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AN INTRODUCTION ON THE BENEFITS OF MOTOR AND SPORTS ACTIVITIES ON SENSORY PROCESSING IN CHILDREN WITH AUTISM SPECTRUM DISORDER (ASD)

Oana Rusu

Faculty of Physical Education and Sport, "Alexandru Ioan Cuza" University of Iasi, Iasi, Romania
ORCID: 0000-0002-7364-6473 | e-mail: broana@uaic.ro

Abstract: ASD is a neurodevelopmental disorder characterized by deficits in behavior and communication and social interaction of the diagnosed person, having negative consequences on functioning and performance in different areas. With different forms of manifestation and degrees of impairment, the individual with ASD presents difficulties in contextual and/or sensory perception of stimuli, which causes maladaptive responses from him/her, often accompanied by motor difficulties. The purpose of this article is to identify the existence of the benefits that the practice of motor and sports activities have on sensory processing in children with ASD. The results highlight that there are associations between sensory processing difficulties and motor impairments, even from the first years of life, with the motor and sensory areas being in neural connection and developing at the same time at an accelerated pace. Practicing motor and sports activities leads to improvements in different areas: physical and mental health, motor skills (oral and visual, gross and fine motor skills, manual dexterity, balance, ability to relax and control body movements), cognitive and sensory processing (memorization, sequencing, attention, cognitive flexibility, inhibitory control of body movements, academic performance), communication and social interaction skills (establishing and maintaining friendships, acceptance from others), adaptive behaviors (reduction of stereotyped and self-aggressive behaviors, self-stimulation, hyperkinetic behavior).

Key words: children with ASD, sensory processing, benefits of physical and sports activities, psychomotor development

Introduction

Autism spectrum disorder (ASD) is part of the group of neurodevelopmental disorders (Diagnostic and Statistical Manual of Mental Disorders -V, 2013) which are defined by the presence of two categories of symptoms: persistent impairments in communication and social interaction in multiple contexts, as well as patterns of behavior, interests, restrictive and repetitive activities. It is persistent throughout life, some symptoms can be observed in the first year of life, but most are visible between 1–2 years, the functioning and performances in the physical, mental, academic and social areas being negatively affected (Peeters, 2009).

Information integration processes (contextual and/or sensory perceptions) are unbalanced, which causes qualitative alterations in the areas of communication and behavior of an individual with ASD. The information received from the environment is taken up with the help of the sensory organs, the brain being able to process it

fragmented like separate puzzle pieces and different, unadapted and non-functional. It takes more time to adjust reactions, process and arrange information as a whole puzzle.

Several studies show that individuals with ASD have a spectrum of sensory processing disorders. They can be mildly affected (sensory differences) or more pronounced (sensory difficulties) going up to a severe impairment (sensory dysfunctions) (Ayres, 2005; Stock Kranowitz, 2022; Oster & Zhou, 2022). The individual's sensory systems (visual, auditory, vestibular, gustatory, olfactory, proprioceptive and tactile) process information from the environment differently, the brain of a child with ASD adapting the functional reactions differently. Depending on the degree of sensitivity to the stimuli received, the individual with ASD has different behaviors (hyper-reactivity, hypo-reactivity, sensation seeking).

Studies also show that a significant percentage of children with ASD have not only sensory difficulties, but motor difficulties as well, the neural connections between these areas being complex and dependent. Therefore, the introduction of motor and sports activities in intervention programs for children with ASD can positively influence the level of physical, mental, social motor health, as well as cognitive and sensory processes.

Materials and Methods

The purpose of this article is to identify the existence of positive effects that the practice of motor and sports activities have on sensory processing in children with ASD. For this, bibliographic references published in several databases (Web of Science, Scopus Database, PubMed, Google Scholar, ResearchGate) were searched, using several key words "benefits/effects of motor activities/exercises among children with ASD", "sensory processing/integration for children with ASD", "psycho-motor development among children with ASD", "effects of motor/physical activities on sensory processing among children with ASD". Inclusion criteria concerned articles published in the last 15 years, in English only, while exclusion criteria referred to articles duplicated in different databases.

The article is structured in several parts. The first part is one of conceptual delimitation, being succinctly presented both the autistic spectrum disorder, but also sensory processing in children with ASD, with reference to sensory integration therapy. The second part aims to present psychomotor development features of children with ASD, identifying the positive influences of practicing motor and sports activities on sensory processing. The article ends by formulating some conclusions and some limitations.

Results

Conceptual delimitations

Several disorders are grouped together in the category of neurodevelopmental disorders. Thus, individuals may be diagnosed with autism, attention deficit and hyperactivity disorder (ADD and ADHD), language development disorders, mental and/or learning disabilities, developmental coordination disorder. These disorders can generate different diagnoses in the area of mental health, individuals can suffer from mood changes, stress, eating disorders, sleep disorders, anxiety, depression, etc. (Male et al., 2023; Muneer & Sultana, 2019).

The deficits of children with ASD, but also with ADHD, target cognitive functions, disturbances in social interactions and repetitive stereotyped behaviors (WHO, 2021). Some children with ASD may have intellectual impairments, which can affect their ability to process, learn, and solve the various situations they encounter. Alteration can refer to the individual's ability to adapt and direct their actions to achieve goals (the executive form

of cognition), as well as to various processes such as attention, memorization, learning, etc. (non-executive form) (DSM-V, 2013). The impairment of cognitive functions is on the spectrum, ranging from profound difficulties in the learning process to average or higher intelligence, where “autistic savants” are included, those who excel in different fields such as mathematics, music, learning foreign languages, etc. This variability of intellectual impairments may determine different degrees of severity in the manifestation of ASD.

Gender is a variable in autism prevalence, with boys being diagnosed more often than girls (3–4 times more common). Early diagnosis and initiation of specialized educational intervention can determine the developmental evolution of the child with ASD. The diagnostic assessment process may be delayed due to the type and severity of the clinical picture of the present symptoms (Male et al., 2023). Not all children with ASD require psychiatric assistance, rather this is considered a specialized educational intervention aimed at training social skills.

Autism spectrum disorder includes different forms of autism, with different degrees of impairment over time in the same child, but also from one child to another, on a scale from mild to severe, with complete or partial clinical picture of the symptoms.

Severe alterations in the area of social interactions and repetitive behaviors, language, as well as intellectual impairments and convulsive episodes are the characteristics of early childhood autism. Children diagnosed with this form have from the first years of life: extreme autistic loneliness, obsessive rigidity when changing routines and contexts that can trigger auto- and/or hetero-aggressive crises, the quasi-absence of language, mechanical memorization not adapted to situations, echolalia, the impossibility of sustaining an authentic communications, hyper-reactivity to different stimuli on different sensory systems (hearing – exaggerated reactions to noises, to different textures of materials and food, to smells, to strong visual stimuli, etc.), automated and repetitive behaviors, lacking spontaneity.

Another less severe form of autism, found after the age of 3, is Asperger's syndrome, which in the clinical picture has symptoms such as: milder speech difficulties, dyslexia, attention deficit hyperactivity disorder (ADHD), average level and above intelligence, disorders in the learning process, rather high level of rigidity when changing routines, under-development of psycho-motor skills, dyspraxia, develops obsessions towards a certain object or theme for which he accumulates knowledge and initiates endless discussions about them, high risk of developing depressive and anxiety disorders in adulthood, sensory disorders with exaggerated reactions to certain strong stimuli. Even though individuals with Asperger's syndrome may have certain disabilities, many of them excel in a field, having exceptional skills (mathematics – memorize numbers, perform mental calculations, memorize texts, events, have spatial memory, musical, artistic skills – drawing, etc.).

The rarest and most severe form of autism is childhood disintegrative disorder (CDD) which manifests itself between the ages of 2 and 4, when cognitive, social and language acquisitions are rapidly lost, with no possibility of recovery, up to the age of two, children apparently developing normally, age-specific. However, until the age of 10, the clinical picture of children diagnosed with CDD includes symptoms such as frequent convulsive episodes, delayed or absent communication skills, especially speech, repetitive and stereotyped behaviors, interests and activities, inability to establish and develop of social relations, initiation and support of interactive and creative games, psycho-motor disorders, control of physiological functions (for example, control of the urinary bladder or bowels).

Most children with ASD, who do not fit the clinical picture of typical autism but have a more severe degree than Asperger's syndrome, can be diagnosed with pervasive developmental disorder, not otherwise specified

(PDD-NOS) or autism atypical. Symptoms are on the spectrum, very different from one child with PDD-NOS, and difficult to diagnose. Symptoms found in this form, with an onset at an older age, include disturbances in the area of social interactions, fewer repetitive stereotypes than in children diagnosed with Asperger's syndrome, superior language skills compared to those found in children with typical autism, but less developed compared to those present in children with Asperger syndrome.

ASD is the result of the action of different factors: genetic (multigenic interactions or spontaneous gene mutations) (Junaid & Pullarkat, 2001), environmental (viral infections, drugs or complications during pregnancy, atmospheric pollutants, etc.) and physiological (dysfunctions in the level of frontal and prefrontal cortex connections and with other parts of the brain) (Bremer et al., 2020; Just et al., 2007; Wass, 2011, quoted by Li et al., 2023).

Sensory processing in children with ASD

Qualitative alterations in the behavioral plan and in the area of communication in the individual with ASD are based on unbalanced processes of information integration – contextual and/or sensory perception. Thus, the context can be perceived differently, fragmented, and the information obtained with the help of the sensory systems is entered into the brain as separate puzzle pieces. Thus, the individual will have difficulties in perceiving the whole and assigning the correct meaning, difficulties in planning and organizing activities, difficulties in understanding his own behavior and that of others. The child with ASD needs more time to process the information received from the sense organs and arrange them into a whole so that they can react adaptively, functionally. The risk of making a mistake in matching the parts is much higher, especially when the amount of information is large. When he/she can no longer manage this processing, the child “explodes”.

Sensory processing disorders are present in a broad spectrum: from differences that represent a mild impairment, to difficulties that appear as a more accentuated form, to dysfunction, the severe form of impairment (Ayres, 2005; Stock Kranowitz, 2022; Oster & Zhou, 2022). The brain of a child with ASD adjusts differently the adaptive, functional reactions to various information received on the 7 sensory systems (proprioceptive, vestibular, visual, tactile, auditory, gustatory, olfactory). The degree of sensitivity determines different behaviors, some of the children being hyper-reactive, others hypo-reactive, while others are looking for sensations to the stimuli received from the environment.

Little et al. (2017) have identified sensory subtypes of behaviors that differ through the interaction of two elements taken from Dunn (2014, quoted by Little et al., 2017): intensity (stimulus detection thresholds – from slow to fast) and self-regulation strategies (from passive to active). These patterns of sensory processing are: registration (high threshold and passive self-regulation) – hypo-reactivity, with a delayed or diminished detection of sensory stimuli; seeking (high threshold and active self-regulation) – includes active engagement in activities or actions that provide intense sensory input; sensitivity (low threshold and passive self-regulation) – hyperreactivity, with an aversion to sensory stimuli; avoidance (low threshold and active self-regulation) – hyperreactivity, with an aversion to sensory stimuli.

Patterns of sensory processing have been associated with activity participation in ASD, internalizing/externalizing behaviors in ADHD, ASD, and typical development and adaptive behavior in ASD (Lane et al., 2010; Kitchin, 2016).

To understand how the co-occurrence of sensory processing patterns affects behavior, research has begun to characterize groups of children based on differences in co-occurring sensory patterns (i.e., sensory subtypes). Lane et al. (2014, quoted by Little et al., 2017) used the short sensory profile to discover the sensory subtypes

of children with ASD. Initially, Lane et al. (2010) identified 3 subtypes: sensory-based inattentive search, motion-sensitive sensory modulation, and taste/odor-sensitive sensory modulation. Later, the same authors (Lane et al., 2010) identified 4 subtypes: adaptive sensory; taste-smell sensitive; postural inattention; generalized sensory difference, whereas Little et al. (2017) identified 5 subtypes: balanced, intense, alert, interested and mild to sensory profiles. The subtypes may reflect variability in all children, not just those with conditions.

Several studies (Schaaf et al., 2011, 2018; Basic et al., 2021) summarize research on the effects that sensory behaviors of people with ASD have on functioning and participation/performance them in her/his activities (Activities of Daily Living/ADLs, play activities, personal care, learning, interaction with family, with others, etc.). Thus, it is estimated that more than 80% of individuals with ASD demonstrate behaviors that may be related to poor sensory modulation, such as self-stimulation (excessive rocking or spinning), avoidance behaviors (such as putting hands over ears in response to typical levels of auditory input), sensory seeking (spinning, chewing, etc.), “withdrawal” behaviors (such as not responding to their name or other environmental cues), attention difficulties (over-reception, under-reception or sensation seeking, combined with a certain degree of persistence, excessive focus and exceptional memory for selective material). Also, difficulties with auditory filtering and sensation seeking in 6–10-year-olds with ASD contribute to poor academic performance and, to a lesser extent, that tactile and auditory sensitivity limits classroom performance.

Lane et al. (2019) conclude that the sensory integration and praxis models of sensory-motor functioning described by Ayres in children with learning and behavioral difficulties are confirmed by advances in neuroscience, with the help of imaging investigations and studies of learning, attention and behavior, making it possible to understand the differential neural functioning that affects their participation and involvement in different activities.

The role of Ayres sensory integration therapy in the intervention program in children with ASD

An intervention program for children with ASD includes several stages (Crăciun et al., 2017). These refer to:

- planning a personalized intervention plan for areas of development (communication, cognitive, autonomy, interaction, motor skills), staged and with the joint effort of the interdisciplinary team (pediatrician, psychiatrist, psychologist, speech therapist, occupational therapist, physical therapist, etc.).
- the choice of different therapies (applied behavioral analysis – Applied Behavioral Analysis/ABA, TEACCH – Treatment and Education of Autistic and Communication Handicapped Children, PECS – Picture Exchange Communication System, HANEN programs, Son-rise, sensory integration therapy, Floor Time, occupational therapies, physical therapy).
- implementing the intervention program in different educational contexts (integrated and/or special system).
- communication relationship with the educators and the correlation of the school program with the one at home.
- compliance with the pharmacological treatment and that of the therapies, the diet.
- coordinating the interventions of the interventional team with the aim of generalizing the behaviors adopted to improve the quality of life of the child with ASD.
- strengthening the child-parent relationship, by educating and training the parents in the attitudinal and behavioral approach towards the child with ASD.

The studies highlight that in order to register progress in the intervention on a person with ASD, several therapies can be used at the same time, in an integrative way, therefore, the joint work of the interdisciplinary team of therapists and parents is necessary (Case-Smith, 2005, 2008; Mastrodinou et al., 2019).

Sensory integration is based on theories of neuroscience, neuropsychology and neurophysiology, which relate to the plasticity and hierarchy of the central nervous system (CNS), brain function, the development of aesthetic integration, the interaction of sensory integration and adaptive behavior, and finally, at the internal level, the motivation of the person to participate in activities with sensory-kinetic experiences (Sianny, 2001, quoted by Mastrodimou et al., 2019).

The concept of sensory integration was developed by Jean Ayres (2005), who argued that it is a neurobiological process, and refers to the administration of sensory stimuli specific to the individual, which processes (CNS), and through this process an adaptive response is produced. Sensory stimuli reaching the brain come from the auditory, optic, vestibular, proprioceptive and tactile systems.

Schaaf et al. (2018) conclude that studies published between 1972 and 2007 suggest that sensory integration interventions help improve outcomes for individualized goals (reading and related skills, sensory-motor skills and motor planning, socialization, behavioral regulation, and attention) over time that, after 2007, they note in the analyzed studies positive results for improving functioning and participation goals of children with ASD, moderate results on improving autistic behaviors and reducing caregiver assistance and emerging but insufficient results related to improving play skills, sensory-motor and language and reduced caregiver assistance with social skills.

Lang et al. (2012) made a synthesis showing the effectiveness or mixed results of sensory therapy in the education and treatment of children with ASD, but at the same time, the lack of benefits, in particular, due to the methodological deficiencies addressed in the analyzed studies.

Sensory integration dysfunction is a disorder in which sensory data is not properly organized in the brain, and this can cause various problems in the individual's development, information processing, and behavior. Thus, stimuli from the vestibular, proprioceptive and tactile systems have a strong effect on the regulatory mechanisms of the nervous system, Ayers' sensory integration uses these senses to facilitate the development of adaptive behavior (Watling & Dietz, 2007).

Ayres concluded that an important role is played by the processing and interpretation of the information received by the child from the environment, with the help of his sensory systems. These brain processes are called "sensory integration." The vestibular system incorporates information received from the inner ear (labyrinth) and detects body movement in space and changes in head position. The tactile system is responsible for coordinating sensory information through touch, giving the ability to feel objects to differentiate them without the use of the visual analyzer. The proprioceptive system includes the sensory information obtained through the musculoskeletal system and provides the individual with the unconscious perception of the location of the body members in space (Willis, 2009; Talay – Ongan & Wood, 2010). Most of the time, the sensory systems work together to send all information to the brain and in turn regulate it. When these cannot cooperate to help regulate the nervous system, the child may experience a sensory integration disorder (Willis, 2009).

Sensory integration therapy (SIT) or sensory processing therapy (SPT) and activities that promote sensory integration are widely used to diagnose and treat disabilities in children with ASD. The treatments based on sensory integration theory that are most often used in working with people with ASD are Sensory Integration Therapy (SIT), Auditory Integration Training (AIT), and Deep Pressure Therapy (DPT) (Green et al., 2006, quoted by Basic et al., 2021).

Sensory integration therapy (SIT) should involve: a) the child's safety; b) opportunities to achieve tactile, vestibular and/or proprioceptive sensory stimulation to support self-regulation, sensory awareness or movement;

c) adequate levels of participant vigilance; d) causing postural, ocular, oral or bilateral motor control; e) new motor behaviors and efforts to organize the movements in time and space; f) preferences in choosing activities and materials; g) activities that are neither too easy nor too difficult; h) activities in which the participant succeeds; i) support for the intrinsic desire to play; j) therapeutic confidence (Parham et al., 2011, quoted by Lang et al., 2012).

The influences of physical and sports activities on the psycho-motor development of children with ASD

Ben Hassen et al. (2023) identified in other studies that 80% of children diagnosed with ASD presented difficulties with coordination and motor skills, deficits in gross and fine motor skills (clumsiness), reduced ankle movement and an abnormal walking pattern (walking top of feet). Furthermore, these children often have impaired static and dynamic postural balance, as a result of defective processing of information coming from the visual, vestibular and proprioceptive systems. For example, in children with ASD, postural instability in the medio-lateral direction in firm/foam surface conditions, both with the eyes open, but especially keeping the eyes closed) (Stins et al., 2015) or in those diagnosed with PDD, a low tactile awareness and an increased proprioceptive input, registering preferences for hard objects and avoiding soft ones (Huri et al., 2014) are found. On the other hand, abnormalities in sensory processing have been detected in 90% of the ASD population showing hypo- or hyper-sensory reactions. Consequently, sensory impairments were included as part of the core definition of autism disorders.

Other investigations prove the association between sensory processing problems and motor impairments in children with ASD starting from the first years of life (Ben Hassen et al., 2023; Purpura et al., 2022). In other words, low performance in sensory processing, and sometimes cognitive skills, can interfere with motor skills, with children with ASD not adapting their motor responses to the environment (time, place and quality), indirectly, negatively influencing their performance in daily activities and social interactions. Therefore, it is necessary to create rehabilitation programs for people with ASD that include both sensory and motor areas, the relationship between them being complex, the neural connections between these regions being affected, resulting in uncoordinated motor responses and altered motor skills.

A synthesis study (Basic et al., 2021) summarizes several studies that have highlighted a series of advances in sensory integration therapy in different areas: motor skills (fine and gross motor skills), communication and interaction skills, occupational performance environment (Kashefimehr et al., 2021); oral and visual-motor skills (Iwanaga et al., 2014; Pfeiffer et al., 2011); nonverbal memory, sequencing, visualization, solving complex problems that require the engagement of certain cognitive and sensorimotor skills (Iwanaga et al., 2014); sensory processing, adaptive behavior, social functioning (Pfeiffer et al., 2011); attention, decrease in self-aggressive behavior in children with ASD (Thompson, 2011).

Also, Basic et al. (2021) identified studies that demonstrated that the use of deep pressure techniques (brushing, massage and squeezing) led to increased calmness (75%), engagement in activities (62.5%), responsiveness to instructions or other environmental stimuli (62.5%), happiness (50%) and communication ability (62.5%) in children with ASD and severe intellectual disability (Brockett, et al., 2014, quoted by Basic et al., 2021). Other authors (Bagatell et al., 2010) reported significant improvements in self-regulation of sitting behavior and participation in learning activities, and in the case of auditory integration training, pre- and post-assessment results indicated an improvement in social awareness, social cognition and social communication (Al-Ayadhi et al., 2013).

Roley et al. (2015) showed that children with ASD experience difficulties in visual praxis (imitation practice, bilateral vestibular integration) but also in somato-praxis, with consequences in their level of participation in activities.

Motor issues are shown in many areas, including functional mobility, physical activity, participation and competence in activities of daily living, and risk of falling (Miller et al., 2024).

Motor and sports activities are included in the therapeutic program of children with ASD, the goals of movement therapy aiming at (re)educating the skills of moving and driving objects (gross and fine motor skills). The exercises and games chosen by the educator/therapist aim at the acquisition of psycho-motor skills (segmental and general coordination, manual dexterity, laterality, spatio-temporal orientation, static and dynamic balance, body schema) with effects on the functioning and motor performance of these children.

Several studies (Arkesteyn et al., 2022; Nacario, 2016; Lee & Hodge, 2017; Carbone et al., 2021; Yu et al., 2018) highlight benefits on physical health of children with ASD: cardiovascular, digestive and cerebral functions (oxygenation and brain development), aerobic capacity and muscle tone, sleep quality and duration.

Other studies attest to positive effects on psycho-social health, improving the quality of life (Muneer & Sultana, 2019; Jia et al., 2023; Ferreira et al., 2018; Alhowikan, 2016). The motor, socio-affective, cognitive and interpersonal skills learned during movement therapy programs are transferred to other contexts, contributing positively to managing these new/other situations. In addition, aggressive and self-aggressive behaviors, self-stimulation, hyperkineticism and stereotypies decreased as a result of the introduction of program of moderate intensity physical exercise of 30 minutes twice a week for 48 weeks (Toscano et al., 2022), kata training techniques 4 times a week for 14 weeks (Bahrami et al., 2012), swimming (technical and games-based forms) for 8 weeks (Marzouki et al., 2022; Pimenta et al., 2016), horse-riding (García-Gómez et al., 2014).

Regular programs of motor activities and sports create routines in children with ASD, which leads to an improvement in well-being, self-control of emotions in interactive contexts, reduce the level of anxiety, depression, self-isolation (Yu et al., 2018; Zhao & Chen, 2018; Randell et al., 2022). In addition, there are studies that show positive effects from a social point of view (establishing and maintaining relationships, acceptance by others, etc.) on children and adolescents with ASD who followed various motor activities, exercises and games in small group sessions (2 to 5 people) and swimming over 8–12 weeks (Zhao & Chen, 2018; Kocak et al., 2021; Jia et al., 2023).

Several studies report a lower or delayed level of gross and fine motor development in children diagnosed with mild and moderate forms of ASD (Muneer & Sultana, 2019; Kashefimehr et al., 2021; Roley et al., 2015; Miller et al., 2024; Sorensen & Zarrett, 2014; Wang et al., 2022; Roşca et al., 2022; Hunt et al., 2023; Abdel Ghafar et al., 2022; Gal et al., 2007; Phytanza et al., 2023; Lourenço et al., 2020), even those with varying degrees of intellectual disability (Gkotzia et al., 2017). Thus, psychomotor skills such as balance (including body posture, control of body movements, but also dynamic balance), general and eye-motor coordination, manual dexterity, muscle tone, movement skills (walking, running, jumping, crossing obstacles) are affected, climbing, crawling) and handling the object (throwing, catching, hitting and kicking, rolling and passing of the ball etc.). Moreover, the sensory-motor functions are also underdeveloped, the sense organs of children with ASD taking in an inappropriate and non-functional way the information from the environment, the behavioral reactions being hyper-reactivity, hypo-reactivity or sensation seeking. The relationship between the level of development of motor skills and social skills is proven, with the association being stronger with fine skills than with gross skills. Manual dexterity among fine motor skills and the ability to control objects among gross motor skills are the most strongly associated with social skills (Ohara et al., 2019).

On the other hand, executive and non-executive cognitive function is positively influenced by the practice of motor and sports activities in children with ASD, with benefits on academic and behavioral performance (Pan et al.,

2017; Milajerdi et al., 2021; Li et al., 2023). Attention, memory, adaptability, inhibitory control of body movements are positively influenced by practicing different types of physical and sports activities: swimming, horse riding, yoga, martial arts, light running and stationary cycling, etc. (Bass et al., 2009; Ward et al. 2013; Tan et al., 2016; Hassani et al., 2020a; Srinivasan et al., 2014; Hassani et al., 2020b; Rech et al., 2022). However, the degree of impairment due to autism, which is associated with a higher risk of comorbidities, is not a predictor of participation in physical activities (Arkesteyn et al., 2022).

The content of motor and sports activity programs is individualized, being adapted by educators/therapists according to each individual, his/her needs and interests, the level of development of psycho-motor and social skills. The goals of therapeutic programs are most often achieved in individual therapeutic sessions. Personalized adaptation, avoiding the feeling of not being understood by the child with ASD by others, the unpredictability of others' actions is considered advantages of individual therapy (Sowa & Meulenbroek, 2012). To the extent that the child acquires knowledge and skills, gets used to the structure of physical exercises and games, activities with another child of the appropriate level can be introduced, the development of communication, awareness of the other's presence and collaboration in carrying out the common task (work in team) making up the objectives of the pair meetings. It is proven that motor and sports activities in groups can also be carried out successfully (Breedved et al., 2010; Lox et al., 2010; Walker et al., 2010, quoted by Sowa & Meulenbroek, 2012).

Conclusions

ASD is a neurodevelopmental disorder characterized by deficits in behavior and communication and social interaction of the person diagnosed, with negative consequences on functioning and performance in different areas. With different forms of manifestation and degrees of impairment, the individual with ASD presents difficulties in contextual and/or sensory perception of stimuli, which causes maladaptive responses from him/her. Sensory processing models and subpatterns are tools to understand the mechanisms, factors that determine differences in functioning and participation in activities (ADLs, play, learning, interaction with others).

Intervention measures for children with ASD aim at an integrated effort of an interdisciplinary team of therapists alongside parents. Along with other therapies, sensory integration therapy, developed by Ayres, is beneficial in treating and educating the child with ASD who uses their senses to facilitate the development of adaptive behavior (stimuli from the vestibular, proprioceptive, and tactile systems have a strong effect on regulatory mechanisms of the nervous system).

Scientific evidence shows that more than 80% of children diagnosed with ASD have deficits in the motor area (gross and fine motor skills, abnormal walking pattern, reduced ankle mobility, coordination, postural and dynamic balance, etc.). In addition, there are associations between sensory processing difficulties and motor impairments, even from the first years of life, with the motor and sensory areas being in neural connection and developing at the same time at an accelerated rate.

Motor and sports activities have positive effects on children with ASD, proven by scientific studies, the influences being shown in different areas: physical health (maintains/reduces the weight index, improves cardiovascular function, increases muscle tone, regulates certain internal functions, oxygenation of the brain, improves sleep in terms of duration and quality), mental health (reduces anxiety and depression, well-being, self-control of emotions, reduces/avoids social isolation, etc.), motor functions (oral and visual, gross motor skills and fine, manual dexterity, balance, ability to relax and control body movements), sensory processing, cognitive processes

(memorization, sequencing, attention, cognitive flexibility, inhibitory control of body movements, academic performance), communication and social interaction skills (establishing and maintaining friendships, acceptance from others), decrease in stereotyped and self-aggressive behaviors, self-stimulation, hyperkinetic behavior.

A number of limitations of this study are identified. Thus, the database search area was relatively limited, considering only the most well-known databases. Expanding the search area may provide opportunities to identify other current bibliographic sources. The search involved the formulation of several phrases that included both autism spectrum disorder, sensory processing in the case of ASD, motor/physical and sports activities in children with ASD, the benefits of these activities as occupational therapy activities included in the therapeutic programs of children with ASD. Expanding the search, by formulating more varied phrases, can also expand the area of coverage and systematization of influences.

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INVESTIGATING NUTRITIONAL AND HEALTH DYNAMICS ACROSS STRATIFIED PROFILES OF OBESITY

Martina Gažarová^{A, B, C}

Faculty of Agrobiology and Food Resources, Slovak University of Agriculture in Nitra, Slovakia
ORCID: 0000-0001-8275-7311

Stanislav Azor^{B, C, D}

Institute of Physical Education and Sports, Technical University in Zvolen, Slovakia
ORCID: 0009-0001-6586-1958 | e-mail: stanislav.azor@tuzvo.sk

Petra Lenártová^{C, D, E}

Faculty of Agrobiology and Food Resources, Slovak University of Agriculture in Nitra, Slovakia
ORCID: 0000-0003-2899-7191

Karin Baisová^{C, D, E}

Institute of Physical Education and Sports, Technical University in Zvolen, Slovakia
ORCID: 0000-0003-4868-8038

^A Study Design; ^B Data Collection; ^C Statistical Analysis; ^D Manuscript Preparation; ^E Funds Collection

Abstract This study examines metabolically healthy obesity (MHO), a subset of individuals with obesity who appear resistant to cardiometabolic diseases. The absence of a standardized definition for MHO has led to significant variability in its classification. In this investigation, 263 participants (64 meeting obesity criteria) underwent body composition analysis via multi-frequency bioimpedance and biochemical assessment using the Boliis 24i Premium system. Statistical analyses were conducted using STATISTICA 13 and MedCalc, with significance set at $p < 0.05$. Although individuals classified as metabolically healthy exhibited elevated anthropometric measurements, their biochemical and somatic parameters remained within normal ranges. Notably, a healthier metabolic profile did not correspond to reduced mortality risk. The findings demonstrate that the choice of MHO definition significantly impacts prevalence estimates within the same population. Stricter criteria produced lower prevalence rates, whereas broader definitions, such as elevated BMI combined with one additional critical parameter, increased prevalence estimates. Using different diagnostic combinations, significant differences in triglycerides, systolic blood pressure, and diastolic blood pressure were observed among MHO subgroups ($p < 0.05$). For instance, combining BMI and HDL identified 56 MHO individuals, whereas BMI and triglycerides identified 38 individuals. These results emphasize the importance of comprehensive consideration of diagnostic criteria in MHO classification. The study cautions against interpreting MHO as an unequivocal state of health due to the diverse health risks associated with obesity, including cardiovascular, metabolic, orthopedic, dermatological, and psychological conditions. The findings underscore the critical need for a standardized MHO definition to enhance diagnostic accuracy and enable meaningful comparisons across populations in future research.

Key words: anthropometry, lipid profile, metabolic health, nutrition, obesity.

Introduction

Obesity is one of the major diseases of civilization and is one of the key risk factors for many non-communicable diseases, including cancer, cardiovascular diseases, diabetes mellitus type 2 and chronic respiratory diseases (Bray et al., 2017; Townsend et al., 2022). In the European region, overweight and obesity affect almost sixty percent of adults and almost every third child (NCD, 2016, 2017). A new WHO obesity report published by the WHO Regional Office for Europe (EURO) reveals that overweight and obesity rates have reached epidemic proportions across the region and are still escalating (WHO, 2022). During the COVID-19 pandemic, there have been adverse shifts in food consumption and physical activity patterns that will impact population health for years to come and will require significant efforts to reverse (Adamčák et al., 2022; Vogel et al., 2022). However, obesity is a disease whose nature, causes and consequences are much more complex than a simple combination of unhealthy diet and physical inactivity (Ladubaum et al., 2014; Brown et al., 2016; Adamčák et al., 2022, 2023).

Correct diagnosis of obesity and interpretation of its nature and risk in relation to morbidity is very important and fundamental (Gažarová et al., 2022). Clear standards are needed for the diagnosis of obesity. Their absence leads to various false-negative or false-positive results, with almost a third of those diagnosed being incorrectly classified as non-obese. For the diagnosis of obesity, the body mass index (BMI) is recommended and is still used in practice although it is known that it can underestimate or overestimate the actual condition. Therefore, its modification as a diagnostic method or its replacement by other anthropometric indices and variables is increasingly discussed (Chooi et al., 2019; Bosy-Westphal & Müller, 2021).

There is more and more discussion about metabolically healthy obesity (MHO), or obesity with normal body mass index values but increased body fat values (Stefan et al., 2017; Eckel et al., 2018; Pluta et al., 2022). In the diagnosis of such obesity, somatic and biochemical parameters of the blood serum are also used, such as systolic (BPs) and diastolic (BPd) blood pressure, triglycerides (TG), high-density lipoproteins (HDL) or glycaemia (GLU). In this context, the opinion is asserted that the use of anthropometric parameters cannot be an independent predictor of the underlying disease. Therefore, anthropometric indicators should be correlated with biochemical and clinical findings to accurately estimate risks for any metabolic disease. One marker of obesity does not necessarily mean the presence of disease or excessive visceral fat, so it is necessary to understand the overall clinical picture rather than making decisions based only on anthropometric parameters. For clinical use, it is necessary to choose suitable indicators depending on which element of the metabolic disease we are monitoring (van Vliet-Ostapchouk et al., 2014; Lavie et al., 2018; Gažarová et al., 2022).

Currently, there is no uniform definition of MHO. Despite the general consensus that a BMI ≥ 30 kg/m² is a prerequisite for the definition of MHO, more than 30 different definitions of metabolic health are used in clinical trials (Rey-López et al., 2014). Metabolically healthy obesity has often been defined by the absence of any metabolic disorder and cardiovascular disease, including type 2 diabetes, dyslipidemia, hypertension, and atherosclerotic cardiovascular disease in an obese person (Lavie et al., 2018; Magkos, 2019). In practice, however, there are great differences regarding the MHO classification criteria and specific cut-off values for each parameter, even to the extent that some cardiometabolic abnormalities have been accepted in the MHO category as well (Rey-López et al., 2014; Magkos, 2019).

In some studies, even people with impaired glucose tolerance, type 2 diabetes, and a history of CVD were considered metabolically healthy because they did not have a sufficient number of specified metabolic abnormalities to be identified as metabolically non-healthy obese (MNHO). Therefore, people reported to have MHO are often

not truly healthy, just have fewer cardiometabolic abnormalities than those defined as individuals with MNHO (Mongraw-Chaffin et al., 2018; Echouffo-Tcheugui et al., 2019).

The need for standardized MHO criteria was addressed a few years ago by the BioSHaRE-EU project (van Vliet-Ostaptchouk et al., 2014; Lavie et al., 2018). This resulted in two levels of stringency for the definition of MHO. Recently, a harmonized definition of MHO in adults has been proposed based on the diagnosis of obesity (BMI ≥ 30 kg/m²) and meeting the following criteria: serum triglycerides ≤ 1.7 mmol/L (≤ 150 mg/dL), HDL > 1.0 mmol/L (> 40 mg/dL) in men or > 1.3 mmol/L (> 50 mg/dL) in women, systolic blood pressure ≤ 130 mmHg, diastolic blood pressure ≤ 85 mmHg, no antihypertensive treatment, fasting blood glucose ≤ 5.6 mmol/L (≤ 100 mg/dL) and no glucose-lowering drug therapy (Lavie et al., 2018).

Aim

The aim of research was to evaluate anthropometric and biochemical parameters and indices, as well as the risk of premature mortality based on the distribution of individuals according to various diagnostic criteria defining metabolically healthy obesity.

Methods

The research group consisted of a total of 263 persons, of which 201 were women and 62 were men. Written informed consent to participate was obtained from all participants prior to participation in the study. For definitive inclusion in the study, we used the following exclusion criteria: age < 18 years, BMI < 30 kg/m², pregnancy or presumption of pregnancy in women, sports at a professional level, presence of serious physical or psychological illnesses, use of medications that could affect study results, contraindications for bioimpedance measurement, increased physical activity just prior to measurement, intake of excessive amounts of coffee, alcohol, and fatty foods ≤ 8 hours prior to testing, and use of diuretics seven days prior to testing.

The study was conducted in accordance with the Declaration of Helsinki and was approved by the ethics committee at the Specialized Hospital of St. Svorada Zobor, n.o. Nitra, Kláštorská 131, 949 01 Nitra as part of implementation of the project *Long-term strategic research on the prevention, intervention and mechanisms of obesity and its comorbidities* (ITMS: 313011V344) co-financed from the resources of the European Regional Development Fund within the Operational Program Integrated Infrastructure (protocol no. 4/071220/2020).

Research Design: Body composition was analyzed by anthropometric measurement, multi-frequency bioelectrical impedance analysis (MF BIA) using InBody 720 (Biospace Co. Ltd., Seoul, Republic of Korea). Body height (H) was measured using a Tanita WB-300 professional electronic medical scale. To assess body composition, the following parameters were measured directly by bioimpedance analysis: fat-free mass (FFM, kg and %), fat mass (FM, kg and %), visceral fat area (VFA, cm²), skeletal muscle (SMM, kg and %). We also obtained data on basal metabolic rate (BMR, kcal) from the BIA analysis.

We measured the proband's blood pressure using an OMRON Microlife AG, 9443 (Widnau/Switzerland) sphygmomanometer with fully automatic operation and the possibility of using a classic or extended inflatable arm cuff. Blood pressure was measured after stabilization of body fluids, at rest, while sitting. Systolic and diastolic pressure with pulse was measured.

Body mass index (BMI) was calculated as weight (kg) divided by the square of height (m²). To calculate the body adiposity index (BAI), we used the formula $BAI = [\text{hip circumference} / \text{height}^{1.5}] - 18$ (%). We calculated waist-

to-hip ratio (WHR) and waist-to-height ratio (WHtR) as waist circumference (cm) divided by hip circumference (cm) or height (cm) (Skrzypczak et al., 2007).

Fat mass (kg), fat-free mass (kg) and skeletal muscle mass (kg) were used to calculate the fat mass index (FMI, kg/m²), fat-free mass index (FFMI, kg/m²) and skeletal muscle mass index (SMMI, kg/m²) as fat mass (kg) divided by height squared (m²), or fat-free mass (kg) divided by height squared (m²), or skeletal muscle mass (kg) divided by height squared (m²).

Body shape index (ABSI) was defined as $WC/(BMI^{2/3} \times height^{1/2})$ and ABSI z-score was calculated based on the mean and standard deviation of ABSI calculated for the given age and sex. ABSI z-score formula: $ABSI\ z\text{-score} = (ABSI - ABSI_{mean}) / ABSI_{SD}$ (Krakauer et al., 2012).

According to BMI, obesity was defined as BMI ≥ 30 kg/m² (Clinical practice guidelines, 2013). We defined metabolically healthy obesity according to several criteria and methodologies. The most important criterion was a BMI ≥ 30 kg/m². According to the strictest criteria, metabolically healthy obesity was defined not only by BMI but also by blood pressure (systolic ≤ 130 mmHg, diastolic ≤ 85 mmHg), glycaemia (≤ 6.1 mmol/L), triglyceridemia (fasting ≤ 1.7 mmol/L) and HDL (>1.03 mmol/L in men and >1.3 mmol/L in women) without medical treatment or present cardiovascular disease. With less strict criteria, we assessed individuals based on the following values: blood pressure (systolic ≤ 140 mmHg, diastolic ≤ 90 mmHg), glycaemia (≤ 7 mmol/L), triglyceridemia (fasting ≤ 1.7 mmol/L) and HDL (>1.03 mmol/L in men and >1.3 mmol/L in women) without medical treatment and cardiovascular disease (van Vliet-Ostapchouk et al., 2014). At the same time, we also defined metabolically healthy obesity under conditions of BMI ≥ 30 kg/m² plus at least one of the following criteria: blood pressure (systolic ≤ 130 mmHg, diastolic ≤ 85 mmHg), glycaemia (≤ 5.6 mmol/L), triglyceridemia (fasting ≤ 1.7 mmol/L) and HDL (>1 mmol/L in men and >1.3 mmol/L in women) (Lavie et al., 2018). The risk of premature death (ABSI z-score) was calculated according to the methodology of Krakauer and Krakauer (Krakauer et al., 2014).

An automatic biochemical analyzer Biolis 24i Premium (Tokyo Boeki Machinery Ltd., Tokyo, Japan) was used to determine biochemical parameters. We focused on determining the following parameters: lipid profile – total cholesterol (total cholesterol = T-CH, mmol/L), low density lipoprotein (LDL, mmol/L), high density lipoprotein = HDL, mmol/L), triglycerides (TG, mmol/L); glycaemia (GLU, mmol/L); uric acid (uric acid = UA, μ mol/L); hsC-reactive protein (hsCRP, mg/L). Venous blood sampling was carried out in a standard way from the fasting patient from a peripheral vein in the elbow socket into a dry sterile tube intended for blood sampling (2x serum gel and 1x EDTA tubes). The blood was subsequently processed according to the need and nature of the analyses. After separating the blood serum and plasma, the samples were stored in a deep-freeze box at a temperature of -80°C until the analyses.

We used Microsoft Office Excel 2016 (Los Angeles, CA, USA) in combination with XLSTAT (version 2019.3.1) for data processing. We performed statistical analysis using the computer software STATISTICA 13 (TIBCO Software, Inc., Palo Alto, CA, USA) and MedCalc software (MedCalc® Statistical Software Ltd, Ostend, Belgium, version 20.113). The normality of the variable distribution was checked by the Shapiro-Wilk test. We performed descriptive analysis using mean $\pm$ standard deviation. For the monitored parameters, we present additional statistical characteristics such as max (maximum value) and min (minimum value). The level of statistical significance was set as $p < 0.05$. Using one-way analysis of variance (ANOVA), we tested differences between variables and compared using Tukey's post hoc test.

Results

Out of the total number of examined persons, 64 (24.3%) of them met the BMI criterion higher than 30 kg/m². Both sexes were represented in the resulting group, men were slightly younger, their average age was 43 ±12 years (min. 21, max. 58). The average age of the women was 54 ±9 years (min. 25, max. 67). Weight was naturally higher in men (104.4 ±9.8 cm) than in women (91.5 ±9.8 cm; $p < 0.001$), which was associated with higher values of fat-free mass (73.3 ±6.3 kg; $p < 0.001$) and skeletal muscle (41.8 ±3.8 kg; $p < 0.001$) in men. The values of these parameters in women averaged 50.5 ±5.3 kg and 27.8 ±3.1 kg, respectively. The basic characteristics of the group are shown in Table 1.

Table 1. Basic descriptive characteristics of the group

	All participants (n = 64)				Male participants (n = 10)				Female participants (n = 54)			
	mean	SD	max	min	mean	SD	max	min	mean	SD	max	min
Age [years]	52	11	67	21	43	12	58	21	54	9	67	25
Basal Metabolic Rate [kcal]	1569	237	2109	1259	1954	136	2109	1661	1461	113	1683	1259
Height [cm]	167	8	185	149	179	6	185	167	164	6	174	149
Weight [kg]	94.3	11.1	131	70.9	104.4	9.8	131	88.6	91.5	9.8	114.2	70.9
Waist circumference [cm]	112	9.2	147	98.2	114	13	147	99	111	8	131	98
Fat-free Mass [kg]	55.49	10.96	80.50	41.20	73.3	6.3	80.50	59.80	50.5	5.3	60.80	41.20
Fat-free Mass [%]	58.69	7.98	78.85	48.37	70.67	7.58	78.85	55.95	55.34	3.77	62.34	48.37
Visceral Fat Area [cm ²]	147	25	224	94	135	37	224	94	151	19	200	116
Fat Mass [kg]	38.81	8.64	57.70	20.30	31.04	10.74	57.70	20.30	40.98	6.58	55.60	29.70
Fat Mass [%]	41.30	7.99	51.58	21.12	29.32	7.60	44.07	21.12	44.66	3.77	51.58	37.64
Skeletal Muscle Mass [kg]	30.88	6.68	45.91	22.43	41.8	3.8	45.91	33.62	27.8	3.1	34	22.43
Skeletal Muscle Mass [%]	32.63	5.01	45.47	25.95	40.31	4.52	45.47	31.83	30.48	2.29	34.90	25.95
Body Mass Index [kg/m ²]	33.75	3.19	42.53	30.01	32.75	3.60	42.53	30.19	34.03	3.05	40.04	30.01
Body Adiposity Index [%]	33.27	3.88	44.70	25.50	28.94	3.30	34.90	25.50	34.48	3.10	44.70	29.90
Waist to Hip Ratio	1.01	0.06	1.19	0.89	1.02	0.08	1.19	0.92	1.01	0.05	1.13	0.89
Waist to Height Ratio	0.67	0.06	0.84	0.56	0.64	0.08	0.84	0.56	0.68	0.04	0.77	0.62
Fat Mass Index [kg/m ²]	14.07	3.54	20.67	6.42	9.82	3.74	18.73	6.42	15.27	2.40	20.67	11.75
Fat-free Mass Index [kg/m ²]	19.68	2.18	25.59	15.85	22.93	1.30	25.59	20.59	18.77	1.34	21.27	15.85
FM/FFM	0.73	0.21	1.07	0.27	0.43	0.17	0.79	0.27	0.82	0.12	1.07	0.60
SMMI [kg/m ²]	10.94	1.40	14.75	8.56	13.08	0.82	14.75	11.62	10.34	0.82	11.84	8.56
ABSI [m ¹¹⁶ /kg ²⁰³]	0.08	0.00	0.09	0.07	0.08	0.00	0.09	0.08	0.08	0.00	0.09	0.07
ABSI z-score	0.43	0.92	2.71	-1.80	0.46	1.42	2.71	-1.80	0.42	0.74	1.70	-1.44
Total Cholesterol [mmol/L]	6.01	1.04	8.47	3.72	5.56	0.94	7.09	3.83	6.14	1.04	8.47	3.72
LDL [mmol/L]	3.60	0.84	5.21	1.77	3.58	0.93	5.01	2.19	3.60	0.83	5.21	1.77
HDL [mmol/L]	1.53	0.34	2.48	0.99	1.32	0.30	2.12	0.99	1.58	0.33	2.48	1.04
Triglycerides [mmol/L]	1.78	1.02	5.00	0.55	2.32	1.25	4.40	0.55	1.63	0.90	5.00	0.58

	All participants (n = 64)				Male participants (n = 10)				Female participants (n = 54)			
	mean	SD	max	min	mean	SD	max	min	mean	SD	max	min
Glycaemia [mmol/L]	5.18	0.71	7.40	4.10	4.87	0.38	5.50	4.20	5.27	0.75	7.40	4.10
Uric Acid [μ mol/L]	344	79	529	178	371	77	507	243	336	79	529	178
hs-CRP [mg/L]	5.00	5.31	28.65	0.02	1.14	0.93	2.64	0.11	6.08	5.53	28.65	0.02
Blood Pressure Systolic	133	14	164	101	133	14	158	110	132	14	164	101
Blood Pressure Diastolic	87	10	117	60	86	11	101	60	87	10	117	68
Pulse [beats per minute]	73	12	117	43	71	11	88	43	73	12	117	51

According to the strictest criteria, in addition to BMI, metabolically healthy obesity is defined by systolic (≤ 130 mmHg) and diastolic (≤ 85 mmHg) blood pressure, blood glucose ≤ 6.1 mmol/L, fasting triglyceridemia ≤ 1.7 mmol/L and HDL >1.03 mmol/L in men and >1.3 mmol/L in women without medical treatment or present cardiovascular disease. Based on BMI values, we found 64 obese subjects in our group, of which 13 (20.3%) met the definition of metabolically healthy obesity based on the strictest criteria. The evaluation of anthropometric and biochemical parameters and indices, as well as the risk of premature mortality based on the distribution of individuals according to defined criteria, is clearly shown in Table 2. Based on the results, between metabolically healthy and metabolically non-healthy obese individuals, we found differences of various extent and severity. However, we found significant differences only in the case of the biochemical parameters TG, GLU, UA and systolic and diastolic blood pressure to the detriment of the MNHO group. In the case of these parameters, the MHO group had values within the reference ranges. We did not find statistically significant differences in the other parameters. For VFA, FM (kg, %), FMI, FM/FFM and HDL, the MHO group had even higher values than the MNHO group. WHR was the same in both groups, as was ABSI and the resulting risk of premature death (high risk in both groups), although ABSI z-score values were higher in MHO. The MHO group had values of many parameters exceeding the upper reference limit. These were mainly WC, VFA, FM, BMI, BAI, WHR, WHtR, FMI, FM/FFM, T-CH and LDL.

Table 2. Stratification and characterization of subjects based on strict and less strict criteria

	Strict Criteria		Less Strict Criteria	
	MHO (n = 13)	MNHO (n = 51)	MHO (n = 17)	MNHO (n = 47)
Age [years]	53.39	51.22	53.06	51.15
Basal Metabolic Rate [kcal]	1510	1584	1543	1578
Height [cm]	167	167	168	167
Weight [kg]	91.78	94.93	91.86	95.17
Waist circumference [cm]	110.15	112.17	109.47	112.59
Fat-free Mass [kg]	52.76	56.18	54.32	55.91
Fat-free Mass [%]	57.34	59.04	58.88	58.63
Visceral Fat Area [cm ²]	148.51	147.07	144.28	148.47
Fat Mass [kg]	39.02	38.75	37.54	39.26
Fat Mass [%]	42.66	40.96	41.12	41.37
Skeletal Muscle Mass [kg]	29.08	31.34	30.09	31.17

	Strict Criteria		Less Strict Criteria	
	MHO (n = 13)	MNHO (n = 51)	MHO (n = 17)	MNHO (n = 47)
Skeletal Muscle Mass [%]	31.59	32.89	32.60	32.64
Body Mass Index [kg/m ²]	33.10	33.92	32.78	34.10
Body Adiposity Index [%]	32.89	33.37	32.53	33.54
Waist to Hip Ratio	1.01	1.01	1.00	1.01
Waist to Height Ratio	0.66	0.67	0.65	0.67
Fat Mass Index [kg/m ²]	14.19	14.05	13.58	14.25
Fat-free Mass Index [kg/m ²]	18.91	19.87	19.20	19.85
FM/FFM	0.76	0.72	0.73	0.73
SMMI [kg/m ²]	10.42	11.07	10.62	11.05
ABSI [m ^{11/6} kg ^{2/3}]	0.0828	0.0825	0.0827	0.0825
ABSI z-score	0.4955	0.4135	0.4064	0.4388
Total Cholesterol [mmol/L]	5.80	6.06	5.96	6.03
LDL [mmol/L]	3.38	3.65	3.45	3.65
HDL [mmol/L]	1.67	1.49	1.73 ^a	1.45 ^b
Triglycerides [mmol/L]	1.06 ^a	1.96 ^b	1.12 ^a	2.02 ^b
Glycaemia [mmol/L]	4.69 ^a	5.31 ^b	4.69 ^a	5.36 ^b
Uric Acid [μmol/L]	279 ^a	360 ^b	284 ^a	365 ^b
hs-CRP [mg/L]	2.74	5.58	2.87	5.77
Blood Pressure Systolic [mmHg]	116 ^a	137 ^b	118 ^a	138 ^b
Blood Pressure Diastolic [mmHg]	76 ^a	90 ^b	79 ^a	90 ^b

Note: ^{ab} – different symbols in the rows mean significant differences in mean intergroup values

With less strict criteria, individuals are assessed on the basis of BMI ≥ 30 kg/m², blood pressure (systolic ≤ 140 mmHg, diastolic ≤ 90 mmHg), blood glucose ≤ 7 mmol/L, fasting triglycerides ≤ 1.7 mmol/L and HDL > 1.03 mmol/L in men and > 1.3 mmol/L in women without medical treatment and cardiovascular disease. After assessing the individuals based on the stated values, we found the presence of 17 subjects with MHO out of 64, which is four more than with stricter criteria. With such a distribution, we found similar results as in the previous case, while again we noted significant differences between MHO and MNHO only within biochemical parameters, namely HDL, TG, GLU, UA and blood pressure. With the exception of HDL, the values were higher in the MNHO group. Of the anthropometric parameters, with the exception of FFM (%) and ABSI, the MNHO group again had higher values. Individuals from the MHO group had values higher than the norm or the upper reference limit for WC, VFA, FM (%), BMI, BAI, WHR, WHtR, FMI, FM/FFM. The risk of premature death was the same and therefore high in both groups, this time the ABSI z-score value was higher in MNHO (no significance; Table 2).

Metabolically healthy obesity is also defined under conditions of BMI ≥ 30 kg/m² plus at least one of the following criteria: blood pressure (systolic ≤ 130 mmHg, diastolic ≤ 85 mmHg), blood glucose ≤ 5.6 mmol/L, fasting triglyceridemia ≤ 1.7 mmol/L and HDL > 1 mmol/L in men and > 1.3 mmol/L in women. We therefore divided and evaluated our obese individuals according to each additional criterion individually. The evaluation of anthropometric

and biochemical parameters and indices, as well as the risk of premature mortality based on the distribution of individuals according to defined criteria, is clearly shown in Table 3.

When dividing the participants into MHO and MNHO according to BMI and HDL, we found that out of 64 of them, up to 56 (87.5%) individuals could be classified into the MHO group. We found significant differences between the formed groups in the case of anthropometric parameters body weight, WC, BMI, WHtR, FFMI, SMMI, but also biochemical parameters such as GLU, UA and HDL in favor of the MHO group. After evaluating the individual parameters, however, even in the group with metabolically healthy obesity, values exceeding the reference limits were found, specifically in the case of WC, VFA, FM, BMI, BAI, WHR, WHtR, FMI, FM/FFM, and also in the case of T-CH, LDL and blood pressure. The ABSI z-score was higher in the MHO group, but overall both groups fell into the category of high risk of premature death.

By dividing the participants according to BMI and TG, we obtained the MHO group with 38 (59.4%) individuals and the MNHO group with 26 (40.6%) subjects. With such a distribution of them, we found significant differences between groups only in the case of TG, UA, and systolic and diastolic blood pressure. Compared to the MNHO group, the MHO group had higher values for body weight, WC, VFA, FM, BMI, BAI, FMI, FM/FFM, HDL and GLU, but in several cases the differences were minimal. Again, also in this case, the parameters WC, VFA, FM, BMI, BAI, WHR, WHtR, FMI, FM/FFM, T-CH, LDL, systolic and diastolic blood pressure reached borderline to above-limit values in the MHO group. The ABSI z-score was lower in the MHO group this time, but both groups had a high overall risk.

The distribution of subjects according to BMI and glycaemia created the MHO group with up to 51 (79.7%) individuals and the MNHO group with 13 (20.3%) individuals. Even between these groups, we found significant differences in the values of some parameters, in the case of FFM (%), VFA, FM (kg, %), SMM (%), BMI, BAI, WHtR, FMI, FM/FFM and GLU and UA. Furthermore, we found that the MHO group had higher values of fat-free mass, skeletal muscle mass, FFMI and SMMI, as well as HDL, but also higher values of ABSI z-score, which placed this group in the category of high risk of premature death, while the group MNHO had an average risk. The values of the other parameters were higher in the MNHO group, although in many cases the differences were small and insignificant. As in the previous cases, the parameters WC, VFA, FM, BMI, BAI, WHR, WHtR, FMI, FM/FFM, T-CH, LDL, systolic and diastolic blood pressure in the MHO group had borderline.

When dividing the subjects into MHO and MNHO according to BMI and systolic blood pressure, we found that out of 64 individuals, 29 (45.3%) could be assigned to the MHO group and 35 (54.7%) to the MNHO group. We found significant differences between the formed groups in the case of anthropometric parameters body weight, WC, BMI and WHtR, but also biochemical parameters such as HDL, TG, GLU, UA and systolic and diastolic blood pressure in favor of the MHO group. After evaluating the individual parameters, however, even in the group with metabolically healthy obesity, values exceeding the reference limits were found, specifically in the case of WC, VFA, FM, BMI, BAI, WHR, WHtR, FMI, FM/FFM, and also in the case of T-CH and LDL. The ABSI z-score was higher in the MNHO group this time, but overall both groups fell into the category of high risk of premature death.

According to the distribution of probands based on BMI and diastolic blood pressure, the MHO group was formed with 26 (40.6%) individuals and the MNHO group with 38 (59.4%) individuals. In this way of assessing the presence of metabolically healthy obesity, we found the least significant differences between groups. These were found only in the case of blood pressure in favor of MHO. We found higher values in this group only in the case of FM, BAI, FMI, FM/FFM, but there were no significant differences, T-CH and LDL had the same value in

both groups. The ABSI z-score was higher in the MNHO group, but both groups fell into the category of high risk of premature death. Also this time, parameters WC, VFA, FM, BMI, BAI, WHR, WHtR, FMI, FM/FFM, T-CH and LDL had borderline or above-limit values. All the above results are summarized in Table 3.

Table 3. Stratification and characterization of subjects based on selected less strict criteria

	BMI + HDL		BMI + TG		BMI + GLU		BMI + BPs		BMI + BPd	
	MHO (n = 56)	MNHO (n = 8)	MHO (n = 38)	MNHO (n = 26)	MHO (n = 51)	MNHO (n = 13)	MHO (n = 29)	MNHO (n = 35)	MHO (n = 26)	MNHO (n = 38)
Age [years]	51.29	54.25	53.00	49.69	50.33^a	56.85^b	51.41	51.86	53.46	50.42
Basal Metabolic Rate [kcal]	1556	1657	1544	1605	1588	1492	1547	1586	1539	1589
Height [cm]	167	167	167	168	168	163	168	167	166	168
Weight [kg]	93.15^a	102.30^b	94.35	94.21	93.81	96.19	91.28^a	96.79^b	92.43	95.57
Waist circumference [cm]	110.86^a	118.10^b	111.81	111.69	110.69	115.96	109.09^a	113.98^b	110.50	112.63
Fat-free Mass [kg]	54.90	59.56	54.32	57.19	56.38	51.96	54.50	56.31	54.10	56.43
Fat-free Mass [%]	58.74	58.41	57.51	60.43	59.80^a	54.37^b	59.37	58.14	58.31	58.96
Visceral Fat Area [cm ²]	145.74	158.71	149.47	144.27	144.14^a	160.01^b	141.96	151.83	145.59	148.57
Fat Mass [kg]	38.25	42.74	40.03	37.02	37.43^a	44.22^b	36.79	40.48	38.33	39.13
Fat Mass [%]	41.26	41.59	42.49	39.58	40.20^a	45.63^b	40.63	41.87	41.69	41.04
Skeletal Muscle Mass [kg]	30.52	33.39	30.13	31.97	31.43	28.73	30.26	31.39	29.99	31.49
Skeletal Muscle Mass [%]	32.62	32.72	31.87	33.74	33.29^a	30.05^b	32.93	32.38	32.29	32.86
Body Mass Index [kg/m ²]	33.34^a	36.65^b	33.97	33.43	33.19^a	35.96^b	32.52^a	34.77^b	33.74	33.76
Body Adiposity Index [%]	33.00	35.16	33.60	32.79	32.60^a	35.91^b	32.33	34.05	33.79	32.91
Waist to Hip Ratio	1.01	1.03	1.01	1.01	1.01	1.03	1.00	1.02	1.01	1.02
Waist to Height Ratio	0.66^a	0.71^b	0.67	0.67	0.66^a	0.71^b	0.65^a	0.68^b	0.67	0.67
Fat Mass Index [kg/m ²]	13.88	15.46	14.57	13.35	13.45^a	16.52^b	13.29	14.72	14.18	14.00
Fat-free Mass Index (kg/m ²)	19.46^a	21.19^b	19.40	20.08	19.74	19.45	19.23	20.05	19.56	19.76
FM/FFM	0.73	0.74	0.77	0.68	0.70^a	0.85^b	0.71	0.75	0.74	0.73
SMMI [kg/m ²]	10.80^a	11.86^b	10.75	11.21	10.98	10.75	10.66	11.16	10.83	11.01
ABSI [m ^{11/6} kg ^{2/3}]	0.0827	0.0815	0.0823	0.0828	0.0826	0.0824	0.0828	0.0823	0.0824	0.0826
ABSI z-score	0.4448	0.3275	0.2956	0.6269	0.4889	0.1999	0.4072	0.4492	0.3592	0.4787
Cholesterol [mmol/L]	6.09	5.46	5.81	6.30	5.91	6.39	6.11	5.93	6.01	6.01
LDL [mmol/L]	3.64	3.27	3.46	3.80	3.56	3.75	3.67	3.54	3.59	3.60
HDL [mmol/L]	1.59^a	1.10^b	1.59	1.44	1.54	1.47	1.62^a	1.45^b	1.52	1.53
Triglycerides [mmol/L]	1.77	1.85	1.12^a	2.74^b	1.77	1.82	1.47^a	2.03^b	1.60	1.90
Glycaemia [mmol/L]	5.10^a	5.74^b	5.20	5.16	4.90^a	6.28^b	4.98^a	5.35^b	5.03	5.28
Uric Acid [μmol/L]	336^a	397^b	324^a	373^b	333^a	387^b	309^a	372^b	338	348
hs-CRP [mg/L]	4.38^a	9.36^b	4.76	5.36	4.72	6.12	3.50^a	6.25^b	3.41^a	6.10^b
Blood Pressure Systolic	131	141	130^a	137^b	131	139	120^a	143^b	124^a	138^b
Blood Pressure Diastolic	86	90	84^a	90^b	86	92	81^a	92^b	77^a	94^b

Note: ^{ab} – different symbols in the rows mean significant differences in mean intergroup values

Discussion

Several researchers have attempted to identify the physiological correlates of metabolically healthy obesity. Stefan et al. (2017) evaluated ~1000 individuals stratified by BMI. The prevalence of the metabolically healthy phenotype decreased as a function of BMI, from 82% in normal weight subjects to 62% in overweight subjects and 42% in obese subjects. It is clear from research that not the amount of adipose tissue, but rather the adequate number of normally functioning adipocytes capable of expanding through hyperplasia in response to excessive nutrient intake, determines normal metabolic regulation and consequently a metabolically healthy state. A metabolically healthy individual may have increased subcutaneous hyperplastic adiposity under conditions of excess caloric intake and may be obese according to BMI criteria, but as long as he can maintain normal metabolic regulation and insulin sensitivity, he may be characterized as an MHO phenotype (Achilike et al., 2015). An individual with MHO should have no evidence of ectopic lipid deposition (normal liver enzymes, normal adiponectin, increased cardiorespiratory fitness) or low-grade inflammation (low hs-CRP), or evidence of insulin resistance/hyperinsulinism (Sjöström, 2013). On the other hand, a subject with MNHO should have metabolic manifestations as well as metabolic abnormalities of insulin resistance and metabolic syndrome. In our case, based on the strictest diagnostic criteria for metabolically healthy obesity, we recorded the above-mentioned attributes. Although the MHO group showed above-limit values of anthropometric parameters such as WC, VFA, FM (kg, %), BMI, BAI, WHR, WHtR, FMI, FM/FFM, but biochemical parameters such as HDL, TG, GLU, UA, hs-CRP and somatic, such as systolic and diastolic blood pressure, were normal. T-CH and LDL showed slightly increased values, but lower than the MNHO group.

However, what is very important, the state of MNHO is not static because it can convert to MHO (Sjöström, 2013). A diagnosis of MHO or MNHO at one point in time does not always translate into lifelong reduced or increased health risk, although maintaining MHO is clearly beneficial in reducing this risk. The risk of all-cause mortality is lower in people with MHO than in people with MNHO (Hamer & Stamatakis, 2012). However, this assumption remains quite controversial (Janiszewski & Ross, 2010; Ruiz et al., 2013), mainly because a healthier metabolic profile of subjects with metabolically healthy obesity does not necessarily translate into a lower risk of mortality (Primeau et al., 2011). This is also confirmed by our results, where the MHO group showed higher ABSI and ABSI z-score values than the MNHO group, even though there were no significant differences and both groups fell into the category with a high risk of premature death.

Body fat percentage does not differ in people with MHO and MNHO when the groups are matched for BMI and gender (Klötting et al., 2012; Cherqaoui et al., 2012). We can also agree in this case, because during our stratification of obese people, we found that the MHO and MNHO groups had similar values not only of the amount, but also of the proportion of fat in body weight without significant differences. Only in one case did we notice statistically significant differences in body fat values between MHO and MNHO, and that was when we divided obese individuals based on less strict criteria according to BMI and GLU.

However, there are significant differences in adipose tissue distribution between MHO and MNHO. People with MHO have less intra-abdominal adipose tissue than people with MNHO (Koster et al., 2010; Chen et al., 2015) but still two to three times more than metabolically healthy lean people (Fabbrini et al., 2013). Although women with MHO tend to have a greater amount of fat in the lower body (thighs or legs) than women with MNHO (Appleton et al., 2013), lower body fat mass among men with MHO and MNHO does not differ. Excess adiposity alone is not responsible for differences in metabolic health between people with MHO and MNHO. It is precisely the differences in the distribution of adipose tissue that differentiate between the MHO and MNHO phenotypes.

Using different definitions of metabolically healthy obesity can lead to a 3-fold spread of its prevalence in the same population (Liu et al., 2019), while lower estimates are obtained when using more stringent criteria. We can unequivocally agree with this statement, because even in our case we found relatively large differences. Based on the strictest criteria, we identified 13 individuals (20.3%) from 64 subjects who met the condition of BMI ≥ 30 kg/m², 17 individuals (26.6%) under less strict criteria and under criteria requiring only a higher BMI and a minimum one other critical parameter, the prevalences were much higher. Based on BMI and HDL, we identified 56 subjects (87.5%), BMI and TG 38 subjects (59.4%), BMI and GLU 51 subjects (79.7%), BMI and systolic blood pressure 29 subjects (45.3%) and BMI and diastolic blood pressure of 26 individuals (40.6%). Notwithstanding these uncertainties, a recent meta-analysis of 40 population-based studies concluded that ~35% of all obese people worldwide are metabolically healthy (Lin et al., 2017). In practice, this means that treatment could target only 2 out of every 3 people with obesity. The term “metabolically healthy obese” is often misinterpreted as an individual without any medical complications and therefore no need for treatment. However, it is important to realize that in addition to cardiometabolic diseases, obesity can also be associated with orthopedic problems, reproductive disorders, depression, asthma, sleep apnea, kidney disease, back pain, skin infections, decreased cognitive functions, social stigma and overall reduced quality of life (Hill & Wyatt, 2013). Therefore, the absence of metabolic risk factors in people with obesity should not be an indication for labeling individuals with obesity as “healthy” and certainly should not be a contraindication for starting treatment.

Although it remains uncertain whether metabolically healthy obese individuals benefit from moderate weight loss (5–10%) to the same extent as their metabolically unhealthy peers (Janiszewski & Ross, 2010), there is no doubt that this amount of weight loss has multiple beneficial effects on metabolically unhealthy subjects with obesity (Magkos et al., 2016). Extent-dependent weight loss reduces visceral adipose tissue and liver fat content and improves multiorgan insulin sensitivity and β -cell function, all of which have been identified as key correlates of metabolic health. As a result, approximately 25–30% of metabolically non-healthy obese individuals convert to a metabolically healthy phenotype after a modest ~10% weight loss, even if the obesity does not resolve (Ruiz et al., 2013). However, smaller weight losses (2–4%) may not be sufficient to induce a shift from an unhealthy to a healthy obesity phenotype, despite significant improvements in several cardiometabolic risk factors (Kantartzis et al., 2011).

Conclusion

The term metabolically healthy obese is often misinterpreted as an individual without any medical complications and thus without the need for treatment. The use of different definitions can lead to a several-fold spread of the prevalence of metabolically healthy obesity in the same population, while lower estimates are obtained using stricter criteria, which is also confirmed by our results. In our case, the MHO group showed above-limit values of anthropometric parameters such as WC, VFA, FM (kg, %), BMI, BAI, WHR, WHtR, FMI, FM/FFM, but biochemical parameters such as HDL, TG, GLU, UA, hs-CRP and somatic blood pressure, systolic and diastolic, were normal; T-CH and LDL showed slightly increased values, but lower than the MNHO group. The state of MHO is not static, as it can convert to MNHO, but also vice versa; a healthier metabolic profile of subjects with MHO does not necessarily translate into a lower risk of mortality. This is also confirmed by our results, where the MHO group showed higher ABSI and ABSI z-score values than MNHO. Body fat percentage did not differ between MHO, MNHO. The absence of metabolic risk factors in people with obesity should not be an indication to label obese individuals as healthy, and certainly should not be a contraindication for starting reduction therapy.

For individuals with Metabolically Healthy Obesity (MHO), effective treatment includes lifestyle interventions such as a calorie-restricted, nutritionally balanced diet (e.g., Mediterranean or high-protein diets) and regular physical activity, combining aerobic and resistance training for at least 150–300 minutes weekly. Behavioral therapy supports adherence, while pharmacotherapy, including GLP-1 receptor agonists, orlistat, or phentermine-topiramate, may aid in weight loss and metabolic improvements. A modest weight loss of 5–10% significantly enhances health markers, and greater losses further reduce risks. For severe obesity unresponsive to other treatments, bariatric surgery is an option. Psychological support and strategies targeting visceral fat, like intermittent fasting and high-intensity interval training, complement these approaches. Regular monitoring and a personalized, evolving treatment plan ensure optimal outcomes.

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RETURN-TO-PLAY PERFORMANCE AFTER INJURY IN NATIONAL BASKETBALL ASSOCIATION LEAGUE BASKETBALL PLAYERS

Alperen Altıntaş^{A, B, C, D}

Department of Coaching Education, Faculty of Sport Sciences, Gazi University, Turkey
ORCID: 0009-0009-5466-1617

Elif Cengizel^{A, B, C, D}

Department of Coaching Education, Faculty of Sport Sciences, Gazi University, Turkey
ORCID: 0000-0001-5148-3821 | e-mail: elifoz@gazi.edu.tr

^AStudy Design; ^BData Collection; ^CStatistical Analysis; ^DManuscript Preparation

Abstract The aim of this retrospective study was to compare the return-to-play performance after injury in National Basketball Association (NBA) players according to their surgery status, skin color, player positions, injury location, type, and duration. Fifty-four NBA players who sustained an injury between 2018 and 2022 seasons were identified and only five matches before and after the injury were examined to determine the acute effect of the injury. A significant decrease in minutes per game (MPG, pre-injury: 27.4 ± 8.4 min, post-injury: 25.5 ± 6.9 min, $p = 0.019$), field goal points (FGP, pre-injury: 5.4 ± 2.9 , post-injury: 2.4 ± 0.3 , $p = 0.008$), and field goal attempted (FGA, pre-injury: 11.6 ± 5.9 , post-injury: 5.2 ± 0.7 , "large" ES: 1.52, $p = 0.004$) in NBA players after the injury. 70.4% of the injured athletes underwent surgery, 72.2% were black skin color players, the most injured player position was guards (37%), the most injured area was the lower extremity (40.7%), 59.3% were fractures, and most of them had an injury duration between 7–30 days (31.5%). The NBA players who returned to play after injury showed a significant decrease in MPG, FGP, FGA. The findings of this research provide important indicators for sports medicine physicians, coaches, and practitioners and can be a guide to understanding how return-to-play performance is affected by injury factors.

Key words: NBA players, injury type, return-to-game, injury location, offensive actions

Introduction

Basketball is an intensely physically demanding sport (Amin et al., 2013) in which athletes' bodies are subjected to intense stress through repeated jumping and pivoting (Begly et al., 2016), and players are at risk for a variety of injuries. The National Basketball Association (NBA) league requires athletes with distinctive athletic characteristics who have the agility to guard and evade defenders, the strength to establish an effective position on the court near the basket, and the height to grab rebounds or shoot over a defender (Minhas et al., 2016). The unique physical demands required for competition (such as explosive accelerations, change of direction or stop in action, and loading of the joints during different acute movements), and high-impact activities, such as repetitive

jumping, sprinting, and full-speed cutting (Begly et al., 2018; Morse et al., 2017) increase the risk of injury for these players in the NBA (Amin et al., 2013; Drakos et al., 2010).

NBA athletes compete on a longer court, for a greater number of minutes per game and times per week, for a longer season, and at an older age than in FIBA basketball (Drakos et al., 2010). Understanding the types of injuries found associated with basketball can help plan for coverage and prevention of injuries (Trojian et al., 2013). In addition, prior injury is associated with up to a 4-fold increase in the risk of re-injury, and treatment of all injuries includes recommendations for when it is safe to resume sports participation (Creighton et al., 2016). Drakos et al. (Drakos et al., 2010) reported 12,594 injuries, 49% of which occurred during the game, and 59,179 missed matches, seen in 19 out of 1000 athletes in their 17-year overview study. They also reported that the most injured area was the lower extremity with 62.4% and 57% were game-related injuries, and the injury rate was not related to height, weight or years of NBA experience. Previous studies in NBA basketball players have reported outcomes after some injuries and operations such as Achilles tendon rupture (Amin et al., 2013; Chauhan et al., 2021; Trofa et al., 2017; Zellers et al., 2016), ACL injury (DeFroda et al., 2021; Harris, Erickson, et al., 2013; Nwachukwu et al., 2017), adductor injuries (Patel et al., 2020), patellar tendon tears (Nguyen et al., 2018), lower extremity injuries (Khan et al., 2018), hip arthroscopy (Begly et al., 2018), shoulder injury (Lu et al., 2020), forearm and hand injuries (Morse et al., 2017), and Jones fractures (Begly et al., 2016). Professional athletes have essentially unlimited tools to ensure optimal recovery following an injury; but only 60% to 70% are able to return to their sport, often at a measurably lower performance level (Amin et al., 2013).

Although factors such as injury type, duration, location, and operation status are associated with some negativities such as being away from the game, career longevity and financial loss in professional athletes (DeFroda et al., 2021; Minhas et al., 2016; Morse et al., 2017), we do not have any information about the acute effect on return-to-play performance specifically in previous studies. The injury scenario brings with it some risks such as athletes making lower earnings, quitting sports, and not being able to perform as before. For example, after ACL reconstruction, 81% of players returned to play, 65% returned to their pre-injury level, and 55% returned to competitions. The annual cost of managing an ACL injury without surgery as a rehabilitation strategy -overall healthcare expenditures- in the USA is reported to exceed \$4 billion, and with surgery it approaches \$3 billion (Sepúlveda et al., 2017). In addition, It is also stated that musculoskeletal injuries in the NBA are the source of half of the financial costs related to health problems (Sarlis & Tjortjis, 2024). This return-to-play information can provide important indicators for players, teams and physicians regarding the careers of athletes. We hypothesize that return-to-play performances of NBA players would have decreased in comparison with preinjury performance. The purpose of our study was to compare performance metrics before and after injury in NBA basketball players. Additionally, we aimed to compare the return-to-play performances of injured players according to their surgery status, skin color, player positions, injury location, type, and duration.

Material and Methods

Data Acquisition

NBA players who sustained an injury between 2018 and 2022 season were identified in this retrospective study. This specific time frame was chosen to present the latest trends and five seasons were included in the research. All injury and return-to-play performance data were collected using publicly available information via methods that have been used and validated in multiple previous investigations (Begly et al., 2018; Begly et al.,

2016; Chauhan et al., 2021; DeFroda et al., 2021; Lu et al., 2020; Minhas et al., 2016; Nguyen et al., 2018; Padaki et al., 2016; Patel et al., 2020) and fifty-four basketball players were identified. All injuries were verified using www.nba.com and confirmed using NBA official team websites, player profiles, press releases, team injury and transaction report, team medical records. Descriptive data for each player, including age, body mass index (BMI), body height, body weight, and position at the time of injury, were collected from NBA team websites and publicly available internet-based information such as basketball-reference.com. Inclusion criteria were the injured player's return-to-play and had played 5 games before and after injury. Exclusion criteria were the athlete not returning to game or inability to access follow-up statistics. This study was approved by the Local Ethics Committee (Research Code: 2023-65).

Return-to-play performance variables

The return-to-play and pre-injury performance data of each player including minutes per game (MPG), field goal points (FGP), field goal attempted (FGA), field goal percentage (FG%), 3-points (3P), 3-point attempted (3PA), 3-point percentage (3P%), free throw points (FTP), free throw attempted (FTA), free throw percentage (FT%), and assist per game (APG) was collected from databases publicly accessible in NBA official website and basketball-reference.com. In order to determine the acute effect of injuries on return-to-play, data on the last 5 matches played before the injury (pre-injury) and the first 5 matches played after the return-to-play (post-injury) were classified and compared according to operation status, skin color, player positions, injury location, injury type and injury duration. The data set was classified as follows:

Operation status: Surgery and non-surgery

Skin color: Black and white players, as mentioned in Furley & Dicks' study (Furley & Dicks, 2014).

Player positions: Guard (G), forward (F), center (C).

Injury location: Lower extremity injury (LE, injuries below the groin area), trunk injury (T, injuries that extend from the groin area to the cervical region but do not include the glenohumeral joint, the arms, and hands), upper extremity injury (UE, injuries that include the glenohumeral joint, and the entire arm below, the hands) and facial injury (F).

Injury type: Fracture and ligament injury.

Injury duration: Very short (0–7 days), short (7–30 days), moderate (30–180 days), long (180–360 days), and very long (more than 360 days).

Data analysis

All descriptive and comparative analyses were performed using SigmaPlot (Systat Software, Inc., San Jose, USA). Data are presented as mean, standard deviation, minimum and maximum value. Shapiro Wilk test was used to determine the normality of data distribution. Paired sample t-test was used to compare return-to-play performance before and after injury within the group. A t-test was conducted for comparisons between groups according to operation status, skin color, and injury type, and one way analysis of variance was performed inter-group comparisons according to player positions, injury location, and injury duration. Effect sizes (ES) were classified using Cohen's d (2013) according to the following scale: trivial <0.2, small 0.2–0.5, moderate 0.5–0.8, and large >0.8. Significance level was set at $p < 0.05$.

Results

Fifty-four NBA league players (mean age: 26.8 ± 4.2 years, height: 200.6 ± 8.3 cm, body mass: 101.2 ± 12.4 kg, and body mass index: 25.1 ± 2.1 kg.m⁻², respectively) were identified with an injury between 2018–2022 season. MPG (pre-injury: 27.4 ± 8.4 min, post-injury: 25.5 ± 6.9 min, “small” ES: .22, $p = 0.019$), FGP (pre-injury: 5.4 ± 2.9 , post-injury: 2.4 ± 0.3 , “large” ES: 1.46, $p = 0.008$), FGA (pre-injury: 11.6 ± 5.9 , post-injury: 5.2 ± 0.7 , “large” ES: 1.52, $p = 0.004$) of NBA players decreased significantly after injury (Table 1). Although there was a decrease in other parameters presented in Table 1 in the return-to-play performance, this difference is not significant.

Table 1. Return-to-play performance of NBA players before and after injury (n = 54)

	Pre-injury			Post-injury			p
	mean $\pm$ SD	min	max	mean $\pm$ SD	min	max	
MPG	27.4 ± 8.4	9.9	42.4	25.5 ± 6.9	10.6	38.8	0.019
FGP	5.4 ± 2.9	0.8	10.8	2.4 ± 0.3	1.0	9.2	0.008
FGA	11.6 ± 5.9	1.4	23.6	5.2 ± 0.7	1.8	19.2	0.004
FG%	47.0 ± 10.7	28.0	83.0	10.5 ± 1.4	4.0	71.0	0.541
3P	1.3 ± 1.1	0.0	4.8	1.0 ± 0.1	0.0	3.8	0.497
3PA	3.7 ± 2.6	0.0	9.6	2.6 ± 0.3	0.0	11.2	0.720
3P%	32.8 ± 12.9	0.0	59.0	16.4 ± 2.3	0.0	100.0	0.565
FTP	2.8 ± 2.2	0.0	8.8	2.2 ± 0.3	0.0	10.6	0.051
FTA	3.6 ± 2.6	0.2	10.4	2.5 ± 0.3	0.0	13.0	0.075
FT%	71.7 ± 19.6	0.0	100.0	20.2 ± 2.8	0.0	100.0	0.848
APG	3.0 ± 2.2	0.2	9.0	2.2 ± 0.3	0.4	11.0	0.438

MPG: Minutes per game, FGP: Field goal points, FGA: 2 Field goal attempted, FG%: Field goal percentage, 3P: 3-points, 3PA: 3-point attempted, 3P%: 3-point percentage, FTP: Free throw points, FTA: Free throw attempted, FT%: Free throw percentage, APG: Assist per game. Data are presented as mean $\pm$ SD, minimum (min), and maximum value, $p < 0.05$.

70.4% of NBA players (n = 38) had surgery after injury, and 29.6% (n = 16) returned to the game without surgery. MPG (pre-injury: 27.3 ± 8.8 min, post-injury: 25.2 ± 6.6 min, “small” ES: 0.35, $p = 0.039$), FGP (pre-injury: 5.5 ± 3.0 , post-injury: 4.9 ± 2.4 , “small” ES: 0.22, $p = 0.015$), FGA (pre-injury: 11.8 ± 5.8 , post-injury: 10.7 ± 5.1 , “small” ES: 0.20, $p = 0.007$) of NBA players who underwent surgery decreased significantly after injury (Table 2). Although there is a quantitative decrease in other parameters – except 3P% and FT% – in basketball players who underwent surgery compared to the pre-injury period, this difference is not significant. Post-injury return-to-play performance was not significantly different in NBA players who did not undergo surgery.

Table 2. Return-to-play performance of NBA players before and after injury according to their operation status (operated n = 38, non-operated n = 16)

		Pre-injury			p*	Post-injury			p*	p**
		mean $\pm$ SD	min	max		mean $\pm$ SD	min	max		
MPG	O	27.3 ± 8.8	9.9	42.4	0.898	25.2 ± 6.6	10.6	36.1	0.609	0.039
	NO	27.5 ± 7.5	12.5	37.2		26.2 ± 7.5	12.4	38.8		0.560
FGP	O	5.5 ± 3.0	1.4	10.8	0.463	4.9 ± 2.4	1.4	9.2	0.569	0.015
	NO	5.1 ± 2.9	0.8	10.8		4.5 ± 2.5	1.000	8.6		0.673

		Pre-injury			p*	Post-injury			p*	p**
		mean $\pm$ SD	min	max		mean $\pm$ SD	min	max		
FGA	O	11.8 $\pm$ 5.8	2.6	23.6	0.524	10.7 $\pm$ 5.1	3.0	19.2	0.653	0.007
	NO	11.0 $\pm$ 6.3	1.4	22.8		10.0 $\pm$ 5.5	1.8	18.6		0.753
FG%	O	46.6 $\pm$ 10.3	28.0	79.0	0.782	45.7 $\pm$ 11.1	4.0	69.0	0.864	0.908
	NO	47.8 $\pm$ 11.9	30.0	83.0		46.2 $\pm$ 9.3	27.0	71.0		0.753
3P	O	1.4 $\pm$ 1.0	0.0	4.8	0.349	1.3 $\pm$ 1.0	0	3.8	0.867	0.167
	NO	1.2 $\pm$ 1.2	0.0	3.6		1.2 $\pm$ 1.0	0	3.4		0.754
3PA	O	3.9 $\pm$ 2.6	0.0	9.6	0.321	3.7 $\pm$ 2.5	0	11.2	0.909	0.139
	NO	3.3 $\pm$ 2.8	0.0	8.0		3.6 $\pm$ 2.8	0	7.8		0.652
3P%	O	33.7 $\pm$ 11.3	10.0	59.0	0.076	33.9 $\pm$ 14.6	0	59.0	0.717	0.588
	NO	30.3 $\pm$ 16.6	0.0	58.0		38.6 $\pm$ 20.1	12.0	100.0		0.226
FTP	O	3.0 $\pm$ 2.3	0.2	8.8	1.00	2.7 $\pm$ 2.2	0	10.6	0.197	0.105
	NO	2.2 $\pm$ 1.9	0.0	7.0		1.8 $\pm$ 1.9	0	7.0		0.635
FTA	O	3.9 $\pm$ 2.8	0.4	10.4	0.256	3.5 $\pm$ 2.7	0	13.0	0.094	0.247
	NO	3.0 $\pm$ 2.3	0.2	8.0		2.3 $\pm$ 2.1	0.4	7.4		0.361
FT%	O	73.2 $\pm$ 18.1	28.0	100.0	0.202	73.6 $\pm$ 15.9	35.0	100.0	0.561	0.357
	NO	68.0 $\pm$ 22.9	0.0	100.0		73.8 $\pm$ 27.7	0	100.0		0.370
APG	O	2.8 $\pm$ 2.1	0.2	9.0	0.308	2.6 $\pm$ 1.9	0.4	7.0	0.315	0.448
	NO	3.6 $\pm$ 2.4	0.2	7.4		3.3 $\pm$ 2.8	0.6	11.0		0.852

O: Operated, NO: Non-operated, MPG: Minutes per game, FGP: Field goal points, FGA: 2 Field goal attempted, FG%: Field goal percentage, 3P: 3-points, 3PA: 3-point attempted, 3P%: 3-point percentage, FTP: Free throw points, FTA: Free throw attempted, FT%: Free throw percentage, APG: Assist per game. Data are presented as mean $\pm$ SD, minimum (min), and maximum value, p*: inter-group comparison, p**: intra-group comparison (pre- vs. post-injury), p < 0.05.

MPG (pre-injury: 28.5 $\pm$ 7.8min, post-injury: 26.0 $\pm$ 6.8min, “small” ES: .34, p = 0.007), FGP (pre-injury: 5.6 $\pm$ 2.9, post-injury: 5.0 $\pm$ 2.4, “small” ES: 0.23, p = 0.017), FGA (pre-injury: 12.3 $\pm$ 6.0, post-injury: 10.7 $\pm$ 5.2, “small” ES: 0.28, p = 0.002) of NBA black skin color players decreased significantly after injury (Table 3). Although there is a quantitative decrease in other parameters of black skin color basketball players – except FG% and 3P% – compared to the pre-injury period, this difference is not significant. Post-injury return-to-play performance was not significantly different in NBA white skin color players.

Table 3. Return-to-play performance of NBA players before and after injury according to skin color (black players n = 39, white players n = 15)

		Pre-injury			p*	Post-injury			p**	p**
		mean $\pm$ SD	min	max		mean $\pm$ SD	min	max		
MPG	B	28.5 $\pm$ 7.8	11.8	42.4	0.111	26.0 $\pm$ 6.8	12.4	38.8	0.389	0.007
	W	24.3 $\pm$ 9.5	9.9	37.6		24.1 $\pm$ 7.2	10.6	33.6		0.906
FGP	B	5.6 $\pm$ 2.9	0.8	10.8	0.319	5.0 $\pm$ 2.4	1.0	9.2	0.302	0.017
	W	4.7 $\pm$ 2.9	1.4	9.2		4.2 $\pm$ 2.5	1.4	8.4		0.285
FGA	B	12.3 $\pm$ 6.0	1.4	23.6	0.149	10.7 $\pm$ 5.2	1.8	19.2	0.479	0.002
	W	9.6 $\pm$ 5.3	2.6	17.0		9.6 $\pm$ 5.3	3.0	17.4		0.980
FG%	B	46.4 $\pm$ 10.1	30.0	83.0	0.512	47.0 $\pm$ 9.6	27.0	71.0	0.209	0.763
	W	48.6 $\pm$ 12.4	28.0	79.0		42.8 $\pm$ 12.7	4.0	54.0		0.159

		Pre-injury			p*	Post-injury			p**	p**
		mean $\pm$ SD	min	max		mean $\pm$ SD	min	max		
3P	B	1.3 $\pm$ 1.0	0.0	3.6	0.460	1.2 $\pm$ 1.0	0.0	3.8	0.601	0.694
	W	1.5 $\pm$ 1.3	0.2	4.8		1.4 $\pm$ 0.9	0.0	2.8		0.537
3PA	B	3.8 $\pm$ 2.7	0.0	9.6	0.931	3.5 $\pm$ 2.6	0.0	11.2	0.533	0.316
	W	3.7 $\pm$ 2.3	0.4	8.2		4.1 $\pm$ 2.5	0.6	7.2		0.242
3P%	B	29.8 $\pm$ 13.1	0.0	59.0	0.003	35.7 $\pm$ 18.1	7.0	100.0	0.737	0.232
	W	40.5 $\pm$ 8.7	25.0	59.0		34.1 $\pm$ 11.4	0.0	45.0		0.066
FTP	B	3.1 $\pm$ 2.4	0.0	8.8	0.121	2.6 $\pm$ 2.4	0.0	10.6	0.205	0.050
	W	2.0 $\pm$ 1.5	0.2	6.4		1.7 $\pm$ 1.3	0.0	4.4		0.606
FTA	B	4.0 $\pm$ 2.8	0.2	10.4	0.075	3.4 $\pm$ 2.7	0.0	13.0	0.170	0.064
	W	2.5 $\pm$ 1.8	0.4	7.2		2.3 $\pm$ 1.9	0.0	6.4		0.730
FT%	B	71.0 $\pm$ 20.7	0.0	100.0	0.652	70.0 $\pm$ 20.8	0.0	100.0	0.226	0.827
	W	73.7 $\pm$ 16.3	50.0	100.0		84.6 $\pm$ 14.2	65.0	100.0		0.635
APG	B	3.4 $\pm$ 2.3	0.2	9.0	0.027	3.2 $\pm$ 2.4	0.4	11.0	0.045	0.471
	W	1.9 $\pm$ 1.6	0.2	5.2		1.8 $\pm$ 1.3	0.6	4.8		0.787

B: Black players, W: White players, MPG: Minutes per game, FGP: Field goal points, FGA: 2 Field goal attempted, FG%: Field goal percentage, 3P: 3-points, 3PA: 3-point attempted, 3P%: 3-point percentage, FTP: Free throw points, FTA: Free throw attempted, FT%: Free throw percentage, APG: Assist per game. Data are presented as mean $\pm$ SD, minimum (min), and maximum value, p*: inter-group comparison, p**: intra-group comparison (pre- vs. post-injury), p < 0.05.

Forward players' MPG (pre-injury: 30.9 $\pm$ 8.2min, post-injury: 27.0 $\pm$ 6.6min, "moderate" ES: 0.52, p = 0.022), FTP (pre-injury: 3.5 $\pm$ 2.5, post-injury: 2.5 $\pm$ 2.0, "small" ES: 0.44, p = 0.018), FTA (pre-injury: 4.4 $\pm$ 3.1, post-injury: 3.2 $\pm$ 2.3, "small" ES: 0.44, p = 0.016), and center players' FGP (pre-injury: 4.8 $\pm$ 2.6, post-injury: 3.7 $\pm$ 2.1, "small" ES: 0.47, p = 0.008), FGA (pre-injury: 9.5 $\pm$ 5.6, post-injury: 8.2 $\pm$ 4.7, "small" ES: 0.25, p = 0.043) decreased significantly after the injury compared to before the injury (Table 4). Although the MPG before injury in NBA players is significantly higher in forward players than in guards (p = 0.017), it was not significantly different according to player positions after injury (p = 0.060). Before the injury, center players had significantly higher FG% (G vs. C p = 0.007) and significantly lower 3P (F vs. C p = 0.006, G vs. C p = 0.035), 3PA (G vs. C p = 0.012, F vs. C p = 0.013), and APG (G vs. C p = 0.003) compared to other positions. After the injury, the FGP of the forward players was significantly higher than the center players (p = 0.012), and the 3P, 3PA and APG of guard players were significantly higher than the center players (p = 0.012, p = 0.010, p = 0.003, respectively). FGA, 3P%, FTP, FTA and FT% were not significantly different between the player positions both before and after the injury (p > 0.05).

Table 4. Return-to-play performance of NBA players before and after injury according to player positions (Guard n = 20, Forward n = 17, Center n = 17)

		Pre-injury			p*	Post-injury			p*	p**
		mean $\pm$ SD	min	max		mean $\pm$ SD	min	max		
MPG	G	26.5 $\pm$ 8.9	9.9	40.8	F vs. C 0.017	26.8 $\pm$ 7.4	10.6	38.8	NS 0.060	0.812
	F	30.9 $\pm$ 8.2	11.8	42.4		27.0 $\pm$ 6.6	16.3	36.9		0.022
	C	24.2 $\pm$ 6.7	10.4	35.5		22.1 $\pm$ 5.6	12.4	29.9		0.079
FGP	G	5.0 $\pm$ 2.9	1.4	10.0	NS 0.173	4.9 $\pm$ 2.6	1.6	8.6	F vs. C 0.012	0.637
	F	6.5 $\pm$ 3.3	1.0	10.8		5.7 $\pm$ 2.3	1.2	9.2		0.146
	C	4.8 $\pm$ 2.6	0.8	10.0		3.7 $\pm$ 2.1	1.0	8.0		0.008

		Pre-injury			p*	Post-injury			p*	p**
		mean $\pm$ SD	min	max		mean $\pm$ SD	min	max		
FGA	G	11.5 $\pm$ 6.2	3.4	22.8	NS 0.163	10.9 $\pm$ 5.5	3.0	19.2	NS 0.083	0.335
	F	13.4 $\pm$ 5.7	2.2	23.6		11.9 $\pm$ 4.9	2.0	18.6		0.061
	C	9.5 $\pm$ 5.6	1.4	19.4		8.2 $\pm$ 4.7	1.8	16.6		0.043
FG%	G	42.2 $\pm$ 5.7	33.0	52.0	C vs. G 0.007	42.4 $\pm$ 13.7	4.0	71.0	NS 0.189	0.949
	F	47.7 $\pm$ 10.3	28.0	76.0		48.0 $\pm$ 7.0	37.0	64.0		0.896
	C	51.9 $\pm$ 13.6	30.0	83.0		47.7 $\pm$ 9.2	33.0	69.0		0.248
3P	G	1.5 $\pm$ 1.1	0.0	3.4	F vs. C 0.006 G vs. C 0.035	1.6 $\pm$ 1.2	0.0	3.8	G vs. C 0.012	0.534
	F	1.8 $\pm$ 1.2	0.2	4.8		1.4 $\pm$ 0.9	0.2	2.8		0.113
	C	0.7 $\pm$ 0.8	0.0	2.6		0.8 $\pm$ 0.8	0.0	2.4		0.796
3PA	G	4.5 $\pm$ 3.0	0.2	9.6	G vs. C 0.012 F vs. C 0.013	4.6 $\pm$ 2.9	0.0	11.2	G vs. C 0.010	0.609
	F	4.4 $\pm$ 2.2	0.6	8.2		4.0 $\pm$ 2.3	1.0	7.4		0.204
	C	2.3 $\pm$ 2.1	0.0	7.0		2.4 $\pm$ 2.2	0.0	6.2		0.710
3P%	G	30.9 $\pm$ 13.2	0.0	58.0	NS 0.174	33.7 $\pm$ 16.2	0.0	59.0	NS 0.853	0.827
	F	35.3 $\pm$ 12.5	10.0	59.0		34.6 $\pm$ 13.8	8.0	56.0		0.879
	C	31.9 $\pm$ 13.6	10.0	59.0		38.6 $\pm$ 20.8	17.0	100.0		0.471
FTP	G	2.4 $\pm$ 2.0	0.2	8.0	NS 0.331	2.5 $\pm$ 2.2	0.0	7.0	NS 0.969	0.763
	F	3.5 $\pm$ 2.5	0.2	8.8		2.5 $\pm$ 2.0	0.0	7.2		0.018
	C	2.6 $\pm$ 2.3	0.0	8.8		2.3 $\pm$ 2.6	0.0	10.6		0.482
FTA	G	3.1 $\pm$ 2.2	0.4	9.8	NS 0.274	3.1 $\pm$ 2.4	0.0	7.6	NS 0.985	0.990
	F	4.4 $\pm$ 3.1	0.2	10.4		3.2 $\pm$ 2.3	0.0	8.0		0.016
	C	3.4 $\pm$ 2.6	0.4	10.0		3.2 $\pm$ 3.2	0.4	13.0		0.766
FT%	G	69.9 $\pm$ 19.6	28.0	100.0	NS 0.339	78.5 $\pm$ 16.9	44.0	100.0	NS 0.721	0.475
	F	76.9 $\pm$ 12.9	57.0	100.0		74.2 $\pm$ 20.2	35.0	100.0		0.378
	C	67.6 $\pm$ 25.3	0.0	100.0		67.7 $\pm$ 23.3	0.0	100.0		0.994
APG	G	4.1 $\pm$ 2.5	0.2	9.0	G vs. C 0.003	3.9 $\pm$ 2.3	0.4	7.4	G vs. C 0.003	0.893
	F	3.1 $\pm$ 2.1	0.6	7.6		2.8 $\pm$ 2.5	0.6	11.0		0.338
	C	1.8 $\pm$ 1.4	0.2	4.2		1.8 $\pm$ 1.1	0.8	4.8		0.820

G: Guard, F: Forward, C: Center, MPG: Minutes per game, FGP: Field goal points, FGA: 2 Field goal attempted, FG%: Field goal percentage, 3P: 3-points, 3PA: 3-point attempted, 3P%: 3-point percentage, FTP: Free throw points, FTA: Free throw attempted, FT%: Free throw percentage, APG: Assist per game. Data are presented as mean $\pm$ SD, minimum (min), and maximum value, p*: inter-group comparison, p**: intra-group comparison (pre- vs. post-injury), NS: No significance, p < 0.05.

The most injured location in NBA players is the lower extremity (40.7%), followed by upper extremity (37.0%), trunk (12.9%) and facial injuries (9.4%). In intra-group comparisons of return-to-play performance before and after the injury, FGP (pre-injury: 8.7 $\pm$ 2.2, post-injury: 6.5 $\pm$ 2.2, "large" ES: 1.0, p = 0.027), FGA (pre-injury: 18.0 $\pm$ 5.0, post-injury: 14.1 $\pm$ 4.7, "moderate" ES: 0.80, p = 0.017), FT% (pre-injury: 89.7 $\pm$ 8.6, post-injury: 77.2 $\pm$ 11.1, "large" ES: 1.26, p = 0.040) of athletes who had trunk injuries decreased significantly (Table 5). In the inter-group comparison of NBA players' performance before and after injury, MPG, FGP%, 3P, 3PA, 3P% and APG were not significantly different according to injury locations (p > 0.05). Post-injury FGA (T vs. LE p = 0.008), FTP (T vs LE p = 0.001, T vs. UE p = 0.013), FTA (T vs. LE p = 0.001, T vs. UE p = 0.010) performance of athletes with trunk injuries was significantly higher than players returning to the game from other injury areas.

Table 5. Return-to-play performance of NBA players before and after injury according to injury location (lower extremity injury n = 22, upper extremity injury n = 20, trunk injury n = 7, fascial injury n = 5)

		Pre-injury			p*	Post-injury			p*	p**
		mean $\pm$ SD	min	max		mean $\pm$ SD	min	max		
MPG	LE	24.8 $\pm$ 7.8	10.4	37.1	NS 0.176	22.7 $\pm$ 6.6	12.4	36.1	NS 0.101	0.345
	UE	28.2 $\pm$ 9.5	9.9	42.4		27.0 $\pm$ 7.3	10.6	38.8		0.671
	T	32.5 $\pm$ 5.5	21.2	37.8		28.0 $\pm$ 5.2	19.6	34.5		0.065
	F	28.2 $\pm$ 7.1	16.4	34.4		27.9 $\pm$ 6.1	19.5	35.5		0.922
FGP	LE	4.4 $\pm$ 2.5	0.8	9.4	T vs. LE 0.001	3.8 $\pm$ 2.0	1.0	8.6	NS 0.050	0.385
	UE	5.4 $\pm$ 2.9	1.0	10.8	T vs. UE 0.008	5.1 $\pm$ 2.5	1.2	9.2		0.779
	T	8.7 $\pm$ 2.2	4.2	10.8	T vs. FY 0.042	6.5 $\pm$ 2.2	2.8	8.2		0.027
	F	5.4 $\pm$ 3.3	2.2	10.6		5.3 $\pm$ 2.8	1.6	8.0		0.936
FGA	LE	9.4 $\pm$ 4.9	1.4	19.8	T vs. LE 0.001	8.2 $\pm$ 4.6	1.8	19.0	T vs. LE 0.008 UE vs. LE 0.039	0.376
	UE	11.7 $\pm$ 6.1	2.2	23.6	T vs. UE 0.010	11.4 $\pm$ 5.0	2.0	18.2		0.892
	T	18.0 $\pm$ 5.0	7.8	22.8	T vs. F 0.049	14.1 $\pm$ 4.7	5.8	18.6		0.017
	F	11.6 $\pm$ 4.6	5.6	16.6		11.6 $\pm$ 5.8	4.4	19.2		0.957
FG%	LE	46.9 $\pm$ 11.1	28.0	79.0	NS 0.969	48.8 $\pm$ 10.5	27.0	71.0	NS 0.314	0.535
	UE	47.2 $\pm$ 10.5	34.0	83.0		43.2 $\pm$ 11.1	4.0	53.0		0.301
	T	48.1 $\pm$ 5.0	39.0	54.0		46.8 $\pm$ 3.7	41.0	53.0		0.656
	F	45.0 $\pm$ 17.5	33.0	76.0		42.6 $\pm$ 13.2	28.0	64.0		0.583
3P	LE	0.9 $\pm$ 0.9	0.0	3.2	NS 0.141	0.9 $\pm$ 1.0	0.0	3.4	NS 0.085	0.860
	UE	1.6 $\pm$ 1.3	0.0	4.8		1.6 $\pm$ 0.9	0.2	3.8		0.959
	T	1.8 $\pm$ 0.9	0.2	3.6		1.2 $\pm$ 0.7	0.4	2.0		0.099
	F	1.4 $\pm$ 0.6	0.6	2.4		1.5 $\pm$ 1.2	0.2	3.4		0.703
3PA	LE	2.8 $\pm$ 2.3	0.0	7.4	NS 0.133	2.5 $\pm$ 2.3	0.0	7.4	NS 0.053	0.714
	UE	4.2 $\pm$ 2.7	0.0	9.4		4.6 $\pm$ 2.4	0.2	8.8		0.606
	T	5.1 $\pm$ 2.5	0.6	8.0		4.0 $\pm$ 1.7	1.2	6.6		0.078
	F	4.4 $\pm$ 3.0	1.6	9.6		4.6 $\pm$ 3.9	1.2	11.2		0.704
3P%	LE	31.4 $\pm$ 12.3	10.0	58.0	NS 0.616	31.5 $\pm$ 14.5	0.0	55.0	NS 0.053	0.565
	UE	32.7 $\pm$ 14.5	0.0	59.0		40.7 $\pm$ 18.1	12.0	100.0		0.098
	T	37.0 $\pm$ 13.4	26.0	59.0		35.1 $\pm$ 16.9	12.0	59.0		0.859
	F	32.6 $\pm$ 9.2	24.0	44.0		27.4 $\pm$ 11.6	7.0	36.0		0.452
FTP	LE	2.0 $\pm$ 1.5	0.0	6.8	T vs LE 0.001	1.6 $\pm$ 1.0	0.0	4.0	T vs LE 0.001 T vs. UE.013	0.253
	UE	2.9 $\pm$ 2.5	0.2	8.8	T vs. UE 0.014	2.4 $\pm$ 2.1	0.0	7.2		0.559
	T	5.3 $\pm$ 2.3	1.8	8.8	T vs. F.020	4.8 $\pm$ 3.1	2.0	10.6		0.478
	F	2.3 $\pm$ 1.9	0.4	4.8		2.5 $\pm$ 2.6	0.0	6.8		0.776
FTA	LE	2.8 $\pm$ 2.0	0.4	9.2	NS 0.069	2.2 $\pm$ 1.4	0.0	6.0	T vs. LE 0.001 T vs. UE 0.010	0.226
	UE	3.7 $\pm$ 3.0	0.2	10.4		3.1 $\pm$ 2.4	0.4	8.0		0.513
	T	5.9 $\pm$ 2.5	2.6	10.0		5.9 $\pm$ 3.8	2.6	13.0		0.948
	F	3.2 $\pm$ 2.7	0.6	7.2		3.2 $\pm$ 2.8	0.0	6.8		0.945

		Pre-injury			p*	Post-injury			p*	p**
		mean ±SD	min	max		mean ±SD	min	max		
FT%	LE	61.9 ±21.3	0.0	100.0	T vs. LE 0.001	72.6 ±17.8	44.0	100.0	NS 0.516	0.137
	UE	75.3 ±15.6	42.0	100.0		73.8 ±24.8	0.0	100.0		0.823
	T	89.7 ±8.6	72.0	100.0	UE vs. LE 0.018	77.2 ±11.1	66.0	96.0		0.040
	F	75.4 ±15.9	57.0	100.0		72.0 ±25.5	38.0	100.0		0.300
APG	LE	2.4 ±2.0	0.2	7.6	NS 0.059	2.2 ±1.5	0.6	5.8	NS 0.265	0.665
	UE	2.8 ±2.2	0.2	7.4		3.2 ±2.8	0.6	11.0		0.620
	T	5.0 ±2.3	1.8	9.0		3.9 ±1.5	2.0	6.0		0.189
	F	3.7 ±2.1	1.4	6.6		3.0 ±2.6	0.4	7.0		0.101

LE: Lower extremity, UE: Upper extremity, T: Trunk, F: Fascial injury. MPG: Minutes per game, FGP: Field goal points, FGA: 2 Field goal attempted, FG%: Field goal percentage, 3P: 3-points, 3PA: 3-point attempted, 3P%: 3-point percentage, FTP: Free throw points, FTA: Free throw attempted, FT%: Free throw percentage, APG: Assist per game. Data are presented as mean±SD, minimum (min), and maximum value, p*: inter-group comparison, p**: intra-group comparison (pre- vs. post-injury), NS: No significance, p < 0.05.

59.3% fractures and 40.7% ligament injuries have been identified in NBA players. While there was a significant decrease in the MPG (pre-injury: 31.3 ±7.2min, post-injury: 25.8 ±6.1min, “large” ES: 0.82, p = 0.001), FGP (pre-injury: 7.2 ±2.4, post-injury: 5.6 ±2.2, “moderate” ES: 0.69, p = 0.007) and FGA (pre-injury: 14.9 ±4.9, post-injury: 12.2 ±4.6, “moderate” ES: 0.57, p = 0.013) performances of players with ligament injuries, the return-to-play performance of players with fractures was not significantly different compared to before the injury (p > 0.05, Table 6). Pre-injury MPG (p = 0.003), FGP (p = 0.001), FGA (p = 0.001), FTP (p = 0.001), and FTA (p = 0.001) of athletes with ligament injuries were significantly higher than athletes with fractures. After the injury, the FGP (p = 0.018), FTP (p = 0.016), and FTA (p = 0.003) performances of the athletes who suffered a ligament injury were significantly higher than those who suffered a fracture.

Table 6. Return-to-play performance of NBA players before and after injury according to injury type (fracture n = 32, ligament injury n = 22)

		Pre-injury			p*	Post-injury			p*	p**
		mean ±SD	min	max		mean ±SD	min	max		
MPG	Fr	24.2 ±8.3	9.9	37.2	0.003	24.8 ±7.8	10.6	38.8	0.626	0.446
	Lg	31.3 ±7.2	11.8	42.4		25.8 ±6.1	13.6	36.9		0.001
FGP	Fr	4.1 ±2.7	0.8	10.8	0.001	4.0 ±2.3	1.0	8.6	0.018	0.634
	Lg	7.2 ±2.4	3.0	10.8		5.6 ±2.2	1.6	9.2		0.007
FGA	Fr	9.1 ±5.5	1.4	22.8	0.001	9.1 ±5.1	1.8	19.2	0.035	1.000
	Lg	14.9 ±4.9	6.0	23.6		12.2 ±4.6	3.0	18.2		0.013
FG%	Fr	46.4 ±12.4	28.0	83.0	0.568	42.5 ±10.7	4.0	54.0	0.088	0.172
	Lg	48.3 ±9.1	32.0	76.0		47.4 ±8.4	33.0	69.0		0.667
3P	Fr	1.2 ±1.0	0.0	3.6	0.105	1.2 ±0.9	0.0	3.4	0.362	0.870
	Lg	1.7 ±1.1	0.2	4.8		1.48 ±1.0	0.0	3.8		0.142
3PA	Fr	3.3 ±2.6	0.0	9.6	0.058	3.5 ±2.7	0.0	11.2	0.312	0.446
	Lg	4.7 ±2.3	1.0	9.4		4.2 ±2.3	0.0	8.8		0.140
3P%	Fr	35.0 ±11.8	10.0	58.0	0.989	37.0 ±18.7	0.0	100.0	0.282	0.510
	Lg	32.5 ±12.3	13.0	59.0		31.6 ±13.0	8.0	55.0		0.508
FTP	Fr	1.9 ±1.7	0.0	7.0	0.001	1.8 ±2.0	0.0	7.0	0.016	0.659
	Lg	4.1 ±2.5	0.2	8.8		3.3 ±2.3	0.8	10.6		0.106

		Pre-injury			p*	Post-injury			p*	p**
		mean $\pm$ SD	min	max		mean $\pm$ SD	min	max		
FTA	Fr	2.4 $\pm$ 1.8	0.2	7.6	0.001	2.2 $\pm$ 2.2	0.0	7.4	0.003	0.634
	Lg	5.2 $\pm$ 2.9	0.6	10.4		4.4 $\pm$ 2.7	1.2	13.0		0.231
FT%	Fr	71.3 $\pm$ 20.9	0.0	100.0	0.321	75.9 $\pm$ 25.2	0.0	100.0	0.686	0.890
	Lg	76.6 $\pm$ 14.7	50.0	100.0		73.2 $\pm$ 13.5	38.0	100.0		0.348
APG	Fr	2.5 $\pm$ 1.9	0.2	6.6	0.048	2.7 $\pm$ 2.3	0.4	7.4	0.597	0.471
	Lg	3.8 $\pm$ 2.5	0.6	9.0		2.2 $\pm$ 0.4	0.6	11.0		0.080

Fr: Fracture, Lg: Ligament injury, MPG: Minutes per game, FGP: Field goal points, FGA: 2 Field goal attempted, FG%: Field goal percentage, 3P: 3-points, 3PA: 3-point attempted, 3P%: 3-point percentage, FTP: Free throw points, FTA: Free throw attempted, FT%: Free throw percentage, APG: Assist per game. Data are presented as mean $\pm$ SD, minimum (min), and maximum value, p*: inter-group comparison, p**: intra-group comparison (pre- vs. post-injury), p < 0.05.

The majority of NBA players had a short-term injury (31.5%, lasting 7–30 days), followed by a moderate (27.8%, 30–180 days), long (14.8%, 180–360 days), very long (14.8%, over 360 days) and very short-term injury (11.1%, 1–7 days), respectively. A significant decrease was determined in the MPG (pre-injury: 28.9 $\pm$ 8.2 min, post-injury: 25.2 $\pm$ 6.3 min, “moderate” ES: .51, p = 0.006), FGP (pre-injury: 6.7 $\pm$ 3.1, post-injury: 5.4 $\pm$ 2.2, “small” ES: 0.48, p = 0.016), FGA (pre-injury: 13.9 $\pm$ 6.4, post-injury: 11.6 $\pm$ 4.8, “small” ES: 0.41, p = 0.008), 3P (pre-injury: 1.5 $\pm$ 0.9, post-injury: 1.1 $\pm$ 0.8, “small” ES: 0.47, p = 0.042), 3PA (pre-injury: 4.2 $\pm$ 2.4, post-injury: 3.4 $\pm$ 2.1, “small” ES: 0.35, p = 0.033) of athletes who had a short-term injury, and MPG (pre-injury: 23.8 $\pm$ 7.3 min, post-injury: 19.1 $\pm$ 4.9min, “moderate” ES: 0.76, p = 0.024), FGP (pre-injury: 3.9 $\pm$ 2.0, post-injury: 2.5 $\pm$ 1.6, “moderate” ES: 0.77, p = 0.026), FGA pre-injury: 7.7 $\pm$ 4.2, post-injury: 5.5 $\pm$ 3.2, “moderate” EB: 0.59, p = 0.03) performances of athletes who had a very long-term injury period decreased compared to the pre-injury period (Table 7). Pre-injury game profiles of NBA players were not significantly different between groups according to injury duration (p > 0.05). However, after the injury, the MPG (M vs. VL p = 0.003, VS vs. VL p = 0.015, L vs. VL p = 0.031, S vs. VL p = 0.032), 2PA (M vs. VL p = 0.004, S vs. VL p = 0.005), 3P (M vs. VL p = 0.002, L vs VL p = 0.049), 3PA (M vs. VL p = 0.001, L vs VL p = 0.028) performances of athletes who had a very long-term injury duration were significantly lower when returning to the game compared to other groups who had a shorter injury duration.

Table 7. Return-to-play performance of NBA players before and after injury according to injury duration (very short n = 6, short n = 17, moderate n = 15, long n = 8, very long n = 8)

		Pre-injury			p*	Post-injury			p*	p**
		mean $\pm$ SD	min	max		mean $\pm$ SD	min	max		
MPG	VS	26.6 $\pm$ 9.3	10.4	35.9	NS 0.492	27.9 $\pm$ 6.7	18.0	36.1	M vs. VL 0.003 VS vs. VL 0.015 L vs. VL 0.031 S vs. VL 0.032	0.528
	S	28.9 $\pm$ 8.2	11.8	42.4		25.2 $\pm$ 6.3	16.3	34.5		0.006
	M	29.2 $\pm$ 8.6	11.3	40.8		27.9 $\pm$ 7.4	10.6	38.8		0.448
	L	24.9 $\pm$ 9.1	9.9	34.4		26.2 $\pm$ 6.1	16.5	35.5		0.551
	VL	23.8 $\pm$ 7.3	12.5	37.1		19.1 $\pm$ 4.9	12.4	26.8		0.024
FGP	VS	4.5 $\pm$ 3.2	1.8	9.4	NS 0.146	4.7 $\pm$ 2.7	2.0	8.6	NS 0.060	0.614
	S	6.7 $\pm$ 3.1	2.0	10.8		5.4 $\pm$ 2.2	2.4	9.2		0.016
	M	5.7 $\pm$ 2.7	1.0	9.2		5.3 $\pm$ 2.4	1.2	8.6		0.401
	L	4.4 $\pm$ 3.0	1.4	10.6		4.7 $\pm$ 2.4	1.6	8.0		0.546
	VL	3.9 $\pm$ 2.0	0.8	7.4		2.5 $\pm$ 1.6	1.0	5.2		0.026

		Pre-injury			p*	Post-injury			p*	p**
		mean $\pm$ SD	min	max		mean $\pm$ SD	min	max		
FGA	VS	10.5 $\pm$ 7.0	2.6	19.8	NS 0.122	10.0 $\pm$ 6.3	3.0	19.0	M vs. VL 0.004 S vs. VL 0.005	0.613
	S	13.9 $\pm$ 6.4	4.6	23.6		11.6 $\pm$ 4.8	4.0	18.6		0.008
	M	12.3 $\pm$ 5.5	2.2	20.2		12.1 $\pm$ 4.9	2.0	18.2		0.751
	L	9.9 $\pm$ 4.8	3.4	16.6		10.2 $\pm$ 4.9	4.4	19.2		0.567
	VL	7.7 $\pm$ 4.2	1.4	16.2		5.5 $\pm$ 3.2	1.8	10.6		0.030
FG%	VS	47.8 $\pm$ 16.8	30.0	79.0	NS 0.815	51.0 $\pm$ 10.8	40.0	71.0	NS 0.357	0.715
	S	47.6 $\pm$ 12.0	28.0	83.0		48.0 $\pm$ 7.4	39.0	69.0		0.921
	M	46.0 $\pm$ 6.5	34.0	56.0		42.0 $\pm$ 12.3	4.0	53.0		0.196
	L	43.7 $\pm$ 13.8	33.0	76.0		43.8 $\pm$ 10.8	28.0	64.0		0.971
	VL	50.1 $\pm$ 6.1	43.0	61.0		47.0 $\pm$ 11.6	27.0	63.0		0.399
3P	VS	1.1 $\pm$ 1.4	0.2	3.2	NS 0.062	1.4 $\pm$ 1.6	0.0	3.4	M vs. VL 0.002 L vs VL 0.049	0.287
	S	1.5 $\pm$ 0.9	0.0	3.6		1.1 $\pm$ 0.8	0.0	2.6		0.042
	M	1.9 $\pm$ 1.3	0.0	4.8		1.8 $\pm$ 0.9	0.6	3.8		0.751
	L	1.1 $\pm$ 0.6	0.2	2.4		1.4 $\pm$ 1.0	0.2	3.4		0.212
	VL	0.5 $\pm$ 0.6	0.0	2.0		0.4 $\pm$ 0.4	0.0	1.2		0.668
3PA	VS	3.2 $\pm$ 3.2	0.4	7.4	NS 0.098	3.4 $\pm$ 3.4	0.0	7.4	M vs. VL 0.001 L vs VL 0.028 M vs. S 0.045	0.504
	S	4.2 $\pm$ 2.4	0.0	8.0		3.4 $\pm$ 2.1	0.0	6.6		0.033
	M	4.7 $\pm$ 2.6	0.2	9.4		5.2 $\pm$ 2.3	1.0	8.8		0.238
	L	3.6 $\pm$ 2.6	1.4	9.6		4.0 $\pm$ 3.2	1.2	11.2		0.215
	VL	1.7 $\pm$ 1.7	0.0	5.4		1.3 $\pm$ 0.9	0.0	2.2		0.431
3P%	VS	33.3 $\pm$ 14.2	10.0	50.0	NS 0.483	27.8 $\pm$ 18.9	0.0	47.0	NS 0.648	0.263
	S	33.6 $\pm$ 11.3	13.0	59.0		37.0 $\pm$ 22.4	8.0	100.0		0.668
	M	34.0 $\pm$ 14.3	0.0	59.0		35.8 $\pm$ 11.9	12.0	56.0		0.691
	L	29.2 $\pm$ 12.4	10.0	44.0		32.8 $\pm$ 12.9	7.0	54.0		0.614
	VL	31.6 $\pm$ 15.9	14.0	58.0		39.0 $\pm$ 11.4	25.0	55.0		0.212
FTP	VS	1.6 $\pm$ 1.9	0.2	5.2	NS 0.342	1.3 $\pm$ 1.4	0	3.4	NS 0.363	0.460
	S	3.0 $\pm$ 2.5	0.0	8.8		2.6 $\pm$ 2.9	0	10.6		0.163
	M	2.5 $\pm$ 1.7	0.4	6.4		2.3 $\pm$ 1.6	0	6.8		0.586
	L	2.9 $\pm$ 3.0	0.2	8.0		2.5 $\pm$ 2.2	0.4	7.0		0.437
	VL	3.8 $\pm$ 2.4	1.8	8.8		3.1 $\pm$ 1.9	1.0	7.2		0.353
FTA	VS	2.3 $\pm$ 2.9	0.2	8.0	NS 0.299	2.0 $\pm$ 1.9	0.4	5.2	NS 0.528	0.682
	S	3.7 $\pm$ 2.6	0.4	10.0		3.4 $\pm$ 3.5	0	13.0		0.303
	M	3.2 $\pm$ 2.1	0.6	7.2		3.0 $\pm$ 1.9	0	6.8		0.681
	L	4.2 $\pm$ 3.7	0.4	9.8		3.2 $\pm$ 2.3	0.4	7.6		0.319
	VL	4.7 $\pm$ 2.6	2.4	10.4		3.9 $\pm$ 2.2	1.8	8.0		0.349
FT%	VS	76.2 $\pm$ 19.9	50.0	100.0	NS 0.205	54.2 $\pm$ 28.2	0	75.0	NS 0.457	0.204
	S	72.5 $\pm$ 25.1	0.0	100.0		73.2 $\pm$ 28.2	0	100.0		0.378
	M	72.6 $\pm$ 15.4	50.0	100.0		70.6 $\pm$ 26.4	0	100.0		0.794
	L	59.6 $\pm$ 16.0	41.7	81.1		73.6 $\pm$ 14.8	50.0	100.0		0.069
	VL	77.8 $\pm$ 15.7	50.0	93.3		76.4 $\pm$ 14.4	56.2	100.0		0.856

		Pre-injury			p*	Post-injury			p*	p**
		mean $\pm$ SD	min	max		mean $\pm$ SD	min	max		
	VS	2.6 $\pm$ 1.4	0.8	4.8	NS 0.891	2.5 $\pm$ 1.3	1.0	4.2	NS 0.812	0.793
	S	3.4 $\pm$ 2.3	0.6	9.0		2.9 $\pm$ 1.9	0.6	6.0		0.120
APG	M	3.1 $\pm$ 2.3	0.4	7.4		3.3 $\pm$ 2.9	0.6	11.0		0.678
	L	3.0 $\pm$ 2.0	0.2	6.6		2.9 $\pm$ 2.7	0.4	7.0		0.973
	VL	2.5 $\pm$ 2.8	0.2	7.6		2.1 $\pm$ 1.7	0.8	5.8		0.500

Injury duration was classified as very short (VS), short (S), moderate (M), long (L), very long (VL), MPG: Minutes per game, FGP: Field goal points, FGA: 2 Field goal attempted, FG%: Field goal percentage, 3P: 3-points, 3PA: 3-point attempted, 3P%: 3-point percentage, FTP: Free throw points, FTA: Free throw attempted, FT%: Free throw percentage, APG: Assist per game. Data are presented as mean $\pm$ SD, minimum (min), and maximum value, p*: inter-group comparison, p**: intra-group comparison (pre- vs. post-injury), NS: No significance, p < 0.05.

Discussion

Understanding factors such as injury type, duration, location, and operation status in basketball can help prevent injuries, and determining return-to-play performance after injury can guide both physicians and coaches and also guide player career planning. In this study, we aimed to compare the return-to-play performances of NBA players with those before the injury. Examining player performances before and after injury using publicly available resources, we determined that the return-to-play performances of NBA players decreased significantly. The present study has important implications for counselling NBA players on expected return-to-play performance. Our main finding is that MPG, FGP, and FGA decreased significantly in NBA players after injury. Additionally, there is a significant decrease in the same return-to-play performance variables in athletes who have undergone surgery and have black skin color. After the injury, there is a significant decrease in MPG, FTP, FTA for forward players, FGP, FGA for center players, and a significant decrease in FGP, FGA, FTA for trunk injuries depending on the injury location. While MPG, FGP, FGA decrease significantly in ligament injuries, there is no significant decrease in return-to-play performance after fracture. In addition, there is a significant decrease in return-to-play performance after short-term (7–30 days) and very long-term (over 360 days) injuries.

In our study, a significant decrease in MPG, FGP, and FGA was observed after the injury compared to before the injury. It has been reported in previous studies that post-injury return-to-play performance decreases significantly in NBA players (Amin et al., 2013; Harris, Erickson, et al., 2013; Khan et al., 2018; Minhas et al., 2016; Nguyen et al., 2018; Nwachukwu et al., 2017). In this current study, although athletes are expected to take less time after injury, it is a remarkable finding that a significant decrease was determined in FGP and FGA, but there was no significant difference in 3P, FT and FPG. Athletes have to make closer contact with opponent athletes under the basket for FG, and they need less for 3P, FT or assist. Therefore, athletes may experience a significant decrease in their FG performance due to the need to avoid contact with the opponent in return-to-play performances and the concern about injury that may accompany this.

Operation status

There are contradictory findings in previous research regarding the impact of operation status on return-to-play performance. Sanchez et al. (2021) reported significantly more MPG, assists, and points per game after Achilles tendon repair in NCAA basketball players. Similarly, Khan et al. (Khan et al., 2018) found that in athletes with lower extremity bone stress injuries, regardless of injury type, those with surgery had significantly better performance at 2 years than those treated without surgery ($\beta = 4.561$; 95% CI, 1.255–7.868) and Begly et al. (2018) found that the NBA players' return-to-play performance after hip arthroscopy was not significantly different compared to before

the operation, and the athletes played an average of 4 more seasons after the operation. In contrast, although a high rate of NBA players returned to the game after anterior cruciate ligament reconstruction (Nwachukwu et al., 2017; Sepúlveda et al., 2017), first season player efficiency ratings significantly declined from pre-injury the first return-to-play season (Nwachukwu et al., 2017). Minhas et al. (2016) also reported NBA players undergoing Achilles tendon rupture repair or arthroscopic knee surgery had significantly worse performance postoperatively compared with other orthopaedic procedures. Similarly, we found a significant decrease in return-to-play performance in athletes who had surgery. Although there was a quantitative decrease in all performance parameters we examined a significant decrease in MPG, FGP and FGA in athletes who underwent surgery. We did not find any significant difference in return-to-play performance in athletes who did not undergo surgery compared to before the injury.

Skin color

To the authors' knowledge, previous NBA league return-to-play studies have not examined post- and pre-injury player performances according to skin color. Although there is strong evidence that NBA players' skin color is not related to their on-court performance statistics (Psathas et al., 2023), we wanted to examine the effect of skin color on return-to-play performance because it is known that black players tend to outperform white players (Psathas et al., 2023). We determined that most of the injured athletes in the five NBA seasons between 2018-2022 were black skin color basketball players (black vs. white basketball players: 72.2% vs. 27.8%) and that black skin color players had longer MPG before injury. It should not be overlooked that, according to the "2023 Racial and Gender Report Card: National Basketball Association" report (Lapchick, 2023), 73.6% of black skin color players played in the NBA league between 2018 and 2022, and this explains the higher percentage of black skin color players in the frequency of injuries. Although return-to-play performance was not significantly different in NBA white skin color players, the MPG, FGP, and FGA performances of black skin color players decreased significantly. These findings can be explained by the fact that they face a greater risk of injury due to having longer MPG. However, it is still recommended that these findings be examined according to player injury types, duration of injury or operation status.

Player positions

Based on our data, forward players' MPG, FTP, FTA, and center players' FGP, FGA decreased significantly after the injury compared to before the injury. We did not find significant differences in return-to-play performance between player positions. The player positions of basketball may also contribute to injury as players have different offensive and defensive roles. Therefore, careful judgment must be used to recommend treatment directed at providing an optimal outcome and return-to-play while also balancing the professional demands of the athlete. DeFroda et al. (2021) found that the return to play rate after anterior cruciate ligament reconstruction was significantly lower for forwards than guards. Harris et al. (Harris, Erickson, et al., 2013) reported that guards' return-to-play performance decreased significantly from their pre-injury level. Patel et al. (2020) found that guards suffered more injuries than forwards and centers (49%, vs. 25% vs. 25%, respectively). We also obtained similar findings in our research. The most injured player positions were guards (n = 20, 37%), then forwards (n = 17, 31.5%) and centers (n=17, 31.5%), respectively. In basketball, there is usually one center, two forwards (power forward and small forward) and two guards (shooting guard and point guard) on the court (Sarlis & Tjortjjs, 2024). Therefore, it is an important point that centers have an equal injury frequency with forwards and close to guards. This can be explained by the requirements of the playing position. Centers may have this injury percentage because they often

rebound and then land, and because they are more often involved in duels under the basket due to their position. This finding may be related to player positions and actions that occur during competition in the game.

Injury location

We found that the most injured location in NBA players is the lower extremity (40.7%), followed by upper extremity (37.0%), trunk (12.9%) and facial injuries (9.4%). This finding is consistent with previous research (Amin et al., 2013; Drakos et al., 2010; Trojian et al., 2013). The unique physical demands (such as explosive accelerations, sudden change or stop in motion, and eccentric loading of the foot during different acute movements) necessary to compete in the NBA place these players at an increased risk for injuries especially in the lower extremity (Amin et al., 2013). Drakos et al. (2010) in a retrospective study of injuries affecting professional basketball players in the NBA over a 17-year period, found that the lower extremity was the most frequently injured body location, accounting for 62.4% of all injuries and 57.8% of all game-related injuries. Interestingly, in our research, we identified performance loss in FGP, FGA, FT% after trunk injuries. As we mentioned before, this finding needs to be analysed according to factors such as injury type, operation status, and injury duration.

Injury type

We have identified 59.3% fractures and 40.7% ligament injuries in NBA players between 2018–2022 seasons. While there was a significant decrease in the MPG, FGP, and FGA performances of players with ligament injuries, the return-to-play performance of players with fractures was not significantly different compared to before the injury. In a 17-year overview of NBA basketball athletes' injuries, lateral ankle strains were the most frequent orthopaedic injury ($n = 1658$; 13.2%), followed by patellofemoral inflammation ($n = 1493$; 11.9%), lumbar strains ($n = 999$; 7.9%), and hamstring strains ($n = 413$; 3.3%). The most games missed were related to patellofemoral inflammation ($n = 10\ 370$; 17.5%), lateral ankle sprains ($n = 5223$; 8.8%), knee sprains ($n = 4369$; 7.4%), and lumbar strains ($n = 3933$; 6.6%) (Drakos et al., 2010). Analysis of injury type revealed that sprains were the most common (27.8%), followed by inflammatory conditions (21.8%) and strains or spasm (21.8%). Although there was a significant decrease in return-to-play performance in NBA players after patellar tendon tears (Nguyen et al., 2018), Achilles tendon rupture (Amin et al., 2013), and micro fracture (Harris, Walton, et al., 2013) performance was observed at the pre-injury level after Jones fractures (Begly et al., 2016). In our research, we determined that ligament injuries most negatively affect return-to-play performance. It should be noted that since our research classifies injury type based solely on type, evaluating return-to-play performance by referring to the severity or specific nature of each injury may provide practitioners with a different perspective.

Injury duration

The majority of NBA players had a short-term injury (31.5%, lasting 7-30 days), and the least duration was a very short-term injury (11.1%, 1-7 days). We found a significant decrease in the MPG, FGP, FGA, 3P, 3PA of athletes who had a short-term injury, and MPG, FGP, FGA performances of athletes who had a very long-term injury (over 360 days) period compared to the pre-injury. Time to return-to-play is directly related to injury types and differs from previous studies. The average return to play time was reported as 10.7-12.3 months after anterior cruciate ligament rupture (DeFroda et al., 2021), 6 months after Achilles tendon rupture (minimum 2.95, and maximum 10.4 months, Zellers et al., 2016), 16-17 days after adductor injury (Patel et al., 2020). Injury duration is a very important indicator due to the financial losses that athletes miss every match and the loss of performance experienced in returning to the game.

Limitations

Our study has several limitations. One of the biggest limitations of our study is that we examined five-game performance of NBA players before and after injury. Examining the performance of athletes over 1 or 2 seasons can be an important indicator of long-term athletic performance. Another limitation is that we do not include control group samples and we only focus on offensive game variables and do not include player efficiency rate. Although this is a comprehensive review of all injuries identified during the study period in NBA players, definitive conclusions may be limited. We used public archives to identify injury incidents. Therefore, we are unable to verify with certainty the correctness of reports. Nevertheless, this method of subject selection has been utilized in multiple high-evidence level studies in sports medicine journals (Begly et al., 2018; Begly et al., 2016; Chauhan et al., 2021; DeFroda et al., 2021; Lu et al., 2020; Minhas et al., 2016; Nguyen et al., 2018; Padaki et al., 2016; Patel et al., 2020). Because of the data acquisition method of the study, details such as past medical, surgical or injury history, surgical technique, and rehabilitation protocols were not available for collection. This retrospective study does not fully answer all questions regarding the impact of injury factors on return-to-play performance, and a prospective study or examination of multiple factors is needed (e.g., return-to-play performance in guards undergoing surgery or upper extremity athletes with ligament injuries). Additionally, examining return-to-play performance in terms of factors that may affect recovery and performance, such as the player's age, general health, and previous injury history, as well as the role of nutrition, physiology, and performance in sport (Irandoust, 2023), may provide a different perspective, although we did not focus on these factors.

Conclusion

Our research showed that the return-to-play performances of NBA players decreased significantly. In this retrospective study, in which we examined player performances according to operation status, skin color, player positions, injury area, injury type and duration, we found a significant decrease in MPG, FGP and FGA performance in NBA players. We think that this finding may be related to the fact that NBA players require more contact with opponent players for FG and that athletes avoid this due to the risk and concern of re-injury in return-to-play. Our research demonstrated that 70.4% of the injured athletes in the 2018-2022 NBA seasons underwent surgery, 72.2% were black skin color players, the most injured player position was guards (37%), the most injured area was the lower extremity (40.7%), 59.3% were fractures, and most of them had an injury duration between 7–30 days (31.5%). During the season, the person caring for a basketball team needs to be prepared to care for common basketball injuries described in this investigation. Further research is warranted to determine whether injury-related factors are important or just a coincidence among this sample size.

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POST-COVID-19 NEURONAL COMPLICATIONS AND IMPACT OF PHYSICAL ACTIVITY ON THE DISEASE SYMPTOMS: A NARRATIVE REVIEW

Ewa Duchnik^{A, C, D}

Department of Aesthetic Dermatology, Pomeranian Medical University, Poland
ORCID: 0000-0003-3855-7595

Joanna Kruk^{A, B, D}

Institute of Physical Culture Sciences, Faculty of Physical Culture and Health, University of Szczecin, Poland
ORCID: 0000-0002-7551-1927 | e-mail: joanna.kruk@usz.edu.pl

Mariola Marchlewicz^{B, C, D}

Department of Dermatology and Venerology, Pomeranian Medical University, Poland
ORCID: 0000-0003-4915-9875

^A Study Design; ^B Data Collection; ^C Statistical Analysis; ^D Manuscript Preparation

Abstract The coronavirus disease 2019 (COVID-19) caused a global health crisis, leading to many pathological alternations regarding cells, tissues, organs, and biological systems. Extensive research during the past three years has revealed that even if symptoms of the COVID-19 infection and disease are not severe, the complications after may be critical. Evidence has indicated that apart from the most characteristic complications caused by COVID-19 infection, such as respiratory tract disorders, severe damage to the central and peripheral nervous systems is possible, resulting in neuronal and mental complications. For this reason, the quality of life of severe COVID-19 survivors requires targeting therapy. The most studies focused on a wide spectrum of COVID-19 complications, however, direct evidence of the virus-specific neuropathogenicity and molecular mechanisms involved in this complication are only emerging.

We have actual scientific knowledge of post-COVID-19 neurological complications and provide the current evidence on biological mechanisms operating in this process. This review also aims to present how inflammation and oxidative stress may contribute to the disease severity. Finally, we discuss the use of physical exercise (PE) interventions to reduce physical and mental complications in COVID-19 survivors. Findings show that dysregulation of the immune system is characteristic for COVID-19 disease severity. PE can increase muscle strength, respiratory function, decrease dyspnea, and improve survivors' quality of life. However, randomized controlled trials and observational studies of higher methodological quality are needed to determine effective, individualized and safe amount of exercise to support the evidence.

Key words: SARS-CoV-2, neuropathogenicity, psycho-physical symptoms, inflammation, oxidative stress, physical exercise

Introduction

Coronaviruses are a large family of viruses related RNA, which includes Severe Acute Respiratory Syndrome (SARS), coronavirus (SARS-CoV-2), and Middle East Respiratory Syndrome-related coronavirus (MERS-CoV) (Hatmal et al., 2020).

A new coronavirus COVID-19 is caused by the SARS-CoV-2 and was first detected in December 2019 in China, spreading to the rest of world (Platto et al., 2021). The virus may lead to many pathological alterations regarding cells, tissues, organs, and systems (Scialo et al., 2020; Xie et al., 2020; Desai et al., 2022; Franke et al., 2022). The current data demonstrate that SARS-CoV-2 leads to an excessive innate immune system response as excessive and uncontrolled secretion of proinflammatory cytokines (Tang et al., 2020; Wang et al., 2020; Wu et al., 2020; Fagni et al., 2021; Hassett et al., 2020; Wang et al., 2021). This mechanism is believed to be the main cause of systemic inflammation, followed by cardiovascular and neurological complications or/and post-covidal other adverse side effects. There is growing evidence that oxidative stress (OS) plays a leading role in inflammation and participates in the pathogenesis of a variety degenerative diseases, including neuronal complications and COVID-19 infection (Uttara et al., 2009; Liguori et al., 2018; Delgado-Roche & Mesta, 2020).

Evidence has presented characteristic complication such as respiratory tract disorders, including damage of the epithelium of bronchi, bronchioles, and respiratory alveoli (Wang et al., 2020; Wang et al., 2021). The SARS-CoV-2 virus can entry the cell via the angiotensin-converting enzyme 2 receptor (ACE2) (Hasset et al., 2020; Scialo et al., 2020; Huang et al., 2021). ACE2 receptors are present in many cell types, including pneumocytes as well as in neurons and glial cells of the brainstem (Hassett et al., 2020; Othman et al., 2020). The presence of viral entry receptors on myelin-forming cells and olfactory neural epithelium shows the possibility of a neurotropic invasion of the SARS-CoV-2 through the olfactory route (Netland et al., 2008; Jiao et al., 2021). Emerging evidence has also shown that the virus can also cross the blood-brain barrier (BBB), which may effectively explain neurovascular dysfunction (Zhang et al., 2021; Davis et al., 2023; Ong et al., 2023). There is also a possibility that multiple routes of SARS-CoV-2 entry into the brain and/or multiple mechanisms can be involved in the pathogenesis of neurological symptoms (Bohmwald et al., 2018). Findings from epidemiological and clinical studies point to physical activity/exercise (PA/PE) of a leading health indicator, and the important, safe, and low-cost tool to combat with physical and negative mood in chronic disease survivors (Pedersen & Saltin, 2015). Several studies indicated that regular PA and programmed PE improve the response to the chronic disease's pharmacotherapy. Furthermore, regular moderate-to-vigorous exercise is considered as a medicine in the treatment/rehabilitation of 26 diseases, including cardiovascular, musculoskeletal, neurological, and cancer diseases (Pedersen & Saltin, 2015; Kramer, 2020). The beneficial effects of PA/PE treatment such as reduced risk of chronic diseases, mortality, and sarcopenia in skeletal muscle have been well documented (Simioni et al., 2018). Regular physical activity has also been reported to protect individuals from severe COVID-19 outcomes and as an effective therapeutic action after COVID-19-related diseases (Sallis et al., 2021), therefore it is important to demonstrate the current evidence in this field.

The present article aims to highlight the current knowledge, regarding neuronal complications observed in patients who suffered from COVID-19, provides evidence post-COVID-19 severe outcomes, discusses an essential role of OS in the disease pathogenesis, summarizes the current findings on the benefit of PA/PE, and presents possible molecular mechanisms involved in the positive effect of PA on coping with the virus.

Post-acute COVID-19 neuronal complications

The most characteristic neurotropic alteration caused by coronavirus is associated with the Central Nervous System (CNS) (Bohmwald et al., 2018). Virus enters the CNS through the olfactory epithelium, where modified neurons are located followed inflammation and demyelination (Franke et al., 2022)

Brann et al. (2020) examined the expression of ACE2 and transmembrane serine protease2 (TMPRSS2) in human olfactory epithelium. The researchers noticed that not the olfactory sensory neurons but olfactory epithelial support cells and stem cells express both genes. The presence of viral entry receptors on the cells of the olfactory epithelium and central and enteric nervous system provides a basis for the possible neural invasion by SARS-CoV-2 through the olfactory and transvaginal route (Kumar et al., 2020).

Furthermore, a higher probability of trans-olfactory route for SARS-CoV-2 brain entry is noted (Andrabi & Andrabi, 2020). Recent studies showed abundant genomic expression of ACE2 in secretory and ciliated cells of the upper respiratory tract and nasal mucosa in humans (Sungnak et al., 2020; Ziegler et al., 2020). Viral invasion of the olfactory nerve may occur from the infected nasal mucosa. Expression of viral binding receptors in non-neural cells of the olfactory epithelium and myelin-forming cells in the CNS (Brann et al., 2020) gives rise to the plausibility of virus entry through the myelin sheath of olfactory nerves (first invading the olfactory bulb, and then spreading transneuronally to more distal brain parts) followed by temporary loss of smell and taste (Kumar et al., 2020).

Data from preclinical studies show that SARS-CoV-2 can access the brain through the olfactory bulb, and from there it reaches the brain *via* trans-neuronal spread, resulting in significant neuronal infection in SARS-CoVreceptor transgenic mice (Netland et al., 2008; Mahalakshimi et al., 2021).

Besides the characteristic symptoms of COVID-19 infection, increasingly acute inflammatory demyelinating polyradiculoneuropathy (AIDP) is reported, and one of its common forms is known as Guillain-Barre syndrome (GBS) (Scheidl et al., 2020). The disease is caused by an aberrant autoimmune response to a preceding infection, which evokes a cross-reaction with gangliosid components of the peripheral nerves, targeting different antigens in the demyelinating and axonal subtypes of GBS. Several pathogens can lead to GBS development among them SARS-CoV (Willison et al., 2016).

Guillain-Barre syndrome's characteristic symptoms are ascending flaccid symmetrical limb paralysis with areflexia, sensory symptoms and involvement of the cranial nerves and segmental demyelination of axons of the neurons. Scheidl et al. (2020) have described a 54-year-old female patient. She was COVID-19 positive (oropharyngeal RT-PCR genetic test) due to a contact with a person who has had a positive test result for this virus. The patient did not suffer from the characteristic symptoms, but areflexia, numbness, and tingling of all extremities were observed. The patient did not suffer any fever, respiratory, nor gastrointestinal symptoms. After many biochemical tests, including C-Reactive Protein (CRP) and SARS-CoV-2 RNA tests in cerebrospinal fluid (CSF), creatinine level, and other blood tests together with p-ANCA, ANA antibodies of which the results showed no abnormalities, an acute inflammatory demyelinating polyradiculopathy (AIDP) commonly known as GBS was diagnosed.

Another case of AIDP was noted by Bigaut et al. (2020). The authors have reported a 43-year-old man with SARS-CoV-2 positive test. Besides cough, asthenia and myalgia in the legs he had neurological complications. Neurologic examination showed a light touch from mid thigh to the feet and the tip of fingers. Moreover, he noted decreased vibration sense in the lower limbs, symmetric weakness of dorsiflexion and extension of the toes, and flexion of the thigh. Additionally, areflexia in the forelimbs apart from the left biceps reflex was noticed. However, after seven days SARS-CoV-2 RT-PCR test was negative, neuronal symptoms were still diagnosed. Nerve conducting

examination at day nine showed two conduction blocks in both peroneal nerves, decreased motor conduction velocities in both peroneal and tibial nerves, and finally increased F-wave latencies, supporting a demyelinating pattern. These authors also presented a 70-year-old woman diagnosed with GBS. Exam revealed that besides respiratory system disturbances, nerve conducting showed a typical demyelinating pattern with a conduction block in the left median nerve, temporal dispersion, upper limb increased, motor distal latencies, diffuse decreased motor, and sensory conduction velocity. In both above-mentioned patients, improvement was observed after treatment with IVIg (2g/kg) (Bigaut et al., 2020).

Similarly, Poyiadji et al. (2020) reported the first presumptive case of acute necrotizing hemorrhagic encephalopathy associated with COVID-19. The mentioned case is also associated with indirect viral nerve injury caused by GBS, which, indeed, is activated by SARS-CoV-2 infection.

The mentioned pathogen leads also to other neurological complications. For example, Paniz-Mondolfi et al. (2020) have described a case report of 74-year-old Hispanic males with a wide spectrum of neurologic post-covid side effects. Besides altered blood biochemical parameters, postmortem examination has shown pleomorphic spherical viral-like particles in frontal lobe brain sections. Additionally, blebbing of viral-like particles coming in/out of endothelial cells within the blood vessels of the brain was also seen, which was evidently associated with transcellular penetration of the active pathogens. The transcellular transport was observed across the brain microvascular endothelial cells into the neural niche. Perikaryons of neurons were noted as distended cytoplasmic vacuoles that contained an enveloped viral particles exhibiting electron density centers with distinct stalk-like peplomeric projections. Interestingly, SARS-CoV-2 in cerebrospinal fluid sample was negative when used RT-PCR test (Paniz-Mondolfi et al., 2020). Moreover, COVID-19 is primarily a respiratory virus, but it has a potential impact on other organs that includes mild acute kidney injury, liver (mild transaminitis), and cardiomyopathy that occurs later during the illness—typically post-extubated after the patient shows respiratory improvement. Preliminary data are complicated by the difficulty of recording symptoms in the range of mild to severe cases, with severe cases getting the most attention. Reports of neurological impact have been limited, but there is concern about encephalitis (presence of the virus in CSF), and meningitis (Huang et al., 2021).

The spectrum of neurologic complications after infection of SARS-CoV-2 turns out to be a very wide range (Klineberg et al., 2021; Franke et al., 2023; Scheibenbogen et al., 2023) (Figure 1).

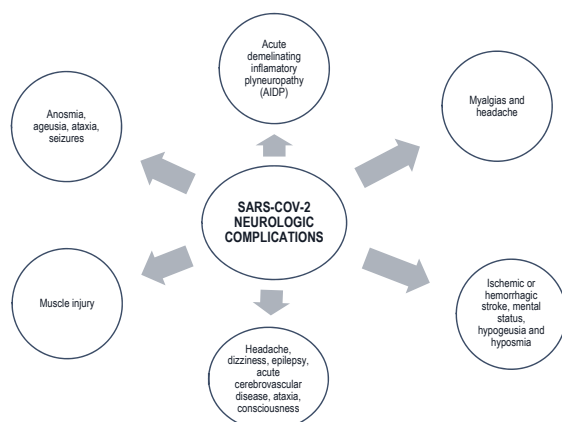


Fig. 1. Major neurological complications associated with COVID-19 infection.

For example, Huang et al. (2021) have reported a cohort study based on six-month consequences observed in patients after COVID-19. In total, 1733 out of the 2469 discharged patients with COVID-19 were enrolled (a median age of 57 years, 897 men). Fatigue or muscle weakness (63%) and sleep difficulties (26%) were the most often observed symptoms. Anxiety or depression was reported among 23% of patients. Risk of anxiety or depression as an important psychological complication and impaired pulmonary diffusion capacity were higher in patients with more severe illness. These results suggest that patients with severe disease need post-covidal care. Another clinical study based on 214 patients with COVID-19 in Wuhan (China) demonstrated a high degree of incidence of neurologic symptoms Singh et al. (2020). Approximately, 36% of patients exhibited neurologic disorders, 8.9% of them suffered from peripheral nervous system disorders, 24.8% from CNS injuries, and 10.7% of patients had skeletal muscle injuries. Over 10% of patients suffered from headache, and 16.8% of patients exhibited dizziness with epilepsy. In addition, acute cerebrovascular disease, impaired consciousness, and ataxia were observed. Of note, ischemic or hemorrhagic stroke, muscle injury, and altered mental status were also noted in seriously ill patients. The neurological complications were related to peripheral nervous system injuries, including hypogeusia (5.6%) and hyposmia (5.1%) with vision impairment and neuropathic pain.

In turn, a study by Li et al. (2020) described 221 patients with severe COVID-19 in Wuhan, China, having neurologic symptoms. Thirteen of them developed a new onset of cerebrovascular disease. One patient was diagnosed with cerebral venous sinus thrombosis. Eleven patients were diagnosed with ischemic stroke and one patient with cerebral hemorrhage. Six ischemic stroke patients received antiplatelet treatment with Clopidogrel or Aspirin and five received Clexane with anticoagulant treatment. Seven patients remained hospitalized; three patients who received antiplatelet treatment died.

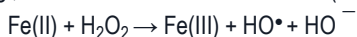
Another research by Xu et al. (2022) have estimated risks and burdens of neurologic disorders at 12 months, following the virus infection in a cohort of 154 068 individuals with COVID-19. The authors found significantly increased risk of a long-term neurologic complications by 42% (HR = 1.42; 95% CI = 1.38–1.47) and burden (70.69, 95% CI = 63.54–78.01) per 1 000 person compared with the historical control cohort (n = 5,859,621) and with the contemporary control cohort (n = 5,638,795). The identified increased risk of the neurological long-term complications included: stroke, peripheral nervous system disorders, cognition and memory disorders, musculoskeletal disorders, sensory disorders, and GBS, among others.

Role of oxidative stress in COVID-19 disease

There is growing evidence that reactive oxygen species (ROS) and nitrogen species (RNS) are involved in a broad spectrum of disease, including inflammation and cancer (Reuter, Gupta, Chaturvedi, Aggarwal, 2010). These species are formed in the human body as product of physiological reactions such as metabolic processes, antimicrobial mechanisms, and inflammation (Valko et al., 2007; Sies & Jones, 2020). The species exhibit beneficial actions at physiological concentrations and deleterious effects at high doses (Sies & Jones, 2020). The most widely studied biological important ROS include free radicals (superoxide anion radical, $O_2^{\bullet-}$; hydroxyl radical, $HO^{\bullet}$; peroxy radical, $ROO^{\bullet}$; perhydroxyl radical, $HOO^{\bullet}$) and molecules without unpaired electrons (non-radicals) (hydrogen peroxide, H_2O_2 ; singlet oxygen, 1O_2 ; hypochlorous acid, $HOCl$; ozone, O_3). In turn, nitric oxide, $NO^{\bullet}$; nitric dioxide, $NO_2^{\bullet}$ and peroxynitrite, $ONOO^-$, are the most important RNS species, considering cellular signaling and redox homeostasis. However, several agents among them viruses can disturb this balance toward oxidation, followed by excessive ROS/RNS generation and by an induction of oxidative stress (OS). Sies (2015, p. 181)

defined OS as “an imbalance between oxidants and antioxidants in favor of the oxidants, leading to disruption of redox signaling and control and/or molecular damage”. Under OS conditions, ROS/RNS are generated for a long time and can cause oxidative damage of DNA, RNA, cellular proteins, membrane lipids, and polysaccharides as well as cause genome instability and mutation, following not efficient repair of DNA damage. ROS/RNS induced oxidative damage to biomolecules can mediate the onset of signaling, activating inflammatory and immune cells which, in turn, trigger ROS formation (Reuter et al., 2010; Chatterjee, 2016). Furthermore, ROS can activate many transcription factors, including nuclear factor-kappa B (NF-κB), nuclear factor erythroid2-related factor (NRF2) (a regulator of the expression of antioxidant proteins); activator protein 1 (AP-1), the tumor suppressor protein (p53), overproduction of transforming growth factor-beta (TGF-β) (Chatterjee, 2016). ROS also stimulate activity of kinases, e.g., protein kinase C (PKC), C-Jun-N-terminal kinase (JNK), and p38 mitogen-activated protein kinase (MAPK), followed by expression of transcription factors and release of proinflammatory cytokines (TNF-α, interleukin-1, IL-1, interleukin-6, IL-6) and chemokines (interleukin-8, IL-8; chemokine receptor 4, CXCR 4), and the specific microRNAs expression (Reuter et al., 2010; Laforge et al., 2020). Evidence has underlined an interrelationship between extensive ROS production, OS, inflammation, and cellular tissue damage (Reuter et al., 2010; Chatterjee, 2016). Furthermore, a direct link between OS, inflammation, and COVID-19 infection has been suggested as likely (Chernyak et al., 2020; Laforge et al., 2020; Schönrich et al., 2020).

A growing amount of evidence has indicated that overproduction of ROS can contribute to the pathogenesis of COVID-19 (Cecchini & Cecchini, 2020; Delgado-Roche & Mesta, 2020). Evidence maintains that immune cells, macrophages, and monocytes are playing prominent roles in inflammation in patients with severe COVID-19 infection (Mehta et al., 2020; Beltrán-García et al., 2020). Recent data has expanded the concept that hyperactivated immune response, dysregulation of ACE2 expression is likely mechanism in severe COVID-19 infection (Cecchini & Cecchini, 2020; Tang et al., 2020). Excessive and uncontrolled secretion of proinflammatory cytokines (“cytokine storm”) consequently triggers inflammatory reactions and may cause blood clotting and vascular thrombosis (Mehta et al., 2020; Tang et al., 2020). It has been hypothesized that the COVID-19 virus may influence on the equilibrium between the NF-κB participating in cytokine expression and NRF2 activation (Cecchini & Cecchini 2020). In critically ill patients with COVID-19, a high neutrophil to lymphocyte ratio and decreased antioxidants concentrations, e.g., SOD3 have been observed. Evidence shows that the reduction of the number of lymphocytes results in a 3-fold increased risk of developing severe COVID-19 (Zhao et al., 2020). The COVID-19 infection can activate neutrophils, and OS is particularly enhanced in individuals with disruption of redox homeostasis, caused, e.g., by age-related immune dysfunction or other chronic diseases, e.g. cardiovascular, obesity, diabetes (Forman & Zhang, 2021). The disruption of oxidation-reduction balance towards the predominance of oxidants over immune function reactions leads to an amplification of ROS formation and aberrant signal transduction pathways as well as peroxidation of red blood cell membranes, and other tissues (Mehta et al., 2020). This evidence finds confirmation in increased levels of proinflammatory cytokines such as TNF-α, IL-6, chemokines, e.g. IL-8, NF-κB, especially in severe COVID-19 infection, (Laforge et al., 2020; Tang et al., 2020). Another suggested mechanism which has been reported to explain the role of ROS in COVID-19 infection is an alteration in Fe(II)/Fe(III) ratio, which can lead to a low concentration of ferrous ion, followed by limited binding of molecular oxygen to heme groups of hemoglobin, thus lower oxygen saturation in the blood (Laforge et al., 2020). Under OS conditions, the high level of ROS including H₂O₂ can decrease the Fe(II) concentration, e.g., in the Fenton reaction as follows (Goldstein et al., 1993):



forming simultaneously a very high reactive oxidant – HO[•]. “Cytokine storm” has been considered as one of the most common causes of mortality in COVID-19 disease. Although the exact mechanisms of cytokine overproduction induced by this disease infection have not been well documented yet, evidence maintains that early detection and control of cytokine generation and blockade of their overproduction as well as immunomodulatory therapy may decrease the risk of developing COVID-19 severity (Fagni et al., 2021). Another potential therapeutic strategy includes restoration of redox homeostasis by antioxidants, e.g., vitamin C, N-acetyl cysteine for controlling ROS production by the mononuclear phagocyte system and neutrophil granulocytes as well as the application of TNF- α inhibitors to block its inflammatory activity (Schönrich et al., 2020; Tang et al., 2020).

Impact of physical activity on post-acute COVID-19 syndrome

Concerning the benefits of PA, evidence exists that exercise plays a significant role in reducing anxiety, fear, fatigue, pain, and has potency to limit the chance of depression in cancer survivors, independently from exercise mode (Craft et al., 2012; Patsou et al., 2017; Odyneys et al., 2019). In addition, exercise improves individuals' muscle strength and mass, tolerance to physical effort, protects against falling, stimulates the immune system and anti-inflammatory cytokines production, mitochondrial biogenesis and cardiovascular function, decreases dyspnea and OS, enhances pulmonary function, neurocognitive abilities, and improves sleep quality, among others (Jimeno-Almazán et al., 2021; Thirupathi et al., 2021). Potentially, PE can influence the most common clinical manifestations of post-COVID-19 syndrome, such as neurological, cardiovascular, respiratory, musculoskeletal, immune system and psychological health and wellbeing (Jimeno-Almazán et al., 2021).

Given that physical inactivity and sedentary lifestyle are the risk factors for multiple chronic diseases, and regular exercise of moderate intensity is preventive against the pathologies like the past-COVID-19 syndrome showing anti-inflammatory and antioxidant actions, therefore it is essential to demonstrate the current evidence in this area.

Several reviews have analysed the effect of post-COVID-19 PE on physical and psychological health of patients with post-acute consequence of the virus infection and clinical effectiveness of exercise rehabilitation (Agostini et al., 2021; Cavigli et al., 2022; Fernández-Lázaro et al., 2022; Fugazzaro et al., 2022; Prado et al., 2022; Yang et al., 2022; Dillen et al., 2023). An overview by Cavigli et al. (2022) demonstrated health problems occurring practically in all biological systems after acute SARS-CoV-2 infection and the literature data on beneficial effect of PE on the patients. The authors found reduced exercise capacity at cardiopulmonary exercise test, early aerobic threshold, and lower levels of performance. Evidence showed that early rehabilitation program composed of aerobic, resistance training, strengthening, respiratory, flexibility, and balance exercises may improve functional capacity and quality of life (QoL) by reduction of psychological stress and mental disorders. According to the literature finding, the authors have given the following characteristics of exercise to combat with acute post-COVID-19 syndromes: frequency – 3–5 times/wk; intensity-aerobic exercise of moderate intensity around ventilatory thresholds 1 (VT1) as effective in enhancing cardiopulmonary system parameters and the immune system's response; frequency and duration – 2–3 sessions/week lasting 20–60 minutes through 4–12 weeks. Exercise dose should include patients' age, stage of disease and their adaptation to exercise. A narrative review by Fernández-Lázaro et al. (2022) of 9 studies, published up till December 2022 as well as previous review by Agostini et al. (2021) of 31 articles on guidance of PE for rehabilitation after acute COVID-19, recommended multidisciplinary (neuromuscular, respiratory, cardiac, and psychological support) rehabilitation engaging for 5–7 days/wk in exercise at moderate intensity. Fernández-Lázaro et al. (2022)

reported improvements in strength, respiratory function, physical fitness and QoL among patients after therapeutic exercise intervention. In turn, a review by Yang et al. (2022), based on 41 articles, published from 20 December 2019 to 30 August 2022, on the impact of PE on patients with acute COVID-19, recommended whole-body exercises “in the form of modified rehabilitation exercise and full body vibration” as more safely therapy in increasing the lung capacity. The authors analysed different exercise programs (training: respiratory muscle, strength, lung group and endurance), proposed by provided studies and recommended for patients at different clinical stage. They underline the need of moderate intensity PE for COVID-19 patients to reduce intracellular and extracellular OS and recommend including of yoga and tai chi to the exercise programs. To combat patients' anxiety and depression, outdoor exercise >30 min/day are recommended. Moreover, the authors state that the dose of PE should be increased gradually to avoid muscle damage. Another review by Prado et al. (2022), which summarised PE recommendations after acute-COVID disease basing on 16 articles studying individuals convalescing from COVID-19, also pointed to aerobic and strength exercises as the most beneficial. The authors state that walking and cycling combined with strength PE should be performed through 30 minutes during session with frequency 3–5 times weekly, and intensity and volume of exercise should be increased gradually. In addition, exercise programs should be individualised, regarding the individual's age, physical conditions, and disease severity. Another systematic review by Dillen et al. (2023), based on 38 studies among them three Randomized Controlled Trials (RCTs) studies, evaluated physical training as a part of the COVID-19 rehabilitation program. They found that PE training programs may reduce fatigue, dyspnea, and chest pain as well as improve physical capacity and QoL. However the evidence, regarding the exercise effect on muscle pain, pulmonary function, cognitive function and psychological well-being, and return to normal physical health is not yet clear.

In turn, a systematic review by Fugazzaro et al. (2022) of PE benefits in rehabilitation of patients with post-acute-COVID-19 syndrome found that rehabilitation programs based on aerobic and/or resistance exercise respiratory physiotherapy, relaxation techniques, yoga, and other exercise interventions significantly improved some of the COVID-19 outcomes, such as muscle strength, walking capacity, sit-to-stand performance and QoL (decreased dyspnea, fatigue, anxiety, and depression). This review included five RCTs that were conducted on 512 patients for 2–48 hours over the course of 6–8 weeks, enrolled in the trials at least 4 weeks after the disease diagnosis. These reviewers concluded that enrolling in RCT intervention exerted beneficial effect on several disease outcomes in the treated patients compared to the controls. However, the authors note of a lack of evidence on the effectiveness of PE interventions on some disease outcomes. The low certainty of the existing evidence may be partly explained by finding of Hasenoehrl et al. (2023) experimental study of 32 participants (11 patients with severe – COVID-19 symptom and 21 patients with mild the disease symptoms). The authors found that cases with severe fatigue have experienced higher benefit from post-COVID-19 PE intervention than those with mild symptoms of the disease.

Moreover, several studies have presented home post-COVID-19 rehabilitation programs and physiotherapy advice helping to increase survivors' physical effort, quality of life, and to decrease their fatigue and psychological problems (Bull et al., 2020; London North West University Healthcare, 2020; WHO, 2020a; WHO, 2020b). For example, The World Health Organization Regional Office for Europe (WHO, 2020a) published a set of basic exercises (worm-up exercises, fitness exercises, strengthening exercises, and brain exercises) managing problems with memory and attention, mental stress, anxiety, or depression, giving simultaneously advice dealing with their timing, duration, intensity, and dose. A home-based physical exercise during social isolation linked to COVID-19 pandemic to keep an active lifestyle, healthy immune and mental conditions are also demonstrated (WHO, 2020b).

Possible biological mechanisms for physical activity benefit

Several plausible mechanisms have been hypothesized to explain how PE intervention may manage post-COVID-19 acute health consequence. Exercise has been recognised as the important innate immune system stimulator that reduces incidence and severity of virus infection by increased cytotoxic ability of the natural killer (NK) cells as well by the stimulation of T-lymphocytes and B-cells production (Fernández-Lázaro et al., 2022). Moreover, PE has ability to increase concentration of interferons in plasma (a family of cytokines having the unique antiviral activity at the cell tissue and organ), such as anti-inflammatory effects and modulation of inflammation. Among other molecular mechanisms that have been proposed for benefit of moderate-vigorous PA regarding reduction of sarcopenia, enhancing the immune system and cardiopulmonary function, among other severe COVID-19 outcomes, inhibiting the renin-angiotensin system (RAS) has been proposed as a key relevant mechanism (Evangelista, 2020). This system involves a cascade of enzymatic reactions, and ACE1 and ACE2 are its essential components. An imbalance between pro-inflammatory ACE1 and anti-inflammatory ACE2 correlates with severe COVID-19 symptoms (Arazi et al., 2021; Najafi & Mahdavi, 2023). Briefly, ACE1 catalyses the synthesis of angiotensin II (Ang-II) that binds to the AT1 receptor, enhances inflammation, induces OS and thrombosis, among others. In turn, ACE2 converts Ang-II to Ang-(1-7) what binds to AT2 receptor, causing adverse effect, i.e., stimulates the ACE2/Ang-(1-7)/MAS axis of the RAS and reduction of inflammation (Delgado-Roche & Mesta, 2020; Najafi & Mahdavi, 2023).

Moderate PE also induces a slight increase in IL-6 concentration that improves glucose and lipid metabolism, thus it enhances anti-inflammatory effect (Nieman & Wentz, 2019). In addition, exercise can decrease excessive secretion of IL-6, TNF- α , CRP and regulate levels of NF- κ B, heat shock protein, IGF-1, and insulin-like growth factor binding proteins, thus it plays an important role in an inhibition of proinflammatory agents (de Lemos et al., 2012; Vina et al., 2012; Kramer, 2020). Findings also showed increased levels of antioxidant enzymes in muscles, enhanced mitochondria synthesis, increased GSH/GSSG ratio and sex hormone binding globulin as well as decreased levels of insulin and glucose in individuals engaged in regular exercise. Moreover, PE is a key factor regulating the levels of ROS/RNS and adaptation to OS and can restore disturbed redox homeostasis, reduce DNA damage, and increase its repair (Gondim et al., 2015) as well as a reductor of psychological stress (Kruk et al., 2019).

Although the positive role of PE in the fight against fatigue and depression is well documented, the exact mechanisms underlying this association remain unknown. It is also hypothesized that exercise leads to an increase in the synthesis and secretion of enkephalins, serotonin, catecholamines (dopamine, adrenaline, and noradrenaline) and beta-endorphins (Pedersen & Saltin, 2015). Enkephalins and endorphins are opioid polypeptides occurring in brain, acting as neurotransmitters and pain modulators (Nam et al., 2019). Endorphins reduce pain and increase the feeling of pleasure. These neuropeptides are involved in the inhibition of substance P (linked to pain and inflammation) and enhance the production of anti-inflammatory cytokines (Shrihari, 2018).

Conclusions

This review summarizes the current evidence on post-acute consequences of SARS-CoV-2 infection, focusing on neuronal complications and the role of post-COVID-19 PE in the physical and psychological health improvement. Evidence has shown that dysregulation of the immune system is a key feature of COVID-19 disease severity. The virus is a pathogen which can lead to Guillian-Barré syndrome development, among others. The reported

data emphasizes that neurological post-COVID-19 side effects can destroy the life of patients both in physical and mental aspects. It is evident that COVID-19 attacks both the CNS and the peripheral nervous system followed by inflammation and demyelination. Evidence clearly also maintains an important role of OS in COVID-19 disease severity, although the biological mechanisms involved in the disease development are far from being understood. Currently, any direct evidence on SARS-CoV-2 specific neuropathogenicity is limited. Therefore, more clinical studies based on the wide complications caused by SARS-CoV-2 are needed. Available studies provide evidence that the effect of OS on the activation of inflammatory pathways in COVID-19 infection has a plausible biological rationale. Several observational studies have also demonstrated that the quality of life of certain subgroups of COVID-19 survivors remains a major health concern and requires targeting therapy. Considering existing literature, aerobic and strength exercise are recommended for individuals convalescing from COVID-19.

The evidence is consistent that PE significantly increase muscle strength, respiratory function, dyspnea, and improves individuals' QoL. The key factors that determine exercise benefit are disease severity, type, intensity, dose, and frequency of PE.

There are several limitations in this review. First, our conclusions are based to large extent on review studies and observational studies on cohort groups, where methodological limitations are common. Second, validity of the observational studies was mostly limited by absence of experimental control groups in majority of exercise treatment studies. Third, the analysed studies, overall, included large variations of COVID-19 tested outcomes, disease severity levels, and post-COVID-19 exercise protocols, among others. Due to these limitations, effectiveness of PE in post-COVID-19 rehabilitation, recommendation of the precise cellular mechanisms, optimal dose of exercise, and timing requires future research. Several gaps have been identified as essential in this area. Above all, there is a need to perform properly designed RCTs with larger sample size that target individuals using exercise rehabilitation programs developed by multiprofessional teams stratified by age, time of hospitalization, and individuals' psycho-physical conditions. Additional research is needed to continue studies on biological mechanisms that may be the most operative during rehabilitation with PE, regarding levels of the disease severity. In this respect, we hope that the reported findings in this review may inspire to conduct experimental studies of higher methodological quality on usage, effective and individualized exercises in the treatment of COVID-19 disease outcomes. In addition, the presentation of the current findings may raise awareness of patients to observe themselves even though they did not have any serious symptoms during active SARS-CoV-2 infection. Longer follow-up studies in a larger population are also necessary to understand the full spectrum of health consequences of COVID-19 severity and address the role of OS in the pathophysiology of this disease. It seems also necessary to develop new strategies for targeting redox sensitive pathways which prevent the secretion of excess proinflammatory cytokines.

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PHYSICAL ACTIVITY ANALYSIS AND COMPARISON OF FEMALE STUDENTS IN URBAN AND RURAL SECONDARY SCHOOLS IN SLOVAKIA

Gabriel Bujdoš^{A, D}

Department of Physical Education and Sports, Faculty of Arts, Matej Bel University in Banská Bystrica, Slovak Republic
ORCID: 0000-0001-5828-4593 | e-mail: gabibujdos@gmail.com

Štefan Adamčák^{B, C}

Department of Physical Education and Sports, Faculty of Arts, Matej Bel University in Banská Bystrica, Slovak Republic
ORCID: 0000-0002-8002-6010

Michal Marko^{A, B}

Department of Music-Theoretical and Academic Subjects, Faculty of Performing Arts, Academy of Arts in Banská Bystrica, Slovak Republic
ORCID: 0000-0003-0054-0667

^A Study Design; ^B Data Collection; ^C Statistical Analysis; ^D Manuscript Preparation; ^E Funds Collection

Abstract Our study aimed to assess and compare the physical activity levels of female students in urban and rural secondary schools in Slovakia, given the well-established health benefits of regular physical activity and the recognized risks of a sedentary lifestyle. Using a short version of the International Physical Activity Questionnaire delivered online via Google Forms, we gathered data from 1271 female students, averaging 17.34 years old, attending the final year of grammar and secondary vocational schools in specific Slovak regions. After categorizing participants based on their residence, statistical analyses, including two-sample t-tests and chi-square tests, were employed with a significance level set at $p < 0.01$ or $p < 0.05$.

Unexpectedly, participants residing in towns with over 30,000 inhabitants exhibited the highest levels of physical activity, yet they also spent the most time sitting during the week (354.69 minutes on average). Statistical significance was found in only two instances at the $p < 0.05$ level: walking physical activity between the first and second group and vigorous physical activity between the second and third group. These findings shed light on the nuanced relationship between residence and physical activity levels among female students in Slovakia.

Key words: IPAQ, physical activity, school

Introduction

As simple as it may sound, being physically active might be the very thing most people from across the world need to significantly change their lives for better. The last few decades have proven that sedentary lifestyle and physical inactivity are two of the leading causes of chronic diseases (Booth et al., 2012). It has gotten exponentially easier to become physically inactive in modern days. Many jobs are remote, as people can work comfortably

from home, there is no need to cook as everything can be ordered in mere seconds via our smartphones, and the whole world can be seen on the screen of a computer. Today, we can find numerous studies pointing out the health impacts of the ongoing decline in physical activity and increase in sedentary lifestyles (Guthold et al., 2018). The World Health Organization is amongst the loudest advocates for the idea of physical activity increase in all the age groups. According to WHO, up to 6-10% of chronic disease and premature deaths are connected to physical inactivity (Booth et al., 2012). Looking at a survey with 1.9 million respondents, physical inactivity is prevalent in wide regions of the world: Africa (27.5%), America (43.3%), Europe (34.8%), Southeast Asia (17%) and Western Pacific (33.7%) (Guthold et al., 2018). As a response to concerning increase of physical inactivity, WHO has introduced its global action plan on physical activity 2018 – 2030 called “More Active People for a Healthier World” (WHO, 2019). This plan targets a 15% reduction in the global prevalence of physical inactivity in adults and adolescents by 2030 (WHO, 2019). Creating active societies, active environments, active people, and active systems are four main objectives of this plan (WHO, 2019).

Noncommunicable diseases (NCDs) are usually long-lasting diseases of slow progression and there are four main types that are directly connected to physical inactivity: cardiovascular diseases, cancer, chronic respiratory diseases, and diabetes (Reiner et al., 2013). Physical inactivity combined with excessive smoking, consumption of unhealthy food, too much alcohol, and an unhealthy lifestyle in general, are the primary reasons for most NCDs (Hu, 2012; Ambrose & Barua, 2004). Increased levels of physical activity and physical fitness have positive effect on our cardiovascular system. The relative risk of dying from a cardiovascular disease is reduced by 25–30% with regular exercise (Macera et al., 2003). Regular exercises reduce all risks of premature death (Warbuton et al., 2006). Exercise is associated with a 20–30% reduction in the incidence of breast cancer in women and a 30–40% reduction in colon cancer in both sexes (Lee, 2003). It is believed that one in 10 deaths could be avoided, had the person been more physically active (Lee et al., 2012). Overall benefits of exercise apply to all bodily systems including cardiovascular, musculoskeletal, respiratory, hormonal, and psychological (Sellami et al., 2018).

As recommended by WHO, adults aged 18–64 years should do at least 150–300 minutes of physical activity with moderate intensity or at least 75–150 minutes of physical activity with vigorous intensity throughout the week. This physical activity should also involve muscle-strengthening activities at moderate or greater intensity that involve all major muscle group for a period of 2 days a week. In addition to physical activity, adults should work on decreasing time spent being sedentary (WHO, 2022).

Decreasing physical activity and increasing sedentary time in Europe are concerning issues. The Special Eurobarometer 525 on Sport and Physical Activity (2022) reports that 45% of Europeans never exercise or engage in physical activity. This figure shows a stabilization compared to previous surveys, such as the 2018 Eurobarometer.

A group of experts developed the EU Physical Activity Guidelines aiming to increase physical activity across the EU (European Commission, 2008). In 2014, World Health Organization in cooperation with the European Commission established the EU Physical Activity Points Network, to work on changing the ongoing decline in physical activity (WHO, 2015).

Material & Methods

Pursuant to the research objective, the focal group encompassed female adolescents enrolled in the final year (4th year) of grammar and vocational secondary schools in the regions of Banská Bystrica and Zvolen, Slovakia. The data collection and questionnaire responses were conducted between April and May 2023. To ensure

a purposeful selection of the target population, the recruitment methodology was periodically adjusted, taking into account factors such as age, gender, and academic year. The criteria for inclusion in the survey group were as follows: a) gender; b) the survey group comprising students from the same academic year in secondary school. To meet the goals of our study, we utilized a condensed version of the International Physical Activity Questionnaire (IPAQ), which consisted of a series of seven questions. The questionnaire was created online using Google Forms. Subjects were enlisted via the Edupage school information system and physical education teachers. The research adhered to the General Data Protection Regulation (GDPR). The study's protocol underwent evaluation and approval from both the physical education teachers of the enrolled students and the principals of the schools attended by the students. Each participant granted verbal consent to partake in the study after reviewing the participant information sheet and demonstrating a satisfactory comprehension of the presented questions. The questionnaire was administered anonymously to ensure the confidentiality of participants' responses.

Data analysis

Statistical analysis in this study was carried out using SPSS (Statistical Package for the Social Sciences). Summary statistics were computed to describe the characteristics of the study participants, while chi-square tests were applied to investigate associations between categorical variables. Additionally, independent samples t-tests were utilized for analyzing continuous variables. A significance level of $\alpha = 0.05$ and $\alpha = 0.01$ was set for statistical tests were applicable.

Upon satisfying the criteria for inclusion in the survey group, a total of 1271 female students from grammar and vocational secondary schools were incorporated into the process of interpreting the study data. The study group was divided into three groups according to the size of population of a town or village, where the schools they attend are located: a) a village with less than 5,000 inhabitants ($n = 511$), b) a small town with more than 5,000, but less than 30,000 inhabitants ($n = 313$), c) a town with more than 30,000, but less than 100,000 inhabitants ($n = 446$).

Table 1. Characteristics of the survey group of grammar and vocational school female students

Survey group characteristics	Village $x < 5000$ inhabitants	Small town $5,000 < x < 30,000$ inhabitants	Town with $x > 30,000$ inhabitants	Overall
Age	17.14	17.30	17.60	17.34
Number of participants	511	313	446	1271

Scoring and data reduction

The data acquired from the questionnaire were transformed into Metabolic Equivalent of Task (MET) units, specifically MET-minutes per week. The calculation of MET-minutes per week involved multiplying the number of minutes engaged in physical exercise per day by the number of exercise sessions per week and then by the corresponding MET coefficient for the intensity level of the physical activity. For instance, vigorous physical activity had a MET coefficient of 8, moderate physical activity had a coefficient of 4, and walking had a coefficient of 3.3. The MET coefficient, which reflects the intensity of exercise, is an indicator of a person's oxygen consumption during physical activity compared to their resting oxygen consumption. Subsequently, survey participants were categorized into three distinct groups using the following criteria:

1. High physical activity – for the classification of high physical activity, individuals were considered to be in this category if they engaged in vigorous physical exercise for three or more days, accumulating a minimum of 1,500 MET-minutes per week. Alternatively, individuals who participated in any combination of vigorous exercise, moderate exercise, and walking for seven or more days, reaching a total of over 3,000 MET-minutes per week, were also classified as having high physical activity.
2. Moderate physical activity – to be classified as engaging in moderate physical activity, individuals needed to meet one of the following criteria: three or more days of vigorous physical exercise, with each session lasting at least 20 minutes; or five or more days of moderate exercise or walking, with each session lasting at least 30 minutes; or five or more days of a combination of vigorous exercise, moderate exercise, and walking, resulting in a total of over 600 MET-minutes per week.
3. Low physical activity – low physical activity refers to a lack of adherence to the criteria for moderate or high physical activity classifications, indicating an accumulation of less than 600 MET-minutes per week.

Results

The first section of our findings examines the participants' general levels of physical activity. As seen in figure 1, females from towns with more than 30,000, but less than 100,000 inhabitants engaged in high physical activity the most, which was a surprising result as we expected the females from the smallest villages to dominate this category. On the other hand, we can see a contrast in the fact that females from the towns with the highest population have also engaged in the low physical activity the most. The highest percentual difference in moderate physical activity levels that have not exceeded 600 MET-minutes per week can be seen between the females from small towns (more than 5,000, but less than 30,000 inhabitants) and those from the towns with more than 30,000 inhabitants. When comparing our results with those from across the world, we've decided to look at female students from Saudi Arabia. On average, 43% were highly active, 28% were moderately active and 29% participated in low levels of physical activity (Aljehani et al., 2022).

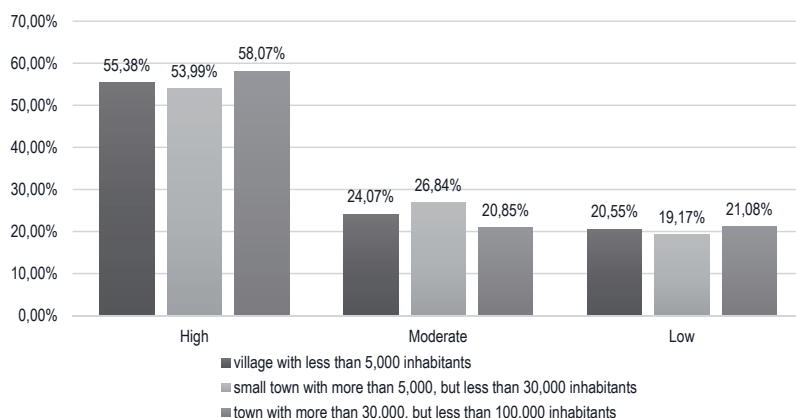


Figure 1. Physical activity levels of female students according to their residence

Table 2. Vigorous intensity level of physical activity of female students attending grammar and vocational schools expressed in MET-minutes/week, time of engagement in physical activity in minutes and days per week

Vigorous intensity	Village $\times < 5000$ inhabitants	Small town 5,000 $< \times > 30,000$ inhabitants	Town with $\times > 30,000$ inhabitants	Overall
Days/week mean	2.20 $p > 0.05$ ($p = 0,569$)	2.13 $p > 0.05$ ($p = 0,780$)	2.17 $p < 0.01$ ($p = 0,759$)	2.17
Time/min median	30 $p > 0.05$ ($p = 0,981$)	30 $p > 0.05$ ($p = 0,161$)	30 $p > 0.05$ ($p = 0,184$)	30
Total Mets/week mean	974.79 $p < 0.01$ ($p = 0,147$)	870.52 $p > 0.05$ ($p = 0,323$)	1050.26 $p < 0.05$ ($p = 0,019$)*	975.60
Total Mets/week median	640	640	720	720

Looking at table 2 we can see that the females living in towns with more than 30,000 inhabitants engaged in physical activity with vigorous intensity the most (1050.26 MET-min/week). All of our results were statistically examined for differences that were $p < 0.05$ statistically significant. When comparing the results of MET-min/week between females from small towns with more than 5,000, but less than 30,000 inhabitants and females from towns with more than 30,000 inhabitants, we have found a statistically significant difference at the level of $p < 0.05$ ($p = 0.019$).

Table 3. Moderate intensity level of physical activity of female students attending grammar and vocational schools expressed in MET-minutes/week, time of engagement in physical activity in minutes and days per week

Moderate intensity	Village $\times < 5000$ inhabitants	Small town 5,000 $< \times > 30,000$ inhabitants	Town with $\times > 30,000$ inhabitants	Overall
Days/week mean	2.02 $p > 0.05$ ($p = 0,192$)	2.17 $p > 0.05$ ($p = 0,325$)	2.12 $p > 0.05$ ($p = 0,705$)	2.09
Time/min median	30 $p > 0.05$ ($p = 0,795$)	30 $p > 0.05$ ($p = 0,511$)	40 $p > 0.05$ ($p = 0,720$)	30
Total Mets/week mean	470.87 $p > 0.05$ ($p = 0,887$)	476.79 $p > 0.05$ ($p = 0,317$)	509.82 $p > 0.05$ ($p = 0,426$)	486.01
Total Mets/week median	240	360	360	320

Physical activity with moderate intensity is the least performed PA amongst all our respondents when compared to others. Once again, female students from largely populated areas tend to engage in moderate PA more than their peers from more densely populated areas. Statistical analysis hasn't shown any statistically significant differences amongst the groups. European women aged 15–24 engage in moderate PA on average for 2.57 days a week, which is considerably higher when compared to our respondents – 2.09 days a week (Moreno-Llamas et al., 2022).

Table 4. Walking physical activity of female students attending grammar and vocational schools expressed in MET-minutes/week, time spent walking in minutes and days per week

Walking PA	Village × < 5000 inhabitants	Small town 5,000 < × > 30,000 inhabitants	Town with × > 30,000 inhabitants	Overall
Days/week mean	3.69 >0.05 (p = 0,154)	3.52 p < 0.01 (p = 0,168)	3.84 p < 0.05 (p = 0,011)*	3.70
Time/min median	45 p < 0.01 (p = 0,522)	40 p > 0.05 (p = 0,591)	45 p < 0.01 (p = 0,864)	45
Total Mets/week mean	693.15 p < 0.01 (p = 0,412)	655.91 p < 0.01 (p = 0,687)	709.49 p > 0.05 (p = 0,255)	689.71
Total Mets/week median	495	416	512	495

Walking PA is the most performed PA amongst our participants. Females with different residence performed walking PA almost 4 days a week on average. 15–24 years old females in Europe walk on average 5 days a week, our participants have underperformed in this particular instance, when on average they haven't hit the 4 day mark. After statistical analysis we have found statistically significant differences between the females from small town with more than 5,000 and less than 30,000 inhabitants compared to those living in towns with more than 30,000 on a $p < 0.05$ level ($p = 0.011$).

Table 5. Time spent sitting in minutes (sedentary lifestyle measurement)

Time spent sitting	Village × < 5000 inhabitants	Small town 5,000 < × > 30,000 inhabitants	Town with × > 30,000 inhabitants	Overall
Time/min mean	354.03	341.88	354.69	351.27
Time/min median	360 p > 0.05 (p = 0,316)	360 p > 0.05 (p = 0,951)	360 p > 0.05 (p = 0,280)	360

Looking at table 5, we can see that female students from small towns with less than 30,000, but more than 5,000 inhabitants spent the least time sitting during the week compared to their counterparts from villages or larger towns. Median sitting time for adults in Europe reported by Loyen et al. (2016) was 300 minutes a week, our female students spent on average one more hour a week sitting, which is quite concerning. Statistical analysis has not shown any significant statistical difference in between groups of our students.

Discussion

Walking PA is the most spread physical activity worldwide. As it stands, it has been the most popular PA amongst our survey participants. Bauman et al. (2009) have screened more than 50,000 people aged 18–65 from 20 different countries. According to their results, it was only countries from Asia (Hong Kong, China) whose weekly MET consisted of more than 50% walking PA. When we compare the results of all the countries, walking PA contributed to only 20% of total weekly MET. Walking as a physical activity is recommended by numerous scholars (Ungvari et al., 2023). Scholars agree that with increased time spent walking a person can reduce risk of cardiovascular diseases, depression, stress, and even prevent strokes and treat anxiety. When we look at different

studies, from Germany for example, their female students have scored almost double of what our participants have – 3,636 MET-minutes/week (Edelmann et al., 2022).

As it stands, overall PA worldwide needs to be increased and there have already been numerous propositions on how we should do it. Positive encouragement, health promotion, creating healthy working environment, surrounding ourselves with people, who are active are one of many of the steps a person can take on their path towards healthy lifestyle and increased physical activity (Tuso, 2015).

Sedentary lifestyle is associated with various health risks such as type 2 diabetes, depression or even cancer (McLaughlin et al., 2020). According to Egan et al. (2019) adolescents spend 50% of their days sedentary and on average during school days this time reaches 63%. Our study participants sedentary behaviour showed signs of worsening when compared to the same age European median. As it stands now, there are multiple actions being made to decrease sedentary behaviour and physical inactivity in workplace (Dieterich et al., 2020). Other studies have shown that a decrease in sedentary behaviour in students can have a positive impact on their academic performance, sleep, or mental development (Pilcher et al., 2017).

Increasing PA is one of the most effective ways of starting to live a healthy lifestyle. As we have proven in this paper, sport and physical activity in general are not only natural, but also essential for us as human beings. In general, older we get, more physically inactive we are (King et al., 2009). Healthy lifestyle is more associated with women, more developed countries and better educated individuals. Good education, correct sources and right leadership allow not only us, but also our children to lead a healthy lifestyle and develop correctly both physically and mentally. Guthold et al. (2018) connect physical inactivity with less developed and poorer countries. According to Polish researchers Iwon et al. (2021) it is the Scandinavian countries (Finland, Sweden and Denmark), who are amongst the leaders in physical activity in the world, on the other hand countries like Bulgaria and Greece are amongst the least active people in the world. Aljehani et al. (2022) reported that female students from Saudi Arabia spent median of 30 minutes a week engaging in vigorous PA, which is the same as our participants. Although when looking at total MET/week median, their female students reported a score of 240 compared to our female students score of 720. When we look at the results of Aljehani et al. (2022), again we can say that their participants have spent more median time engaging in moderate PA (60 minutes a week) than our participants (30 minutes a week). Female students from Saudi Arabia are also outperforming our participants, when showing slightly better results at 693 MET-minutes/week on average compared to our 689.71. Our findings are also being compared to those of Llamas et al. (2022), who conducted a screening of results from various parts of Europe. European females aged 15–24 reportedly walk an average of 5 days per week, but our participants have fallen short, averaging less than 4 days weekly in this regard.

Conclusion

Our study was conducted with use of widely used International Physical Activity Questionnaire (IPAQ). It has been widely adopted and used in numerous global and European surveillance programs and is considered as one of the most utilized validated physical activity questionnaires. Furthermore, the Eurobarometer incorporates questions from this PAQ, making it a crucial resource for decision-making within the European Union (Sember et al., 2020).

The mean sum of total physical activity interpreted in MET-minutes/week of our female participants was 2151.32. Comparing these results with female students from Saudi Arabia, we can state that our participants slightly overperformed their counterparts from the Middle East by 117.32.

According to a study by Løyen et al., (2016) average sitting time across European countries in the age group of 18–24 years old is a median of 300 minutes a day. Comparing that number with our results, we can see that all our surveyed groups have spent 60 more minutes or one hour a day more than that. Looking at these results, we can conclude that after 7 years since the original article has been published, we are moving closer to physical inactivity.

Physical inactivity as a fast-spreading phenomenon has lately been on raise as not so long ago, we as humanity have witnessed another pandemic (COVID-19) and once again locked ourselves in our homes and not exercised as much as before. It's been more than 3 decades since WHO issued its first recommendations for sufficient exercise and thus trying to increase physical activity. Considering the latest global estimates revealing that a significant proportion of the population falls short of meeting the recommended guidelines for aerobic exercise, with approximately 27.5% of adults and a staggering 81% of adolescents failing to do so, there arises an immediate and pressing necessity to enhance levels of physical activity.

In our study, we have demonstrated substantial variations in physical activity levels based on gender and a comparison of different nationalities. Hence, it can be inferred that these activity levels also differ according to culture and nationality. This research holds the potential to inform students about their own physical activity levels, offer guidance on methods to enhance them, specify the recommended duration of active engagement for maintaining good health, and potentially facilitate a comparison between students of the same age from diverse countries.

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THE INFLUENCE OF A SPECIFIC SPRINT RESISTED SWIMMING TRAINING PROGRAMME ON THE INTRA-CYCLIC VELOCITY VARIATION OF YOUNG FEMALE FRONT CRAWL SWIMMERS

Ioannis K. Valkoumas^{A, B, C, D}

Democritus University of Thrace, School of Physical Education and Sports Science, Department of Physical Education and Sports Science, University Campus, 69100, Komotini, Greece
ORCID: 0009-0002-0859-2218 | e-mail: jval2551@gmail.com

Vassilios Gourgoulis^{A, B, C, D}

Democritus University of Thrace, School of Physical Education and Sports Science, Department of Physical Education and Sports Science, University Campus, 69100, Komotini, Greece
ORCID: 0000-0001-6857-2564

^AStudy design, ^BData collection, ^CStatistical analysis, ^DManuscript preparation

Abstract The aim of the current study was to investigate the effect of an 11-week sprint resisted swimming training programme on the front crawl mean swimming velocity and the intra-cyclic velocity variation (IVV). Twelve female swimmers assigned into an experimental (N = 6) and a control group (N = 6) followed the same training programme including a specific sprint protocol. The only difference between the two groups was the use of a swimming parachute from the experimental group during the specific sprint protocol. A 50 m maximal intensity front crawl trial, before and after the 11-week intervention period, was recorded by 4 digital video cameras. The Ariel Performance Analysis System was used for the digitization of selected anatomical landmarks and two-way repeated measures ANOVAs were performed for the statistical treatment of the data. After the intervention programme, the experimental group showed a significant increase in the mean swimming velocity, the stroke rate, the propulsive phase duration and the index of coordination, and a significant decrease in the non-propulsive phase duration, the total stroke duration and the IVV. These modifications could be considered a positive effect, helping the swimmers to become more efficient to overcome the inertial forces and to improve their swimming performance.

Key words: resisted swimming, intra-cyclic velocity variation, arm coordination, stroke rate

Introduction

In competitive swimming, the emphasis of every training protocol is focused on the swimming velocity improvement. Sprint resisted swimming is one of the most popular and effective training forms, leading to swimming performance enhancement after a certain training period. The positive effect of the sprint resisted swimming training is confirmed by several studies. Morrison et al. (2005) investigated the effect of 6 weeks of sprint resisted swimming training and found a 2.5% improvement in the 100 m front crawl performance of elite swimmers. Girolid

et al. (2006) after a 3-week training period, reported a 2% improvement in the 100 m front crawl performance and Mavridis et al. (2006) who studied the influence of sprint resisted swimming after 12 weeks of training in front crawl swimmers come to similar conclusions. They found a swimming performance improvement of 3.53%, 3.15% and 3.19% on 50 m, 100 m and 200 m front crawl, respectively. Grznár et al. (2018) after an 8-week training period, found also that swimming with swimming parachute was more effective in developing speed and speed-power capabilities when compared to swimming in natural conditions. More recently, Gourgoulis et al. (2019) investigating the effect of an 11-week sprint resisted swimming training protocol on young female front crawl swimmers, observed similar significant improvement in the 50 m ($3.22 \pm 1.89\%$), 100 m ($4.78 \pm 1.28\%$) and 200 m ($5.11 \pm 2.30\%$) front crawl performance and Valkoumas et al., (2023) after the same training period reported a significant mean swimming velocity improvement of $4.38 \pm 1.99\%$.

However, despite the well-documented positive influence of the sprint resisted swimming training on swimming performance, it is also crucially important to identify the primary parameters which cause this improvement. It is well known that the swimming velocity (v) is the product of stroke rate (SR) and stroke length (SL) ($v = SR * SL$) and according to previous studies the swimming velocity increase after a sprint resisted swimming training is attributed to a stroke rate increase (Girolid et al., 2006; Gourgoulis et al., 2019; Valkoumas et al., 2023). Similarly, Amara et al. (2021) after 9 weeks of concurrent resistance training, between resistance on dry land and resistance in water, including water parachute, reported increased swimming velocity due to improved stroke rate, with no change in the stroke length. Nonetheless, there is not extending data regarding the underlying mechanism that causes this positive modification. In an attempt to answer this issue, Valkoumas et al. (2023) investigated the effect of 11 weeks sprint resisted swimming training on the mean swimming velocity and the arm coordination in young female swimmers. Their results confirm previous findings regarding the swimming velocity improvement due to stroke rate increase. This increase was attributed to a significant reduction of the non-propulsive phases, leading to an index of coordination (IdC) increase, which was accompanied by reduced lag time between the propulsive actions of the two arms and increased propulsion continuity. These modifications caused a decrease of the total stroke duration, leading to an increased stroke rate and consequently an increased mean swimming velocity.

However, water resistance is unavoidable to any aquatic locomotion. Each swimmer's movement causes a reactive resistive force, which is applied from the water against this movement (Schleihau, 2004; Toussaint & Beek, 1992). During front crawl swimming, this resistive force is constantly changed, depending on the swimmer's body shape and velocity. At the same time, the action of the swimmer's limbs produces propulsive forces to overcome the water resistance. Consequently, swimming velocity is characterized by instantaneous accelerations and decelerations during a complete stroke cycle. These fluctuations of the instantaneous swimming velocity within a stroke cycle are defined as intra-cyclic velocity variation (IVV) (Barbosa et al., 2006). According to previous research, the magnitude of the IVV could be considered an essential factor for the swimming performance (Fujishima & Miyashida 1999; Alberty et al., 2004; Figueiredo et al., 2012; Barbosa et al., 2013; Figueiredo et al., 2013; Matsuda et al., 2014; Figueiredo et al., 2016). Barbosa et al. (2013) reported that age group swimmers, who achieved higher mean swimming velocity, showed significantly lower IVV. Matsuda et al. (2014) who investigated the IVV in front crawl swimmers of different levels, reported similarly that the mean IVV in all tested swimming velocities was 26% lower in elite swimmers, compared to beginners. These findings are also supported by Fujishima and Miyashita (1999), who concluded that the significantly lower IVV values lead to a higher average swimming velocity.

Nonetheless, apart from the influence of the sprint resisted swimming training on the temporal organization of the stroke (Valkoumas et al., 2023), to the best of our knowledge the behaviour of IVV has been studied only concerning the acute effect of sprint resisted swimming (Gourgoulis et al., 2013), while no previous research investigated the effect of sprint resisted swimming training on the IVV after a certain time period.

To bridge this gap of knowledge, the aim of the current study was to investigate the effect of an 11-week sprint resisted swimming training on the intra-cyclic velocity variation (IVV) in young female swimmers. It was hypothesised that after the 11-week sprint resisted swimming training period the swimmers would reduce their IVV, and this positive modification would potentially explain the swimming velocity increase.

Material and Methods

Participants

Twelve female swimmers (age: 13.08 ±0.9 years, height: 1.58 ±0.05 m, mass: 48.3 ±6.9 kg, training age: 3.92 ±0.9 years), who partook regularly (6 days per week) in swimming training, voluntarily participated in the study. All swimmers participating in the study had front crawl as main stroke and were specialized in middle distance events. The experimental procedure was in accordance with the ethical standards and the Declaration of Helsinki, was approved by the Institutional Review Board at Democritus University of Thrace (number of approval: 8/09-05-2022), was explained to the swimmers and their parents, and a written consent was provided from all the participants and their guardians. The study was conducted between September and December 2022.

Design

Before the beginning of the experimental process conducted in a 25 m in-door swimming pool, a standard 1000 m warm up routine was performed by all the swimmers. Subsequently, they swam two 50 m front crawl trials with maximal intensity and a recovery time of 30 min between them, to avoid any potential fatigue effect. They were timed by two experienced timekeepers and the average time for the fastest trial was used to assign the swimmers randomly into an experimental (35.90 ±0.57 s) and a control group (35.67 ±1.60 s), with no significant difference between them, as it was revealed by the Welch’s two samples t-test ($t_{(6,231)} = 0.113, p = 0.747$), which was conducted because the homogeneity of variance assumption was not met.

After their assignment into groups, all the swimmers followed the same weekly training programme for 11 weeks, with an average daily training volume of 4.5 km. Both groups trained 6 days per week and their training schedule, apart from the common training, additionally contained a specific sprint protocol on 4 of the 6 days (Table 1) and it was then the main training goal.

Table 1. Resisted sprint training programme

Monday	Tuesday	Thursday	Friday
3 × (6 × 15 m) ⁽¹⁾	2 × (4 × 25 m) ⁽²⁾	3 × (6 × 15 m) ⁽¹⁾	2 × (4 × 25 m) ⁽²⁾

⁽¹⁾ 60 s rest between 15 m and 5 min between sets
⁽²⁾ 90 s rest between 25 m and 5 min between the sets

This specific sprint protocol was performed by both groups in front crawl, at maximal intensity and the only difference between the groups was the use of a swimming parachute by the experimental group, during the sprint

sets. The swimming parachute had a chute of 40.64 cm, and it was tethered to a 2 m long tube, which was fastened on a belt around the swimmer's waist.

Methodology

Before the start of the 11-week training period and immediately after its end, the swimmers performed a 50 m front crawl sprint trial at maximal intensity. These trials were performed with a push start in the water, to avoid the effect of diving from the block, and the movements were recorded during the first lap of the trial in the middle of the pool (between 17 and 20 m from the starting wall) to eliminate any possible breakout effect. Moreover, the participants were instructed to hold their breath in this section to avoid any breathing effect.

The underwater movement was recorded using 4 digital video cameras with a sampling frequency of 50 Hz. Each video camera was placed behind a specific periscope system and their synchronization was achieved through a LED system, which was visible in each camera's field of view. A parallelepiped frame, with 24 control points on it, was used for the calibration of the recorded space. The dimensions of this calibration frame were 1 m for the transverse (X), 1 m for the vertical (Z) and 3 m for the longitudinal (Y) axis, which was aligned with the direction of the swimmer's motion. Apart from the 24 control points, 8 additional validation points on the calibration frame were used for the calculation of the root mean square (RMS) error of their 3-dimensional reconstructed coordinates, to determine the accuracy of the calibration procedure (Gourgoulis et al., 2008). The RMS error was 2.53 mm, 2.78 mm and 5.28 mm for the X, Z and Y axes, respectively.

Each arm stroke was divided into four distinct phases:

- the entry & catch phase, which corresponded to the time between the hand's entry into the water and its maximal forward displacement in the longitudinal direction,
- the pull phase, which lasted from the maximal displacement of the hand in the forward direction until the time where the hand passed under the shoulder,
- the push phase, which corresponded to the time from the end of the pull phase until the exit of the hand, out of the water (Figure 1) and
- the recovery phase, which lasted from hand's exit until its re-entry into the water.

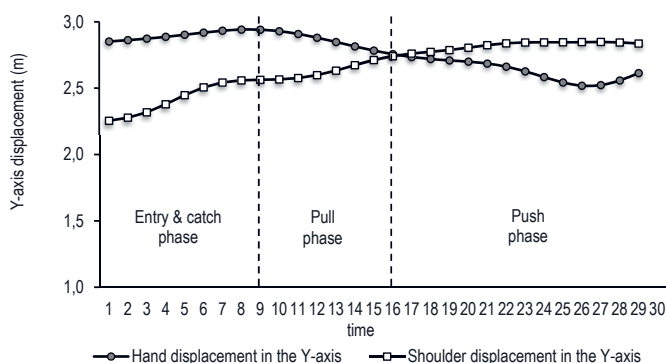


Figure 1. Determination of the boundaries of the underwater stroke phases

The recovery and the entry & catch phase are considered non-propulsive phases, while the pull and the push phase are considered propulsive phases of the arm stroke (Chollet et al., 2000). To determine the duration of the separate phases of the arm stroke, two complete successive right and left arm strokes were digitized, and the mean value of each arm stroke phase was calculated.

Eight anatomical landmarks were marked with a black waterproof pen on each swimmer's body, corresponding to:

- the great trochanter of the right and left femur, which was used to estimate the velocity of the hips and the mean swimming velocity,
- the acromion of the right and left scapula, which was used to determine the end of the pull and the begin of the push phase and
- the 2nd and 5th metacarpophalangeal joint of the right and left hand, the midpoint of which was used for the determination of the hand's motion (Gourgoulis et al., 2013).

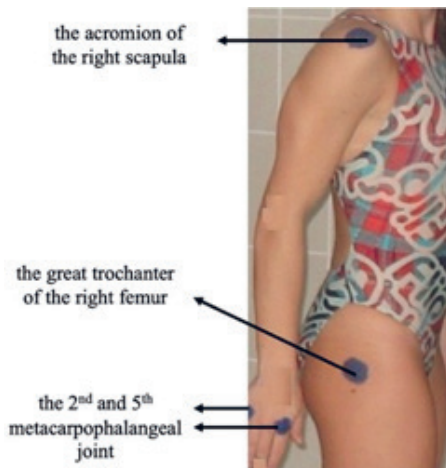


Photo 1. Illustration of the marked points on the swimmer's body (right side), that used for the digitization process

The digitization of these anatomical landmarks was performed using the Ariel Performance Analysis System (APAS, Ariel Dynamics, San Diego, Cal., USA), and the Direct Linear Transformation (DLT) procedure was used for the 3-dimensional reconstruction. A low-pass digital filter with a cut-off frequency of 6 Hz was selected for smoothing the raw position-time data, after residual analysis for a wide range of cut-off frequencies (Winter, 1990).

The average velocity of the right and left hip in the longitudinal axis, during a complete right and left arm stroke, respectively, was used for the estimation of the intra-cyclic velocity fluctuations. Each arm stroke was defined as the movement from the hand's entry into the water, until its re-entry, and before averaging, time normalization was performed to the hip velocity curves using linear interpolation due to the different duration of the arm strokes. For the detailed evaluation of the hip intra-cyclic velocity variation two different approaches were used. The first approach was the calculation of the coefficient of variation (CV) (Equation 1), where SD is the standard deviation of the horizontal velocity of the hip and corresponds to the mean horizontal velocity of the hip:

$$\text{Coefficient of Variation} = \frac{SD}{\bar{X}} \quad (1)$$

The second approach (Equation 2) was the calculation of the relative hip intra-cyclic velocity variation (relative HIVV) as the difference between the maximum ($V_{\max}$) and minimum ($V_{\min}$) values of the hip velocities, normalized for the mean velocity of the stroke cycle (V_{mean}):

$$\text{relative HIVV} = \frac{V_{\max} - V_{\min}}{V_{\text{mean}}} \quad (2)$$

However, according to Gonjo et al. (2023) when IVV is investigated through the coefficient of variation (Equation 1), could be highly biased because the velocity fluctuation is normalized by the mean velocity. This is appropriate only if the intra-cyclic velocity standard deviation (SD) has proportional relationships with the mean velocity and both increase or decrease to the same extent. Correspondingly, when IVV is estimated using the relative HIVV (Equation 2), the difference between the maximum and minimum velocity ($V_{\max} - V_{\min}$) should be changed proportional with the mean velocity. For this reason, both CV and relative HIVV should not be interpreted alone, but always together with the mean, the SD, and the difference between the maximum and minimum velocity. Consequently, to avoid masking the source of outcome by any possible mean hip velocity effect on the CV and the relative HIVV, the SD of the time-series velocity data and the difference between the maximum and minimum hip velocity ($V_{\text{Hip}_{\max}} - V_{\text{Hip}_{\min}}$) were also calculated separately in both groups before and after the end of the intervention programme.

The index of coordination (IdC) (Chollet et al., 2000), which corresponds to the mean value of the time lag (LT_1 , LT_2) between the starting of the propulsive phase of the one arm and the end of the propulsive phase of the other arm, was calculated according to equation (3), where T corresponds to the mean duration of a complete arm stroke:

$$\text{IdC} = \left[\frac{LT_1 + LT_2}{2} \right] \times \frac{100}{T} \quad (3)$$

To calculate the IdC are necessary two and half arm strokes (Gourgoulis et al., 2013; Chollet et al., 2000). Despite the limited length (3 m) of the calibration frame in the longitudinal direction (Y), which was aligned with the swimming direction, the participants due to their young age and short height were able to perform within this space one and half arm stroke with the one arm (right or left arm) and one arm stroke with the other arm (left or right), depending on which arm was first entered into the calibrated area.

The stroke length (SL), the stroke rate (SR) and the mean swimming velocity (v) were also calculated. The stroke length was calculated as the average value of the forward displacement of the left and right hip in the longitudinal axis, during a complete left and right arm stroke (Gourgoulis et al., 2013), while the stroke rate was defined as the inverse of the arm stroke total duration (T) ($SR = 1/T$). The mean swimming velocity (v) was calculated as the product of stroke rate and stroke length ($v = SR * SL$).

Statistical Analysis

Two-way repeated measures analysis of variance (ANOVA) was used for the statistical treatment of the data. The “group” (control group vs experimental group) was the between factor and the “time of measurement” (pre vs post the 11-week intervention training programme) was the within factor. The assumptions of normally distributed samples and the sphericity were verified using the Shapiro-Wilk test and the Mauchly test respectively, and both

were satisfied. The level of significance was set as $p < 0.05$. The Cohen's f effect size was also calculated for each F -statistic, and considered small, medium, and large when its value was 0.10, 0.25, and 0.4, respectively, based on the benchmarks suggested by Cohen (Cohen, 1988).

Results

The results of the current study are presented in Table 2 and Table 3. Table 2 contains the descriptive statistics (mean $\pm$ SD), and Table 3 contains the ANOVA repeated measures results (F -values, p -values, and Cohen's f effect sizes), respectively.

Table 2. Mean and standard deviation of all variables before (pre) and after (post) the 11-week intervention training programme, in the control and the experimental group.

Variable	Group	Pre	Post
Mean swimming velocity (m/s)	Control	1.27 $\pm$ 0.07	1.26 $\pm$ 0.07
	Experimental	1.25 $\pm$ 0.11	1.31 $\pm$ 0.11
Stroke rate (cycles/s)	Control	0.91 $\pm$ 0.11	0.90 $\pm$ 0.11
	Experimental	0.99 $\pm$ 0.09	1.04 $\pm$ 0.11
Stroke length (m)	Control	1.41 $\pm$ 0.17	1.42 $\pm$ 0.16
	Experimental	1.29 $\pm$ 0.21	1.28 $\pm$ 0.21
CV	Control	0.29 $\pm$ 0.09	0.23 $\pm$ 0.04
	Experimental	0.27 $\pm$ 0.09	0.13 $\pm$ 0.03
Relative HIVV	Control	1.37 $\pm$ 0.50	1.00 $\pm$ 0.18
	Experimental	1.26 $\pm$ 0.43	0.62 $\pm$ 0.18
SD	Control	0.37 $\pm$ 0.12	0.30 $\pm$ 0.06
	Experimental	0.35 $\pm$ 0.13	0.17 $\pm$ 0.05
VHip _{max} - VHip _{min}	Control	1.76 $\pm$ 0.69	1.26 $\pm$ 0.29
	Experimental	1.58 $\pm$ 0.55	0.82 $\pm$ 0.27
IdC	Control	-7.76 $\pm$ 4.35	-8.61 $\pm$ 4.37
	Experimental	-13.19 $\pm$ 5.43	-8.47 $\pm$ 1.18
Entry & catch phase duration (s)	Control	0.28 $\pm$ 0.07	0.28 $\pm$ 0.07
	Experimental	0.20 $\pm$ 0.04	0.16 $\pm$ 0.02
Pull phase duration (s)	Control	0.18 $\pm$ 0.03	0.18 $\pm$ 0.03
	Experimental	0.22 $\pm$ 0.04	0.22 $\pm$ 0.05
Push phase duration (s)	Control	0.24 $\pm$ 0.04	0.25 $\pm$ 0.05
	Experimental	0.18 $\pm$ 0.07	0.27 $\pm$ 0.07
Recovery phase duration (s)	Control	0.41 $\pm$ 0.05	0.42 $\pm$ 0.07
	Experimental	0.43 $\pm$ 0.07	0.39 $\pm$ 0.04
Propulsive phase duration (s) (pull + push)	Control	0.42 $\pm$ 0.07	0.43 $\pm$ 0.08
	Experimental	0.40 $\pm$ 0.04	0.49 $\pm$ 0.07
Non-propulsive phase duration (s) (recovery + entry & catch)	Control	0.69 $\pm$ 0.06	0.71 $\pm$ 0.07
	Experimental	0.63 $\pm$ 0.10	0.54 $\pm$ 0.04
Total stroke duration (s)	Control	1.11 $\pm$ 0.12	1.13 $\pm$ 0.13
	Experimental	1.02 $\pm$ 0.10	0.97 $\pm$ 0.11

Table 3. Interaction between the two factors ["group": control vs experimental, "time of measurement": before (pre) vs after (post) the 11-week intervention training programme] and simple effect *F*-values (within each level combination of the other factor), *p*-values, and Cohen's *f* of all variables.

Variable			<i>F</i> -value	<i>p</i> -value	Cohen's <i>f</i>
Mean swimming velocity	interaction		49,897	0,001*	2,23
	control	pre vs post	4,175	0,068	0,65
	experimental	pre vs post	63,144	0,001*	2,51
	pre	control vs experimental	0,120	0,736	0,11
	post	control vs experimental	1,066	0,326	0,33
Stroke rate (SR)	interaction		7,519	0,021*	0,87
	control	pre vs post	0,940	0,355	0,31
	experimental	pre vs post	8,459	0,016*	0,92
	pre	control vs experimental	1,642	0,229	0,41
	post	control vs experimental	4,808	0,053	0,69
Stroke length (SL)	interaction		0,283	0,606	0,17
	control	pre vs post	0,193	0,670	0,14
	experimental	pre vs post	0,098	0,760	0,10
	pre	control vs experimental	1,161	0,306	0,34
	post	control vs experimental	1,691	0,223	0,41
CV	interaction		2,694	0,132	0,52
	control	pre vs post	2,089	0,179	0,46
	experimental	pre vs post	14,188	0,004*	1,19
	pre	control vs experimental	0,082	0,781	0,09
	post	control vs experimental	24,391	0,001*	1,56
SD	interaction		2,243	0,165	0,47
	control	pre vs post	2,158	0,173	0,46
	experimental	pre vs post	12,865	0,005*	1,14
	pre	control vs experimental	0,109	0,749	0,11
	post	control vs experimental	14,705	0,003*	1,21
Relative HIVV	interaction		0,969	0,348	0,31
	control	pre vs post	3,718	0,083	0,61
	experimental	pre vs post	11,023	0,008*	1,05
	pre	control vs experimental	0,169	0,689	0,13
	post	control vs experimental	13,209	0,005*	1,15
VHip _{max} -VHip _{min}	interaction		0,604	0,455	0,25
	control	pre vs post	3,986	0,074	0,63
	experimental	pre vs post	9,586	0,011*	0,98
	pre	control vs experimental	0,228	0,643	0,15
	post	control vs experimental	7,710	0,020*	0,88

Variable			F-value	p-value	Cohen's <i>f</i>
IdC	interaction		10,148	0,010*	1,01
	control	pre vs post	0,467	0,510	0,22
	experimental	pre vs post	14,602	0,003*	1,21
	pre	control vs experimental	3,645	0,085	0,60
	post	control vs experimental	0,005	0,946	0,00
Entry & catch phase duration	interaction		7,732	0,019*	0,88
	control	pre vs post	0,155	0,702	0,12
	experimental	pre vs post	12,526	0,005*	1,12
	pre	control vs experimental	5,387	0,043	0,73
	post	control vs experimental	19,700	0,001*	1,40
Recovery phase duration	interaction		7,211	0,023*	0,85
	control	pre vs post	1,141	0,311	0,34
	experimental	pre vs post	7,451	0,021*	0,86
	pre	control vs experimental	0,230	0,642	0,15
	post	control vs experimental	1,112	0,316	0,33
Pull phase duration	interaction		3,077	0,110	0,55
	control	pre vs post	0,385	0,549	0,20
	experimental	pre vs post	3,462	0,092	0,59
	pre	control vs experimental	2,930	0,118	0,54
	post	control vs experimental	3,536	0,089	0,59
Push phase duration	interaction		13,158	0,005*	1,15
	control	pre vs post	0,095	0,765	0,10
	experimental	pre vs post	29,568	0,001*	1,72
	pre	control vs experimental	3,601	0,087	0,60
	post	control vs experimental	0,393	0,545	0,20
Propulsive phase duration (pull + push)	interaction		12,880	0,005*	1,14
	control	pre vs post	0,035	0,855	0,06
	experimental	pre vs post	27,703	0,001*	1,67
	pre	control vs experimental	0,526	0,485	0,23
	post	control vs experimental	2,200	0,169	0,47
Non-propulsive phase duration (entry & catch + recovery)	interaction		10,702	0,008*	1,03
	control	pre vs post	0,802	0,392	0,28
	experimental	pre vs post	13,920	0,004*	1,18
	pre	control vs experimental	1,680	0,224	0,41
	post	control vs experimental	27,951	0,001*	1,67

Variable		F-value	p-value	Cohen's <i>f</i>
Total stroke duration	interaction	6,471	0,029*	0,80
	control pre vs post	1,310	0,279	0,36
	experimental pre vs post	6,016	0,034*	0,78
	pre control vs experimental	1,662	0,226	0,41
	post control vs experimental	5,144	0,047*	0,72

* $p < 0.05$

The results revealed a significant interaction between the “group” and the “time of measurement” factor in the mean swimming velocity, and the stroke rate. Analyzing the simple effects, which are the effect of the one factor within each level of the other factor, a significant increase of both variables after the 11-week intervention training period was observed only in the experimental group, with large effect sizes. On the contrary, neither a significant interaction, nor significant simple effects was observed for the stroke length, which remained unchanged after the intervention programme in both groups.

In the variables related to the intra-cyclic velocity variation, namely the CV, the relative HIVV, the SD, and the $V_{Hip_{max}}-V_{Hip_{min}}$, no significant interactions were found between the “group” and the “time of measurement” factors, while the analysis of the simple effects indicated a significant decrease of all these variables only in the experimental group, with large effect size. In the control group decreases were also observed, with large effect sizes, but these changes were not statistically significant.

Concerning the temporal characteristics of the stroke, the IdC showed a significant interaction between the two factors, and the analysis of the simple effects revealed a significant reduction after the intervention period only in the experimental group, with large effect size, while the control group remained almost unaffected. Regarding the duration of the stroke phases, the results revealed significant interaction and significant decrease of the total stroke duration, the entry & catch, the recovery and the non-propulsive phase duration, only in the experimental group, with large effect sizes. On the other hand, the duration of the push and the whole propulsive phase were significantly increased in the experimental group, while no significant modifications were found in the control group, in all the above phase durations.

Discussion

The results of the current study revealed a significant increase of the mean swimming velocity only in the experimental group ($4.55 \pm 2.08\%$), confirming previous findings (Gourgoulis et al., 2019; Valkoumas et al., 2023). This swimming velocity increase was accompanied by a significant reduction of the intra-cyclic velocity fluctuation, which was statistically significant only in the experimental group. The used approaches in the current study to assess velocity fluctuations within a stroke cycle, namely the coefficient of variation (CV) and the relative hip intra-cyclic velocity variation (relative HIVV), demonstrated significant decreases only in the experimental group ($46.97 \pm 23.16\%$ and $45.49 \pm 24.47\%$, respectively), with large effect sizes, while the control group remained almost unaffected. Due to the possibility both CV and relative HIVV to be biased, because they were normalized by the mean hip velocity, if the intra-cyclic velocity standard deviation (SD) and the difference between the maximum and minimum hip velocity ($V_{Hip_{max}}-V_{Hip_{min}}$), respectively, were not changed to the same extent with the mean hip velocity (Gonjo et al., 2023), the SD and $V_{Hip_{max}}-V_{Hip_{min}}$ were also calculated separately. A reduction of CV and relative HIVV

values do not necessarily reflect a decrease of the velocity fluctuations, because a significant increase of the mean hip velocity, as in the experimental group in the current study, could result a significant decrease of the CV and the relative HIVV, masking the source of outcome. However, in line with the findings concerning CV and relative HIVV, a significant reduction was also observed in both variables (SD and $V_{Hip_{max}}-V_{Hip_{min}}$) only in the experimental group ($44.51 \pm 24.12\%$ and $42.97 \pm 25.46\%$, respectively), highlighting the reduction of the IVV after the 11-week sprint resisted swimming intervention programme. According to previous studies, IVV is an essential factor for swimming performance evaluation (Fujishima & Miyashida, 1999; Figueiredo et al., 2012; Barbosa et al., 2013a; Figueiredo et al., 2013; Barbosa et al., 2013b; Matsuda et al., 2014; Figueiredo et al., 2016). It is indicated that small IVV values lead to reduced work to swim at a certain swimming speed and less energy must be consumed to overcome inertial forces (Barbosa et al., 2006; Barbosa et al., 2010; Figueiredo et al., 2012; Matsuda et al., 2014; Gourgoulis et al., 2018; Fernandes et al., 2023). Nigg (1983) stated that a 10% increase of a swimmer's IVV value could result to a 3% additional energy demand. Nonetheless, the energy cost expenditure was not measured in the current study, and this should be considered a limitation, which could be an interesting field for future research. Furthermore, only discrete variables and not entire time-series were investigated. Although time normalization was performed for all the hip velocity curves using linear interpolation and averaged for all participants of the experimental and the control group, before and after the 11-week intervention training programme, respectively, providing evidence to support the previous results (Fig. 2), more sophisticated analysis, such as Statistical Parametric Mapping (SPM) (Pataky et al., 2015), should be applied in future studies to verify and strengthen the findings of the current study.

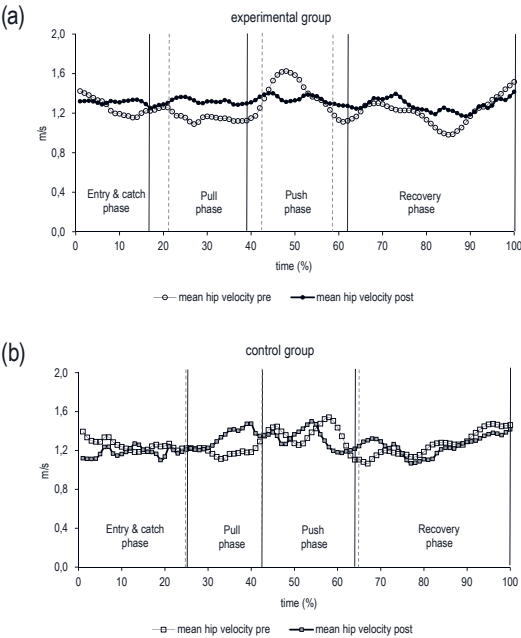


Figure 2. Normalized mean hip horizontal velocity of the experimental (a) and the control group (b), before (pre) and after (post) the 11-week intervention training programme.

Concerning the relation between sprint resisted swimming and IVV, previous studies observed an acutely significant increase of the IVV during the pull of an added resistance, especially during the non-propulsive entry & catch phase (Gourgoulis et al., 2013), which could be considered a negative modification (Barbosa et al., 2013). This acutely increase of the velocity fluctuation during the non-propulsive phases has been attributed to the obvious inability of the swimmers to compensate the additional resistive forces provided by the added resistance with the propulsive forces generated by the action of their limbs. However, after a certain training period, during free swimming without any additional resistance, as in the current study, the swimmers significantly reduce the duration of the non-propulsive phases and the intra-cyclic velocity fluctuations. This change should be considered a positive modification after the sprint resisted swimming training and indicates that swimmers become able to overcome more effectively the water resistance with the generated propulsive forces by the action of their limbs. The significant reduction of the non-propulsive phases after the sprint resisted swimming training period also caused a significant decrease of the total stroke duration (T) and consequently resulted to an increase of the stroke rate (SR), as it is the inverse of the total stroke duration ($SR = 1/T$). The stroke rate along with the stroke length (SL) are the two components determining the swimming velocity ($v = SR * SL$) [6]. It seems that, in line with previous findings (Girolid et al., 2006; Valkoumas et al., 2023), after the sprint resisted swimming training are primarily modified the temporal characteristics of the stroke, namely the duration of the distinct phases and the stroke rate, while the stroke length, which is related with the magnitude of the propulsive forces and is an indicator of the swimming efficiency (Pendergast et al., 2006; Toussaint & Beek, 1992), remained unchanged.

The re-organization of the distinct stroke phases, namely the significant decrease of the non-propulsive phases and the simultaneously significant increase of the propulsive phases in the experimental group, also affects the coordination mode between the alternate action of the two arms, increasing the propulsion continuity (Chollet et al., 2000; Seifert et al., 2005). This is reflected to the significant increase of the Index of Coordination (IdC), which is shifted from a catch-up towards an opposition mode. Nevertheless, the swimmers of the experimental group in the current study remained in catch-up mode, confirming the findings of previous studies, which clearly pointed out that young female swimmers always adopt a catch-up coordination mode (Figueiredo et al., 2016; Silva et al., 2019). According to Seifert et al. (2004) only elite swimmers could adopt an opposition coordination mode and it is suggested that the catch-up mode should not be considered a technical mistake. However, the boundaries of the propulsive and non-propulsive phases for the calculation of the IdC were determined in the current study using only the direction of the hand's movement and not the direction of the resultant propulsive force produced by the swimmer's hand. In addition, the limited visibility of the selected points, especially on the hand when entering the water due to splashing and whitewater, which is an unavoidable issue particularly in sprint swimming, could cause errors in the accurate determination of the hand's entry into the water and the beginning of the arm stroke. Consequently, the duration of the separate phases may be over- or underestimated (Gourgoulis et al., 2013) and should be considered with caution.

Summarizing, the results of the current study revealed that a specific 11-week sprint resisted swimming training programme significantly increase the front crawl mean swimming velocity of young female swimmers with small training experience. This improvement is attributed mainly to positive modifications of the temporal characteristics of the stroke and consequently could be considered an effective training form. However, in addition to the aforementioned limitations, several others should be acknowledged. The small size of the sample and the limited training experience of the participants must be highlighted, while, given their young age, possible

anthropometric modifications due to growth after the 11-week period could potentially affect the research findings. Unfortunately, such data were not collected after the intervention and it would be significantly interesting to observe them in future experimental designs, including larger sample, male and older swimmers. Furthermore, the use of the hip instead of the center of mass for the calculation of the swimmer's velocity and its IVV, constitutes another weakness. It is well known that the use of the center of mass is a more accurate approach. However, its calculation is more complicated and needs additional testing equipment. Therefore, in the current study it was selected the hip, which velocity curve follow similar pattern with the center of mass (Maglischo et al., 1987). Moreover, there were not estimated neither the propulsive, nor the resistive forces generated by the actions of the swimmers' limbs, which extensive investigation could give a deeper explanation of the underlying mechanism responsible for the IVV reduction and the swimming velocity improvement. In addition, it would be highly interesting in future studies, in order to gain more information about the sources of the stroke rate modifications, to investigate the effect of the sprint resisted swimming training on the swimmer's hand velocity relative to the body, both at maximal and submaximal intensities, because the absolute hand velocity is not only affected by the angular velocity of the upper limb joints, but also by the linear velocity of the body.

Conclusion

Despite the limitations of the current study, the results suggest that after a specific 11-week sprint resisted swimming training programme young female swimmers can significantly increase their front crawl mean swimming velocity. This improvement is attributed to a decreased duration of the non-propulsive phase, and simultaneously to increased propulsive phase duration, stroke rate and propulsion continuity. These modifications are reflected in increased IdC values and accompanied by reduced IVV, indicating that swimmers became more efficient to overcome the inertial forces. Thus, it could be concluded that sprint resisted swimming is an effective training form for young female swimmers and could be applied to improve their swimming performance mainly affecting the temporal characteristics of the stroke.

Practical Implications

The findings of the current study could create a practical and useful training tool for swimming coaches. The training sets presented in the current study could be added in a weekly micro-cycle training using parachute, to improve the swimming speed in front crawl stroke. This sprint resisted swimming training method, after an 11-week period, could significantly modify the inter-arm coordination, increasing the propulsion continuity and reducing the intra-cyclic velocity variation, leading to increased swimming performance.

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DEVELOPING LIFE SKILLS THROUGH PHYSICAL EDUCATION: SOCIAL SKILLS AND TEAMWORK IN MOROCCAN SECONDARY SCHOOL STUDENTS

Abdelmajid Ouaddou^{A, B, C, D}

Sociology and Psychology Laboratory, Faculty of Letters and Human Sciences-Dhar El Mahraz, Sidi Mohamed Ben Abdellah University, Fez, Morocco
ORCID: 0009-0005-9145-6867 | e-mail: abdelmajid.ouaddou@usmba.ac.ma

Abdelkrim Kanbaaj^{A, B, C, D}

Sociology and Psychology Laboratory, Faculty of Letters and Human Sciences-Dhar El Mahraz, Sidi Mohamed Ben Abdellah University, Fez, Morocco

^AStudy Design, ^BData Collection, ^CStatistical Analysis, ^DManuscript Preparation, ^EFunds Collection

Abstract Life skills are a combination of psychosocial and interpersonal skills that can have an impact on physical, mental and social well-being. Social skills include the ability to make judgments and act in different social situations. Physical education (PE) can play an important role in developing life skills in Moroccan secondary school students.

This cross-sectional study aims to examine the impact of handball on the development of social and teamwork skills in 150 Moroccan secondary school students, and to explore the relationship between social skills and teamwork.

In our research, we used two different methods to gain an in-depth understanding of students' views on how they perceived the development of their social and teamwork skills. To do this, we conducted mixed-method research using both the Sports Life Skills Scale (LSSS) and participant observation on a sample of 150 schoolchildren, including 76 boys and 74 girls aged between 14 and 20, in the rural BITT commune of El Hajeb (Morocco), during a 12-session handball learning cycle during the school season (2022/2023).

Data analysis was performed using multivariate analysis of variance, Pearson correlation and multiple regressions. The results showed that BITIT secondary school students felt they were developing their teamwork skills with ($WM = 3.62$, $SD = 0.662$) and their social skills with ($WM = 3.54$, $SD = 0.740$) through playing handball. There was a significant correlation ($r = 0.429$; $p < 0.01$) between social skills and teamwork skills.

The results of this study suggest that team sports can be an excellent medium for the development of social skills and teamwork in students. In this way, students not only improve their physical health, but also acquire essential skills that will be useful in all areas of their lives.

Key words: life skills, social skills, teamwork, physical education, Moroccan secondary school students, handball

Introduction

It is becoming increasingly clear that the development of life skills in young people is crucial. These skills do not only benefit individuals but also have positive effects on society as a whole. By helping young people acquire

essential life skills, we set them up for success and ensure they have the tools they need to meet the challenges ahead. From communication and problem-solving to time management and decision-making, life skills are essential to personal and professional growth. It's up to all of us to help young people develop these skills and reach their full potential. Life skills are influenced by a complex combination of family, social, educational, personal and socio-economic factors.

Life skills fall into three broad categories: thinking skills, social skills, and emotional skills. Social skills promote healthy relationships with others by developing an individual's ability to communicate, co-operate, and lead. Thinking skills enhance an individual's ability to make decisions, effectively solve problems, and think creatively, critically, and analytically (Prajapati et al., 2016).

According to the World Health Organization, "life skills are a set of psychosocial competencies that enable individuals to cope effectively with the challenges of everyday life. These skills play an essential role in promoting health in general, in terms of physical, mental and social well-being" (WHO, 1994).

Life skills are involved in a multitude of different contexts, such as health, education, sport, culture, art and the professional world. Life skills education is linked to major health and social issues (WHO, 1996).

Physical and sports education (P.E) as a teaching subject, provides an environment conducive to the development of life skills, through the practice of individual and collective physical activities. It gives young people the opportunity to learn from their own experiences, and from the experiences of others, through personal and interpersonal interaction. This method is described in the social learning theory developed by Bandura & Walters (1977). According to social learning theory, learning is seen as an active process involving the acquisition, processing and structuring of lived experiences.

Research has also found that the particular features of sport (demands for hard work, competition, social aspects) expose youth to lived experiences that can lead to life skills learning (Camiré & Kendellen, 2016; Holt et al., 2017).

It has now been widely demonstrated that sport in general, and physical education and sport in particular, is a tool for developing young people's life skills (leadership, teamwork and social skills). In fact, team sports athletes who train on a weekly basis perceive a higher degree of social competence (de Subijana et al., 2022). What's more, practicing soccer in high school can facilitate students' positive development through the acquisition of a set of life skills (Camiré & Trundel, 2013).

Teaching handball as part of physical education and school sport in Moroccan schools remains a propitious environment for the psychological and social training of learners through communication and interaction with team members. Moroccan schools teach handball, a collective sporting activity that develops a range of skills through interaction and confrontation. Each school year, it is planned with two practical sessions of two hours each week, separated by a minimum of 48 hours.

With this in mind, we set out in this study to identify the role of Handball in the development of two essential life skills: teamwork and social skills in a group of Moroccan high school students.

Material and methods

Sampling

The study involved 150 randomly selected high school students aged 14 to 20.

Research environment

The present study was carried out at the BITTI Qualifying High School, located in the rural commune of Ait Ouallal Bitit, in the province of El Hajeb, in the Fez-Meknes region of central of Morocco. According to the last census of 2014, this commune had a population of 14316 inhabitants, with predominantly agricultural activities.

Handball teaching in Moroccan secondary schools is based on the skills-based approach, a learning method that emphasises the acquisition of skills rather than knowledge. During the school season in which our research was conducted, 6 learning cycles of 12 sessions were programmed (3 individual activities: sprinting, long jump, and gymnastics; and 3 collective activities: basketball, handball, and volleyball). The handball lessons, which took place on a regulation court and lasted 2 hours a week, separated by at least 48 hours of rest, offered learning situations aimed at developing a set of skills linked to the activity and life skills, but in an implicit way, to mixed groups of 5 to 7 pupils. A match situation is proposed at the end of the session to mobilize and apply what has been learned during the situations.

Date of research

The study was carried out in November of the 2022–2023 school season.

Procedure

To answer our research questions, we carried out explanatory research based on a mixed-methods approach and chose handball as our support activity. The choice of this sporting activity is based on the fact that it calls on a range of skills (individual, communicative, social) enabling team members to achieve common goals.

Data collection and analysis

QUANTITATIVE APPROACH

We used the Life Skills Scale of Sport (LSSS), developed and validated by Cronin & Allen (2017), it is composed of 8 life skills. This scale uses the radical "This sport has taught me to...". Previous research has provided evidence regarding the factorial validity, test-retest reliability and reliable internal consistency of this scale in young participants involved in sports, as reported by Cronin & Allen (2017).

To meet our research objectives, we limited ourselves to two skills: teamwork skills (9 items) and social skills (10 items). These items are evaluated on a 5-point Likert-type scale, ranging from 1 "not at all" to 5 "very much". To answer the life skills scale, students were organized into groups. Explanations in Arabic dialect were given to the students before answering the scale items.

A preliminary test is set up and the (LSSS) methodology is applied. To ensure objective responses, participants were divided into heterogeneous groups of five students for the tests.

QUALITATIVE APPROACH

In order to gain a better understanding of the students' behavior and social interactions and their impact on the team's work during the learning sessions, we opted for the method of participant observation, which allows the researcher to become actively involved in the group. The fact that one of the researchers was the statutory teacher of the pupils involved in the research facilitated the implementation of all the stages of the participant observation

method, and it was him who taught the physical education classes. In addition, the circumstances were favorable for holding certain interviews with a heterogeneous group of randomly selected students involved in the research, and these interviews took place at the end of the last period of the learning session. Detailed notes were taken of observations, experiences, and interactions with team members, as well as informal interviews with learners, to obtain additional information. The participants were faced with several questions:

- Does handball help you develop your social skills? How?
- Does handball help you develop your teamwork skills? How?
- Is there a relationship between social skills and teamwork skills?

STATISTICAL ANALYSIS

Data were analyzed using Statistical Package for Social Sciences (SPSS), Version 25.

ETHICAL CONSIDERATION

One of the researchers, the legal physical education (PE) teacher of the group of students concerned, had the opportunity to discuss with them the possibility of participating in the study before it began. They were informed that the results of the study would be published, and they maintained their anonymity and privacy. They expressed their desire to contribute to the research. Oral consent was obtained.

Results and discussion

PARTICIPANT CHARACTERISTICS

The current study was carried out on a randomly selected sample of 150 students: 76 boys (50,67%); and 74 girls (49,33%).

Table 1. Distribution of the sample according to age, sex and school level (own work)

	Age		Sex		School level	
	14–17	18–20	Boys	Girls	Tc	1Bac
Frequency	112	38	76	74	62	88
Percentage	74.67	25.33	50.67	49.33	41.33	58.67

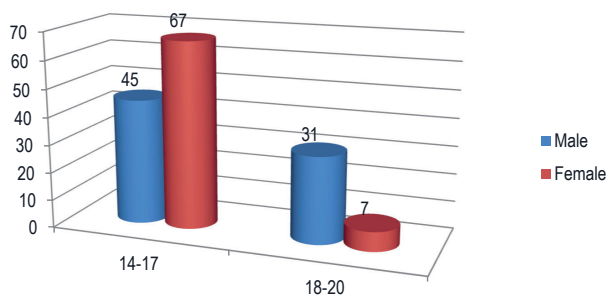


Figure 1. Distribution of the sample according to age, sex (own work)

Table 1 shows the distribution of participants by age, gender and educational level.

- The majority of participants were aged between 14 and 17, with 112 (74.67%) in this age bracket. This suggests that this research focuses primarily on adolescents. The 18 to 20 age bracket has 38 participants (25.33%), also indicating a strong representation of young adults, albeit slightly lower than the first bracket.
- The sexes are virtually balanced, with 76 boys (50.67%) and 74 girls (49.33%). This suggests that the study achieved a fairly equitable representation of both sexes.

STATISTICAL ANALYSIS

Teamwork

- *Distribution by age group and sex*

Table 2. Distribution of response averages by age and sex (own work)

	14–17 years		18–20 years	
	Male	Female	Male	Female
Low	4	4	1	–
Medium	10	26	9	3
High	31	37	21	4

Table 2 shows the distribution of average scores for responses in terms of developing teamwork skills through handball.

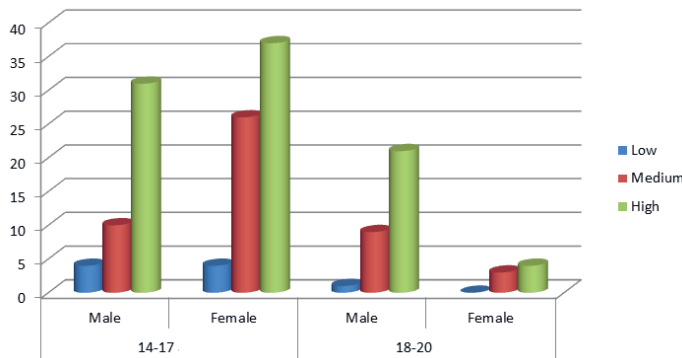


Figure 2. Distribution of response averages by age and sex (own work)

The results in Figure 2 show a distinct distribution of teamwork skill levels according to the age and gender of students practicing handball.

The majority of boys aged 14 to 17 achieve a high level of teamwork skills. This suggests that handball is highly effective for this particular group. Girls in the same age group also show a high level of teamwork skills.

For the 18–20 age group, boys show a high level of teamwork skills, while girls in the same age group show low levels of teamwork skills compared to younger girls.

Table 3. Descriptive statistics of the development of teamwork skills through team sport (own work)

N	Item		Not at all	A little	Some	A lot	Vey much	Mean	T test	Standard deviation	Rank
1	Accept suggestions for improvement from others	N	10	17	26	40	57	3.78	7.627	1.252	5
		%	6.7	11.3	17.3	26.7	38				
2	Cooperate with others	N	2	4	11	50	83	4.39	20.176	0.842	1
		%	1.3	2.7	7.3	33.3	55.3				
3	Change my behaviour for the good of the team	N	4	11	15	59	61	4.08	12.967	1.020	3
		%	2.7	7.3	10	39.3	40.7				
4	Work well withing a team	N	2	7	22	44	75	4.22	15.655	0.954	2
		%	1.3	4.7	14.7	29.3	50				
5	Accept criticism from others	N	35	35	40	23	17	2.68	-3.022	1.297	8
		%	23.3	23.3	26.7	15.3	11.3				
6	Give constructive criticism to others	N	40	43	28	24	15	2.54	-4.304	1.309	9
		%	26.7	28.7	18.7	16	10				
7	Resolve conflict with others	N	17	27	26	41	39	3.39	3.521	1.345	7
		%	11.3	18	17.3	27.3	26				
8	Work with others for the good of the team	N	7	14	18	57	54	3.91	9.909	1.129	4
		%	4.7	9.3	12	38	36				
9	Resolve conflicts between teammates members	N	18	15	22	48	47	3.61	5.542	1.341	6
		%	12	10	14.7	32	31.3				
Weighted mean								3.62			
Standard deviation									0.662		

Table 3 shows the descriptive statistics for the development of teamwork skills through handball, and shows that the values reported on this skill ranged from 2.54 to 4.39. Average scores on the LSSS 1–5 response scale revealed that BITIT high school students perceived that they were developing their teamwork skills through the practice of handball. From which we can see that the highest average was for item 2 (Cooperate with others) ($M = 4.39$, $SD = 0.842$), followed by item 4 (Work well within a team), ($M = 4.22$, $SD = 0.954$), followed by item 3 (Change behavior for the good of the team), ($M = 4.08$, $SD = 1.020$), with answers “Very much” (55.3%, 50%, 40.7%) and “A lot” (33.3%, 29.3%, 39.3%).

While the lowest mean was given to item 8 (Accept criticism from others), ($M = 2.68$, $SD = 1.297$), followed by item 6 (Give constructive criticism to others), ($M = 2.54$, $SD = 1.309$).

The weighted mean of the development of teamwork skills through handball was ($M = 3.62$) with a ($SD = 0.662$), indicating that the trend of (handball develops teamwork skills) is “Very much”, as a general trend according to 5 points Likert scale, since 3.62 lie in the interval [3.4–5]. So, the average of Handball develops teamwork skills is (3.62), which is considered a high level; since the intervals of level as follows:

Low: [1–2.6]

Medium: [2.6–3.4]

High: [3.4–5]

Social skills
– Distribution by age group and sex

Table 4. Distribution of response averages by age and sex (own work)

	14–17 years		18–20 years	
	Male	Female	Male	Female
Low	4	4	1	0
Medium	10	26	9	3
High	31	37	21	4

Table 4 shows the distribution of average scores for responses in terms of developing social skills through handball.

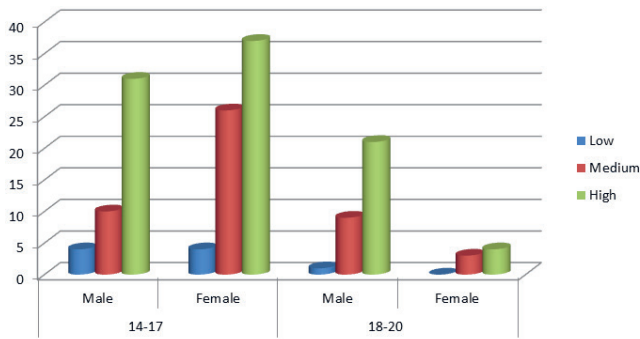


Figure 3. Distribution of response averages by age and sex (own work)

The distributions of average social skills scores by age group (Figure 3) shows that the majority of boys aged 14 to 17 were able to develop their social skills through handball. For girls in the same age bracket, a similar trend is observed. Girls even seem to outperform boys in terms of social skills development, which may indicate greater receptiveness or commitment to handball.

In the 18–20 age group, boys also show a majority having developed social skills. Whereas the development of social skills through handball practice among girls is low compared to younger girls. Suggesting that this group could benefit from additional educational strategies to improve their social skills.

Compared with boys, it seems that girls develop better social skills more often, especially between the ages of 14 and 17. This may be due to differences in social behavior, sensitivity to social and sporting activities, or socio-cultural expectations.

Table 5. Descriptive statistics for the development of social skills through handball (own work)

N	Item		Not at all	A little	Some	A lot	Very much	Mean	T test	Standard deviation	Rank
1	Make friends	N	10	11	27	44	58	3.86	8.747	1.204	3
		%	6.7	7.3	18	29.3	38.7				
2	Behave appropriately in social situations	N	5	25	28	59	33	3.60	6.649	1.105	5
		%	3.3	16.7	18.7	39.3	22				
3	Interact in various social settings	N	17	28	45	42	18	3.11	1.105	1.182	9
		%	11.3	18.7	30	28	12				
4	Maintain close friendships	N	8	24	28	41	49	3.66	6.539	1.236	4
		%	5.3	16	18.7	27.3	32.7				
5	Help others when they need it	N	3	10	19	58	60	4.08	13.407	0.987	1
		%	2	6.7	12.7	38.7	40				
6	Conduct myself properly when I am around others	N	9	23	36	47	35	3.51	5.258	1.180	7
		%	6	15.3	24	31.3	23.3				
7	Get involved in group activities	N	15	33	31	46	25	3.22	2.161	1.247	8
		%	10	22	20.7	30.7	16.7				
8	Help others without them asking for help	N	30	36	32	32	20	2.84	−1.472	1.331	10
		%	20	24	21.3	21.3	13.3				
9	Stand up for myself	N	4	10	27	40	69	4.07	12.183	1.072	2
		%	2.7	6.7	18	26.7	46				
10	Socialize with others	N	13	23	24	53	37	3.52	5.066	1.257	6
		%	8.7	15.3	16	35.3	24.7				
Weighted mean								3.54			
Standard deviation									0.740		

Table 5 shows Descriptive statistics for the development of social skills through handball, and shows that the values reported on this skill ranged from 2.84 to 4.08. Average scores on the LSSS 1–5 response scale revealed that BITIT high school students perceived that they were developing their social skills through the practice of handball. From that we find that the highest average was for item 5 (Help others when they need it), ($M = 4.08$, $SD = 0.987$) followed by item 9 (Stand up for myself), ($M = 4.07$, $SD = 1.072$), followed by item 1 (Make friends), ($M = 3.86$, $SD = 1.204$), with “Very much” by percent (40%, 46%, 38.7% respectively) and “A lot” by percent (38.7%, 26.7%, 29.3% respectively).

While the lowest average was awarded to item 3 (Interact in various social settings), ($M = 3.11$, $SD = 1.182$), followed by item 8 (Help others without them asking for help), ($M = 2.84$, $SD = 1.331$). The weighted average of development of social skills through handball was ($M = 3.44$) with ($SD = 0.670$), which indicate that the trend of (Handball develop social skills) is “A lot”, as a general trend according to 5 points Likert scale, since 3.54 lie in the interval [3.4–5].

So, the average of the handball develops social skills is (3.54) which consider a high level; since the intervals of level as follow:

Low: [1–2.6]
Medium: [2.6–3.4]
High: [3.4–5]

CORRELATIONAL ANALYSIS

In this study, we carried out correlation analyses between the different scales used. The results presented in Table 6 show that there is a significant positive correlation between social skills and teamwork ($r = 0.429$; $p < 0.01$). This indicates that an improvement in social skills is linked to better team collaboration, and vice versa, with a high degree of trust in this relationship.

Table 6. Correlation between the two variables of study (own work)

	Teamwork	Social skills
Teamwork	1.00	0.429**
Social skills	0.429**	1.00

** Correlation is significant at the 0.01 level

Correlational analysis between the various teamwork and social skills items reveals that a certain teamwork items has a very strong relationship with social skills.

Figures 4, 5, 6, 7, and 8 show this highly significant relationship:

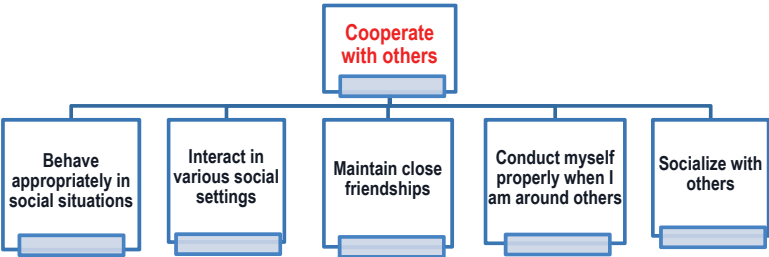


Figure 4. Social skills strongly correlated with teamwork skills: “Cooperate with others” (own work)

Cooperation with others is strongly linked to a variety of social skills. Students who cooperate well with their peers tend to be socially adept, maintain close relationships and behave well in a variety of social contexts.



Figure 5. Social skills strongly correlated with teamwork skills: "Change my behavior for the good of the team" (own work)

Students with the ability to adapt their behavior for the good of the team show a strong correlation with their ability to form and maintain friendships, as well as proactively help others. This demonstrates that behavioral adaptability is a key skill for effective social interactions.



Figure 6. Social skills strongly correlated with teamwork skills: "Resolve conflict with others" (own work)

Conflict resolution is strongly linked to social involvement and mutual aid. Students who are able to resolve conflicts are also those who are actively involved in group activities and proactively offer their help.



Figure 7. Social skills strongly correlated with teamwork skills: "Work with others for the good of the team" (own work)

Working with others for the good of the team is linked to social skills such as the ability to form friendships, engage socially and offer help. This underlines the importance of social engagement in effective teamwork.



Figure 8. Social skills strongly correlated with teamwork skills: "Resolve conflicts between teammates members" (own work)

Conflict resolution contributes to the development of social skills and the effective functioning of teams.

QUALITATIVE ANALYSIS

Based on the results of the qualitative data obtained from the participant observation method, and interviews conducted with students during the different phases of the learning session (the introductory part reserved for warm-ups, the fundamental part, and the final part reserved for regulation and calming down), it was found that the first factor affecting students' behavior towards their colleagues is the choice of members when forming teams, which is generally dominated by parameters such as friendly relations, level of practice and certain emotions. This often has a positive effect on all members and the performance of the team as a whole. It also helps to create an atmosphere of effective communication, cooperation, and solidarity, allowing students to demonstrate a range of collaborative, communicative, and conflict-management behaviors within their teams to achieve common goals. Having friends in PE class can make the experience much more enjoyable and can help alleviate any negative aspects that may come along with it (White et al., 2021).

While the teams formed randomly, the members showed antisocial behavior towards their teammates, and even towards the opposing team. This can sometimes lead to the exclusion of undesirable team members, requiring the intervention of the teacher to help team members overcome problems and encourage them to cooperate and accept each other, either by proposing appropriate solutions or by imposing standards that guarantee equal opportunities for all students.

It also turned out that some students who managed to overcome these difficulties relied on a set of personal skills, such as self-confidence, flexibility in handling situations, and making the right decisions at the right time.

The young high school students in our study felt that their practice of the handball activity enabled them to develop a range of social and teamwork skills, given that the handball activity is the first learning cycle programmed during the school year and that the other team sports programmed could in some way influence the development of students' social and teamwork skills, which could be studied in future research.

The lack of infrastructure enabling our teenagers to take part in other sporting, artistic, and cultural activities may explain the weakness in some life skills, such as interaction in various social contexts, and participation in group activities. From this point of view, physical education and sport remains ideal environment for young students to experience social interaction situations, enabling the development and transfer of a range of life skills that can facilitate school life both inside and outside the school.

In addition, numerous studies have shown the important role of physical education in the development of life skills and in the transfer of these skills to other areas of life, such as respect, goal-setting, concentration, leadership and teamwork (Pierce et al., 2017). A study about group cohesion and positive youth development in team sport athletes concluded that team sports play a positive role in youth development by promoting group cohesion and enhancing personal and social skills (Bruner et al., 2014).

This is clearly evidenced by the results of this study, which indicate that teamwork is associated with social skills.

Interestingly, participants in our study had slightly higher total scores for life skills (social skills, and teamwork skills (4.39 vs. 4.11) compared to the scores of participants in a UK study of young footballers (Mossman & Cronin, 2019).

As far as the relationship between social skills and teamwork is concerned, the results obtained show that there is a fairly strong relationship between these two social factors, but they do not depend solely on social skills, but rather on personal skills (self-confidence, decision-making, responsibility, psychological tone), and emotional skills (emotional intelligence, empathy and understanding of others' feelings, stress and pressure management).

At the end of the study, it emerged that the participants felt they had developed their social skills through their participation in physical education sessions, and more specifically in the learning handball.

Conclusion

Despite some of the difficult social and economic conditions they face, BITIT students' participation in physical education classes in general, and handball in particular, helps them to develop a range of life skills such as social and teamwork skills. Most of the students participating in this research expressed that their participation in physical education and sports activities, particularly team sports, helped them to develop their social skills, which in turn positively affected their teamwork.

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DOES TRAINING WITH TENDO DESTABILIZERS LIMITING BARBELL STABILITY ENHANCE POWER AND VELOCITY IN BENCH PRESS AND PULL EXERCISES AMONG RECREATIONAL TRAINEES?

Mateusz Rynkiewicz

Faculty of Biological Sciences, Institute of Sport, Tourism and Nutrition, University of Zielona Góra, Zielona Góra, Poland

ORCID: 0000-0001-5645-5862 | e-mail: m.rynkiewicz@wnb.uz.zgora.pl

Abstract The aim of the study was to analyze the effects of training protocol on maximal power during concentric phase of movement. Changes in maximal power were studied in individuals subjected to conventional strength training and strength training using TENDO destabilizers limiting barbell stability in recreational trainees without prior strength training experience. The study contains 3 randomized groups, 2 experimental and 1 control. After 4 weeks of the training program, the subjects underwent a retest following the same protocol as prior to the experiment. During bench press and bench pull, peak maximal power and peak velocity were recorded, along with an average for each repetition and for the series of six repetitions. After 4 weeks of the training program, subjects from group A and B showed a significant improvement in best bench pull and press. The relative improvement in power in experimental group with destabilizers was 18% ($p \leq 0.05$), significantly higher compared to group without destabilizers (12%, $p \leq 0.05$).

The hereby presented results document the effectiveness of power-oriented training with destabilizers. The improvement observed in the experimental group was most evident in the case of bench pull power. The use of destabilizers is an effective method for improving power, especially in bench pull exercises. This training method also effectively develops stabilization, coordination, and movement control under conditions of reduced barbell stability.

Key words: upper-body strength enhancement, instability-based interventions, unstable barbell, motor control improvement, resistance training adaptations

Introduction

In recent years, the differences between the best athletes have continued to decrease, and consequently winning a medal is frequently a matter of tenths of a second. This was one of the reason for searching for more effective training methods. Many athletes have already reached the limits of their performance and are unable to overcome larger training loads. Furthermore, they need new training stimuli. Thus, novel methods of improving training efficiency have been studied extensively for years.

Another aim of currently ongoing research is to identify training methods that can promote the use of previously acquired general preparation skills during more specialist activities (Platonov, 2004). For example kayakers should have high level of strength and endurance, and they could develop it in gym, but they need to manifest it during paddling (Rynkiewicz, 2009). Strength training contributes greatly to improvements in maximal power and strength

(Kraemer & Ratamess, 2004). Power output is primarily determined by muscle mass, types of muscle fibers, and number of simultaneously activated motor units (Moritani, 2008). In inexperienced hammer throwers, implementation of a 14-week strength-oriented training resulted in a 12–18% increase in muscle mass and a 6–12% increase in the distance of throw (Terzis et al., 2008). While short-term training aimed at the development of muscle power promotes a smaller increase in muscle mass, it probably contributes to improvement in neuromuscular capacity (Vissing et al., 2008; Winchester et al., 2008; Cormie et al., 2011). The development of maximal power contributes to improvements in the sports performance of sprinters (Blazevich & Jenkins, 2002; Cornin & Sleivert, 2005). Practical experience shows that a program of power-oriented training approximately four weeks long may be sufficient to considerably improve this parameter (Jolley et al., 2016).

Coordination exercises are a vital component of training, especially if the athlete should present with adequate power and velocity under unstable conditions (Starosta, 2008). Currently, strength training using unstable surfaces is gaining substantial popularity. Strength exercises performed on unstable surfaces were shown to promote greater activation of the trunk and extremity muscles, especially those responsible for stabilization of the body (Anderson & Behm, 2004; Holtzmann et al., 2005; Marshall & Murphy, 2006; Vera-Garcia et al., 2007). However, sports training including exercises that require high levels of stability may result in a decrease in the athlete's strength, power, speed, and extent of movements (Anderson & Bejm, 2004; Willardson, 2004; Drinkwater et al., 2007; Behm & Colado, 2012; Zemková et al., 2012). Most studies on destabilized strength training focus on athletes; however, its applicability to recreational trainees remains underexplored (Behm et al., 2013).

Strength training with destabilizers is an interesting form of workout under unstable conditions (Rynkiewicz & Rynkiewicz, 2014). In everyday practice, athletes use various belts and chains with attached weights mounted onto a barbell. Destabilizers (TENDO Barbell De-Stabiliser), which are made of springs with a weight in between that is placed onto a barbell (Fig. 1), are a ready-to-use solution. During exercise, destabilizers sway in the sagittal and transverse planes, and the weight placed between the springs generates oscillations. The construction allowed rotational movement of the bar around its longitudinal axis with an attached 5 kg weight (Rynkiewicz & Rynkiewicz, 2014). Due to this construction, the number of degrees of freedom of the barbell increases considerably, making the exercise markedly more challenging. While previous studies, such as Anderson & Behm (2004), involved experienced athletes with significant resistance training backgrounds (7.9 ± 4.4 years), the present study focuses on recreationally active individuals without prior resistance training experience. This distinction highlights the novelty of our approach and its relevance to untrained populations. Most studies on strength training under unstable conditions focus on professional athletes, leaving a gap in understanding its applicability to recreational trainees.

The aim of the study was to analyze the effects of the training protocol with destabilizers on maximal power during concentric phases of movement. Changes in maximal power output were studied in individuals subjected to conventional strength training and strength training with destabilizers. Moreover, a control group, not involved in any form of training, was included. We hypothesized that training with TENDO destabilizers would result in greater improvements in power and velocity in recreational trainees. The findings of this study may offer insights for recreational trainees seeking to improve their power and coordination through novel training methods.

Material and Methods

Experimental Approach to the Problem

The study subjects were randomized into three groups of 10 persons each. Individuals from two experimental groups participated in a power-oriented training program of three sessions weekly for a period of four weeks, which corresponded to a total of 12 training units. The training days were always Monday, Wednesday, and Friday. Based on previously published data (Behm, 1995), we assumed that such a duration of the training program is sufficient to induce changes in neuromuscular capacity.

Participants completed two familiarization sessions lasting 60 minutes each, during which they were introduced to TENDO destabilizers and underwent 1RM testing. The familiarization session were conducted one week before the experiment. Participants performed warm-up exercises at 30–40% 1RM, with loads adjusted based on their Rate of Perceived Exertion (RPE = 5). During each training session, each subject performed four series with ten repetitions of the following exercises in the same order: bench presses (Fig. 1), bench pull (Fig. 2). The order of test exercises was randomized for each participant to avoid bias. The external load was set at 50% of body weight or approximately 45% of the previously determined 1RM during familiarization. Consecutive series were divided by 2-min breaks to provide an optimal restitution. Each workout was designed as a station training. A trained observer ensured correct technique, including full range of motion, consistent pace, and verbal motivation during all exercises. After completing all exercises scheduled for a given session, the subjects participants performed light stretching and relaxation exercises targeting the major muscle groups used during training. Participants were required to attend all sessions, with flexibility provided only in cases of illness or emergencies.



Figure 1. First phase of bench press exercise with destabilizer



Figure 2. Bench pull exercise with Tendo Weightlifting Analyzer

Participants were randomly assigned to experimental groups experimental with destabilizers and experimental without destabilizers or the control group using a computer-generated randomization sequence. Training sessions for both experimental groups followed the same protocol, but in group with destabilizers, two destabilizers, each with a 5-kg weight, were mounted onto a barbell (Fig. 3). Subjects from experimental with destabilizers exercised with a conventional barbell with weights, additionally equipped with two destabilizers, each with a 5-kg weight attached. Participants from group without destabilizers worked out with a conventional barbell with stably fixed weights.

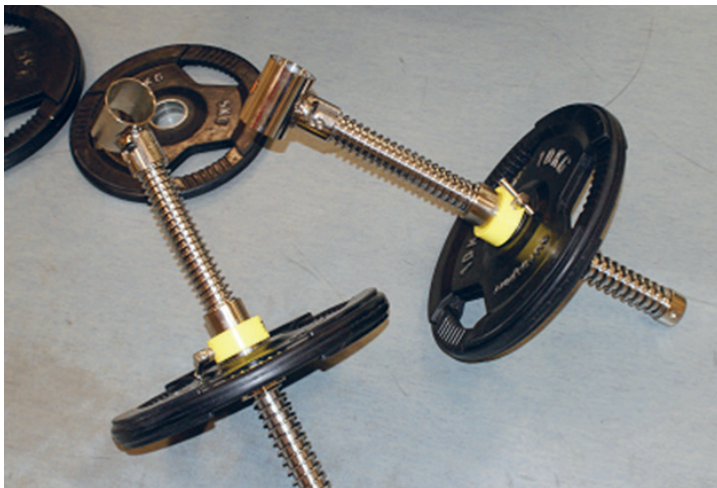


Figure 3. Elements of destabilizer mounted on a barbell

After four weeks of the training program, the subjects underwent a retest following the same protocol as prior to the experiment.

Before the proper experiment, personal data of the subjects were collected along with information on their previous involvement in sports training and their present and past medical histories. On the first day of the experiment, the body heights of participants were measured and their body compositions were determined by means of bioelectrical impedance analysis with a multi-frequency monitor (Tanita MC980, Japan). The examination took place in the early morning after an overnight fast.

Then, the subjects had three hours to eat breakfast and to familiarize themselves with the testing procedure and experimental training program. Subsequently, they returned to the laboratory to participate in the power tests. The same procedure was repeated at the end of the experimental training program.

Determination of power output and velocity

The test started with a standard warm-up including a low-intensity run and stretching of upper and lower extremities. Then, strength exercises with light weights were applied. Each subject attempted all exercises twice. A Tendo Weightlifting Analyzer (Slovakia) was used to determine the movement power and velocity of the barbell in concentric phase (Fig. 2). Each participant performed a series of six repetitions of each exercise in the shortest possible time; the load corresponded to one-half of the athlete's body weight ± 2.5 kg. During bench presses and bench pulls, the maximal peak power and peak velocity were recorded, along with an average power and average velocity for each repetition and for the entire set of six repetitions. The TENDO transducer cable was attached at the center of the barbell during both bench presses and bench pulls.

Participants

From group of 46 students of Physical Activity and Sport we selected a total of 30 excluding professional athletes, and currently and 6 months back performing strength training. Any of the participants performed any power or professional training before. Contributors could withdraw from the study at any point without providing a reason. Participants were randomized to one out of two experimental groups with destabilizers and without destabilizers or to the control group (C). All of them knew training and testing exercise. The control group was comprised of 10 men (age = 22.1 ± 0.88 years, body weight = 70.4 ± 7.24 kg, body height = 1.77 ± 0.04 m). Participants were instructed to avoid resistance or power training during the study period. Recreational physical activities such as swimming, football, or basketball were allowed but were restricted to a maximum of 3 hours per week. Compliance was monitored through weekly self-reports. Experimental group A included 10 men (age = 23.9 ± 2.33 years, body weight = 82.5 ± 15.7 kg, body height = 1.79 ± 0.07 m) subjected to power-oriented training with destabilizers, and experimental group B was comprised of 10 men (age = 22.4 ± 0.70 years, body weight = 69.1 ± 7.19 kg, body height = 1.77 ± 0.08 m) who participated in conventional power training. All subjects were in good health and undertook recreational physical exercise regularly, approximately three times a week but not strength training and without any supplementation. Written informed consent to participate in the project was sought from all the study subjects. The protocol of the study followed the principles and policies of the Declaration of Helsinki and was approved by the Local Bioethics Committee at the Karol Marcinkowski University of Medical Sciences in Poznan (Poland).

Statistical Analyses

The following statistical procedures were applied to verify the study hypothesis. Arithmetic means and standard deviations were calculated for each study variable. Paired t-tests were used to compare pre- and post-training values within groups, while between-group comparisons were conducted using ANOVA with post hoc Tukey

tests. Statistical significance was accepted at a level of $p \leq 0.05$. All statistical analyses were conducted with Statistica 9.0 software (StatSoft, Inc., 1984–2011, license no. AXAP012D837210AR-7).

Results

All results are provided in Table 1. After four weeks of the training program, subjects from group with destabilizers showed a significant improvement in the average power by 12% ($p \leq 0.05$) (Fig. 4) and average velocity by 15% ($p \leq 0.05$) of the best bench-pull repetition. In group without destabilizers, statistically significant improvement pertained solely to the average velocity by 10% ($p \leq 0.05$) during the best repetition. The relative improvement in group with destabilizers turned out to be significantly greater than in group without destabilizers.

Table 1. Peak power and peak velocity of barbell in bench presses and bench pulls obtained in group with destabilizers, group without destabilizers, and control group before and after the experimental exercise protocol

	Control group		Group without destabilizer		Group with destabilizer	
	Power [W]	Velocity [m/s]	Power [W]	Velocity [m/s]	Power [W]	Velocity [m/s]
Pull one repetition average values						
Pre-exercise	421.9	1.19	427.6	1.25	432.7	1.11
Post-exercise	480.0	1.35	475.7	1.39*	560.2*	1.42*
Variation	15%	14.6%	12.6%	11.9%	33.5% §	33.4% §
Pull peak values						
Pre-exercise	512.4	1.45	493.8	1.45	506.6	1.29
Post-exercise	564.7	1.59	584.6*	1.70*	658.4*	1.68*
Variation	11.3%	10.8%	18.94%	18.3%	33.5% ‡	33.6% ‡
Pull average of entire set values						
Pre-exercise	370.7	1.04	366.5	1.07	390.9	1.00
Post-exercise	417.6	1.17	436.7*	1.27*	500.2*	1.27*
Variation	13.7%	13.2%	20.3%	19.4%	34.4%	34.3%
Push one repetition average values						
Pre-exercise	376.4	1.07	381.9	1.12	380.8	1.03
Post-exercise	394.9	1.12	412.7	1.21	453.9*	1.13
Variation	5.5%	5.5%	8.6%	7.9%	21.5%	10.2%
Push peak values						
Pre-exercise	488.6	1.38	472.6	1.39	526.1	1.34
Post-exercise	493.6	1.40	478.8	1.40	521.1	1.37
Variation	1.3%	1.3%	1.8%	1.1%	-0.5%	2.94%

	Control group		Group without destabilizer		Group with destabilizer	
	Power [W]	Velocity [m/s]	Power [W]	Velocity [m/s]	Power [W]	Velocity [m/s]
Push entire set values						
Pre-exercise	352.1	1.00	347.0	1.02	380.4	0.96
Post-exercise	362.3	1.03	380.2	1.11*	384.3	0.99
Variation	3.3%	3.3%	10.2%	9.5%	3.2%	3.24%

* P < 0.05: significantly different compared to the pre-exercise value.
† P < 0.05: significantly different compared to control group vs group without destabilizers
‡ P < 0.05: significantly different compared to control group vs group with destabilizers
§ P < 0.05: significantly different compared to group without destabilizers vs with destabilizers

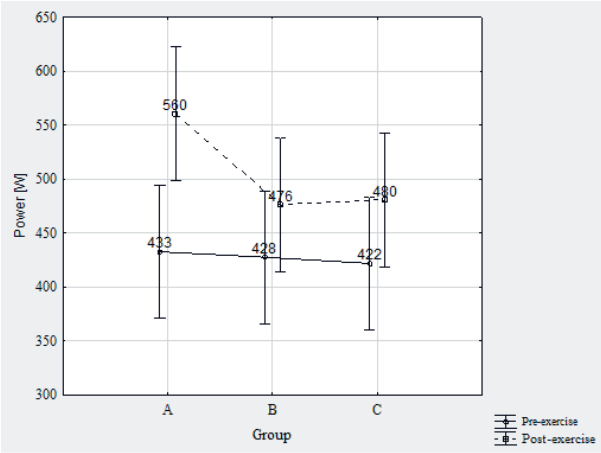


Figure 4. The average power for each repetition developed during bench pulls in group with destabilizers, group without destabilizers, and control group before and after the experiment

In group with destabilizers, maximal peak power during bench pulls increased by 18% ($p \leq 0.05$), while group without destabilizers showed a 12% improvement ($p \leq 0.05$). No significant changes were observed in the control group (Fig. 5). The relative increase in the maximal peak power and peak velocity of subjects from group with destabilizers turned out to be significantly greater than that of individuals from control group.

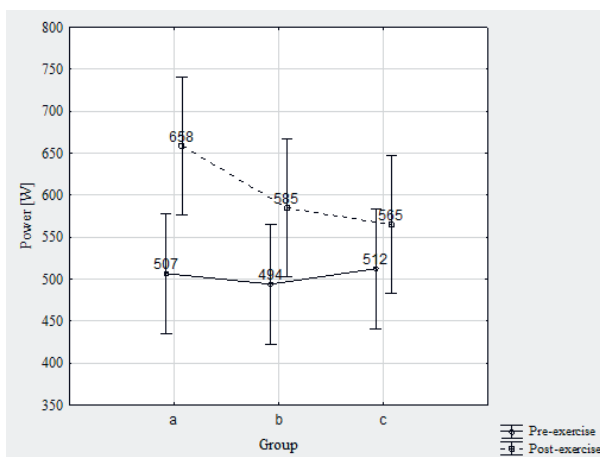


Figure 5. The maximal peak power developed during bench pulls in group with destabilizers, group without destabilizers, and control group before and after the experiment

Furthermore, individuals from group with destabilizers and group without destabilizers showed a significant improvement in the average power and average velocity for entire set bench-pull repetitions (Fig. 6).

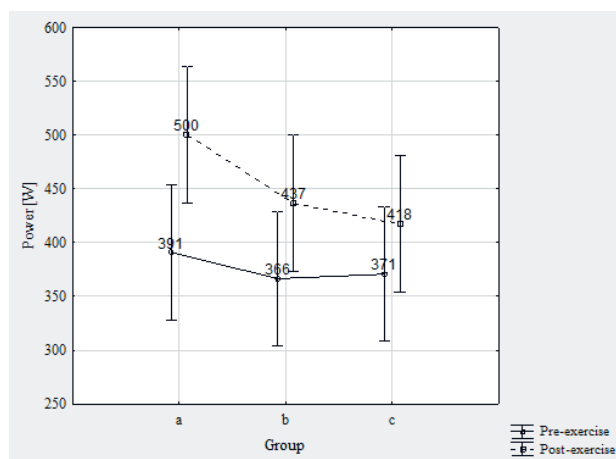


Figure 6. The average power of the entire set developed during bench pulls in group with destabilizers, group without destabilizers, and control group before and after the experiment

Regarding bench presses, participants from group with destabilizers showed a significant improvement in the average power of the best repetition (Fig. 7) and subjects from group without destabilizers showed a significant improvement in the average velocity for entire set.

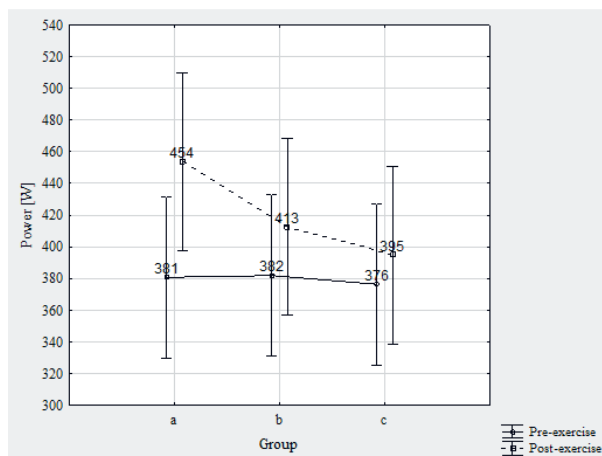


Figure 7. The average power for each repetition developed during bench presses in group with destabilizers, group without destabilizers, and control group before and after the experiment

Discussion

Striving to improve the results achieved by their athletes, coaches search for novel training methods that provide better sports performance or similar effects in a shorter time. However, the new methods do not necessarily improve the workout effectiveness, which is frequently associated with a limited number of training modalities that can stimulate further progress in adult athletes. This should not, however, discourage us from research on novel training modalities. For example, in kayaking it was concluded that power of bench press power and bench pull power was related to results in kayak paddling (Rynkiewicz et al., 2014). Obviously, not all newly identified modalities are equally effective in sports training, and therefore their applicability should be previously verified in individuals exercising on a recreational basis; only the modalities that proved to be effective in this group should then be verified in competitive athletes. Not infrequently, novel training modalities modulate only a selected component of athletes' preparation, which is not reflected by better sports performance.

Muscle power can be improved by means of various types of strength training, including maximal power-oriented training and explosive exercises with light extra loads (Clutch et al., 1983; Bauer et al., 1990; Adams et al., 1992; Wilson et al., 1993). For example, Hakkinen and Komi (1986) demonstrated that 24 weeks of training with high extra loads promotes a 7% increase in muscle power. In our study, the subjects involved in the experimental training with destabilizers achieved markedly better results than other participants. However, a substantial improvement was also documented in participants who worked out without destabilizers, which implies that the training protocol used in this study has been chosen appropriately. Athletes from group A showed a similar degree of improvement in all analyzed power and velocity parameters, which also points to high effectiveness of the training. In turn, the fact that the relative improvement observed in group A was significantly greater than that in group B points to the beneficial effects of destabilizers.

The lack of strength training experience in participants may have influenced the observed improvements, as neural adaptations are typically more pronounced in untrained individuals (Cormie et al., 2011). Interestingly,

subjects from control group showed a similar degree of improvement (10–15%) to individuals from group without destabilizers, which suggests that the better outcome may also be partially associated with mastering a new motor exercise, in this case, bench pulls. However, the improvement documented in control group was not statistically significant and consequently might reflect better results achieved by individual subjects from this subset. Control group weren't allowed to perform strength training during the experiment, but it is possible that some of them did not follow the recommendations.

Noticeably, similar differences were not observed in the case of bench pulls. This might reflect the completely different technique of movement during this exercise. During bench presses, the subject can observe the barbell and, using reverse feedback, may correct its movement at each repetition. In contrast, during bench pulls, the subject's face is directed towards the bench and therefore he or she is unable to correct barbell movements (Fig. 3). The only information about the trajectory of movement originates from proprioceptors, which may negatively affect the ability to perform repeated dynamic movements in persons with low levels of motor coordination. Symmetry of the exercise was a common problem encountered by the study subjects. This was particularly evident in subjects from group with destabilizers, in whom application of the destabilizers interfered considerably with the ability to perform dynamic movements; in extreme cases, the destabilizer placed on one side of the barbell underwent a 180° rotation and was oriented upwards. This may explain why despite the increase in the average power of the best repetition, subjects from group with destabilizers showed less improvement in the average power of all six bench press repetitions than individuals from group without destabilizers 95% CI: 15–21%,

Even if 10–15% of the improvement documented here resulted from mastering the technique of movement, the training with the destabilizers still promoted an additional 18–24% progression in the results. Consequently, this form of workout should be considered effective; other authors also reported a 12–21% increase in power after implementation of this form of strength training (Terzis et al., 2008). The greater magnitude of improvements observed in the present study, compared to those reported in studies involving trained athletes (Anderson & Behm, 2004), can be attributed to the neural adaptations that are more pronounced in untrained individuals.

The results presented herein document the effectiveness of power-oriented training with destabilizers. Unlike previous studies on athletes, the current findings highlight the applicability of destabilizer training for recreational trainees. The improvement observed in the experimental group was most evident in the case of bench-pull power.

Practical Applications

The use of destabilizers is an effective method for recreational trainees to improve power and coordination under unstable conditions. This training method may be applicable not only to recreational trainees but also to individuals in rehabilitation or those seeking to improve neuromuscular coordination.

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VALIDITY AND RELIABILITY ANALYSIS AMONG THREE DIFFERENT FAT ASSESSMENT METHODS IN TRAINED INDIAN MALE ATHLETES

Yumnam Momo Singh^{A, B, C, D}

Department of Sports Anthropometry, Sports Authority of India, Netaji Subhas National Institute of Sports, Old Moti Bagh, Patiala, Punjab-147001, India
ORCID: 0009-0001-2858-0807 | e-mail: yumnammomosingh.sai@gmail.com

Surojit Sarkar^{C, D}

Department of Exercise Physiology, Sports Authority of India, Netaji Subhas National Institute of Sports, Old Moti Bagh, Patiala, Punjab-147001, India
ORCID: 0000-0002-0853-343x

Anurag Chaurasia^{B, C, D}

Department of Sports Anthropometry, Sports Authority of India, Udhav Das Mehta (Bhai Ji) Central Regional Centre, Gram-Gora, Bishenkheri, Suraj Nagar, Bhopal, Madhya Pradesh- 462044, India
ORCID: 0000-0002-3962-8730

^AStudy Design, ^BData Collection, ^CStatistical Analysis, ^DManuscript Preparation

Abstract Background: The present study aims to investigate the criterion validity and reliability of three different BF% assessing methods i.e., skinfold caliper (SF), bioelectrical impedance analysis (BIA), and air-displacement plethysmography (BOD POD). Methods: Present study was conducted on 51 trained male Indian athletes (aged: 19–29 years). The BF% was measured via SF, BIA, and BOD POD with standard protocol. Statistical analysis was done using SPSS software. Results: The BF% from BIA was reported significantly ($p < 0.001$) higher than skinfold ($\Delta 28.7\%$), and BOD POD ($\Delta 25.4\%$). Very good reliability was found for BOD POD vs skinfold [with ICC = 0.891 (0.809–0.938)] and good reliability for Skinfold vs BIA [ICC = 0.669 (–0.207–0.895)] and BIA vs BOD POD [ICC = 0.736 (–0.164–0.912)]. Pearson's correlation depicted a positive correlation among various BF% methods (Pearson's r varies = 0.800 to 0.849; $p < 0.01$). Limits of agreement were reported significant for skinfold vs BIA ($p < 0.001$, $\beta = -0.530$), and BOD POD vs skinfold ($p < 0.01$, $\beta = 0.453$). Conclusion: Validity analysis depicts that BIA overestimates BF% in male athletes compared to BOD POD and SF methods. All BF% methods were found reliable although BOD POD vs Skinfold depicted major reliability (ICC = 0.891) over other methods.

Key words: body composition, body fat estimate, bioelectrical impedance analysis, BOD POD, skinfold caliper

Introduction

In sports, achieving peak physical performance is not just a goal; it's a prerequisite for success. Accurate body fat percentage assessment is critical in tailoring training regimens, optimizing performance, and ensuring the overall

well-being of athletes (Campa et al., 2020; Ackland et al., 2012). Body composition, the proportion of body fat to lean mass, significantly influences an athlete's strength, endurance, agility, and recovery, making it a fundamental metric in sports science and training (Mathisen et al., 2023). Precise body fat percentage assessment is relevant in sports for several reasons. Firstly, an optimal balance between lean muscle mass and body fat is crucial for athletes to achieve their peak power-to-weight ratio, a key determinant of performance in many sports (Huovinen et al., 2015). Secondly, understanding an athlete's body fat distribution can provide insights into injury risk and susceptibility and guide injury prevention strategies (Ezzat et al., 2016). Lastly, body fat assessments play a vital role in monitoring the effectiveness of training programs, allowing for adjustments to optimize performance gains and recovery (Halson, 2014).

Given the diverse range of sports and the unique physical demands each place on athletes, there is a clear need for a nuanced understanding of body composition (Martín-Rodríguez et al., 2024). The importance of individualized training programs tailored to the specific demands of a sport cannot be overstated. Herein lies the significance of a comparative analysis of different body fat assessment methods in the context of sports. The plethora of available methods, such as Anthropometric measurements, Bioelectrical Impedance Analysis (BIA), and advanced techniques like BOD POD, each offers distinct advantages and limitations (Antonio et al., 2019; Esco et al., 2015; Sirirat et al., 2020). A comprehensive understanding of these differences is essential for sports professionals to make informed decisions about the most appropriate method for their athletes. Factors such as accuracy, ease of use, and practicality in sports are crucial considerations (Staśkiewicz et al., 2023).

Previously studies have already been conducted on the functional and analysis differences among various BF% measuring methods (Antonio et al., 2019; Esco et al., 2015; Sirirat et al., 2020; Fields et al., 2002). Although separate test-retest and validity studies were there for BIA, BOD POD, and skinfold measurement not in a comparative manner. The research work was very scanty in terms of comparative study among BOD POD, BIA, and skinfold measures in the adult population (Bi et al., 2018; Burns et al., 2019). And in terms of sports population then to the Indian sports population context, the present study might be one of the pioneer ones. Thus, the present study aims to investigate and standardize the criteria for validity and reliability among three various BF% assessment methods i.e., Air-displacement Plethysmography (BOD POD), Bioelectrical Impedance Analysis (BIA), and Skinfold Caliper (SF).

Material & Methods

Subject selection: The present cross-sectional study was conducted on 51 trained male Indian athletes (mean age = 23.29 ± 2.64 years) from Sports Authority of India, NSNIS, Patiala. All participants were free from any physical injury, or medication and recruited only after proper clinical examination. Participants had at least 4 years of professional training experience. Data collection was done in the morning sessions and all participants were instructed to restrict alcohol and caffeine-containing drinks as well as to refrain from intense physical activity within 24 hours with a minimum of 12 hours fasting. All the BF% assessment methods were measured on the same day. Informed consent was obtained from each athlete before data collection. The research was undertaken in compliance by following the guidelines of the Helsinki Declaration.

Body weight (kg) and height (cm) were measured by using a Digital BMI Machine (SECA 284, Seca Deutschland, Germany) working with a precision of 0.1 kg, and 0.1 cm respectively, and BMI value in the device

was recorded. Tests were conducted under laboratory conditions at a controlled temperature of 22°C (Forejt et al., 2023).

Skinfold Analysis: Skinfold thickness measurements were performed using the GPM Skinfold caliper (DKSH Switzerland Ltd.), working nearest to 0.2 mm. Skinfold measurement was done from four sites i.e., biceps, triceps, subscapular, and suprailiac on the right side of the body following the standard protocol of ISAK (Manual ISAK, 2019). Body density was estimated using the Durnin and Womersely equation (Durnin & Womersely, 1974), and the BF% was then calculated from the Brozek equation (Brožek et al., 1963).

Bioelectrical Impedance Analysis (BIA): A tetra polar method using 8-touch electrodes and multifrequency (6-frequency: 1, 5, 50, 250, 550, 1000 kHz, measuring current: approx. 180µA) BIA device (ACCUNIQ BC 720, SELVAS Healthcare Inc.) was used to measure the BF%. The palms and soles of the participants were cleaned with isopropyl alcohol before testing. Participants were instructed to grip the handle electrodes with fingers and palms correctly, stretch both arms, and spread at a 30° angle with the body. The participants were asked to remove any metal accessories and wear light clothes. Standard guideline as per the manufacturer's manual was followed for the testing (Yang et al., 2018).

Air displacement plethysmography (ADP): The ADP was used to assess the BF% via using the BOD POD, version 5.4.6 (COSMED, Concord, CA, USA). Proper quality control procedure and pre-testing calibration (49.894 L of calibration volume) were done as per the manufacturer's instruction manual (COSMED, 2019). The body density model under the BOD POD was calculated using the Brozek equation (Brožek et al., 1963), and predicted thoracic gas volume was selected. During testing, participants were instructed to breathe normally and remain quiet, still, and relaxed. Two or three volume measurements were carried out (50 sec. each) and conclusive results for weight, body volume, thoracic volume (predicted), body density, fat, and fat-free mass were recorded. Before the study, all participants were instructed to wear Form-fitting Speedo or Lycra/spandex-type swimsuits or single-layer compression shorts (without padding). Wearing a cap to compress the hair on the head was also recommended (Dempster & Aitkens, 1995; Fields et al., 2001).

Statistical analysis: Statistical Package for Social Sciences (SPSS), version 21 (SPSS Inc., Chicago, IL, USA) was used to analyze the data statistically. Data were expressed as mean $\pm$ standard deviation (SD). The Shapiro-Wilk test was conducted to check the normality distribution. Criterion validity was assessed with Pearson correlation coefficients to quantify the relationship between fat values measured during three different test protocols (Skinfold, BIA, and BOD POD), whilst two-way ANOVA was used to compare differences in the magnitude of power values calculated among three groups. Correlation coefficients ranging from 0.4–0.59 were categorized as indicating a moderate linear relationship, 0.6–0.79 were categorized as strong, and >0.8 were categorized as very strong (Evans, 1996). The relative reliability of test outcome variables measured from the Skinfold, BIA, and BODPOD was assessed by intra-class correlation coefficients (ICC) using a 2-way random model with absolute agreement and 95% CIs. ICC values were interpreted using the following guidance: 0.41–0.60 as moderate reliability, 0.61–0.80 as good reliability, and >0.81 as very good reliability (Altman, 1991). The absolute reliability of the same data was quantified using the 95% limits of agreement (LOA) method originally described by Bland and Altman (Bland & Altman, 1986). Linear regression analysis was also used using the difference between measurements as the dependent variable, and the average of the measurements as the independent variable to check the proportional biases. Cronbach's alpha is used to measure the internal consistency of test outcome variables and a reliability

coefficient of 0.70 or higher is considered “acceptable” in most social science research situations (Taber, 2018). In all cases, a probability level (confidence interval) of 95% was considered to check the significance level.

Results

Table 1 summarizes the descriptive statistics of general anthropometric characteristics including age, height, body weight, and BMI. The average height, weight, and BMI were 176.06 ± 8.03 cm, 70.60 ± 14.27 kg, and 22.57 ± 2.88 respectively.

Table 1. Descriptive analysis of general anthropometric variables.

Variables	Age (years)	Height (cm)	Weight (kg)	BMI (kg/m ²)
Mean $\pm$ SD	23.29 $\pm$ 2.64	176.06 $\pm$ 8.03	70.60 $\pm$ 14.27	22.57 $\pm$ 2.88
Min.–Max.	19.00–29.00	161.20– 197.10	49.30–107.00	17.98–29.44

Values are expressed as mean $\pm$ SD, BMI = body mass index, Min. = minimum value, Max. = maximum value.

Table 2 depicts the comparative analysis result of BF% among three different body composition measuring protocols. The fat % values of the BIA protocol were found to be significantly ($p < 0.001$) higher than the other two methods i.e., skinfold (Δ 28.7%), and BOD POD (Δ 25.4%). The post hoc analysis depicts that the major group mean difference varied among BIA vs skinfold, BOD POD (F value = 17.387). Group variance was found to be lower in the case of SF measures in comparison to higher among both BIA and BOD POD.

Table 2. Comparative analysis of BF% among used fat-measuring methods.

Methods	Mean $\pm$ SD	Range	Variance
SF	12.28 $\pm$ 3.74	16.81	13.96
BIA	17.24 $\pm$ 5.17	22.90	26.68
BOD POD	12.85 $\pm$ 4.93	21.50	24.12
F value (sig.)		17.387 ***	
Post hoc		BIA vs SF, BP	

Values are expressed as mean $\pm$ SD, *** $p < 0.001$, BP = BOD POD, SF = skinfold, BIA = bio-electrical impedance analyzer.

Table 3 illustrates the comparative analysis of BF% among the used three methods. The result shows very good relative reliability was found for BOD POD vs Skinfold [with ICC = 0.891 (0.809–0.938: 95% CI)] and good relative reliability was found against Skinfold vs BIA [with ICC = 0.669 (–0.207–0.895: 95% CI)], and BIA vs BOD POD [with ICC = 0.736 (–0.164–0.912: 95% CI)]. Pearson's correlation study found a positive and strong correlation among various studied fat-measuring protocols where Pearson's r varies from 0.800 to 0.849 with a statistical significance level of $p < 0.01$. However, the highest level of correlation was found among skinfold vs BIA (Pearson's $r = 0.849$). Internal consistencies for comparisons of power variables obtained from both tests were calculated using Cronbach's alpha. A higher internal consistency was found for all the measured cases (α varies from 0.888–0.893) including the highest α for both skinfold vs BIA and BOD POD vs skinfold (Cronbach's alpha = 0.893).

Table 3. Intra-class correlation (ICC), Cronbach's alpha of the test variables of Skinfold, BIA, and BOD POD.

Methods	ICC (95% CI)	Pearson's r	Cronbach's alpha
SF vs BIA	0.669 (–0.207–0.895)	0.849**	0.893
BIA vs BOD POD	0.736 (–0.164–0.912)	0.800**	0.888
BOD POD vs SF	0.891 (0.809–0.938)	0.838**	0.893

** = $p < 0.01$ level, SF = skinfold, BIA = bio-electrical impedance analyzer, ICC = intra-class correlation, CI = confidence interval.

Table 4 depicts the linear regression model which revealed the Bland-Altman analysis of male athletes. The linear regression analysis revealed that both means of differences and limits of agreement were only found to be significant in the case of skinfold vs BIA ($p < 0.001$, $\beta = -0.530$), and BOD POD vs skinfold ($p < 0.01$, $\beta = 0.453$) but the regression between BIA vs BOD POD (low $\beta = 0.084$) does not show any significant difference.

Table 4. Linear regression model for interpretation of Bland-Altman Plots.

Dependent variable	Independent variable	Unstandardized coefficients (β)	Significance	R ²
Difference of fat in SF vs BIA	Mean of fat in SF vs BIA	–0.530	<0.001***	0.281
Difference of fat in BIA vs BOD POD	Mean of fat in BIA vs BOD POD	0.084	0.558 ^{ns}	0.007
Difference of fat in BOD POD vs SF	Mean of fat in BOD POD vs SF	0.453	0.001**	0.205

** = $p < 0.01$, *** = $p < 0.001$, ns = not significant, BIA = bio-electrical impedance analyzer, SF = skinfold, R² = coefficient of determination.

Bland-Altman plots illustrating the distribution of the difference scores for BF% between tests of three different fat-measuring methods skinfold, BIA, and BOD POD were depicted in Figures 1A, 1B, and 1C respectively. The upper and lower lines represent 95% confidence intervals with means or bias ± 1.96 SD. The LOA between BOD POD vs skinfold, BOD POD vs BIA, and BIA and Skinfold methods varies from +5.895 to –4.735% (Fig. 1A), +1.876 to –10.641% (Fig. 1B), and +10.462 to –0.537%, (Fig. 1C) respectively.

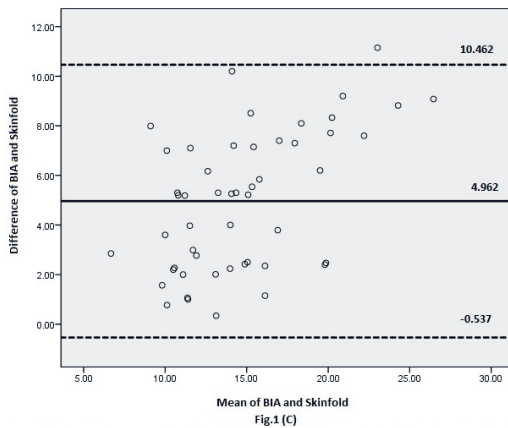
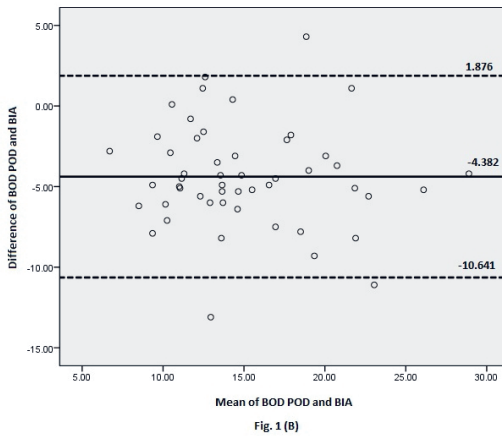
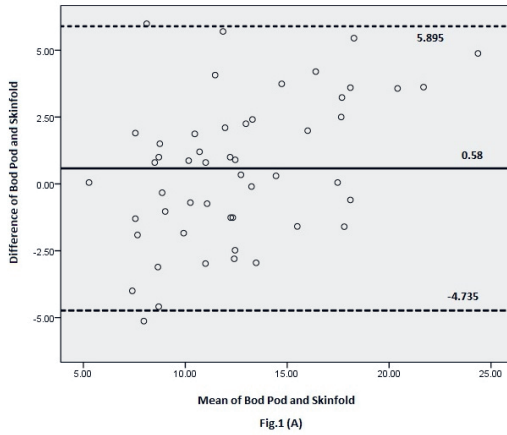


Figure 1. Bland-Altman plots illustrating the distribution of the difference scores of BF% measures for (A) BOD POD vs Skinfold, (B) BOD POD vs BIA, and (C) BIA vs Skinfold

Discussion

The present results reported that the fat measure from the BOD POD ($12.85 \pm 4.93\%$) and SF ($12.28 \pm 3.74\%$) method was found to be the lowest data set for the present studied population in comparison to the BIA ($17.24 \pm 5.17\%$) method. The present study result correlated with previous studies where the range of the BOD POD data was found to be lower in comparison to the bioelectrical impedance data (Bi et al., 2018; Burns & Fu, 2019; Long et al., 2019).

Increased interest in comparing body composition via various methods has led to a focus on several studies evaluating the effectiveness of different methods. Earlier research found that the accuracy of BIA and SF measurements for BF% was affected by the participant's body weight status (Oeffinger et al., 2014; Aandstad et al., 2014). On the other hand, the BF% assessed by the BIA method was significantly higher when compared with hydrostatic weighing and SF measurements for both male and female athletes, suggesting that BIA may overestimate BF% and the BIA method depends on the hydration status of the individual (Schubert et al., 2019). The dehydration state can lead to an overestimated BF% and over-hydration can lead to an underestimate of the BF% (Burns & Fu, 2019; Ekingen et al., 2022; Williams & Bale, 1998). Interestingly SF is another reliable and validated method to measure BF% but the data accuracy in SF truly depends on the skill set of the scientist (Aandstad et al., 2014; Lohman & Pollock, 1981).

Group variance is lower in the case of SF (variance = 13.96) whereas the variance for BIA (variance = 26.68) and BOD POD (variance = 24.12) was found to be much higher when compared with the SF data. However, intra-class variance was found to be nil when compared between BIA and BOD POD. Depending on the differences among the group variance and ICC the present study reported excellent reliability found against BOD POD vs Skinfold [ICC = 0.891 (0.809–0.938)], while the other two aspects BIA vs BOD POD [ICC = 0.736 (–0.164–0.912)], and Skinfold vs BIA [ICC = 0.669 (–0.207–0.895)] depicted good reliability. Pearson's correlation coefficient showed a significant ($p < 0.01$) strong correlation while the binomial correlation among various BF% methods.

The BOD POD method tends to give slightly higher fat measures than the skinfold method and much variability between the two methods was present as indicated by the relatively large LOA (+5.895 to – 4.735%, Fig. 1A), this could be due to individual differences in body composition (Duren et al., 2008). The mean difference between the BOD POD and BIA methods is shifted towards negative values, indicating a systematic bias (Fig. 1B). The LOA (+1.876 to –10.641%, Fig. 1B) is quite wide, suggesting a substantial level of disagreement between BOD POD and BIA methods. In the case of the BIA and Skinfold method (Fig. 1C), there is a systematic bias, BIA method is consistently higher than the Skinfold method across the range of measurements (Schubert et al., 2019). The limits of agreement are wide (+10.462 to –0.537%, Fig. 1C), which suggests that the two methods have substantial variability in their differences.

Overall, the linear regression analysis through the Bland-Altman plot depicted that the mean of difference and LOA were found to be significantly different among both SF vs BIA ($p < 0.001$) and BOD POD vs SF ($p < 0.01$). The present result might be due to the narrow range and variance of SF (range = 16.81, and variance = 13.96) in comparison to both BIA and BOD POD with comparatively wider ranges and variance (Montgomery et al., 2017). This finding suggests that while each method has its merits, reliance on a single method for body fat assessment may lead to skewed interpretations of an athlete's physical composition.

Limitation

The present samples were male athletic population (19–29 years) and non-obese type; thus, it limits the study in terms of generalizing the study result from younger - older, obese - sedentary, and even from a gender perspective. The study has another limitation regarding using selected/ specified BIA devices (single and multi-frequency; even brand-wise device variations) and prediction equations used for BF% estimation via the SF method. Lastly, the thoracic gas volume for BOD POD assessment was an estimated value that might be counted as another limitation.

Conclusion

The present study underscores significant methodological discrepancies while measuring BF via various methods. Validity analysis of the present result depicts that BIA overestimates BF% in male athletes in comparison to BOD POD and SF methods. The variation in the limit of agreement study via the Bland-Altman plot analysis depicted a significant difference among both SF vs BIA and BOD POD vs SF. The study also reported a narrow range and variance for SF (range = 16.81, and variance = 13.96) in comparison to both BIA and BOD POD which have wider range and variance comparatively. Pearson's correlation coefficient showed a significant ($p < 0.01$) strong correlation while the binomial correlation among various BF% methods. Among all three BF% measuring methods, BOD POD vs Skinfold (ICC = 0.891) depicted very good reliability. In contrast, the other two aspects BIA vs BOD POD (ICC = 0.736), and Skinfold vs BIA (ICC = 0.669) depicted good reliability. All the BF% methods used in the present study were reliable and validated for BF% assessment and can be used according to the need of the test and availability of the equipment. However, the longitudinal studies for monitoring purposes should not interchange BF% measuring methods.

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