & Swärd, 2009), golf and baseball (Lee, Tuite, & Rosas, 2010), gymnastics (Parikh, Case, Hogarth, & Abzug, 2020), badminton, basketball, handball (Kaplan, 2016), tracking, shooting, swimming, volleyball, karate, and futsal (Noormohammadpour et al., 2016). These sports usually require a player to apply a throwing technique or movement that involves shoulder and upper arm action above their head at one point or the other in the game. The athletes must also coordinate their movements in a kinetic chain from the feet to their hands (Kibler, 1998).

The execution of skills during competition and training requires the overhead athletes to perform multiple times within that period, whether it is acute or chronic. Hence the likeliness of developing a stronger side of the body is very evident. This is especially true for athletes or players in one-sided games, such as squash, badminton, and water polo. Unfortunately, this leads to muscle imbalance (Kraan et al., 2019), which has been linked to the occurrence of injuries as it substantially increases the risk due to the differences in strength, and this is directly correlated with the reduced performance of the athletes (Page, Frank, & Lardner, 2011).

Various training has been suggested to improve performance, but the mechanics applied by athletes, including shoulder elevation, increase the risk of injuries (Edmonds & Dengerink, 2014). The risks of overhead injuries are attributable to the distinct mechanics applied in the shoulder region,

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including external rotation, abduction, and elevation. In addition, injuries may result from muscle imbalance, making the athletes prone to weakness in the shoulder and elbow (Noguchi, Demura, Takahashi, Demura, & Mori, 2014).

A well-structured rehabilitation programme is useful in the treatment of overhead sports injuries attributed to muscle imbalance. The biomechanics and frequencies of how the athletes use their body parts in the overhead sports determine injury patterns (Murray, Goudie, Petrigliano, & Robinson, 2013). For example, injuries to the upper limbs of athletes in overhead sports may vary depending on the specific aspects of that sport.

*Most Common Injuries in Overhead Sports*

Overhead athletes are susceptible to a significant number of injuries, with 18.3% and 21.4% upper extremity damages occurring during game and practice, respectively (Hootman, Dick, & Agel, 2007). Researchers argue that the majority of the injuries in overhead sports are a result of reduced training sessions. Koh and Dietz (2005) reported that a temporary reduction in sports activities increases the risks of injury when the players resume their schedule. However, some of the players maintain their training despite being in pain, thus increasing their risk of suffering injuries while attempting to improve performance. In addition, in overhead sports, athletes are expected to coordinate their movement at the shoulder, wrist, and elbow joints (Escamilla, Fleisig, Barrentine, Zheng, & Andrews, 1998; Fleisig et al., 1996). Therefore, during training or game competitions, the players tend to overuse the upper limbs, thus increasing the risk of joint disorders in the shoulder and elbow.

Studies have discovered injuries to the shoulder as a common occurrence among overhead sport athletes (Fahlstrom & Soderman, 2007). Shoulder pain is more common among badminton players. Shoulder pain is recognized as one of the most frequent injuries that affect female and male athletes. Nearly 30% of the overheard sports athletes suffer a shoulder injury in their careers (Laudner & Sipes, 2009). Researchers also reported injury prevalence of approximately 34.7% to 66.7% in swimming and diving, respectively (Roos et al., 2015). Athletes are at risk of developing chronic conditions as they continue engaging in sports despite the pain. Studies have suggested that limited muscle strength increases the risk of shoulder injuries in overhead sports (Pennock et al., 2018; Atan, Yüceloğlu Keskin, Çamlidağ, & Derebaşi, 2019). Moreover, the excessive range of motion applied to the shoulder also contributes to shoulder pathology among overhead athletes.

The increased popularity of overhead sports, such as baseball, tennis, and golf, has led to a rise in the number of people participating in sports activities (Wilk et al., 2009). Moreover, almost one in every four members of a family participates in these sports; therefore, hospitals and other health facilities are attending to more patients with elbow injuries (Wright, Hegedus, Tarara, Ray, & Dischiavi, 2018). Lee, Tuite and Rosas (2010) claimed that although injuries vary between adults and children, the risk factors are similar, including deconditioned state, suboptimal mechanics, and improper equipment. Equally, the biomechanical demands placed on the athlete's elbow during upper extremity activities increase the risk of joint disorder (Zellner & May, 2013; Lam & Siow, 2012).

Parikh et al. (2020) also mentioned the so-called gymnast wrist as one of the injuries attributed to overhead sports. Excessive weight-bearing activities in the upper extremity result in a chronic wrist condition properly known as radial epiphysitis. Wrist injuries are commonly observed in gymnasts since they exert extreme pressure on the vulnerable region of the wrist. Moreover, tennis players are also susceptible to distinct wrist pathologies due to the stress fractures attributed to ulnar impaction and damages to the triangular fibrocartilage (Gil & Kakar, 2019). In addition, players may experience posterosuperior labral tears, supraspinatus avulsions, and scapular dyskinesis. Thus, the majority of these athletes are susceptible to various injuries, including in the elbow, wrist, and shoulder (Putty, 2010), Low Back Pain (LBP), and because of the excessive force and stress applied during the activity of throwing or playing the overhead sports (Wilk et al., 2015).

*Incidence of Muscle Imbalance*

Overhead sports are closely related to injuries caused by a muscle imbalance in the elbow, wrist, shoulder, and lower back regions. In addition, muscle imbalance exposes athletes to an increased risk of joint disorders (Noguchi et al., 2014). Researchers have discovered that the alterations in muscle imbalance and flexibility are common among overhead athletes (Burkhart, Morgan, & Kibler, 2003), and hence proper balance to an athlete's muscles is crucial for flexibility and stability in preventing potential injuries in the shoulder region. Athletes rely on muscles in distinct regions, such as the shoulder (Page et al., 2011), to enhance muscle performance during different motions and mobility in sports activities. However, muscle imbalances result in movement impairments due to changes in arthrokinematics, which may cause structural damages. Page (2011) claimed a deficit in the strength or flexibility in one muscle, such as an agonist, has to be compensated by another muscle, which in this case, is the antagonist muscle, thus leading to a dysfunction. Wang, Macfarlane and Cochrane (2000) also related muscle imbalance to isokinetic muscle strength, whereby musculoskeletal discomfort, pain, and weaknesses in the shoulder regions are attributed to concentric and eccentric contractions on the dominant and non-dominant shoulders of athletes.

According to Page, Frank and Lardner (2011), muscle imbalance is attributable to weaknesses in different regions of the upper limb, including the lower and middle trapezius, infraspinatus, deltoid, serratus anterior, and when coupled with the tightness of levator scapula, upper trapezius, and pectorals, it increases the risk of structural damage for the athletes. Lin, Wu, Wang and Chen (2005) argued that increased activities in the trapezius muscle could result in substitution in scapular movement as compensation for the glenohumeral motion impairment. Athletes may be required to apply abnormal scapular motion, including increased upward rotation and excess elevation of the scapula (Challoumas, Artemiou, & Dimitrakakis, 2017). The players should understand that abnormal scapular motion causes imbalances in muscle activity. The imbalances can occur due to upward rotation and elevation of the scapula by the upper trapezius coupled with the contraction of the lower trapezius to maintain the equilibrium of the scapula (Wright et al., 2018).

Studies have also discovered a positive relationship between isokinetic evaluations and muscle imbalance. In sports in which athletes are expected to exercise overarm throwing, cases of imbalances in muscle strength have been identified in relation to isokinetic evaluations (Codine, 1997; Edouard, Damotte, Lance, Degache, & Calmels, 2013; Andrade et al., 2010). While exercising a throwing technique, athletes are expected to apply concentric and eccentric contractions (Olivier & Daussin, 2019). Although the concentric action influences the throwing velocity, the eccentric contraction acts as a break limiting an increase in distraction force experienced in the upper limb (Sirota, Malanga, Eischen, & Laskowski, 1997). The use of a mixed ratio in internal and external rotators by concentric and eccentric actions increases the risk of shoulder imbalance, resulting in injuries.

Wang, Macfarlane and Cochrane (2000) argued that overhead sports such as volleyball, tennis, swimming, and javelin throwing require players to engage in repetitive forceful arm actions. The actions in these sports place an excessive eccentric load on the rotator cuff muscles of an athlete's shoulder, thus exposing them to injury. Therefore, an injured rotator cuff muscle is more likely to lose the capacity to maintain stability with the antagonist, and as a result of the imbalance in the shoulder region, an athlete is at increased risk of shoulder impingement. Moreover, Nekooei et al. (2019) argued that the majority of the overhead throwers face a similar problem, which involves an imbalance in the shoulder movement strength. Minimal internal or external glenohumeral rotations may cause injuries such as shoulder and LBP, and hence have a negative effect on the performance of athletes.

Researchers have identified differences in dominant and non-dominant sides of overhead athletes that are also responsible for potential injuries. The dominant shoulder of an overhead athlete is different from the non-dominant in terms of strength, morphology, muscular balance, and range of motion (Borsa, Laudner, & Sauers, 2008). Some of the sports activities may require the players to rotate the dominant arm at the maximum position while attempting to maintain a balance and level of accuracy. In volleyball, for instance, players try to produce high velocity and large forces on their arms by rotating the dominant shoulder; although they may achieve the expected results of accuracy, they end up being exposed to injuries attributed to muscular imbalance. In water polo, an overhead sport that exposes athletes to a number of injuries, especially to the shoulder region, players are expected to exhibit higher work in eccentric and concentric action and display high muscle endurance performance. Olivier and Daussin (2019) argued that the dominant shoulder of most water polo players tends to be stronger than their non-dominant shoulder. This imbalance increases the risk of injury to the shoulder region of an athlete participating in water polo.

Athletes are likely to suffer injuries attributed to muscle imbalance because of the different muscle forces applied in the dominant and non-dominant arm. The dominant arm applies muscle force nearly 10% greater than the non-dominant arm (Betchol, 1954; Gedela, Kirby, & Huhtala, 2008). Zuzgina and Wdowski (2019) considered the asymmetric nature of movements of an athlete's shoulder as a crucial cause of strength imbalances. Volleyball players are exposed to asymmetries between their dominant and non-dominant sides. However, other than the strength imbalances attributed to dominant and non-dominant shoulders, external and internal rotators play a crucial role in stabilizing the glenohumeral joint, and the failure to achieve a balance results in injuries.

The present systematic review looks into the occurrence of muscle imbalance and the risk of injuries linked to it, as well as the recommendation by the research.

## Methods

The present study conducted a literature search for potential articles on databases such as PubMed, PsycInfo, ScienceDirect, and on the internet using Google Scholar. An additional search was carried out on the following databases ResearchGate and Web of Science. Keywords used to perform the search include muscle imbalance, overhead sports, dominant and non-dominant sides, and injuries. Database and internet searches centred on articles and papers within the period from 2010 to 2020. After identifying the potential papers and articles, screening of abstracts and full-text was carried out to select sources that would be assessed for eligibility using the "Strengthening the Reporting of Observational Studies in Epidemiology." Eligibility of the sources would help examine potential bias in the study. Relevant studies that passed the eligibility test were included in the review, as shown in Figures 1 and 2.

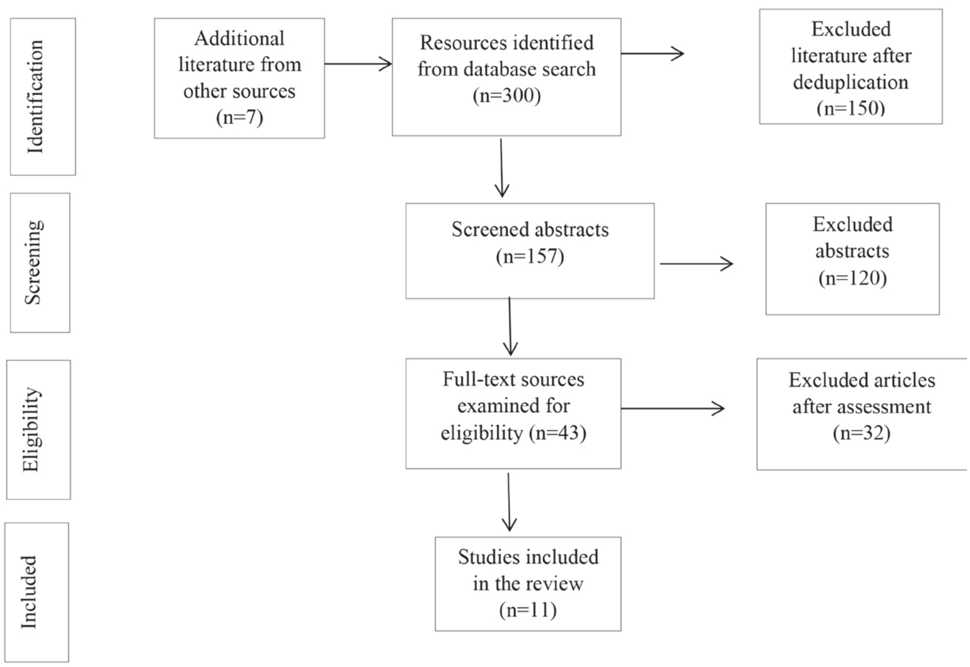


FIGURE 1. Preferred reporting items for systematic reviews flow diagram of included studies

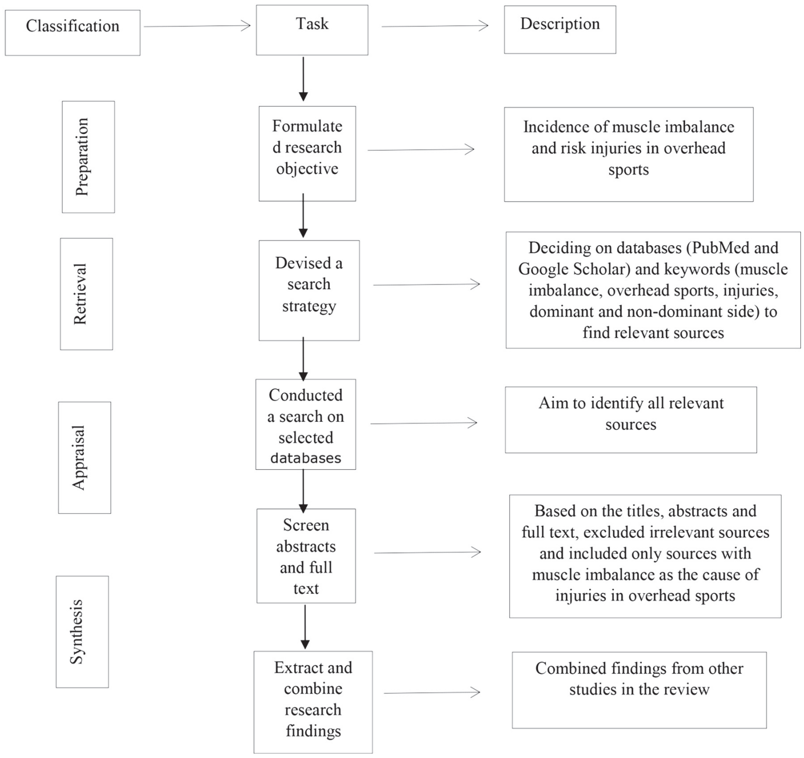


FIGURE 2. Search strategy implemented ih the systematic review of the study

*Selection Criteria*

All studies were first searched for on the internet using Google Scholar and different databases, including PubMed, PsycInfo, Web of Science, ResearchGate, and ScienceDirect. After that, the study screened the literature on the title and abstract using the following criteria; the target population (male and female overhead sport athletes, with overuse injury or pain of the shoulder, elbow, wrist, and lower back), design of the study (inclusive of all designs such as cross-sectional, systematic review, and case-control studies), and study outcomes (prevalence of injuries among overhead athletes associated with the incidence of muscle imbalance).

## Results

The search strategy implemented in the review yielded 307 studies, and after deduplication, 157 studies were screened. The study tested 157 abstracts and excluded 120, leaving 43 of the sources for eligibility assessment. Only 11 out of the 43 assessed sources were selected for the systematic review (Figure 1). From Table 1 below, the eleven studies reported muscle imbalance as a key factor in overhead sports injuries.

**Table 1.** Occurrence of Muscle Imbalance in Overhead Sports

| Source | Injury occurs or may occur | Overhead Sport game | Subjects | Imbalance | Recommends |
|---|---|---|---|---|---|
| Atan et al., 2019 | Shoulder injury | Badminton | 14 healthy badminton players (13.07±2.01 years), (153.64±9.18 cm), (44.71±7.28 kg) who played badminton for at least five years. | The players' dominant biceps muscle volumes were greater than the muscle volumes that they did not control. The grip power of their dominant hands even surpassed the other hand. | To focus on specific training to strengthen their bodies' non-dominant hand to avoid muscle imbalance and injury occurrence |
| Zuzgina & Wdowski, 2019 | Injury or shoulder pathology. | Volleyball | 19 university level volleyball players (9 men, (81.3±8.0 kg), (21±1 years)]; 10 women, (66.0±8.2 kg), (19±1 years)). | Both men and women displayed asymmetric external/internal relationships with higher non-dominant ratios. | To achieve a balance between rotors outside and inside. |
| Olivier & Daussin, 2019 | An asymmetry in terms of force, shoulder tendon pain. | Water polo | 28 female players, (10 non-competitive players and 18 competitive players (19-25 years) | The dominant shoulder is heavier than the non-dominant shoulder. | To improve external rotation (ER) with analytical gestures. Since the water did not provide solid help to regulate the wave, a specific training out of water should be included. |

*(continued on next page)*

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| Source | Injury occurs or may occur | Overhead Sport game | Subjects | Imbalance | Recommends |
|---|---|---|---|---|---|
| Oleksy, Czarny, Bajorek, Król, & Mika, 2018 | Shoulder injury. | Volleyball | 18 male volleyball players (21-26 years), (186.6±8.4 cm), (85.7±9.8 kg). | Muscle weakness of the shoulder in dominant and non-dominant. | No recommendation given. |
| Pennock et al., 2018 | Oedema or proximal widening of humeral physis, labral tear, partial rotator thickness tear, acromioclavicular joint abnormality, subacromial bursitis, and significant tuberosity cystic alteration. | Baseball | 23 baseball players (10-12 years). | Compared to the non-dominant arm, the dominant arm is 8.5 times more likely to have MRI abnormalities. | To use and implement the Early Sports Guidelines. |
| Correia et al., 2016 | LBP. | Tennis | 35 players contributed to the report. (28 males, 7 females, ages 18.54 ± 3.00 years). | Asymptomatic participants had greater endurance periods for the flexor and the right side bridge. Lower extensor muscle activation, less rates of co-contraction and less abdominal endurance. | Tennis coaches and clinicians should pay attention to the abdominal capacity of their athletes and evaluate the ability of lumbar stability exercises to stimulate specific trunk muscles. |
| Sung et al., 2016 | Core and non-dominant arm muscle. The damage to the trunk, usually caused by poor posture and improper swinging or by reduced strength of the trunk muscle. | Golf | 60 elite golfers (23 to 25 years). | The dominant arm has a muscle strength of about 10% higher than the non-dominant arm. | To enhance the exercises of both central and non-dominant arm will provide the elite or professional golfers with an appropriate, tailored training programme. |
| Couppe et al., 2014 | Excessive or minimal ROM in the shoulder may lead to shoulder diseases such as instability and impingement. | Badminton | 31 adolescents; 12 females, (16.8 + 1.6 years), and 19 males (17.1 + 1.6 years). | Internal and external motion ranges were smaller on the dominant side compared to the non-dominant side on both group's players. | Preventive strength training with proper restitution to stabilize and support the rotator cuff could be even more necessary in females than males to minimize the risk of shoulder injury. |
| Noguchi et al., 2014 | In baseball players, joint upper limb injuries such as baseball elbow (medial epicondylitis) and rotator cuff tears are normal due to overuse and throwing with poor technique. | Baseball | 33 Fit, Right-handed, university players (20.4 + 1.1 years) with an average baseball experience. | Correlations between the muscle strength for handgrip and elbow flexion of both the upper limbs were important and moderately strong at all loads. | A training programme to overcome the gaps in skill. For example, light load dumbbell or tube training may be used to improve the strength of the weaker side subscapular muscles and help prevent joint damage. |
| Tonin, Stražar, Burger, & Vidmar, 2013 | Shoulders injury (changes in rotational strength, symptoms of SICK scapula syndrome, and glenohumeral (GH) joint capsule muscle instability contracture). | Volleyball and Handball | 36 female players were split into two groups: the symptomatic group included 14 athletes (positive shoulder injury history and detailed shoulder tests) and the asymptomatic group included 22 athletes (negative shoulder injury history and other testing of the shoulder). | Reduced internal rotation and increased external rotation, lower spiking and traditional ratios, lower eccentric external rotor peak torques, and slightly lower eccentric internal rotor peak torques on the dominant side relative to the non-dominant side. | Adjusted clinical and isokinetic shoulder exercise. |

## Discussion

Findings indicated a significant correlation between muscle imbalance and damages such as lower back, shoulder, wrist, and elbow injury among overhead athletes. Muscle imbalance exposes athletes to an increased risk of joint disorders (Noguchi et al., 2014). Moreover, players of overhead sports are likely to suffer injuries attributed to muscle imbalance because of the different muscle forces applied in the dominant and non-dominant arms (Sung, Park, Kim, Kwon, & Lim, 2016). Scholars maintain that the dominant arm applies muscle force nearly 10% greater than the non-dominant arm (Betchol, 1954; Gedela et al., 2008). The dominant shoulder of most players tends to be stronger than their non-dominant shoulder. This imbalance increases the risk of injury to the shoulder region of an athlete participating in an overhead sport such as water polo (Olivier & Daussin, 2019). Another study identified an imbalance among golf athletes in the dextral arm muscles and sinistral arm muscles (Sung et al., 2016). Athletes who are unskilled in using the sinistral muscles depend on dextral muscles and are required to strengthen the dominant upper limb to maintain a balance between their arms (Sung et al., 2016).

Results of the review illustrated that muscle imbalance is attributable to weaknesses in different regions of the upper limb, including the lower and middle trapezius, infraspinatus, deltoid, serratus anterior, and when coupled with the tightness of levator scapula, upper trapezius, and pectorals which increases the risk of structural damage for the athletes (Page et al., 2011). The study also found the asymmetric nature of movements of an athlete's shoulder as a crucial cause of strength imbalances. Overhead sports, such as swimming and baseball, were found to expose athletes to functional impingement as a result of instability and muscle imbalance.

Additionally, the systematic review found that the external and internal rotators play a crucial role in stabilizing the glenohumeral joint, and a failure in achieving a balance results in injuries among overhead athletes. Muscle imbalance in the dominant and non-dominant sides of volleyball athletes exposed them to shoulder injuries. The results of the review added to existing research findings that confirm the association between muscle imbalance and overhead sports injuries. Wang, Macfarlane and Cochrane (2000) also related muscle imbalance to isokinetic muscle strength; musculoskeletal discomfort, pain, and weaknesses in the shoulder regions are attributed to concentric and eccentric contractions on the dominant and non-dominant shoulders of athletes.

Another study found that muscle imbalance associated with differences in the dominant and non-dominant arms to have a significant effect on baseball players. The study reported that the dominant arm was likely to have an abnormality on MRI that was 8.5 times more than the non-dominant arm, most of the baseball athletes are at risk of being diagnosed with rotator cuff injury, internal impingement lesions, and labral tears (Pennock et al., 2018).

In another study, the researchers discovered differences in trunk fatigue and the activation profile among tennis athletes, the players suffering from LBP were found to have minimal endurance time for their abdominal muscles. Furthermore, the extensor muscle activation procedure was also distinct among the players. The study reveals the importance of addressing problems with abdominal muscles and the activation of distinct trunk muscles, especially in lumbar stability activities, to help minimize the impact of muscle imbalance (Correia et al., 2016).

Noormohammadpour et al. (2016) also examine the prevalence of LBP in distinct overhead sports among female athletes. Research results involving 1,059 overhead athletes with a median age of 23.1 years indicate a 39.0% prevalence of LBP with badminton (42.4%), basketball (47.9%), and karate (44.0%). Lumbar kinematics tests during tennis serves also showed higher lateral flexion moments in LBP matches, which could be a possible injury mechanism (Fett, Trompeter & Platen, 2019).

Oleksy et al. (2018) discovered that differences in contralateral muscle fatigability might result in muscle imbalance and hence expose athletes to acute injury. However, a lack of differences in shoulder muscles of the dominant and non-dominant sides may not be a significant cause of pathological changes among volleyball players. The study concluded that asymmetric shoulder loading for volleyball athletes should not be assumed to be a potential risk factor for injuries to the shoulder region.

In another study that sought to evaluate the difference in dominant and non-dominant functioning of non-athletes and athletes' arms, it was found that the dominant shoulder of handball and volleyball players had more scapular downward and upward rotation, especially in scapular rest (Hosseinimehr, Anbarian, Norasteh, Fardmal, & Khosravi, 2015). In contrast, the study found no significant asymmetry in the dominant and non-dominant shoulders of non-athletes in distinct abduction angles when performing a scapulohumeral rhythm or upward scapular rotation. Also, from the review, the study found that muscle imbalance resulted from side-related adaptations of musculoskeletal and the different techniques used in frequency and pattern of the dominant and non-dominant arm.

Tonin et al. (2013) examined rotational mobility transitions associated with muscle imbalances from which the study identifies repetitive overhead movements, such as a decrease in the dominant external rotation, a higher deficit of the dominant eccentric external rotation peak torques, and a higher dominant rotator fatigue association with previous pain injury in the shoulders. Specific physiological shifts are interrelated (rotational mobility, symptoms of SICK scapula, and glenohumeral muscular imbalances). As a means of prevention and recovery for the at-risk athletes.

The study also revealed some of the crucial muscles that help overhead athletes avoid potential injuries, including the use of core muscles, rotator cuff muscle in strength training to enhance the strength of external rotation muscle (Couppe et al., 2014). The dextral arm muscles and sinistral arm muscles, and core muscles are essential for the golf and badminton players since they stabilize the backbone and maintain a player's pelvis balance in swinging motion (Sung et al., 2016). Scholars have also identified other muscles crucial for athletes, such as the trapezius muscles and serratus anterior, which are important in maintaining a balance during upward rotation. Moreover, Lantz and McNamara (2003) identified additional muscles crucial among overhead sports players, including the middle trapezius, rhomboids, and lower trapezius muscles, which help maintain the stability of scapula that may result in shoulder injury attributed to muscle imbalance.

The importance of muscle fatigue as a risk factor for shoulder injury in overhead athletes was highlighted by Andrade et al. (2016). A higher incidence of late-game injury than early-game injury was documented and indicated that this fatigue might affect muscle strength balance and thus shoulder joint stabilization.

## Conclusion

The overall findings of this study showed that overhead athletes are susceptible to shoulder, elbow, lower back, and wrist injuries attributed to muscle imbalances in either the dominant or non-dominant side. Athletes should engage in training and therapeutic programmes that help them learn techniques of avoiding potential injuries. Preventive strength training can help players balance and stabilize the rotator cuff muscle and minimize the chances of injuries. Furthermore, training allows players to learn proper throwing and pitching techniques, as well as restoring neuromuscular function to minimize the impact of muscle imbalance. Findings from the systematic review indicated that limited studies focus on the non-dominant side; thus, further research should focus on muscle imbalance in non-dominant upper limbs and its connection to overhead sport injuries and provide important programmes and exercise that can stabilize muscles in the non-dominant side.

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**Conflict of Interest**
The authors declare that there are no conflicts of interest.

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SportMont

REVIEW PAPER

# Reviewing the Relationship between Physiology of Breathing and Physical Activity in Anxiety Disorders

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**Abstract**

The possible influence of the quality of breathing on physical activity remains the subject of numerous scientific studies in different fields, including not only the most basic physiological and biological concepts but also the fields of psychiatry, psychology, and neuroscience. The literature about the relationship between breathing and psychophysiological factors is continuously growing, and several studies have investigated the influence of breathing techniques on human beings. This review aims to give a literature overview of the respiratory function impact on psychopathology, taking into account anxiety disorders, physical activity, and the relationship between them. Literature investigating different topics involving the influence of breathing on anxiety disorders, the influence of breathing on physical activity and related anxiety disorders showed an association between them even if this relationship is not well clarified. Regular physical activity could become even a primary or preferential treatment. Relaxation techniques, as well as motor visualization, mindfulness, and even oral appliances, could help people improve their general condition with the improvement of the control of their psychophysical performance. Further literature with different physical activities and experiences regarding psychodynamic treatments could assume a new scenario.

***Keywords:*** *mindfulness, relaxation techniques, panic disorder, psychopathology*

## Introduction

Accounts of physically active people (e.g., fitness exercise) shed light on the phenomenon of anxiety problems widespread in the physical activity field and often experienced by younger athletes (Ford, Ildefonso, Jones, & Arvinen-Barrow, 2017) and by high-level athletes. Stiene (1992) reported a case of a young basketball player with dyspnea and chest pain who had lost consciousness for twenty seconds due to having a syncope during a match. After having excluded all the possible organic causes by applying adequate cardiologic, neurologic, and metabolic testing, the episode was considered a panic attack with psychogenic aetiology.

As extensively elaborated by the scientific literature, chest pain is often associated with the typical symptom of air hunger, leading subjects to think that they are close to death (Durazzo, Gargiulo, & Pellicano, 2018). Beyond the empirical evidence, the possible influence of the quality of breathing on sports performance remains the object of numerous scientific studies in different fields, including not only the most basic physiological and biological concepts but also the fields of psychiatry, physiology, and neuroscience (Bordoni, Purgol, Bizzarri, Modica, & Morabito, 2018). In particular, recent studies in the field of neurobiology have shown a close relationship between breathing and the nervous system involved in stress responses (Yackle et al., 2017).

Moreover, a strong relationship between breath rate, mood state, and autonomic nervous system state has been shown (Zaccaro et al., 2018). Fast breathing stimulates brain

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activity at a higher rate, triggering it to activate the sympathetic nervous system, accelerating the release of stress hormones, increasing heartbeat, blood pressure, muscle tension, sweat production, anxiety, and even panic disorder (see, e.g., Dratcu, 2000). The interest in the scientific literature about the relationship between breathing and the brain is continuously growing; several studies have investigated the influence of breathing techniques, especially yoga, on sports performance. While the growing importance of breathing techniques and exercise is obvious in the training of swimmers and apnoea athletes (Lomax, Tasker, & Bostanci, 2015), where the optimization of pulmonary function is directly related to the performance, the interest in the application of these techniques in other sports fields is also increasing (Zhang et al., 2015). The focus of researchers is on studying the relationship between respiratory function and anxiety, hypothesizing a relationship between breathing and the brain beyond the direct physiological connections (Carter & Carter, 2016; Zaccaro et al., 2018). This literature review aims to show the scientific framework of the impact of respiratory function on psychopathology concerning anxiety and panic disorders related to sports performance.

Intensity differentiates a panic attack from an anxiety attack (Figure 1). According to the medical definition, "Panic attacks are acute anxiety attacks"; they are episodes of anxiety that happen suddenly and end just as quickly, usually lasting between 5 and 30 minutes (DSM-5; American Psychiatric Association, 2013). A panic attack is also a relatively common phenomenon; it is estimated that about one in twenty people experiences one during their lifetime (Kessler et al., 2006); females predominate.

According to DSM-5 (American Psychiatric Association, 2013), the most common physical symptoms regarding panic attack are feelings of choking and breathing blockage, feelings of tightness or even chest pain, palpitations, sweating, tremors, abdominal pain, and nausea, and vomiting. Equally violent psychological symptoms accompany these different somatic symptoms. If the anxiety crisis is a crisis of malaise, a heart that is pounding, or difficulty in breathing, the panic attack is fierce. More physical symptoms are present: palpitations, an impression of suffocating (even being strangled), pain or chest discomfort, feeling dizzy, nausea, hot flashes, decreolization (feeling of unreality or strangeness of the outside world), depersonalization (feeling alien to one's own body).

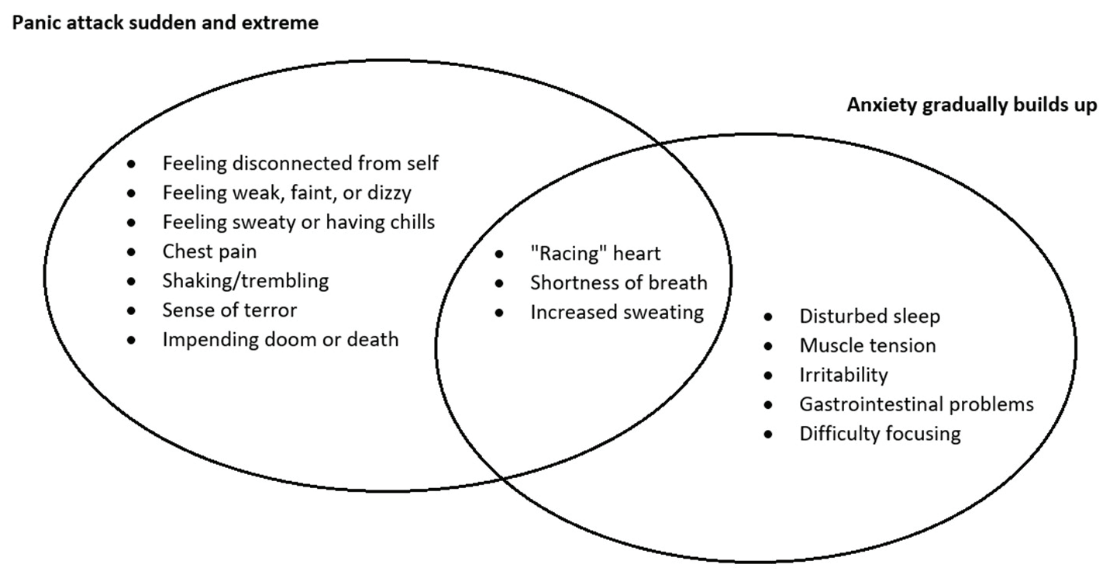


FIGURE 1. Panic attack vs Anxiety attack symptoms

**Breathing and Panic Disorder**

*Panic disorder: the respiratory subtype*

According to the last edition of the Diagnostic Manual of Mental Disorders (DSM-5; American Psychiatric Association, 2013), panic disorder is considered as a single diagnostic category included in a broader group of anxiety disorders. Thirteen physical and cognitive symptoms characterize anxiety disorders: palpitations, tachycardia, increased perspiration, tremors, chest pain, nausea, abdominal disturbs, vertigo, fainting, chills, hot flushes, paraesthesia, derealization, depersonalization, fear of losing control or "going crazy", and fear of death, dyspnea, and suffocation. These clinical symptoms define a particular disorder subtype known as the respiratory subtype (Freire et al., 2008). Consequently, patients with respiratory symptoms are classified in the respiratory subtype group, while patients with the predominance of other physical or cognitive symptoms are in the nonrespiratory subtype group. Freire, Perna and Nardi (2010) state that further studies are necessary to determine a sufficient possibility of identifying the respiratory subtype of panic disorder. In particular, these authors assume that other factors that should be considered are cultural differences, smoking tobacco, alcohol assumption, or the response to specific therapeutic treatments. Furthermore, it is suggested that this research not based merely on the symptomatologic profile but also that respiratory tests, neuroimaging, and genetic tests be performed. For example, respiratory testing is very important in obese people, given that a relationship between body mass index and lung function has been determined, which also varies with age, race, and geographical region (Wang, Sun, Hsia, Lin, & Li, 2017).

Moreover, the literature describes that obese binge eaters have significantly higher frequencies of typical and atypical panic symptoms and agoraphobia than controls do (Zoccali et al., 2004). It can be inferred that there is a mutual influence between difficulty breathing and obesity, which, in turn, makes these people more exposed to psychological problems. Finally, those people in the respiratory subtype should pay greater attention to their physical sensation, developing significant anticipatory anxiety contributing to lowering the threshold of panic activation in relationship with external and internal stimuli. For these reasons, subjects in the respiratory subtype present quite catastrophic perceptions regarding their symptoms compared to the nonrespiratory subtype (Song, Kim, Heo, & Yu, 2014).

The close relationship between panic disorder and respiratory function, which is a part of the nonrespiratory subtype, encouraged researchers to specifically investigate the nature of this relationship, considering the hypothesis of a causal relationship. It was especially hypothesized that panic disorder could be related to an anomaly of physiological mechanisms of the respiratory function. As discovered in the late 1990s (Perna, Bertani, Politi, Colombo, & Bellodi, 1997; Perna, Giampaolo, Caldirola, & Bellodi, 2004), respiratory control mechanisms play a crucial role in the origin of abnormal anxiety and panic disorder. A team from the Laboratory of Panic and Respiration of the Psychiatric Institute of the University of Rio de Janeiro carried out a series of tests in order to evaluate the presence of physiological anomalies of breathing in subjects affected by panic disorder; the experimentation included the evaluation of hyperventilation, apnoea, CO2 inhalation and caffeine consumption, demonstrating that there is an increase of anxiety, and panic attack risk was noticed in subjects with panic disorder during these tests (Nardi et al., 2007; Nardi et al., 2006). Specifically, the hyperventilation syndrome, which can be observed during panic attacks, has been characterized as having two forms: chronic and acute (Gorman et al., 1994). Gorman, Kent, Sullivan and Coplan (2000) discussed a model by which it is possible to highlight that disturbed breathing could provoke bursts of hyperventilation and respiratory alkalosis, which can result in dizziness, palpitations, and tremors, which, in turn, worsen fear and anxiety. However, the existence of an evolved "false suffocation alarm" has also been proposed, which can trigger panic attacks caused by the brain that incorrectly signals a lack of useful air; so the brain activates maladaptive autonomic responses to suffocation, demonstrating that CO2 sensitivity might play a crucial role in breathing disorders (Preter & Klein, 2008). Of the two proposals, hyperventilation has particularly been considered closely related to panic attacks, leading the researchers to describe the hyperventilation syndrome (R. Zeng, Chen, & M. Zhang, 2018) as a real triggering cause of this phenomenon. According to this hypothesis, subjects affected by panic disorder could be considered to be chronically affected by hyperventilation in a hypomanic alkalosis state (a condition with blood pH higher than the normal value of 7.4). This hypothesis is based on the evidence of at least three experimental data groups: a) panic attacks and hyperventilation syndrome have a common symptomatology (dyspnea, palpitations, tremors, paraesthesia, fainting); b) hyperventilation syndrome is present in about 40% of subjects with panic disorder (Nardi et al., 2001); c) the hyperventilation test (during which the subject is asked to hyperventilate for 4 minutes (30 breaths/minute)) causes symptoms the same as what was reported happening during panic attacks by subjects with panic disorder (Nardi et al., 2004). However, according to the authors (Nardi et al., 2001), such empirical evidence is insufficient to establish an etiological relationship between breathing and spontaneous panic attacks.

Griez and Perna (2003) reported that panic disorder is not necessarily related to any objective respiratory pathology, and the normal physiology of respiration is maintained in subjects suffering from panic disorder. The tendency of those subjects to hyperventilate or to panic when encountering respiratory stimuli, such as inhaling carbon dioxide, seems mostly to activate a network of fear reactions. Nardi and his colleagues (2001) hypothesized the existence of subclinical anomalies in respiration and other functions of homeostasis in the body. Fear control is quite complex, and the brain areas involved are represented by the amygdala and its projections in the brain stem, hippocampus, and medial prefrontal cortex. The amygdala is abnormally sensitive in subjects suffering from an anxiety disorder in which the prefrontal cortex, usually able to modulate the amygdala's activity, fails his control; this is the so-called "insufficient top-down control" (Dong et al., 2019). This theory could explain why these subjects react positively to both medical and psychological therapies.

Furthermore, it has been demonstrated that mindfulness approaches can improve the prefrontal cortex efficiency and its control on the amygdala activity (Cheng et al., 2010). Therefore, the anomalies in different neurochemical systems could be the expression of complex relationships that intervene between the brain circuits, so panic disorder should be entirely interpreted due to multiple complex interactions between different brain circuits (Nardi et al., 2009).

Finally, studies conducted since the end of the 1990s also tended to exclude a causal relationship between breathing anomalies and panic disorder (Perna et al., 2004). A study based on the analysis of the entropy index in subjects with panic disorder compared with healthy subjects showed that these subjects are characterized by an entropy index higher in the basic respiratory model (Caldirola et al., 2004). This finding suggests a higher level of irregularity and complexity in their respiratory function; even if this could be lead to panic attacks, it does not imply a causal relationship between these two phenomena.

*From physiology to neurobiology*

Current research seems to pay more attention to the complexity of the panic disorder phenomenon, an approach that tends to exclude a one-way relationship with the physiology of breathing. The field of neurobiology seems to be the most promising one as far as this issue is concerned. A study by Yackle et al. (2017) focused on the analysis of neural mechanisms and centres at the basis of the relationship between breathing and the brain. In particular, they found a small, molecularly defined neuronal subpopulation in a breathing rhythm generator that directly projects to a brain centre, which plays a key role in generalized alertness, attention, and stress. Among the 3000 neurons of the pre-Bötzinger complex, responsible for initiating respiratory movements, a group of about 175 neurons seem to send projections directly to the locus coeruleus, a part of the brain that has a key role in the general supervision, in focusing attention, and in stress responses (Yackle et al., 2017). The pre-Bötzinger complex should act as a "respiratory pacemaker" involved in all kinds of breathing associated with different emotions: regular, relaxed, excited, panting, sobbing, and sighing. Thus, it was hypothesized that different neuronal subtypes of the respiratory centre were related to different kinds of breathing. After more than 60 neuronal subtypes were identified in the brain stem of the respiratory centre, their role in breathing was studied in rats by selectively eliminating each subtype. It was found that while there were no changes in breathing after eliminating the identified neurons, the rats stayed unusually calm even exposed to stimuli that generally induce a stress response (Yackle et al., 2017).

These findings could be both proofs of a neurological origin of the relationship between respiration and panic disorder and the basis for developing new clinical therapies for panic attacks (Wemmie, 2011). In particular, isolated neurons could be identified with specific molecular markers, and it would be possible to develop new drugs that can selectively act on specific neuronal subtypes (Hockley et al., 2020). Breathing is a complex phenomenon characterized by both automatic and voluntary behaviour; the voluntary behaviour centres that control it coincide with superior neural functions. Both automatic and voluntary behaviour can be influenced by mindfulness and meditative practice techniques, which could positively influence the treatment of psychiatric disorders (Hofmann & Gómez, 2017; Zeng et al., 2018).

Breathing control, therefore, seems to play a crucial role of primary importance effectively, not only at the basic physiological level (it is a known fact that oxygen consumption is increased in stress conditions) but also in the context of superior cognitive activities such as focused attention or the mindful stress control. Consequently, mindful control of breathing results as a fundamental instrument to optimize respiratory potential and modulate the emotions that affect daily life (De Giorgio, 2016) and breathing itself (Allen & Friedman, 2012; Arch & Craske, 2006). Meditation techniques based on the control of breathing, used for centuries for promoting concentration and relaxation before an important and demanding physical and mental performance, seem to be effective on the neuronal mechanisms that regulate the relationship between breathing and the brain (Yackle et al., 2017; Young et al., 2018).

### Breathing and Physical Activity

*Physical activity and psychopathology*

Respiratory dysfunctions related to panic attack symptoms are among the principal causes of avoiding physical exercise (Muotri & Bernik, 2014). It should be underlined that panic attack is not a DSM-5 disorder; thus, it cannot be considered a real psychiatric disorder. However, it could be defined as a disorder in case of repeated panic attacks without a clear trigger cause, thus keeping the subject in a continuous state of concern. According to the DSM-5, avoiding physical exercise represents a maladaptive change of behaviour, which can be compared to a whole reorganization of daily life, including a limitation of daily activities, from leaving the house to avoiding agoraphobic situations and, finally, ensuring aid in case of a panic attack. Regardless, the scientific literature seems to be addressed to demonstrating that physical activities could have a positive effect on reducing symptoms in subjects suffering from panic disorder (Aylett, Small, & Bower, 2018). In their review, Aylett et al. (2018) emphasized that people with a diagnosis of anxiety disorder according to the DSM IV criteria, or high anxiety levels/anxiety sensitivity levels on a validated anxiety rating scale, receive greater benefit from high-intensity than low-intensity exercise, with a significant effect size of -0.38 (95% CI -0.68 to -0.08).

Moreover, the follow-up scores in high-intensity exercise regarding the investigated literature indicate that improvement in anxiety levels is permanent for several months after training, with a non-significant effect size of -0.33 (-0.74, 0.08). The study of anxiety and its relationship with other psychological variables, as well as its consequences, has a long history in the scientific literature in sports medicine. Nowadays, every sport psychology and psychiatry manual includes a chapter about anxiety disorders (Currie & Owen, 2016). In recent decades, several theoretical instruments have been developed to measure sport-specific anxiety traits. For example, at the end of the 1970s, the "Sport Competition Anxiety Test" was developed (Martens, 1977): a one-dimensional measure unable to differentiate between somatic and cognitive components of anxiety. In the 1990s, this model was integrated by another research study in order to include two dimensions of the disorder and, in particular, to represent the anxiety disorder in all its somatic, cognitive, and affective complexity. For this purpose, another multidimensional model was developed, called the "Sport Anxiety Scale" (Smith, Smoll, & Schutz, 1990). Smith himself implemented it in his updated version "Sport Anxiety Scale-2" in the 2000s. The latter has higher factorial validity and considers numerous psychological measures with particular attention to childhood and adolescence periods (Smith, Smoll, Cumming, & Grossbard, 2006).

However, these models are applicable only within the world of sport, to subjects who regularly practice sports activities and not subjects who intend to do intense physical exercise as a potential cure for anxiety disorders. Therefore, a specific approach should instead be applied to professional athletes. According to a study by Ströhle et al. (2009), as the anxiolytic effect of physical exercise is well known both in healthy subjects and subjects affected by anxiety or psychiatric disorders, it should be underlined that the agonistic physical activity could have a negative effect on the latter, causing an increase of disorders instead of a decline. In addition, in this case, some differentiations should be done regarding both the physical activity type and the type of disorder from which the subject is suffering.

Szabadi (1988) assessed the psychological effects of different types of physical exercise in subjects with different mental disorders, such as anxiety, depression, and mood disorders. In particular, Szabadi distinguished aerobic or cardio-respiratory exercises, such as long-distance running, anaerobic exercises (based on muscular strength), such as weightlifting, exercises for relaxation, and exercises for coordination and flexibility, such as yoga. The author considered different variables, such as the diagnosis of the subject assessed and the selection of treated groups and the training regime, and found that regular aerobic exercise can have positive psychological effects in subjects affected by anxiety disorders and depression.

According to a study published by Heidary et al. (2011), subjects mainly doing aerobic exercises have a lower stress level and a better ability to control stressful conditions. These findings led to a hypothesis of including physical exercise in primary and secondary preventive plans and therapeutic plans for psychiatric disorders, on the same level as psychotherapy and psychopharmaceuticals (A. Byrne & D.G. Byrne, 1993). The scientific literature seems to demonstrate that moderate physical exercise (20 minutes sessions) for at least 12 weeks positively affects stress control (A. Byrne & D.G. Byrne, 1993). Considering that secondary negative effects of physical activity, applied to subjects under treatment for anxiety, depression and mood disorders, have still not been observed, this activity could be indicated as a primary and preferential treatment (A. Byrne & D.G. Byrne, 1993; Ströhle et al., 2009). However, more recent literature (summary findings presented in Table 1) demonstrates that also anaerobic exercise, in particular yoga and its variations, has a great effect on psychological indexes, including anxiety (Breedvelt et al., 2019; De Giorgio, Padulo, & Kuvačić, 2018; Kuvačić et al., 2018; Telles et al., 2019).

It is important to note that regular and constant physical exercise could also assume traits of addiction in subjects with anxiety and obsessive disorders (Bär & Markser, 2013; Johnson, 1995). Thus, in subjects with dysphoria, physical activity could negatively affect their mental health if the habitual physical exercise programme is interrupted (Paluska & Schwenk, 2000). A typical example is "obligatory runners" or compulsive runners, who practice intense physical activity as an absolute need instead of pleasure (Hoffman & Krouse, 2018; Johnson, 1995).

This condition could be considered similar to a strict alimentary regime; Yates hypothesized that it could be a symptom of the same psychopathological structure as anorexia nervosa (Yates, Leehey, & Shisslak, 1983), based on which the so-called "athletic anorexia" was introduced (Bär & Markser, 2013). In particular, Yates et al. (1983) compared a group of anorexic men with a group of marathon runners and observed some similarities in both personality features and socio-cultural habits. In this respect, studies regarding personality are well developed and concentrated on the obsessive-compulsive traits of athletes with addiction to physical activity and perfectionistic and narcissistic rituals observed in this category of subjects (Stillman, Cohen, Lehman, & Erickson, 2016). Epling and Pierce (1996) and other authors have observed that excessive physical exercise can cause a loss of appetite and decreased food intake, leading to active anorexia and to the phenomenon of "self-starvation", meaning death caused by lack of food.

Interestingly, though physical activity has many positive effects on the nervous system and the brain (De Giorgio et al., 2018; Stillman et al., 2016), in some cases, it could be associated with, or even cause, psychological or psychiatric disorders related to anxiety and panic disorder in the context of high-level agonistic physical activity (Chekroud et al., 2018). Jones (1995), for example, considers the need of deepening the research in this field to investigate the sport-specific psycho-social factors involved in the psychopathological symptoms noticed in these subjects. Reardon (2017) carried out a recent study that gives a clear insight into the relationship between psychiatric disorders and physical activity. In particular, the author explains how physical activity could be the origin of developing a psychiatric disorder or deepening an existing one. This is often the case of eating disorders in athletes, such as gymnasts or bodybuilders, who are under constant pressure to control their weight for competitions. Similarly, in athletes who started their sporting career due to pre-existing psychiatric disorders, so that the developed symptom becomes somehow adaptive to the sporting activity undertaken, an example could be seen in subjects with attention deficit disorder and hyperactivity who started physical activity at an early age in order to dissipate their excessive energy (Reardon, 2017). Finally, a contingent coincidence between sport and mental disorder could be present in subjects with stress-related or genetic mental disorders.

Reardon (2017) observed a small number of studies on anxiety disorder compared to studies on depressive disorders. As far as anxiety disorder is concerned, it is fundamental to distinguish physiological anxiety symptoms related to the contingency of competition from pathological disorders. It is also quite frequently observed that there is an overlapping between these types of symptoms. If anxiety is present before the competition, it can also have a positive effect on the performance, whereas psychopathological anxiety disorder could be disabling for an athlete's life as well as performance, leading to avoidance of physical activity as determined by the respiratory symptoms of panic disorder (Paluska & Schwenk, 2000).

In most cases of anxiety disorders and, in particular, panic disorders in professional athletes, cognitive-behavioural therapy is generally recommended, owing to its absence of influence on sports performance, with side effects generally reported in the pharmacological therapy with benzodiazepine and beta-blockers (D. Baron, Reardon, & S. Baron, 2013). Cognitive-behavioural therapy can also be complemented by antidepressant drugs, such as fluoxetine and selective serotonin re-uptake inhibitors (SSRI; Baron et al., 2013). In some sports, anxiety can also be accompanied by panic. Among the most studied examples in this regard, sport diving should be mentioned, for which anxiety and panic disorder are directly and explicitly related to respiratory function. In fact, many of the numerous accidents occurring at an amateur or competitive level in this sport are related to panic reactions (Morgan, Raglin, & O'Connor, 2004).

Studies carried out by Morgan et al. (2004) in the Sports Psychology Laboratory of Madison-Wisconsin University showed the importance of a clear awareness of one's respiratory function related to one's traits and psychological state in the practice of sport diving activities. In extreme cases, such as for the selection of special armed forces, a screening of any kind of psychiatric and psychological disorders is performed before any evaluation of athletic, endurance, and training capacities of subjects. During diving, self-control of the psychophysical reactions to stressful or dangerous situations is more fundamental than in any other sport. For this reason, the teaching of correct breathing was suggested to be included in educative programmers, similar to sexual and nutrition education (Starosta, 2013). Starosta observed that learning "rational breathing" techniques consisting of a conscious connection between breathing and movement rhythm could improve sports performance and the general state of health of the subject. Regarding specific sport fields, Starosta outlines a detailed summary of the respiratory modalities suggested for each sport exercise and discipline aiming to diffuse an "art of breathing" as proposed by Asian cultures.

**Table 1.** Summary findings of physical activity effects in psychopathology

| Study | Type of exercise | Population | Results |
|---|---|---|---|
| Szabadi (1988) | Regular aerobic or cardio-respiratory exercises | Participants affected by anxiety disorder and depression | + Psychological effects |
| Bär and Markser (2013); | Regular and constant physical exercise | Participants with eating disorders, exercise addiction, chronic traumatic encephalopathy, and mood disorders in overtraining syndrome | Physical and mental strains endured by elite athletes might influence the onset and severity of their psychiatric disorder |
| Johnson (1995) | Regular and constant physical exercise | Participants who perform exercise to avoid the unpleasantness of guilt and anxiety which occurs when an exercise bout is missed | Assume traits of addiction |
| Paluska and Schwenk (2000) | Habitual physical exercise programme interrupted | Participants with dysphoria | Effects on mental health |
| Heidary et al. (2011) | Aerobic exercises | Participants mainly doing aerobic exercises | ↓ Stress level + better ability to control stressful conditions |
| Hoffman and Krouse (2018) | Excessive physical exercise | Participants were asked if ultramarathon was bad for their health | ↓Of appetite and ↓ food intake (real active anorexia) leading to the phenomenon of "self-starvation", i.e., death caused by lack of food |
| De Giorgio et al. (2018); | Anaerobic activities (yoga) | Participants with non-specific chronic low back pain were investigated for anxiety, kinesiophobia and pain | + Effects on psychological indexes related to anxiety, kinesiophobia, pain |
| Kuvačić et al. (2018) | Anaerobic activities (yoga) | Participants with chronic low back were investigated for disability, anxiety, depression, and pain | + Effects on psychological indexes related to depression anxiety, pain, and life quality perception |
| Telles et al. (2019) | Anaerobic activities (yoga) | Participants working in occupations requiring vigilance | Sleep improvement ↓Anxiety while increasing vigilance. |

Legend: +: positive; ↓: decrease; -: negative

*Hypnosis, motor visualization, and relaxation techniques*

Research proved that intense physical effort could be the origin of a panic attack, thus leading Morgan (1995) to consider self-control of the effort and exercise intensity as a possible solution to the problem of excessive fatigue in the field of sport diving. Techniques, such as hypnosis, motor imagery, and relaxation, are accurately reported by Morgan et al. (1995) (summary findings presented in Table 2); in particular, hypnotic suggestion seems to be extremely effective in creating ideal psychophysiological conditions for relaxation, creating a hypometabolic state (Garvin et al., 2001; Young & Taylor, 1998). An alteration of cardiovascular responses was reported when subjects at rest underwent suggestions related to the performance of physical exercise (Wang & Morgan, 1992). These responses were even proportional to the intensity of the effort suggested during the hypnotic session.

Metabolic and cardiovascular effects of hypnotic suggestion techniques were then compared with those obtained with the techniques of motor imagery (Conroy & Hagger, 2018). Motor imagery and real physical exercise seem to have the same neural mechanism of motor programming (Holmes & Calmels, 2008; Moran et al., 2012). Furthermore, it was observed that during an imagined sequence of movements, the activation of the cortical areas in charge of body movement is similar to what is observed during the real execution of the same sequence of movements (Holmes & Calmels, 2008). Based on these results, experts suggest addressing research to analyse specific features of subjects that use this technique to identify differences in the imaginative ability and in the preference of one technique over another to improve the desired sports performance. Regarding relaxation techniques, most studies point out that subjects more prone to anxiety have a higher probability of experiencing respiratory disorders (Morgan, 1995), which is the starting point of most relaxation techniques. However, several studies emphasize the concept that anxiety leads to better performance in many athletes; consequently, the application of these techniques is not appropriate (Silva, 1990). This concept is represented by the distinction between positive or performance stress (eustress) and counterproductive or performance undermining stress (distress). Thus, specific relaxation exercises should be useful when symptoms of anxiety lead to avoidance of physical exercise.

In sport divers, lower respiratory frequency is associated with better performance (Griffiths et al., 1981; Morgan, 1995). On this topic, Bachrach and Egstrom (1987) reported that breathing could represent a fundamental signal in recognizing the stress level of athletes. Therefore, the psychophysical monitoring of divers by personnel from the surface is principally concentrated on the respiratory rate. However, this does not imply that there is necessarily a causal relationship between breathing and performance and, thus, the training of these athletes should aim to reduce the respiratory frequency. In contrast, reducing the respiratory frequency could be useful in subjects with panic disorder, for whom breathing control has been proven to have a significant influence. Starting in the 1970s, research in the treatment of panic disorder included the development of techniques based on respiratory frequency control (Lum, 1976). A study conducted by Clark, Salkovskis, and Chalkley (1985) at the Department of Psychiatry of Oxford University, was organized into three phases: 1) the subjects suffering from panic disorder were asked to perform voluntary hyperventilation in order to provoke a mild panic attack; 2) the subjects were then explained the physiological effects of this over-breathing in order to let them associate the cause of their panic attacks to the hyperventilation related to stress rather than catastrophic phenomena, such as heart attacks, epilepsy, or mental diseases; 3) the subjects were finally trained to control their breathing using proper techniques for managing the hyperventilation related to stressful situations. After two weeks of treatment, the result was a substantial reduction of the frequency of panic attacks related to conditions usually considered as stressful, with a further improvement, respectively, after six months and two years after the beginning of the treatment. The efficiency of hyperventilation in panic disorder has also been confirmed by recent literature (Meuret & Ritz, 2010; Wollburg et al., 2011).

**Table 2.** Summary findings of different approaches and their functions

| Study | Type of technique | Functions |
|---|---|---|
| Clark et al. (1985) | Techniques based on respiratory frequency control | Reduction of the frequency of panic attacks related to conditions usually considered as stressful after two weeks of treatment, with a further improvement, respectively, after six months and two years after the beginning of the treatment |
| Wang and Morgan (1992) | Hypnosis | Alteration of cardio-vascular responses proportional with the intensity of the effort suggested during the hypnotic session |
| | Motor visualization | Increase in the area of cerebral blood flow when subjects are led to imagine handling a tennis racket and hitting a ball on the wall |
| Morgan (1995) | Relaxation techniques | Higher probability of experiencing respiratory disorders in subjects more prone to anxiety |
| Young and Taylor (1998) | Hypnosis | Create ideal psychophysiological conditions for relaxation, turn into a hypometabolic state |
| Holmes and Calmels (2008) | Motor visualization | Similarity in the activation of the cortical areas in charge of body movement between this technique and to what was observed during the real execution of the same sequence of movements |

*Physical activity and mindfulness*

The term "mindfulness" represents a group of mental techniques that aim to achieve a mental state characterized by knowledge and acceptance of each thought, feeling or emotion in the specific instant in which they are experienced (Baron et al., 2013; Ludwig & Kabat-Zinn, 2008) (summary findings presented in Table 3). Gardner and Moore (2007) called it Mindfulness-Acceptance-Commitment (MAC), enlightening the aspect of the subject's acceptance and commitment of present instant feelings. The mindfulness techniques were developed for treating subjects with chronic diseases (Farver-Vestergaard et al., 2018; Grazzi et al., 2017), but then they were successfully applied in the field of psychiatry for the treatment of anxiety and depression disorders (Zhang et al., 2015; Zhang et al., 2019), and then were adapted and structured as innovative models based on understanding and acceptance of one's state of health (De Giorgio et al., 2017; De Giorgio et al., 2017; Gulotta et al., 2015; Padovan et al., 2018; Padovan et al., 2018). Considering that mindfulness is focused on the present moment, it seems particularly intended for athletes, as for their constant need to concentrate on a specific task related to the exercise they are doing. For this reason, there is an analogy between these techniques and the mental state of "flow", defined by a Hungarian psychologist Csikszentmihalyi (1977), frequently translated in the sport field as agonistic trance. It refers to an experience characterized by the athlete's total involvement in a specific exercise, focusing on the target result until being pulled away by a flux or a water stream (Swann et al., 2017). Due to this involvement, the result of this experience is particularly positive and gratifying.

The mindfulness techniques have origin in millenary Buddhist techniques and aim to achieve a state of wellness. The subject should selectively concentrate on "here and now", with an approach free from any judgment and with acceptance for the lived moment to obtain the result. It consists of creating space between perception and response, which makes the subject able to adopt reflective and reflexive behaviour. In the sport context, these techniques are associated with cognitive-behavioural therapy to be applied for treating anxiety disorders (Alsubaie et al., 2017). Breathing represents a primary component of mindfulness techniques. The athlete is asked to concentrate exclusively on his breathing. One of the most important aspects of breathing leading to relaxation is breathing through the nose, for the presence of nitric oxide (Chambers et al., 2001), which has bronchodilator and vasodilator effects, and because breathing helps to normalize the respiratory volume.

Different methods are proposed to keep stress and anxiety under control (Baron et al., 2013; Goodger & Broadhead, 2016). These techniques generally connect the application of respiratory techniques with mindfulness and concentration techniques. An example could be the "Wim Hof" method, a technique that was recently developed based on the personal experience of the Dutch world record holder Wim Hof, famous for his resistance tests at sub-zero temperatures, performed thanks to a series of advanced respiratory and meditation techniques developed over the years. Based on cycles of deep breathing alternating with apnoea phases, this method should permit a modification of body physiology thanks to the control of breathing. This technique has the aim of oxygenating the tissue and optimizing oxidation of the energetic substrates, determining the activation of thermogenesis. Researchers from the Wayne State University (Detroit, MI, USA) studied the Wim Hof method and recently published a study establishing that these techniques could be applied in the treatment of psychiatric disorders and autoimmune diseases (Muzik et al., 2018). This study hypothesized that the Hof ability should be related to increased sympathetic innervation and glucose consumption in intercostal muscles. The imaging techniques revealed that the Wim Hof meditation technique allows generating heat that is dissipated in the pulmonary tissue, controlling the blood flow temperature in the pulmonary capillaries. The researchers also hypothesized that human beings could generate an analgesic response to stress with the production and release of opioids and cannabinoids. This effect should have the power to induce a feeling of wellness and to control one's mood and anxiety. This process could also be applied in the field of psychiatry (Muzik et al., 2018).

In the sport context, it is important to stress that breathing and self-control techniques, although with physiological consequences, are based on cognitive-behavioural methodology, aimed to treat the symptoms and not the cause of the problem. In particular, relaxation techniques will not solve conflicts related to athletes' emotional or family problems that caused the anxiety disorder, but they will eliminate or reduce the impact of anxiety on athletes' performance. The relaxation techniques based on breathing control are particularly effective for controlling stress in the resumption of physical activity after injuries or accidents on the field (Reesee et al., 2012). The awareness that the athlete's psychology is not exclusively related to sports performance during training or competition but also to his whole life and personality has led to a more complex meaning of the term "performance". In this wider context, it will be necessary to include not only all the situations directly related to physical activity, such as the mental state of an athlete in the period of rehabilitation from an injury but also all those situations not directly related to agonistic activities (Ford et al., 2017).

**Table 3.** Summary findings of different mindfulness techniques and their functions

| Study | Type of technique | Functions |
|---|---|---|
| Reese et al. (2012) | Relaxation techniques | Eliminate or reduce the impact of anxiety on athlete's performance |
| | Relaxation techniques based on breathing control | Effective for the control of stress in the resumption of physical activity after injuries or accidents on the field |
| Muzik et al. (2018) | Wim Hof method | Treatment of psychiatric disorders and autoimmune diseases |
| | Wim Hof method | Generate heat that is dissipated in the pulmonary tissue, controlling the temperature of the blood flow in the pulmonary capillaries |

## Conclusions

Most of the psychological literature regarding anxiety disorders in sports is principally related to the cognitive-behavioural aspects and rarely to other psychodynamic, narrative, humanistic, or existential approaches. Research in the field of sport psychology and psychiatry, going beyond the field of the physical body, does not have a clear epistemological address as organic medicine does. The scientific literature shows an association between breathing and panic disorder, even if a causal or unilateral relationship does not express this. An athlete has different options for recognizing a problem and dealing with it. In this context, sport, with proper awareness, starting as an originating factor of anxiety disorder, could become even a primary or preferential treatment. This result could be achieved with different techniques that involve rational breathing, mindfulness, or relaxation techniques that can contrast anxiety disorders and even improve sports performance.

Finally, research is also concentrated on interesting results regarding the use of oral protection appliances for improving sports performance by enhancing respiratory function, though the influence of these appliances on the athlete's psychopathological background is still to be investigated.

Further literature analysis of sports experience related to psychodynamic treatments could relieve an interesting scenario, while future reviews should focus on establishing the impact of the physio-psychological aspect in each kind of sport activity.

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**Conflict of Interest**
The authors declare that there are no conflicts of interest.

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REVIEW PAPER

# The Effects of Different Exercise Programmes on Body Composition and Body Mass in Adults: A Review Article

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**Abstract**

The present systematic review will compile, analyse, and synthesize current results regarding the effects of various exercise programmes on body composition and body mass. Method: searching electronic databases such as PubMed, MEDLINE, Google Scholar, ScienceDirect, ERIC and compiling studies on the effects of various exercise programmes on reduction of body mass and changes to body composition. The range of the dates of publication is 1994–2020. The studies included healthy adult individuals and excluded values for body weight. Results: based on 16 analysed studies outlining the advantages of aerobic programmes for reductions in body mass and endurance resistance programmes for improvement in body composition parameters, a combined type of exercise is recommended as the best option. The recorded intensity of exercise ranged from 40–80% of maximum heart rate (MaxHR), with a weekly workout frequency of 3–5 times for 40–60 min, for six to 48 weeks. Moderate-intensity aerobic training of 60% MaxHR gave the best results for reducing body mass, while interval training with greater intensity of 80% MaxHR showed inconsistent results. Circuit resistance training indicated both positive and negative results for improvement in body composition parameters; exercise intensity varied from 50–70% MaxHR. Conclusion: various exercise programmes provide an effective group type of work, leading to significant effects in reducing body mass and positive changes in body composition.

***Keywords:*** *body composition, physical activity, effects, exercise programmes, weight loss*

## Introduction

Physical activity is connected to body weight, body composition, and physical fitness and is defined as any movement made by activating the skeletal muscles, which causes energy consumption (Caspersen, Powell, & Christenson, 1985). Physical exercise is defined as a planned and systematic activity whose aim is to maintain or improve health, body composition, and mass (Caspersen et al., 1985). In addition, physical exercise is one of the most important types of behaviour that controls and regulates body mass in the long run (Wadden et al., 1997; Pronk & Wing, 1994). In contrast to that, a sedentary lifestyle, changes in diet and, as the most important factor, physical inactivity, lead to obesity. Obesity is an illness defined as increased mass depots in the human body, leading to health issues (World Health Organization, 2000). Being overweight is not the only problem caused by physical inactivity; there are also changes to body composition to be considered. The relative values of the muscles, fat, water, bone content, as well as the other vital parts of the human body as the parameters of body composition, precisely indicate the state of health of individuals, and as such must be monitored and analysed during physical exercise programmes (Corbin, Pangrazi, & Franks, 2000).

Various physical exercise programmes have been applied and studied over time; most of them are aerobic (Drobnik-Kozakiewicz, Sawczyn, Zarebska, Kwitniewska, & Szumilewicz, 2013; Patel et al., 2017), strength endurance

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training (Bryner et al., 1999; Faigenbaum & Westcott, 2009), and combined training types (Ballor, Harvey-Berino, Ades, Cryan, & Calles-Escandon, 1996; Kim et al., 2016). There are also various types of training, such as circuit training, which includes various stations at which exercises are performed sequentially and for which rest depends on each exercise. Each station covers a different region of the body and only one set of exercises (Kim et al., 2018; Mosher, Underwood, Ferguson, & Arnold, 1994). Interval training focuses attention on high-intensity intervals, which are reduced during training, after which short breaks or lower intensity exercise is implemented (Bishop, 2013; Pourabdi, Shakeriyan, Pourabdi, & Janbozorgi, 2013; Elmer, Laird, Barberio, & Pascoe, 2016).

Since being overweight has gone global as a problem, numerous researchers have studied the effects of various forms of exercise programmes on the changes in body composition and reduction in body mass. In order to draw conclusions from a large number of existing studies, it is necessary to provide a systematic review and generate a conclusion. Thus, this systematic review aims to compile, analyse, and synthesize existing research results that focus on the effects of various exercise programmes on body composition and reduction in body mass.

## Methods

To search the existing literature, the following electronic databases were used: PubMed, MEDLINE, Google Scholar, ScienceDirect, ERIC, from 1994 to 2020. The search was carried out using the following key terms: body composition, physical activity, effects, exercise programmes, and weight loss. The research strategy was modified for each electronic database, where possible, to increase sensitivity. Furthermore, all the titles and abstracts were reviewed for potential studies that could be included in the systematic review. In addition, the lists of references of previous reviews and original research papers were also analysed.

The relevant studies were obtained following a detailed overview by three authors if they met the criteria for inclusion. The inclusion and exclusion criteria will be described.

*Inclusion criteria*
*Type of study*

Non-controlled randomized and non-randomized longitudinal studies of the effects of different exercise programmes on body composition and reduction of body mass, along with studies written in English, were all included in the analysis.

*The sample of participants*

The participants included both sexes, age 19–63 years: their health status was healthy without deformities and chronic diseases that affect normal movement functions and performing different exercises. The exception to the disease that was included was the overweight subjects.

*Type of intervention*

Studies that determine the effects of different exercise programmes on body composition and body-weight reduction.

*Type of output results*

Studies were included if effects and changes after the application of different exercise programmes to body composition and weight reduction are shown.

*The exclusion criteria*

The exclusion criteria included: a) studies that included participants younger than 19 and older than 63 years; b) studies that examined only the impact of diet; c) if the study did not analyse the effect of at least one exercise programme of the subjects.

## Results

The search identified 756 potentially relevant studies, and another eight were identified by reviewing the references. After the duplicate studies were removed and the titles and abstracts analysed, 75 studies remained. Finally, by reviewing their entire texts, according to the criteria for inclusion, 16 studies remained. Figure 1 represents the schematics of the process for compiling, analysing and eliminating studies.

In Table 1 are shown 16 studies, which are presented by references-years, subjects, type of exercise programme, method-test and results.

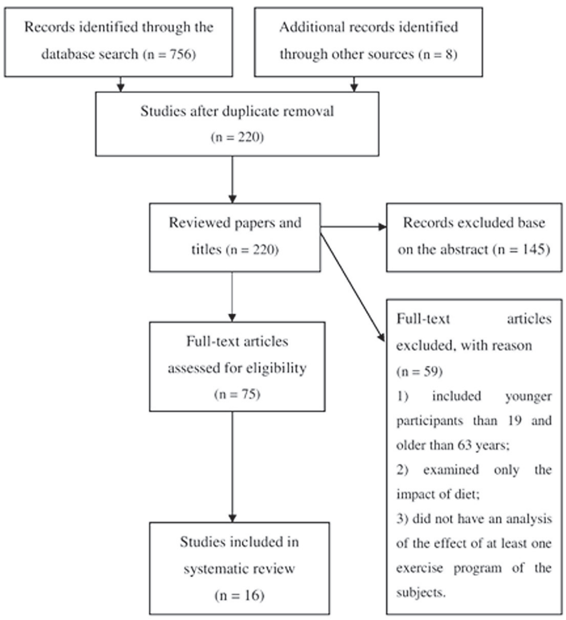


FIGURE 1. A diagram of the course of analysis of the papers

**Table 1.** Systematic review and characteristic of included studies

| Author and year | Subjects | | | | Exercise program | Method and measured variables | Results |
|---|---|---|---|---|---|---|---|
| | n | Gender (M F) | Age | Group-Type of program | Duration and description | Test | |
| Geliebter et al. (1997) | 65 | M-25 F-40 | 19-48 | E1-20-Tr S+Dc; E2-23-A Tr+Dc; E3-22-Dc | 8 W (3 times per W by E1-60 min and E2-30 min)- 8 exercises 3 sets × 6 reps; I-70% MaxHR | RMR, BS, BM, PsT, BC, ST, Dc and VO2peak BIA, MMS, Q, Ca, Ds, Treadmill and Cycle ergometer | ↓ BM between groups no statistically significant result, E1 smallest ↓ FFM (p=0.05) relative to E2 and E3, in all 3 groups ↓ BF, E1, ↑ MM in arms ($p < 0.05$) relative to E2 and E3. |
| Ballor et al. (1996) | 18 | M-8 F-10 | 61±1 | E1-9-Tr S; E2-9-A Tr | 12 W (3 times per W by E1-60 min and E2-20-60 min)- 8 exercises 3 sets × 6 reps; I-50% MaxHR | RMR, BC, Du, 1RM and VO2peak BIA, MMS and Treadmill. | ↓ BM in E2 (p<.05), (-2.5 -+ 0.6 kg) relative to E1 (0.4 -+ 0.9 kg)(p=0,05). In E2, 8 out of 9 subjects were additionally ↓ BM, and 6 out of 9, in E1 ↑ BM ↑ 1RM in E1 (p=0,05), FFM in E1 (1.5 -+ 0.8) are different (p<0.05) from E2 (-0.6 +_ 0.4). ↓ BF in E2 (p<0.05) for 5%, while in ↨ E1. |
| Kim et al. (2016) | 28 | M-17 F-11 | 19-35 | E1-10-A Tr; E2-10-Tr S; C-8 | 8 W (5 times per W by E1and E2-60 min)- 11 exercises 3 sets × 10-12, I-65-80% of 1RM reps; I-65-80% MaxHR | RMR, BS, PsT, WC, MM, BC, MS, Du and VO2peak BIA, Ultrasound, Q, Treadmill, Cycle ergometer, MMS, ISO and Ds. | E1and E2 have significant differences in BC, BM, BMI, BF, MM relative to C. There are negative r between BS and BF (r=−0.407, p=0.031). |
| Elmer et al. (2016) | 12 | M-12 | 19-23 | E1-6-A Tr; E2-6-A Tr | 8 W (3 times per W by E1and E2-30 min)- I-70% -80%; and intervals- 1min 50%-100% | BS, BC, MS, Du, VVO2max and VO2peak Treadmill, DEXA, Ds and St. | E2, ↓ in android type BF, 36.78 ± 9.60 to 34.18 ± 11.39 % (p=0.046). While in E1, ↨ (34.98 ± 8.23–33.13 ± 9.87 %, p=0.24) or between groups, (p=0.67), or not in BM inside and between groups (E1- 81.9 ± 10.0–80.6 ± 9.5 kg, p = 0.24; E2-90.2 ± 21.1–90.6 ± 21.9 kg, p=0.65; between groups, p = 0.21), %Fat (E1-28.23 ± 7.03–27.32 ± 7.66 %,p=0.21; E2- 27.90 ± 7.97–26.37 ± 9.01 %, p=0.10; between groups, p=0.55), also in gynoid type BF (E1-33.97 ± 6.45–33.97 ± 7.38 %, p=1.00; E2 32.15 ± 7.63–31.13 ± 8.43 %, p=0.55, between groups, p=0.55), Lbm (E1- 24.1 ± 4.4–26.3 ± 8.1 kg,p=0.54; E2 32.0 ± 10.2–31.3 ± 10.9 kg, p=0.93). |
| Wadden et al. (1997) | 128 | F-128 | 41.1±8.6 | E1-29-Dc; E2-31-A Tr+Dc; E3-31-Tr S+Dc; E4-29-A Tr,Tp S+Dc | 48 W (3 and 2-3 times per W by E2, E3 and E4-60 min)- 10 exercises 2 sets × 10-14 reps; moderate I | REE, BC, BM and Dc BIA, MMS, St and Ds. | E1, E2, E3 and E4 had average value of ↓ BM, 16.5 ± 6.8 kg in 24th W, which ↑15.1 ± 8.4 kg in 48th W, p=0.001. All subjects had significant changes in FFM and BF. |
| Kostrzewa-Nowak et al. (2015) | 34 | F-34 | 19-24 | E1-10; E2-12 and E3-12-A Tr (by BMI) | 12 W (3 times per W by E1, E2 and E3-60 min)- I-50%-65% MaxHR. | BS, BM, BC, BMI, ST, Du,VO2peak and VO2/AT BIA, Ca, Cycle ergometer, and Ds. | A Tr in all E1, E2 and E3 ↓ BM (for 4.3 kg, p=0.003), BMI (for 1.3 kg/m2, p=0.003), FFM (for 2.1 kg, p=0.002), total water (for 0.4 kg, p=0.036), %fat (for 3%, p=0.002), ST ↓E1 in BM (for 4.2 kg, p=0.005), BMI (for 0.9 kg/m2, p=0.005), ST (for 3.3 mm, p=0.028 |
| Drobnik-Kozakiewicz et al. (2013) | 19 | F-19 | 19-21 | E1-19-A Tr | 10 W (3 times per W by E1-60 min)-I-70% MaxHR. | BM, BC, BMI and VO2peak BIA, Cycle ergometer, ISO and Ds | ↨ BC and BMI. |

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**Table 1.** Systematic review and characteristic of included studies

| Author and year | Subjects | | | | Exercise program | Method and measured variables | Results |
|---|---|---|---|---|---|---|---|
| | n | Gender (M F) | Age | Group-Type of program | Duration and description | Test | |
| Pourabdi et al. (2013) | 26 | F-26 | 19-23 | E1-16-A Tr; C-10 | 6 W (3 times per W by E1-30 min)-interval 4 sets by 4 min and 30s, I- 60-75% MaxHR. | BM, BC, BMI, ST, Du and VO2peak BIA, Treadmill, Ca and Ds | ↓ E1 for %BF, 35.72±1.67% to 34.34±1.7 %, (p≤0.05). Mean and St.deviation at ↓BM 69.88±6.11 and 65.5±6.15, and also ↓ at BMI, (p≤0.05), ↨ in Lbm (p=0.234). |
| Fleck et al. (2006) | 12 | F-12 | 39-44 | E1-12-A Tr+Tr S | 14 W (3 times per W by E1-60 min)-11 exercises 1-3 sets × 8-12 reps; I-60-70% MaxHR | BM, BC, BMI, MS, 1RM, VO2peak and Du Treadmill, DEXA and Ds. | ↑ in7-th W before and training time (13.1%–17.8%), between training time and after (10.8%–14.1%), and between, before and after training time (25.5%–30.9%), ↓ % BF (1.4%) and Lbm (2.2%), (p≤0.05). Positive r before and after test in 1RM in 3 exercise and Lbm (r=0.58–0.90) |
| Paoli et al. (2010) | 40 | M - F | 56±2.7 | E1-10-Tr S; E2-10-A Tr+Tr S; E3-10-A Tr+Tr S; C-10 | 12 W (3 times per W by E1, E2 and E3-50 min)-6 exercises 3 sets × 15 reps; I-65-75% MaxHR | BM, BC, BMI, MS, BS, 1RM, WC, VO2peak and Du Treadmill, Ca and Ds | ↓ E2 and E3 relative to C in BM, ↓ E3 in %BF relative to E1 and E2, ↓ E3 in WC relative to C, (p=0.05). |
| Mosher et al. (1994) | 33 | F-33 | 18-23 | E1-17-A Tr +Tr S; C-16 | 12 W (3 times per W by E1-45 min)-15 exercise I-40-50% of 1RM; I-75-85% MaxHR | BM, BC, BMI, MS, 1RM, ST, Du and VO2peak Treadmill, Ca and Ds. | A Tr (interval) +Tr S, ↑ BC, while ↓ ST and %BF (p≤0.05). |
| Butts & Price (1994) | 95 | F-95 | 30-63 | E1-68-Tr S; C-27 | 12 W (3 times per W by E1-60 min)-12 exercises 3 sets × 8-12 reps | BM, BC, MS, ST and Du Hydrostatic tank, Ca and Ds | ↓E, in %BF and ST, (p<0.001) while ↑ BC-FFM, and ↨BM, ↑MS shows most progress in body parts that had weakest results on initial measurement. |
| Kim et al. (2018) | 20 | F-20 | 20-27 | E1-10-Tr S; C-10 | 12 W (3 times per W by E1-60 min)-10 exercises 3 sets × 8-12 reps I-50-70% MaxHR | BM, BC, BS, BMI, MS, WC and Fl BIA, ISO and Ds | ↓E1, in BM (F=11.954, p<0.05), %BF (F=15.110, p<0.05), and BMI (F=12.182, p<0.05) relative to C, but ↨ Lbm (F=0.088, p=0.968). |
| Sperlich et al. (2017) | 19 | F-19 | 21-25 | E1-11-Tr S+A Tr; C-8 | 9 W (3 times per W by E1-60 min)-3 sets × 20-60s reps, I-65% MaxHR | BM, BC, BMI, WC, MS, BS, PsT and VO2peak BIA, Q, Treadmill, and Ds | Both types of programs ↑ BM, BMI, WC, FM and FFM (p<0.05). |
| Kerksick et al. (2009) | 161 | F -161 | 38.5±8.5 | E1-11-Du+Tr S; E2-17; E3-48; E4-37 and E5-41-Dc+Tr S; C-7 | 14 W (3 times per W by E1-30 min)-14 exercises 2 sets × 30 s reps, I-60-80% MaxHR | BM, BC, BMI, WC, REE, MS, DT, PsT, BS, 1RM, DI(controlled) and VO2peak Treadmill, DEXA, MMS, Q and Ds | All E groups with Tr S and any type of D had changes relative to C, for ↓ WC (p<0.05 – 0.001), ↓ BM in E2, E4 and E5 (p<0.05 – 0.001) relative to other groups.↓ FM in E3 the most (95% CI: -5.2, -3.2 kg), E4 (-4.0, -1.9 kg) and E5 (-3.8, -2.1 kg) relative to other groups. ↓ %BF in E3, E4 and E5. |
| Bryner et al. (1999) | 20 | M-3 F-17 | 38 | E1-10-Dc+Tr S; E2-10-Dc+A Tr | 12 W (4 times per W by E1and E2-60 min)-10 exercises 3 sets × 8-15 reps; I-free choice | BM, BC, BMI, RMR, 1RM, Dc and VO2peak Treadmill, MMS and Ds | ↑E1 and E2, ↓BM more in E2 then E1 (p=0.01), in ↓E1 for Lbm (51.3±10.7 to 47.3±7.0) (p=0.05), while ↨E2. |

Legend: E-experimental group; C-control group; Tr S-strength training (endurance with interval and circuit type) for (whole body with 6-11 exercises by 2-3 sets by 6-15 reps); A Tr-aerobic training (intensity are moderate-high, 50-80% MaxHR and interval type, 1-4 min intervals); Dc-diet controlled; Du- diet uncontrolled; I-intensity; BIA-bioelectrical impedance; Ds-digital scale; Ca-caliper; ST-skinfold thicknesses; BM-body mass; WC–waist circumference; BC-body composition (BF-body fat; MM-muscle mass; MS-muscle strength; Lbm-lean body mass-ratio of BM and BF; FM-free fat; FFM-fat-free mass; AF–abdominal fat; DT-tissue density); MaxHR-maximal heart rate; ISO-isokinetic strength by dynamometer; Fl-flexibility; VO2peak-peak oxygen consumption; VVO2max-maximal aerobic velocity; VO2/AT-anaerobic threshold; 1RM-one repetition maximums; RMR-resting metabolic rate; REE-resting energy expenditure; BS-parameters of blood sample; PsT-psychological test; Q-questionnaire; St-stadiometer; DEXA– duel energy X-ray absorptiometry; MMS-metabolic measurement system; BMI-body mass index; M-man; F-female; W-week; n-number of subjects; r–corelation; p-statistical significance; s–seconds; m–meter; Kg–kilogram; min-minute; ↓-decrease; ↑-increase; ↨-no changes

## Discussion

Participating in physical activity and adequate exercise programmes can ensure a positive effect on the body composition parameters, as well as help maintain body weight within the framework of normal values. Aerobic exercise programmes and strength endurance training, which is either circuit or interval in nature, contribute to that aim (Wadden et al., 1997).

Based on the results compiled from existing studies, we can unambiguously conclude that overweight individuals, individuals with a disbalance in the homeostasis of body composition, and individuals trying to prevent obesity should participate in prescribed physical exercise programmes. In addition, we should mention the trend indicated in existing literature in which the monitoring and control of one's diet accompanied with physical exercise contribute to achieving the best effects (Bryner et al., 1999).

The results of studies that focused on aerobic exercise programmes indicate positive effects on the reduction in body mass and improvement in the parameters of body composition (Pourabdi et al., 2013; Kostrzewa-Nowak et al., 2015; Elmer et al., 2016). For example, Pourabdi et al. (2013) implemented an interval training programme on 16 participants for a six-week period. Four sets on a treadmill, with interval intensity ranging from 60–75% of MaxHR three times a week, led to positive effects. The results also indicate a significant decrease in the percentage of body fat from 35.72±1.67% to 34.34±1.7%, ($p \leq 0.05$), the average value of body mass 69.88±6.11 and 65.5±6.15, and values of BMI ($p \leq 0.05$).

Elmer et al. (2016) implemented an eight-week exercise programme on a small sample of participants (12). It also included an interval method on the treadmill, with an interval intensity of 1 min at a tempo of 50% and the second min at 100%, then 50% up to 110%, and another moderate-intensity method, which ranged from 70% to 80% of the maximum aerobic running speed. The results of the moderate programme indicate a significant decrease in the android type of participants in terms of the percentage of body fat 36.78±9.60 up to 34.18±11.39%, (p=0.046). Unlike in previous results, this interval method did not lead to significant changes (34.98±8.23–33.13±9.87%, p=0.24) either between groups (p=0.67), or in body mass within and between groups (E1(interval)- 81.9±10.0–80.6±9.5 kg, p=0.24; E2(moderate)- 90.2±21.1–90.6±21.9 kg, p=0.65; between groups p=0.21), nor in the gynoid type for the percentage of body fat (E1 (interval)- -33.97±6.45–33.97±7.38 %, p=1.00; E2 (moderate) 32.15±7.63–31.13±8.43 %, p=0.55, between groups p=0.55), lean body mass (E1(interval) - 24.1±4.4–26.3±8.1 kg, p=0.54; E2 (moderate) 32.0±10.2–31.3±10.9 kg, p=0.93).

In contrast to the results obtained by Elmer et al. (2016), the results of Kostrzewa-Nowak et al. (2015) followed 12 weeks of interval method training indicate positive effects on 34 female participants in three variations of training intensity, which were ascribed to groups of participants based on their BMI. The intensity was 50%, 55%, 60%, and 65% of the maximum heart rate. The results for all the participants indicate a significant decrease in body mass (by 4.3 kg, p=0.003), BMI (by 1.3 kg/m2, p=0.003), FFM (by 2.1 kg, p=0.002), total water content (by 0.4 kg, p=0.036), percentage of body fat (by 3%, p=0.002), skinfolds, while the group with normal BMI values did not show significant changes, and instead maintained the same values. Changes in the undernourished group of female participants in terms of values of body mass improved (by 4.2 kg, p=0.005), BMI (by 0.9 kg/m2, p=0.005), skinfolds (by 3.3 mm, p=0.028).

In contrast to the previous findings, Fleck et al. (2006) did not determine significant changes in the decrease of body mass and BMI, nor did Drobnik-Kozakiewicz et al. (2013) in the parameters of body composition and BMI. Fleck et al. (2006), in addition to aerobic training of an intensity of 60-70% of MaxHR, included three sets of full-body strength endurance training for 60 min but still did not obtain positive effects among their female participants. The only significant decrease was noted in the percentage of body fat (1.4%) and lean body mass (2.2%), ($p \leq 0.05$). An increase in strength was noted along with regional changes in upper body composition ($p \leq 0.05$). In the study of Drobnik-Kozakiewicz et al. (2013), a step aerobics programme at 70% of MaxHR over 10 weeks did not lead to significant changes in the BMI or body mass.

The second group of studies focused on the effects of strength endurance training (J. W. Kim, Ko, Seo, & Y. P. Kim, 2018; Butts & Price, 1994). Butts and Price (1994) implemented full-body circuit training on adult female participants (68) for 12 weeks, three times a week for 60 min. Like the results of the aerobic programme, these results also indicate positive effects on the reduction of the percentage body fat and skinfolds ($p<0.001$). In addition, an increase in the FFM parameter of body composition was noted, body mass remained the same, while an improvement in the muscle power of the body parts, which were the weakest at the initial testing, was determined. The same results were noted in the study of Kim et al. (2018), which also included female participants (10), based on full-body strength endurance training, which was carried out over three weekly sets of 60 min each for 12 weeks. The intensity of training was set at 50-70% of MaxHR. A significant decrease was noted in: body mass (F=11.954, $p<0.05$), percentage body fat (F=15.110, $p<0.05$), WC (F=13.951, $p<0.05$) and BMI (F=12.182, $p<0.05$) compared to the control group.

Interesting strength training and aerobic training combinations were also studied (Sperlich et al., 2017; Kim et al., 2016; Mosher et al., 1994; Paoli et al., 2010). A combination of both training programmes in the study of Sperlich et al. (2017) was implemented on female participants (10) during a nine-week programme. The intensity of the strength-endurance training was set at 65% of MaxHR, and moderate intensity, as defined on the Borg scale. Both types of programmes significantly decreased body mass, BMI, waist circumference, and FM, and led to an improvement in FFM and muscle strength ($p<0.05$). A study of similar duration was carried out by Kim et al. (2016) for eight weeks, with training sessions five times a week for 60 min, in which the participants trained following prescribed programmes. The same intensity of 65-80% of the maximum load was set. The results confirmed the positive effects of both types of programmes on body composition parameters, BMI, reduction in body mass, amount of body fat, and muscle mass compared to the control group ($p<0.005$). In addition, a positive correlation was noted between haematological parameters and muscle mass (r=0.432, p=0.022) and a negative correlation between haematological parameters and body fat (r=–0.407, p=0.031). A higher intensity combination training of 85% 1RM for 12 weeks with 60 min training sessions was included in the study of Mosher et al. (1994), which showed positive changes among the female participants. A significant increase in maximum oxygen uptake, muscle strength, improvement in body composition, decreased skinfolds, and percentage of body fat (p≤0.05) was also noted. A greater mixed sample of participants in Paoli et al. (2010), following the same programme duration at an intensity of 65% of MaxHR, also experienced an improvement in body mass, percentage body fat, and waist circumference compared to the control group (p=0.05).

Extensively detailed studies that included controlling the participants' diet and their calorie intake along with combined or individual aerobic programmes and strength endurance training have also noted positive changes (Geliebter et al., 1997; Wadden et al., 1997; Kerksick et al., 2009; Bryner et al., 1999). A study was carried out on a large sample of female participants (161) divided into five groups (Kerksick et al., 2009). It included full-body strength endurance training divided over two sets at an intensity of 60–80% of MaxHR over 14 weeks, combined with five different diets. Significant changes were noted for all groups compared to the control, including waist circumference (p<0.05–0.001) and body mass, for groups E2, E4, and E5 (p<0.05 – 0.001) compared to others. In addition, the greatest loss decrease noted for FM for group E3 (95% CI: -5.2, -3.2 kg), E4 (-4.0, -1.9 kg) and E5 (-3.8, -2.1 kg) relative to other groups. In addition to a decrease in the percentage of body fat for groups E3, E4 and E5, all groups exhibited an improvement in muscle strength, (p<0.05). A complex study that analysed and included 128 female participants lasted the longest, for 48 weeks, and included diets and combined exercisers programmes, aerobic and strength endurance training for four groups (Wadden et al., 1997). Moderate training intensity, which included 40 min of aerobic and 60 min of circuit resistance training over two sets, proved to have significant effects on all groups, leading to a decrease in the mean values of body mass of 16.5±6.8 kg in week 24, which increased to 15.1±8.4 kg in week 48, p=0.001. All of the participants showed signs of significant changes in body composition-FFM and body fat. The difference noted between the aerobic and strength endurance training programmes was reflected in the significant decrease in energy consumption at rest in week 24, favouring the aerobic programme group.

Overall, the results indicate generally positive effects of various programmes on the reduction of body mass and changes in body composition of the participants, except for the results obtained in two studies, Geliebter et al. (1997) and Fleck et al. (2006), which showed no signs of a reduction in body mass.

## Conclusion

Based on all analysed studies, a general conclusion was defined, indicating that both aerobic exercise programmes and strength endurance training programmes have a very effective group type of work, which leads to a positive impact on body weight loss and improvements in body composition parameters. The advantage of aerobic exercise is the possibility of greater weight loss, while the advantage of strength training is the greater improvement in the parameters of body composition, made possible by the decrease in the percentage of body fat while maintaining body weight in the normal value range for adult participants. Both types of exercise programmes, for 12 weeks, three times per week with moderate intensity 50-75% MaxHR, had shown better results than others programme variations. It can also be noted that a short programme protocol of six to eight weeks of interval type aerobic training leads to similar positive effects on body weight with the same training duration and frequency.

Finally, based on all the results of the studies, we can conclude that different physical exercise programmes contribute to the decrease in overweight mass and to maintaining normal body weight by reducing the amount of adipose tissue and improving metabolic processes in the human body, which leads to reductions in the body mass index values, thus lowering the risk of obesity and improving all the haematological parameters and quality of life of adults.

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**Conflict of interest**
The authors declare that there are no conflicts of interest.

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# Guidelines for Authors

Revised September 2019

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Original Scientific Paper

Elite Soccer Players from Montenegro

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Word count: 2,946

Abstract word count: 236

Number of Tables: 3

Number of Figures: 0

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All authors are required to provide word count (excluding title page, abstract, tables/figures, figure legends, Acknowledgements, Conflict of Interest, and References), the Abstract word count, the number of Tables, and the number of Figures.

## 2.2. Abstract

The second page of the manuscripts should be the abstract and key words. It should be placed on second page of the manuscripts after the standard title written in upper and lower case letters, bold.

Since abstract is independent part of your paper, all abbreviations used in the abstract should also be explained in it. If an abbreviation is used, the term should always be first written in full with the abbreviation in parentheses immediately after it. Abstract should not have any special headings (e.g., Aim, Results…).

Authors should provide up to six key words that capture the main topics of the article. Terms from the Medical Subject Headings (MeSH) list of Index Medicus are recommended to be used.

Key words should be placed on the second page of the manuscript right below the abstract, written in italic. Separate each key word by a comma (and a space). Do not put a full stop after the last key word. *See* example:

**Abstract**

Results of the analysis of

***Key words:*** *spatial memory, blind, transfer of learning, feedback*

## 2.3. Main Chapters

Starting from the third page of the manuscripts, it should be the main chapters. Depending on the type of publication main manuscript chapters may vary. The general outline is: Introduction, Methods, Results, Discussion, Acknowledgements (optional), Conflict of Interest (optional). However, this scheme may not be suitable for reviews or publications from some areas and authors should then adjust their chapters accordingly but use the general outline as much as possible.

#### 2.3.1. Headings

Main chapter headings: written in bold and in Title Case. *See* example:
- ✓ **Methods**

Sub-headings: written in italic and in normal sentence case. Do not put a full stop or any other sign at the end of the title. Do not create more than one level of sub-heading. *See* example:
- ✓ *Table position of the research football team*

#### 2.3.2 Ethics

When reporting experiments on human subjects, there must be a declaration of Ethics compliance. Inclusion of a statement such as follow in Methods section will be understood by the Editor as authors' affirmation of compliance: "This study was approved in advance by [name of committee and/or its institutional sponsor]. Each participant voluntarily provided written informed consent before participating." Authors that fail to submit an Ethics statement will be asked to resubmit the manuscripts, which may delay publication.

#### 2.3.3 Statistics reporting

SM encourages authors to report precise p-values. When possible, quantify findings and present them with appropriate indicators of measurement error or uncertainty (such as confidence intervals). Use normal text (i.e., non-capitalized, non-italic) for statistical term "p".

#### 2.3.4. 'Acknowledgements' and 'Conflict of Interest' (optional)

All contributors who do not meet the criteria for authorship should be listed in the 'Acknowledgements' section. If applicable, in 'Conflict of Interest' section, authors must clearly disclose any grants, financial or material supports, or any sort of technical assistances from an institution, organization, group or an individual that might be perceived as leading to a conflict of interest.

## 2.4. References

References should be placed on a new page after the standard title written in upper and lower case letters, bold.

All information needed for each type of must be present as specified in guidelines. Authors are solely responsible for accuracy of each reference. Use authoritative source for information such as Web of Science, Medline, or PubMed to check the validity of citations.

#### 2.4.1. References style

SM adheres to the American Psychological Association 6th Edition reference style. Check "American Psychological Association. (2009). Concise rules of APA style. American Psychological Association." to ensure the manuscripts conform to this reference style. Authors using EndNote® to organize the references must convert the citations and bibliography to plain text before submission.

#### 2.4.2. Examples for Reference citations

One work by one author
- ✓ In one study (Reilly, 1997), soccer players
- ✓ In the study by Reilly (1997), soccer players
- ✓ In 1997, Reilly's study of soccer players

Works by two authors
- ✓ Duffield and Marino (2007) studied
- ✓ In one study (Duffield & Marino, 2007), soccer players
- ✓ In 2007, Duffield and Marino's study of soccer players

Works by three to five authors: cite all the author names the first time the reference occurs and then subsequently include only the first author followed by et al.

- ✓ First citation: Bangsbo, Iaia, and Krustrup (2008) stated that
- ✓ Subséquent citation: Bangsbo et al. (2008) stated that

Works by six or more authors: cite only the name of the first author followed by et al. and the year

- ✓ Krustrup et al. (2003) studied
- ✓ In one study (Krustrup et al., 2003), soccer players

Two or more works in the same parenthetical citation: Citation of two or more works in the same parentheses should be listed in the order they appear in the reference list (i.e., alphabetically, then chronologically)

- ✓ Several studies (Bangsbo et al., 2008; Duffield & Marino, 2007; Reilly, 1997) suggest that

**2.4.3. Examples for Reference list**

Journal article (print):

Nepocatych, S., Balilionis, G., & O'Neal, E. K. (2017). Analysis of dietary intake and body composition of female athletes over a competitive season. *Montenegrin Journal of Sports Science and Medicine, 6*(2), 57-65. doi: 10.26773/mjssm.2017.09.008

Duffield, R., & Marino, F. E. (2007). Effects of pre-cooling procedures on intermittent-sprint exercise performance in warm conditions. *European Journal of Applied Physiology, 100*(6), 727-735. doi: 10.1007/s00421-007-0468-x

Krustrup, P., Mohr, M., Amstrup, T., Rysgaard, T., Johansen, J., Steensberg, A., Bangsbo, J. (2003). The yo-yo intermittent recovery test: physiological response, reliability, and validity. *Medicine and Science in Sports and Exercise, 35*(4), 697-705. doi: 10.1249/01.MSS.0000058441.94520.32

Journal article (online; electronic version of print source):

Williams, R. (2016). Krishna's Neglected Responsibilities: Religious devotion and social critique in eighteenth-century North India [Electronic version]. *Modern Asian Studies, 50*(5), 1403-1440. doi:10.1017/S0026749X14000444

Journal article (online; electronic only):

Chantavanich, S. (2003, October). Recent research on human trafficking. *Kyoto Review of Southeast Asia, 4*. Retrieved November 15, 2005, from http://kyotoreview.cseas.kyoto-u.ac.jp/issue/issue3/index.html

Conference paper:

Pasadilla, G. O., & Milo, M. (2005, June 27). *Effect of liberalization on banking competition*. Paper presented at the conference on Policies to Strengthen Productivity in the Philippines, Manila, Philippines. Retrieved August 23, 2006, from http://siteresources.worldbank.org/INTPHILIPPINES/Resources/Pasadilla.pdf

Encyclopedia entry (print, with author):

Pittau, J. (1983). Meiji constitution. In *Kodansha encyclopedia of Japan* (Vol. 2, pp. 1-3). Tokyo: Kodansha.

Encyclopedia entry (online, no author):

Ethnology. (2005, July). In *The Columbia encyclopedia* (6th ed.). New York: Columbia University Press. Retrieved November 21, 2005, from http://www.bartleby.com/65/et/ethnolog.html

Thesis and dissertation:

Pyun, D. Y. (2006). *The proposed model of attitude toward advertising through sport.* Unpublished Doctoral Dissertation. Tallahassee, FL: The Florida State University.

Book:

Borg, G. (1998). *Borg's perceived exertion and pain scales*: Human kinetics.

Chapter of a book:

Kellmann, M. (2012). Chapter 31-Overtraining and recovery: Chapter taken from Routledge Handbook of Applied Sport Psychology ISBN: 978-0-203-85104-3 *Routledge Online Studies on the Olympic and Paralympic Games* (Vol. 1, pp. 292-302).

Reference to an internet source:

Agency. (2007). Water for Health: Hydration Best Practice Toolkit for Hospitals and Healthcare. Retrieved 10/29, 2013, from www.rcn.org.uk/newsevents/hydration

## 2.5. Tables

All tables should be included in the main manuscript file, each on a separate page right after the Reference section.

Tables should be presented as standard MS Word tables.

Number (Arabic) tables consecutively in the order of their first citation in the text.

Tables and table headings should be completely intelligible without reference to the text. Give each column a short or abbreviated heading. Authors should place explanatory matter in footnotes, not in the heading. All abbreviations appearing in a table and not considered standard must be explained in a footnote of that table. Avoid any shading or coloring in your tables and be sure that each table is cited in the text.

If you use data from another published or unpublished source, it is the authors' responsibility to obtain permission and acknowledge them fully.

### 2.5.1. Table heading

Table heading should be written above the table, in Title Case, and without a full stop at the end of the heading. Do not use suffix letters (e.g., Table 1a, 1b, 1c); instead, combine the related tables. *See* example:

- ✓ **Table 1.** Repeated Sprint Time Following Ingestion of Carbohydrate-Electrolyte Beverage

### 2.5.2. Table sub-heading

All text appearing in tables should be written beginning only with first letter of the first word in all capitals, i.e., all words for variable names, column headings etc. in tables should start with the first letter in all capitals. Avoid any formatting (e.g., bold, italic, underline) in tables.

### 2.5.3. Table footnotes

Table footnotes should be written below the table.

General notes explain, qualify or provide information about the table as a whole. Put explanations of abbreviations, symbols, etc. here. General notes are designated by the word *Note* (italicized) followed by a period.

- ✓ *Note.* CI: confidence interval; Con: control group; CE: carbohydrate-electrolyte group.

Specific notes explain, qualify or provide information about a particular column, row, or individual entry. To indicate specific notes, use superscript lowercase letters (e.g. [a, b, c]), and order the superscripts from left to right, top to bottom. Each table's first footnote must be the superscript [a].

- ✓ [a]One participant was diagnosed with heat illness and n = 19.[b]n =20.

Probability notes provide the reader with the results of the texts for statistical significance. Probability notes must be indicated with consecutive use of the following symbols: * † ‡ § ¶ || etc.

- ✓ *P<0.05,†p<0.01.

### 2.5.4. Table citation

In the text, tables should be cited as full words. *See* example:

- ✓ Table 1 (first letter in all capitals and no full stop)
- ✓ ...as shown in Tables 1 and 3. (citing more tables at once)
- ✓ ...result has shown (Tables 1-3) that... (citing more tables at once)
- ✓ ....in our results (Tables 1, 2 and 5)... (citing more tables at once)

## 2.6. Figures

On the last separate page of the main manuscript file, authors should place the legends of all the figures submitted separately.

All graphic materials should be of sufficient quality for print with a minimum resolution of 600 dpi. SM prefers TIFF, EPS and PNG formats.

If a figure has been published previously, acknowledge the original source and submit a written permission from the copyright holder to reproduce the material. Permission is required irrespective of authorship or publisher except for documents in the public domain. If photographs of people are used, either the subjects must not be identifiable or their pictures must be accompanied by written permission to use the photograph whenever possible permission for publication should be obtained.

Figures and figure legends should be completely intelligible without reference to the text.

The price of printing in color is 50 EUR per page as printed in an issue of SM.

#### 2.6.1. Figure legends

Figures should not contain footnotes. All information, including explanations of abbreviations must be present in figure legends. Figure legends should be written bellow the figure, in sentence case. *See* example:

- ✓ **Figure 1.** Changes in accuracy of instep football kick measured before and after fatigued. SR – resting state, SF – state of fatigue, *p>0.01, †p>0.05.

#### 2.6.2. Figure citation

All graphic materials should be referred to as Figures in the text. Figures are cited in the text as full words. *See* example:

- ✓ Figure 1
  - × figure 1
  - × Figure 1.
  - ✓ ….exhibit greater variance than the year before (Figure 2). Therefore…
  - ✓ ….as shown in Figures 1 and 3. (citing more figures at once)
  - ✓ ….result has shown (Figures 1-3) that... (citing more figures at once)
  - ✓ ….in our results (Figures 1, 2 and 5)... (citing more figures at once)

#### 2.6.3. Sub-figures

If there is a figure divided in several sub-figures, each sub-figure should be marked with a small letter, starting with a, b, c etc. The letter should be marked for each subfigure in a logical and consistent way. *See* example:

- ✓ Figure 1a
- ✓ …in Figures 1a and b we can…
- ✓ …data represent (Figures 1a-d)…

## 2.7. Scientific Terminology

All units of measures should conform to the International System of Units (SI).

Measurements of length, height, weight, and volume should be reported in metric units (meter, kilogram, or liter) or their decimal multiples.

Decimal places in English language are separated with a full stop and not with a comma. Thousands are separated with a comma.

| Percentage | Degrees | All other units of measure | Ratios | Decimal numbers |
|---|---|---|---|---|
| ✓ 10% | ✓ 10° | ✓ 10 kg | ✓ 12:2 | ✓ 0.056 |
| × 10 % | × 10 ° | × 10kg | × 12 : 2 | × .056 |

| Signs should be placed immediately preceding the relevant number. | | |
|---|---|---|
| ✓ 45±3.4 | ✓ p<0.01 | ✓ males >30 years of age |
| × 45 ± 3.4 | × p < 0.01 | × males > 30 years of age |

## 2.8. Latin Names

Latin names of species, families etc. should be written in italics (even in titles). If you mention Latin names in your abstract they should be written in non-italic since the rest of the text in abstract is in italic. The first time the name of a species appears in the text both genus and species must be present; later on in the text it is possible to use genus abbreviations. *See* example:

- ✓ First time appearing: *musculus biceps brachii*

Abbreviated: *m. biceps brachii*

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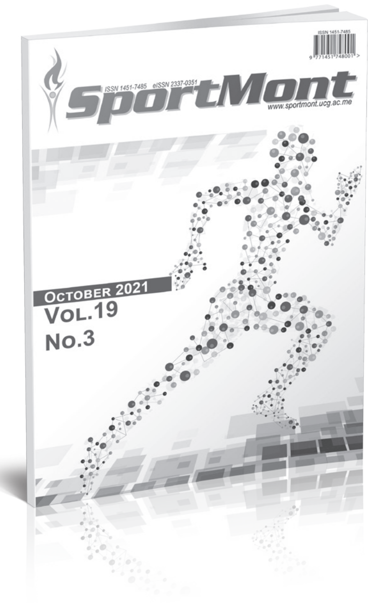


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- Fast publication time;
- Peer review by expert, practicing researchers;
- Post-publication tools to indicate quality and impact;
- Community-based dialogue on articles;
- Worldwide media coverage.

SM is published three times a year, in February, June and October of each year. SM publishes original scientific papers, review papers, editorials, short reports, peer review - fair review, as well as invited papers and award papers in the fields of Sports Science and Medicine, as well as it can function as an open discussion forum on significant issues of current interest.

SM covers all aspects of sports science and medicine; all clinical aspects of exercise, health, and sport; exercise physiology and biophysical investigation of sports performance; sport biomechanics; sports nutrition; rehabilitation, physiotherapy; sports psychology; sport pedagogy, sport history, sport philosophy, sport sociology, sport management; and all aspects of scientific support of the sports coaches from the natural, social and humanistic side.

Prospective authors should submit manuscripts for consideration in Microsoft Word-compatible format. For more complete descriptions and submission instructions, please access the Guidelines for Authors pages at the SM website: http://www.sportmont.ucg.ac.me/?sekcija=page&p=51. Contributors are urged to read SM's guidelines for the authors carefully before submitting manuscripts. Manuscripts submissions should be sent in electronic format to sportmont@ucg.ac.me or contact following Editors:

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**Zoran MILOSEVIC**, *Editor-in Chief – zoranais@eunet.rs*
**Jovan GARDASEVIC**, *Managing Editor – jovan@ucg.ac.me*

**Publication date:** Autumn issue – October 2021
Winter issue – February 2022
Summer issue – June 2022

# MONTENEGRIN SPORTS ACADEMY

Founded in 2003 in Podgorica (Montenegro), the Montenegrin Sports Academy (MSA) is a sports scientific society dedicated to the collection, generation and dissemination of scientific knowledge at the Montenegrin level and beyond.

The Montenegrin Sports Academy (MSA) is the leading association of sports scientists at the Montenegrin level, which maintains extensive co-operation with the corresponding associations from abroad. The purpose of the MSA is the promotion of science and research, with special attention to sports science across Montenegro and beyond. Its topics include motivation, attitudes, values and responses, adaptation, performance and health aspects of people engaged in physical activity and the relation of physical activity and lifestyle to health, prevention and aging. These topics are investigated on an interdisciplinary basis and they bring together scientists from all areas of sports science, such as adapted physical activity, biochemistry, biomechanics, chronic disease and exercise, coaching and performance, doping, education, engineering and technology, environmental physiology, ethics, exercise and health, exercise, lifestyle and fitness, gender in sports, growth and development, human performance and aging, management and sports law, molecular biology and genetics, motor control and learning, muscle mechanics and neuromuscular control, muscle metabolism and hemodynamics, nutrition and exercise, overtraining, physiology, physiotherapy, rehabilitation, sports history, sports medicine, sports pedagogy, sports philosophy, sports psychology, sports sociology, training and testing.

The MSA is a non-profit organization. It supports Montenegrin institutions, such as the Ministry of Education and Sports, the Ministry of Science and the Montenegrin Olympic Committee, by offering scientific advice and assistance for carrying out coordinated national and European research projects defined by these bodies. In addition, the MSA serves as the most important Montenegrin and regional network of sports scientists from all relevant subdisciplines.

Over the years the Montenegrin Sports Academy (MSA) has established a productive pool of vital partnerships within the sports science related industry. Apart from two-way visibility, these partnerships provide mutual exchange of scientific research and competence.

Most of the MSA activities and services it provides would not be possible without the continuous support of its partners.

The Montenegrin Sports Academy very much appreciates the support of:

Ministry of Science of Montenegro
Ministry of Education of Montenegro
Ministry of Health of Montenegro
University of Montenegro
Montenegrin Olympic Committee
Institute of Public Health of Montenegro
European College of Sports Science
Volleyball Federation of Montenegro
Faculty for Sport and Physical Education a University of Montenegro
Athletic Federation of Montenegro
Regional Diving Center
Karate Federation of Montenegro
Karate club "Budućnost"
Football Club "Sutjeska"
Football Club "Mladost"
Water Polo and Swimming Association of Montenegro

The main scientific event organized by the Montenegrin Sports Academy (MSA) is the annual conference held in the first week of April.

Annual conferences have been organized since the inauguration of the MSA in 2003. Today the MSA conference ranks among the leading sports scientific congresses in the Western Balkans. The conference comprises a range of invited lecturers, oral and poster presentations from multi- and mono-disciplinary areas, as well as various types of workshops. The MSA conference is attended by national, regional and international sports scientists with academic careers. The MSA conference now welcomes up to 200 participants from all over the world.

**CRNOGORSKI OLIMPIJSKI KOMITET**
**MONTENEGRIN OLYMPIC COMMITTEE**

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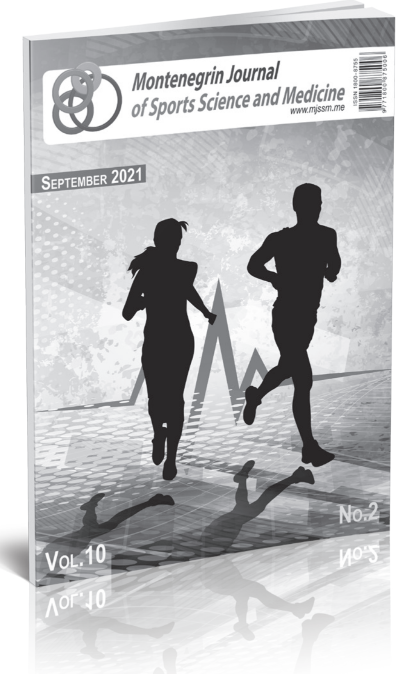
Montenegrin Journal of Sports Science and Medicine

# MONTENEGRIN JOURNAL OF SPORTS SCIENCE AND MEDICINE




ISSN 1800-8755

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Montenegrin Journal of Sports Science and Medicine (MJSSM) is a print (ISSN 1800-8755) and electronic scientific journal (eISSN 1800-8763) aims to present easy access to the scientific knowledge for sport-conscious individuals using contemporary methods. The purpose is to minimize the problems like the delays in publishing process of the articles or to acquire previous issues by drawing advantage from electronic medium. Hence, it provides:
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- Fast publication time;
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MJSSM is published biannually, in September and March of each year. MJSSM publishes original scientific papers, review papers, editorials, short reports, peer review - fair review, as well as invited papers and award papers in the fields of Sports Science and Medicine, as well as it can function as an open discussion forum on significant issues of current interest.

MJSSM covers all aspects of sports science and medicine; all clinical aspects of exercise, health, and sport; exercise physiology and biophysical investigation of sports performance; sport biomechanics; sports nutrition; rehabilitation, physiotherapy; sports psychology; sport pedagogy, sport history, sport philosophy, sport sociology, sport management; and all aspects of scientific support of the sports coaches from the natural, social and humanistic side.

Prospective authors should submit manuscripts for consideration in Microsoft Word-compatible format. For more complete descriptions and submission instructions, please access the Guidelines for Authors pages at the MJSSM website: http://www.mjssm.me/?sekcija=page&p=51. Contributors are urged to read MJSSM's guidelines for the authors carefully before submitting manuscripts. Manuscripts submissions should be sent in electronic format to office@mjssm.me or contact following Editors:

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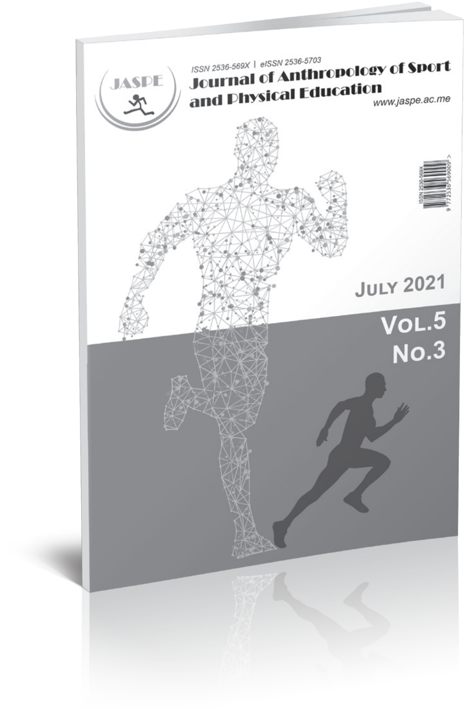
**Publication date:** Spring issue – March 2022
Autumn issue – September 2022

JASPE

# Journal of Anthropology of Sport and Physical Education

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Journal of Anthropology of Sport and Physical Education (JASPE) is a print (ISSN 2536-569X) and electronic scientific journal (eISSN 2536-5703) aims to present easy access to the scientific knowledge for sport-conscious individuals using contemporary methods. The purpose is to minimize the problems like the delays in publishing process of the articles or to acquire previous issues by drawing advantage from electronic medium. Hence, it provides:

- Open-access and freely accessible online;
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- Worldwide media coverage.

JASPE is published four times a year, in January, April, July and October of each year. JASPE publishes original scientific papers, review papers, editorials, short reports, peer review - fair review, as well as invited papers and award papers in the fields of Anthropology of Sport and Physical Education, as well as it can function as an open discussion forum on significant issues of current interest.

JASPE covers all aspects of anthropology of sport and physical education from five major fields of anthropology: cultural, global, biological, linguistic and medical.

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**Bojan MASANOVIC**, *Editor-in Chief – bojanma@ucg.ac.me*

**Publication date:** Autumn issue – October 2021
Winter issue – January 2022
Spring issue – April 2022
Summer issue – July 2022

# EAPA-BCH

SCIENTIFIC PROJECT

## Efekti autofagije i fizičke aktivnosti na tjelesnu kompoziciju, indeks tjelesne mase, stres, zdravstveno ponašanje, kognitivne sposobnosti i društvenu uključenost starijih osoba

**(Projekat finansiran od strane Ministarstva nauke, direktorijata za mlade, a koji sprovodi Fakultet za sport i fizičko vaspitanje Univerziteta Crne Gore)**

Glavni cilj projekta je da se primjenom naprednih praksi utvrde efekti autofagije i fizičke aktivnosti na tjelesnu kompoziciju, indeks tjelesne mase, trenutni nivo doživljaja stresa, zdravstveno ponašanje, kognitivne sposobnosti i nivo društvene uključenosti starijih osoba.

Projekat ima i svoj radni dio koji podrazumijeva organizovanje besplatnog vježbanja starijim osobama 3 puta nedeljno u trajanju od 6 mjeseci.

Učesnici mogu biti sve osobe iznad 50 godina a prijave se primaju na mail adresu fakultetzasportnk@ucg.ac.me i telefon fakulteta +38240235207. Svi su koji žele da uzmu aktivno učešće u ovom projektu koji njima može unaprijediti život, a naučnoj zajednici Crne Gore može donijeti značajna teorijska znanja koja će se u budućnosti koristiti u praktične svrhe su dobrodošli.

Svim učesnicim će na početku biti ponuđena najsavremenija dijagnostika, koja će im pružiti uvid u vlastito zdravstveno stanje, kako fizičko tako i kada su neki psihološki parametri u pitanju. Nakon toga će učesnici biti prema sopstvenim interesovanjima podijeljeni u grupe koje će raditi prema različitim programima.

1. Prva grupa će vježbati 3 puta nedeljno 6 mjeseci u prostorijama Fakulteta za sport i fizičko vaspitanje.

2. Druga će samo primjenjivati izmijenjeni način ishrane i voditi tačnu evidenciju o stepenu poštovanja zadataka koji im se postave. Ishrana će biti takva da se napravi pauza u unošenju hrane u trajanju 16 sati između poslednjeg dnevnog obroka i prvoga obroka u sledećem danu, a sve u cilju pokretanja procesa Autofagije koji ima blagotvorno dejstvo na organiza.

3. Treća grupa će kombinovati vježbanje i izmijenjenu ishranu, tj. biće kombinacija prethodno pomenutih zadataka.

4. Četvrta grupa će biti kontrolna. Njeni članovi će proći dijagnostiku i pomoći da se utvrdi kakve su prirodne promjene u organizmu za pomenuti šestomjesečni period, odnosno da li ih ima.

Svim prijavljenim osobama, koje imaju interesovanje za to, će prije poćetka rada biti održana dva predavanja o pomenutom izmijenjenom načinu ishrane koji danas postaje sve popularniji u svijetu pa ga primjenjuju i vrhunski sportisti poput Novaka Đokovića.

Još jednom treba napomenuti da će svaka od 4 grupe na poklon dobiti najsavremeniju dijagnostiku kompletnog psihofizičkog stanja koja je inače i nedostupna i skupa.

Prijavljivanje može da počne odmah, broj učesnika za grupe koje bi vježbale u prostorijama fakulteta je ograničen.

VLADA CRNE GORE
MINISTARSTVO NAUKE

Fakultet za sport i fizičko vaspitanje
Univerzitet Crne Gore

**Fakultet za sport i fizičko vaspitanje Univerziteta Crne Gore**
**Narodne omladine bb, Niksic, 81400, Montenegro**
**Mobile: +38267257393; Phone: +38240235207; Fax: +38240235207**

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CRNOGORSKA SPORTSKA AKADEMIJA

MONTENEGRIN SPORTS ACADEMY

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Dubrovnik - Croatia