Ph.D. Program in Health Promotion and Cognitive Sciences
Sport and Exercise Sciences Research Unit
Department of Psychology, Educational Science and Human Movement

WEARABLES AND TELECOACHING FOR FUNCTIONAL RE-EDUCATION AND SPORTS PERFORMANCE: TOWARDS A NEW TRAINING PARADIGM

PhD Coordinator

Professor **GIUSEPPA CAPPUCCIO**

PhD Student

Dott. **IGNAZIO LEALE**

Supervisor

Professor **GIUSEPPE BATTAGLIA**

Co-supervisors

Professor **MANUEL GÓMEZ-LÓPEZ**

PhD CICLE XXXVIII

Academic Year 2024/2025

INDEX

Abstract
Acknowledgements
List of abbreviations
List of table and figures

Chapter I - Introduction

1.0 General Introduction

1.1 Technology in Sport: An Overview

1.2 Technology in Functional Re-education: An Overview

1.3 Aims and Objectives of the Thesis

Chapter II – Telecoaching: Concepts and Applications

2.0 Chapter II Overview

2.1 Telecoaching in Neurology: Principles and Practice

2.2 Telecoaching in Rare Neurological Diseases: Focus on Charcot-Marie-Tooth (CMT)

2.3 Telecoaching in Migraine: Principles and Practice

2.4 Telecoaching in Elderly Populations: Promoting Functional Independence

2.5 Challenges and Future Directions in Telecoaching

2.6 Telecoaching: Guidelines and Practical Applications

Chapter III – Wearable Devices for Monitoring and Support

3.0 Chapter III Overview

3.1 GPS Technology: Applications in Sport and Functional Monitoring

3.2 Wearable Inertial Sensor: Applications in Sport and Functional Monitoring

3.3 Smartwatch and Other Wearables: Health and Activity Tracking in Re-Education and Daily Life

3.4 Privacy and Ethical Considerations in Technology

Chapter IV – Personal Contributions and Research Experience

4.0 Research Activities and Skill Development

4.1 Collaborations with Clinical and Sport Institutions

4.2 International Research Exposure

4.3 Publications and Dissemination

4.4 Other Articles Published

Chapter V – Conclusion

References

Appendix

1. *Articles under review*
2. *Attended Conferences*
3. *Co-authored abstracts*
4. *Co-supervised master thesis*

Abstract

The integration of digital technologies into sport sciences and functional re-education has opened new frontiers in the monitoring, management, and personalization of training and therapeutic interventions. Among these innovations, telecoaching (TC), the remote delivery of coaching and re-education support via digital platforms, has emerged as a promising tool to promote adherence, engagement, and functional outcomes across diverse populations, including elderly individuals, patients with neurological disorders, and athletes. Simultaneously, wearable technologies such as Global Positioning Systems (GPS) and smartwatches allow for continuous, real-time collection of physiological, kinematic, and behavioural data, supporting a more precise understanding of individual responses and needs. This thesis explores a new paradigm in functional re-education and sport performance monitoring by examining the application of TC and wearable devices in both clinical and sport contexts. It aims to provide a deeper understanding of how these tools can be integrated to support personalized, data-driven interventions. Across the article, particular attention is given to the role of TC in various settings, including neurological rehabilitation, rare neurological diseases such as Charcot-Marie-Tooth (CMT), and elderly population, highlighting its potential to extend care beyond traditional environments. Furthermore, this thesis analyses the role of wearable devices in remote monitoring, differentiating the contributions of Wearable Inertial Sensor (typically used in sport performance tracking) and smartwatches (commonly applied in clinical and daily-life settings). These tools are critically examined in terms of their technical capabilities, usability, and potential integration into TC platforms.

To support this theoretical framework, the thesis includes multiple systematic reviews and original studies that aim to:

- define and structure TC methodologies adapted to various populations;
- assess how wearable technologies can be used to monitor and personalize functional re-education and training processes;
- explore how data from these devices can inform clinical decisions, enhance remote coaching, and support recovery and performance outcomes.

The work contributes to a growing body of evidence supporting the combined use of TC and wearable technologies, offering practical implications for researchers, clinicians, and

coaches. It suggests that the synergistic application of these tools represents a promising new paradigm in both the optimization of physical function and the personalization of care and training.

List of main abbreviations

Abbreviations list	
TC	Telecoaching
GPS	Global Positioning Systems
CMT	Charcot-Marie-Tooth
PWDs	People with Disabilities
mHealth	Mobile Health
MS	Multiple Sclerosis
PD	Parkinson's disease
AD	Alzheimer's disease
QoL	Quality of Life
MT	Music Therapy
BBS	Berg Balance Scale
ISDs	Inertial Sensors Devices
IMUs	Inertial Measurement Units
TUG	Timed Up-and-Go
1RM	One Repetition Maximum
HR	Heart Rate
MET	Metabolic Equivalent Task

Acknowledgements

I would like to express my deepest and heartfelt gratitude to ***Professor Giuseppe Battaglia***, my PhD supervisor, whose guidance, support, and mentorship have been invaluable throughout this challenging journey. Beyond providing expert advice, he has been a constant source of encouragement, patience, and inspiration. His belief in my potential, his trust in my ideas, and the freedom he gave me to pursue my own interests have allowed me to grow both as a PhD student and as a person. Professor Battaglia's dedication, wisdom, and ability to guide with both rigor and humanity have been fundamental to the completion of this work, and I feel truly privileged to have had the opportunity to learn from him.

I am also deeply grateful to ***Professor Antonino Bianco*** for instilling in me the importance of dedication, rigor, and perseverance in both research and academic life. His expertise, guidance, and constant availability have been a source of inspiration, and his example has motivated me to approach challenges with determination and resilience.

I would like to sincerely thank ***Professor Manuel Gómez-López*** for hosting me at his university in Spain during my international research period. His generosity, warmth, and personal attention made my stay not only academically enriching but also deeply memorable on a human level. This experience broadened my horizons, allowed me to engage with new methodologies, and created lasting friendships and professional relationships that I will carry with me throughout my career.

My gratitude also goes to ***Professor Valerio Giustino***, whose knowledge, insightful guidance, and encouragement have greatly contributed to the quality of my research. His support has been instrumental in helping me refine my ideas and achieve the goals of this work.

I am profoundly thankful to ***my family*** for their love, patience, and encouragement throughout this journey. Even when they may not have fully understood the daily demands of my work, their unwavering support has been a constant source of strength and motivation.

Finally, I wish to express my deepest gratitude ***to my girlfriend, Federica***. Her patience, understanding, and unwavering support have been a constant source of strength throughout the most challenging moments of this journey. She has shared in my joys and frustrations and offered encouragement when I needed it most. Every achievement in this PhD is also hers, and her belief in me has made this accomplishment truly meaningful. I am incredibly grateful to have had her by my side throughout this journey.

To all colleagues, mentors, friends, and collaborators who have contributed directly or indirectly to my doctoral journey: thank you. Your support, guidance, and inspiration have made this experience both rewarding and unforgettable.

"Success is not final, failure is not fatal: it is the courage to continue that counts".

List of table and figures

Table 1. Telecoaching Approach in Different Neurological Disorders
Table 2. The PICOS framework
Table 3. The aim of the manuscripts and relative characteristics of the sample
Table 4. Type of treatment and protocol in telecoaching.
Table 5. The PICOS framework
Table 6. The aim of the studies and relative characteristics of the samples.
Table 7. Types of program in telecoaching.
Table 8. Characteristics of the studies included
Table 9. Description of intervention, training program, and results of the studies included
Table 10. Characteristics of the participants.
Table 11. Performances at T0 and T1 of the TG.
Table 12. Descriptions of the external load indicators.
Table 13. Descriptive statistics of the external load indicators
Table 14. Descriptive statistics of the external load indicators for each official match.
Table 15. External load indicator differences among playing positions (central back, external striker, full back, midfielder, wide midfielder).
Table 16. Highest and lowest external load indicator differences among playing positions (central back, external striker, full back, midfielder, wide midfielder).
Table 17. One-way ANOVA test results.
Table 18. Multiple comparison test results.
Table 19. Statistical analysis of parameters considered using the Wilcoxon matched-pairs signed ranks test
Table 20. Statistical analysis of parameters considered using the Friedman test.

Figure 1. Flow Diagram representing the selection process of manuscripts
Figure 2. The flow diagram representing the selection process of records
Figure 3. Flow Diagram representing the entire selection process
Figure 4. Division of participants into the two groups
Figure 5. Microcycle training program
Figure 6. Supervised outdoor walking program. X: axial loading.
Figure 7. (A). TC: resistance training exercises with series and repetitions. (B). TC: free walking.
Figure 8. Results of the comparisons between T0 and T1: (A) kg expressed by the right hand in the handgrip test; (B) kg expressed by the left hand in the handgrip test; (C) time to perform the TUG test; (D) seconds for the execution of the Sit To Stand of the SPPB; and (E) score of the balance of the Tinetti scale. ***, $p < 0.001$.
Figure 9. Playing position's cinematic indicators (TD, DHSR, WD) during the first half of official matches. Legend: TD, Total Distance; MS, WD, Walking Distance; DHSR, Distance High-Speed Running; MD, midfielder; CB, central back, ES, external striker, FB, fullback, WM, wide midfielder; $p < 0.05$ for differences between playing positions (1 difference with midfielder; 3 difference with external striker; 4 difference with full back; 5 difference with wide midfielder).
Figure 10. Playing position's mechanics indicators (N◦INTACC, N◦INTDEC) during the first half of official matches. Legend: N◦INTACC, Number of Intense Accelerations; N◦INTDEC, Number of Intense Decelerations; $p < 0.05$ for differences between playing positions (3 difference with external striker; 5 difference with wide midfielder).
Figure 11. Playing position's metabolic indicators (DLMP, DHMP, DEMP, DMMP) during the first half of official matches. Legend: DLMP, Distance Low Metabolic Power; DHMP, Distance High Metabolic Power; DEMP, Distance Elevated Metabolic Power; DMMP, Distance Max Metabolic Power; $p < 0.05$ for differences between playing positions (2 difference with central back; 3 difference with external striker; 4 difference with full back; 5 difference with wide midfielder).
Figure 12. Flow diagram
Figure 13. Dog agility course

Chapter I – Introduction

1.0 General Introduction

Since the early 21st century, the role of technology in sport has undergone a profound and irreversible transformation, driven by the rapid advancement of digitisation and technological innovation across all sectors of society. The emergence of the Internet, mobile technologies, and digital platforms has positioned technology as a central component of sporting practice at both professional and amateur levels [1]. These developments have not only enhanced the efficiency of sport but have also made it more engaging, accessible and demanding. Traditionally, sport was seen mainly as a recreational activity, but increasing internationalisation and professionalisation, largely driven by technological advances, have brought significant structural and cultural changes. Today, fans and consumers are able to follow their favourite sporting events, teams, and athletes in real time or on demand, via digital platforms and social media, at virtually any time and from any location [2]. In this context, it is now widely recognised that future developments in sport, particularly at the professional level, will be closely tied to ongoing technological evolution [3]. However, the growing integration of technology into sport also raises important ethical concerns related to competitive fairness, equitable access to technological tools, the protection of personal data, and the fundamental nature of athletic performance. These issues have received growing attention in the scientific literature, which has explored their implications, challenges, and possible future developments [4-8]. Effective integration of technology into sport and rehabilitation requires a critical, evidence-based approach that encourages innovation while respecting fundamental principles.

1.1 Technology in Sport: An overview

Sports technology includes a wide range of tools, devices, and digital solutions aimed at enhancing athletic performance, supporting decision-making, reducing injury risk, and improving the overall sports experience for both professional athletes and the general audience [9]. Examples include wearable devices for performance monitoring, software for data management and analysis, tools for injury prevention and early detection, smart sports infrastructures, and digital platforms designed to engage fans [10].

The use of technology in sport is not limited to the professional level. While elite leagues such as the NBA, MLB, and football federations have incorporated advanced analysis and scouting systems to optimise performance and recruitment, school, youth, and amateur sports are increasingly adopting tools such as heart rate monitors, tracking applications, and video analytics platforms [11-13]. Similarly, recreational athletes benefit from accessible technologies like smartwatches and fitness monitoring applications. Moreover, the impact of technology in sport extends beyond athletes to managers, coaches, athletic trainers, data analysts, and fans. Digital tools facilitate the planning of seasons and competitions, management of logistics and registrations, processing of statistics, and automation of loyalty programmes [14]. For instance, goal-line technology systems are now employed in various sports to enhance objectivity of refereeing decisions, contributing to fairer competition management. Currently, the most used technologies include [10,15,16]:

- Wearable technologies, including smartwatches, GPS devices, Wearable Inertial Sensor and biometric sensors, enabling real-time monitoring of physiological, kinematic, and behavioural parameters.
- Communication devices, such as helmets with integrated earphones, that facilitate real-time interaction between athletes and technical staff.

- Sleep and recovery analysis systems, essential for maintaining long-term athletic performance.
- Virtual reality tools that provide realistic simulations to support athletes' technical and mental preparation.

The fan experience has also been transformed by the introduction of digital devices and applications. The integration of immersive visors, wearable display technologies such as Apple Vision Pro, enables fans to follow sporting events in multiple ways, increasing engagement and personalisation. The main advantages of sports technology can be summarised as follows:

- More effective and personalised training
- Accident prevention and risk management
- Improved quality of visual and interactive experiences
- Support for athlete recruitment through data analysis
- Optimisation of event planning and management

Overall, technology in sport today represents a cross-cutting strategic factor that enhances performance, supports functional rehabilitation, improves technical management, and promotes innovative engagement with the sports experience at all levels. Technology is a fundamental element in the development and practice of Paralympic sport, playing a crucial role in enabling athletes with disabilities to reach their full potential [17]. The tools and technological solutions employed in this context not only facilitate the execution of motor actions specific to the sport but often constitute a necessary condition for participation itself. A prominent example is sports prostheses; their introduction and ongoing evolution have enabled Paralympic athletes to achieve performance levels that in some cases surpass those attainable by a biological human body. The case of South African sprinter Oscar Pistorius, known as the "Blade Runner," is emblematic in this regard.

Pistorius competed in the 400 meters using two carbon fibre blade-shaped prostheses, a technology that some analyses suggest may have provided a mechanical advantage exceeding 30% compared to able-bodied athletes [4]. His attempt to compete in the Olympics alongside able-bodied athletes sparked intense debate across scientific, technical, and ethical domains. Other notable examples of technological advancement in Paralympic sport include high-performance racing wheelchairs and flexible J-shaped prosthetic feet, such as the Flex-Foot Cheetah. Modern racing wheelchairs are constructed using ultra-light materials like carbon fibre and designed with aerodynamic principles, typically featuring a three-wheel configuration to enhance mechanical efficiency [18]. This design improves force transmission and reduces fatigue, enabling athletes to achieve higher speeds more quickly and with less effort. However, the adoption of such advanced technologies in Paralympic sport raises significant concerns regarding equity and accessibility. State-of-the-art racing wheelchairs and custom sports prostheses are costly and often affordable only to athletes from economically advanced backgrounds. This creates a clear disparity between athletes from developed countries and those from less affluent regions, significantly affecting their opportunities to access high-level international competitions [18]. In some disciplines, such as wheelchair basketball and wheelchair rugby, the use of a wheelchair is a necessary and standardized condition for participation. In others, such as track racing, prosthetic technologies can potentially provide a competitive advantage, fuelling ongoing debate about the balance between functional compensation and technological enhancement. In summary, Paralympic sport represents one of the clearest and most complex contexts in which the interaction between technology and athletic performance is observed. Reflection on these issues requires a critical analysis that considers biomechanical, regulatory, social, and ethical implications.

1.2 Technology in Functional Re-education: An Overview

Functional re-education is a therapeutic approach aimed at restoring or improving physical, motor, and functional abilities following injury, illness, or disability. Exercise is a fundamental component of a healthy lifestyle for all individuals, including people with disabilities (PWDs), particularly those with functional and motor impairments [19,20]. A substantial body of scientific evidence supports the benefits of physical activity in PWDs, both for the prevention and for the management and treatment of chronic or secondary health conditions [21,22]. Regular participation in physical exercise is also linked to better decision-making, healthier lifestyle habits, and overall improvements in psycho-physical well-being [23-25]. The literature has consistently demonstrated that exercise can alleviate physical pain [26,27], enhance mental and emotional well-being [23,28], and support the regulation of key physiological systems, with beneficial effects on circadian rhythms, cardiovascular function, and metabolic processes [29,30]. However, despite strong evidence of its benefits, a significant portion of the population, particularly in the United States, does not engage in regular physical activity. Rates of physical inactivity are even more pronounced among individuals with disabilities, exacerbating existing health disparities and contributing to increased health inequities in PWDs [26,31]. Traditionally, participation in exercise programs has required physical attendance at fitness centres, gyms, healthcare facilities, or clinic [31-34]. However, this traditional model poses multiple accessibility barriers for people with disabilities, including structural obstacles, limited transportation options, perceived environmental insecurity, and the absence of architecturally accessible facilities [31,34,35]. In response to these critical challenges, recent years have seen a growing interest in solutions that deliver physical activity directly to the home environment, challenging the long-standing notion that exercise must occur in community-based settings [36,37]. The COVID-19 pandemic acted as a catalyst for the widespread adoption of remote exercise interventions, prompted by the closure or restricted access to health and recreational facilities [31,36]. This shift has supported the development of alternative, remotely delivered models that reduce environmental barriers, enhance usability, and lower the costs associated with participation [33,35,38]. At the same time, the growth of telemedicine and mobile health (mHealth) technologies has made it possible to deliver inclusive, accessible, and personalized exercise programs [39,40]. The integration of digital platforms, wearable devices, and TC solutions offers new opportunities for promoting physical activity among people with disabilities, with potentially measurable benefits for both physical and psychological health [30,41,42]. Telehealth is defined as "the delivery and facilitation of health and related services, including medical care, provider and patient education, health information services, and self-management, via telecommunication systems and digital communication technologies" [43,44]. In recent years, the growing adoption of telehealth has significantly transformed healthcare delivery, expanding the reach of therapeutic interventions into home and remote settings. The health emergency triggered by the COVID-19 pandemic further accelerated this shift, establishing tele-exercise and remote rehabilitation as safe and viable options during periods of enforced social distancing [45,46]. In this context, physical activity interventions supported by telehealth have emerged as effective alternatives to traditional in-person treatments, ensuring therapeutic continuity even when access to healthcare facilities is limited.

However, the use of telehealth is not without its limitations, particularly in the context of motor re-education and physical rehabilitation. The effectiveness of digital interventions may be compromised by several factors, including:

- The complexity of the technological platforms employed;
- Unclear or ambiguous user instructions;
- The requirement for stable internet connectivity (Wi-Fi or mobile data);
- Limited digital literacy among certain target populations, such as older adults.

In such cases, digital rehabilitation may prove less effective or less acceptable compared to traditional, in-person rehabilitation approaches.

Moreover, the heterogeneity in the modes of intervention delivery, such as the presence or absence of features like automated reminders, remote supervision, personalized feedback, and synchronous communication, introduces an additional layer of variability. This methodological diversity presents significant challenges for clinical research, complicating direct comparisons across studies and limiting the generalizability of findings. Current evidence indicates that the effectiveness of remote rehabilitation depends largely on well-designed interventions, user-centered usability, and the appropriate tailoring of programs to the specific needs and characteristics of everyone.

Therefore, while telehealth holds significant potential for expanding access to rehabilitation services and enhancing continuity of care, it remains essential to further investigate the most effective design principles. Particular attention must be given to ensuring inclusivity, ease of use, and the provision of adequate technical support, especially for the most vulnerable populations.

1.3 Aims and Objectives of the Thesis

The primary aim of this thesis is to advance knowledge and evidence on the application of technologies in sport and motor re-education. This work seeks to provide a comprehensive understanding of the complex relationships between technology, physical activity, and sports performance. These topics are investigated across two experimental chapters, each targeting specific objectives.

- **Chapter II – Telecoaching: Concepts and Applications** provides an overview of the application of TC in the context of physical re-education, with a particular focus on neurological and rare neurological disorders. This section includes both literature reviews and original studies that offer in-depth insight into the subject. The chapter also extends the analysis to the use of TC in the sports domain, with particular emphasis on workload management and recovery monitoring.

- **Chapter III – Wearable Devices for Monitoring and Support** provides an overview of the application of wearable devices in both the motor re-education context and the sports and performance domain. Specifically, it addresses the use of smartwatches for monitoring fitness parameters in young adults, as well as the application of Wearable Inertial Sensor technology for training load assessment and recovery management. These topics are explored through original experimental studies conducted as part of this research.

At the conclusion of this section, we will also discuss the limitations associated with the application of technologies in both motor re-education and sports contexts. These include challenges in data management, the lack of direct interpersonal contact between coach and athlete, and ethical concerns, particularly regarding the continuous monitoring of health and performance, which may infringe on personal privacy. Furthermore, disparities in access to advanced technologies highlight issues of equity and inclusivity within these fields.

Chapter II – Telecoaching: Concepts and Applications

2.0 Chapter II Overview

In the contemporary digital era, the widespread diffusion of internet access and personal communication technologies has significantly transformed healthcare delivery. Among the emerging modalities, TC has gained increasing relevance as an alternative to traditional face-to-face consultations with healthcare providers. Preliminary evidence suggests that TC may offer comparable clinical effectiveness to in-person visits, while also enhancing access to nutritional and health services and contributing to cost containment in healthcare systems. TC involves the use of personal communication devices, such as smartphones, tablets, or computers, to deliver remote support, including assessment, counselling, and treatment planning. This modality helps mitigate common barriers to in-person care, including time constraints, childcare responsibilities, geographic distance, and lack of transportation. However, despite these advantages, TC also faces notable challenges. Digital literacy and technological proficiency can limit participation for some patients, while technical issues, connectivity problems, and concerns about data privacy and security may hinder the overall experience. Addressing these barriers is essential to ensure equitable access and maintain the quality of care. As with any innovative healthcare model, the acceptability of TC among both providers and patients is critical to its successful implementation. Existing studies report high satisfaction levels, with patients frequently rating the quality of TC as equivalent to that of conventional in-person services.

2.1 Telecoaching in Neurology: Principles and Practice

List of publications/projects discussed within Chapter II:

Leale, I., Vinciguerra, C., Di Stefano, V., Brighina, F., & Battaglia, G. (2025). *Effectiveness of Telecoaching and Music Therapy in Neurological Disorders: A Narrative Review and Proposal for a New Interventional Approach*. Healthcare (Basel, Switzerland), 13(7), 826. https://doi.org/10.3390/healthcare13070826

INTRODUCTION

A study published in the Lancet Neurology as part of the Global Burden of Disease research found that in 2021, more than three billion people, equivalent to 43% of the global population, were affected by neurological conditions. This reflects an 18.2% increase compared to 1990 and a 1.5 increase over the past two decades [47]. Neurological disorders, including neurodevelopmental conditions and diseases affecting the nervous system, were identified as the leading cause of disability worldwide [47], accounting for a total of 168 million years lived with disability. Among the conditions examined were multiple sclerosis (MS), Parkinson's disease (PD), Alzheimer's disease (AD), and migraine, all of which present significant challenges for both patients and healthcare professionals due to their complexity and substantial impact on Quality of Life (QoL) [48,49]. The recent World Health Organization's Action Plan outlines a comprehensive strategy based on five objectives to improve brain health worldwide [49]: (a) increasing policy priority; (b) providing effective, timely, and responsive diagnosis, treatment, and care; (c) implementing promotion and prevention strategies; (d) promoting research and innovation; and (e) strengthening the public health approach. This plan emphasizes the importance of collaboration among stakeholders in the health sector and beyond, promoting the involvement and empowerment of individuals with neurological disorders, along with their caregivers and families [50]. In recent years, there has been a growing interest in integrating innovative therapeutic approaches for the treatment of neurological disorders [51]. The COVID-19 pandemic necessitated significant adaptations in healthcare practices, leading professionals to comply with social distancing guidelines and quarantine protocols. As a result, many transitioned from in-person consultations to virtual modalities, accelerating the adoption of telemedicine interventions [52]. In this context, non-conventional therapeutic approaches, such as TC, are gaining attention for their potential to enhance patients' QoL and overall well-being. TC is a new intervention approach that utilizes digital technologies, such as a phone, personal computer, or tablet, to provide personalized support and continuous monitoring, enabling individuals to access training programs remotely [39]. This innovative approach can improve treatment adherence, enhance self-efficacy, and promote greater involvement in health management. Another important emerging approach is music therapy (MT), which involves the clinical and evidence-based use of music interventions to achieve individualized therapeutic goals, addressing physical, emotional, mental, social, and cognitive needs within a structured therapeutic relationship [53-56], either "in person "as well as in "remote and virtual" mode

[57]. MT has been shown to improve overall benefits for QoL and well-being, and it positively influences the nervous system by modulating the parasympathetic, dopaminergic, and opioid receptors [58]. The application of TC and MT can be particularly significant for neurological patients, who often experience social isolation and heightened anxiety [59,60]. Indeed, the remote accessibility of these therapies helps to overcome geographical and logistical barriers, which is essential for individuals with mobility challenges, a common issue among neurological patients [61]. Ultimately, these innovative approaches may be more sustainable and cost-effective in the long term, potentially reducing the financial burden associated with conventional treatment modalities. Thus, this narrative review examines the use and effectiveness of TC and MT in individuals with neurological disorders, analysing the available evidence. Through a critical synthesis of the literature, the review aims to develop practical recommendations for health and exercise professionals, highlighting implications for practice and future directions. Additionally, this study proposes a strategic design for interventions that integrate TC and MT. The integration of TC and MT highlights their complementary nature, offering a more comprehensive approach to patient care. This integrated perspective can enhance treatment outcomes by simultaneously addressing both the physical and emotional needs of patients.

METHODS

This narrative review was developed in accordance with the Assessment of Narrative Review Articles guidelines [62]. It analyses the existing literature on the understanding, management, and treatment of neurological disorders, with a particular focus on non-pharmacological approaches such as TC and MT. Specifically, it explores their mechanisms of action, clinical applications, and potential benefits in enhancing quality of life and overall well-being in individuals with neurological conditions. Eligible articles were identified through a manual search of the following databases: PubMed, Scopus, and Web of Science. The search was conducted up to 10 January 2025. The following terms and keywords were used in combination with the Boolean operators “AND” and “OR”: “music therapy”, “musicotherapy”, “telecoaching”, “telehealth”, “home exercise”, “physical activity”, “exercise”, “neurological disorders”, and “neurological diseases”. To ensure comprehensive coverage, additional relevant articles were identified by screening the reference list of selected studies. Only peer-reviewed, English-language articles focusing on the recent advancements in the understanding and treatment of neurological diseases were included. Eligible studies encompassed randomized controlled trials, non-randomized controlled trials, and observational studies. Articles that did not provide information on TC programs or MT interventions were excluded. The selected studies were analysed through a qualitative synthesis approach. Key findings were categorized based on intervention type, study design, target population, and main outcomes. The findings are presented in structured subsections, each addressing key aspects of TC and MT intervention, including their effectiveness, mechanisms of action, and potential clinical implications.

RESULTS

In recent years, numerous studies have investigated innovative strategies to promote healthy behaviours in individuals with neurological disorders, offering promising advancements in treatment and care. Among the most notable emerging interventions are TC and MT, both of which have shown encouraging results in improving health outcomes and QoL in this population.

Telecoaching and Parkinson's Disease

PD is one of the neurological disorders in which the TC approach has been most applied [63]. Several studies have assessed the effectiveness of TC-based training programs in this population. One prominent study conducted by Gandolfi and Colleagues (2017) compared postural stability improvements following remotely supervised virtual reality (VR)-based home balance training with sensory integration-based balance training (SIBT) conducted in a clinical setting [64]. In this multicentre study, 76 patients with PD were randomly assigned to either the TC group or the SIBT group. The intervention program consisted of 21 sessions, each lasting 50 min, conducted three times a week for 7 weeks. In the TC group, each session began with a short warm-up, including stretching exercises for the upper and lower limbs. The central phase involved ten exercises tailored to the patient's specific clinical condition, utilizing the Wii Fit and balance board. In the SIBT group, the training session also began with a short warm-up phase, followed by static and dynamic balance exercises performed under various sensory conditions. Each exercise was repeated five to ten times, depending on the patient's abilities, with gradual increases in intensity and volume to promote improvement. Patients were assessed before and after the intervention, as well as at one-month follow-up, using the Berg Balance Scale (BBS), Activities-Specific Balance Confidence, 10-Meter Walking Test, Dynamic Gait Index, Parkinson's Disease Quality of Life questionnaire. The number of falls in the previous month was also recorded. Additionally, a cost analysis was conducted to compare the two approaches. The results showed a significant improvement in BBS scores in the TC group ($p = 0.04$) and a significant Time × Group interactions effect in the Dynamic Gait Index for the SIBT group ($p = 0.04$). Both groups demonstrated improvements in all outcome measures over time, except for fall frequency. The cost analysis revealed that the TC group incurred lower treatment and equipment costs compared to the SIBT group.

Yang and Colleagues (2016) also investigated the effectiveness of TC using VR in comparison to conventional balance training in individuals with PD [65]. A total of 23 participants were randomly assigned to either the TC group (n = 11) or the control group (n = 12). Both groups completed 12 training sessions, each lasting 50 min. The TC group engaged in VR-based exercises combined with a balance board, focusing on postural maintenance and dynamic tasks that simulated daily activities. In contrast, the control group participated in conventional, therapist-supervised training, which included static and dynamic exercises aimed at improving balance. The primary outcome measure was the BBS, while secondary outcomes included the Dynamic Gait Index, the Timed Up-and-Go (TUG) Test, the Parkinson's Disease Questionnaire, and the motor score of the Unified Parkinson's Disease Rating Scale. Assessments were conducted at baseline, after the training program (6 weeks, post-test), and at week 8 (follow-up). Both groups showed improvements across all outcome measures compared to baseline. However, no statistically significant differences were observed between the two groups at either the post-test or follow-up assessments.

Atterbury and Welman (2017) employed a TC approach to evaluate the effectiveness of a home-based balance training program compared to a conventional therapist-supervised training program in individuals with mild to moderate PD [66]]. A total of 40 participants were divided into two groups: the TC group (n = 16), which performed home exercises, and the control group (n = 24), which engaged in therapist-supervised sessions. Both groups completed 8 weeks of training, with three sessions per week, each lasting between 40 and 60 min. Each session comprised a 10-min warm-up, 15–40 min of balance exercises, and 10 min of cool-down. Outcome measures included the Timed-Up-and-Go Test, Functional Gait Analysis (FGA), Activity-Specific Balance Confidence (ABC) Scale, and Intrinsic Motivation Inventory. Both groups exhibited improvements in the FGA, with a significant increase in step length ($p < 0.05$). However, enhancements in the ABC Scale (p = 0.05), stride velocity (p = 0.0006), and cadence (p = 0.046) were observed only in the control group, which received therapist supervision. Additionally, the control group demonstrated significantly higher motivation levels (p = 0.002).

Telecoaching and Multiple Sclerosis

Another neurological disorder in which the effectiveness of the TC approach has been investigated is multiple sclerosis (MS). An important study by Pagliari and colleagues (2016) evaluated the effectiveness of TC using VR compared to conventional rehabilitation intervention for patients with MS [67]. This multicentre, randomized, controlled trial involved 70 participants, with 35 assigned to the TC group and 35 to the control group. Both groups completed 30 training sessions, consisting of five sessions per week, each lasting 45 min. The TC group engaged in exercises using a dedicated VR Rehabilitation System Kit that incorporated digital cognitive and motor content, with asynchronous training monitored remotely by a therapist. In contrast, the control group received active treatment, which included conventional motor and cognitive exercises. The main outcomes assessed included the cognitive and psychological motor profiles of the participants, measured by the Multiple Sclerosis Quality of Life-54, the Mini-Balance Evaluation System Test (Mini-BESTest), and the State-Trait Anxiety Inventory (STAI). The findings revealed that 63.3% of the TC group experienced improvements in the physical domain of QoL (p = 0.045). Furthermore, the TC group demonstrated significantly greater enhancements compared to the control group in the Mini-BESTest domains of balance (p = 0.014), postural control (p = 0.024), and dynamic walking (p = 0.020) at post-treatment. Additionally, higher adherence rates were observed in the TC group compared to the control group (86.67% vs. 80.0%).

Hoang and colleagues (2015) employed a TC approach to evaluate whether step training could improve physical and neuropsychological measures related to falls in individuals with MS [68]. This randomized controlled trial involved 50 patients with moderate disability, who were divided into two groups: a TC group (n = 28) and a control group (n = 22). Participants in the TC group engaged in two interactive exergames, participating in two 30-min sessions per week over 12 weeks. The first exergame utilized open-source software (Stepmania) (https://www.stepmania.com/) to create a rhythmic video game, synchronizing movements with visual stimuli displayed on a monitor. The second exergame focused on fast and precise movements involving both lower limbs. Conversely, participants in the control group continued with their usual physical activity. The primary outcomes of the study included Choice Stepping Reaction Time (CSRT) and Stroop Stepping Test (SST) time. Secondary outcomes included measures of balance (postural sway and CSRT components), gait speed, cognitive tests, and the Nine-Hole Peg Test (9-HPT). The TC group demonstrated statistically significant improvements in CSRT and SST, as well as in open-eye oscillation, the 9-HPT, and gait speed compared to the control group. Additionally, a non-significant trend toward fewer falls was observed in the intervention group. Importantly, no adverse events were reported during the intervention program.

Güngör and colleagues (2022) utilized a TC approach to evaluate the effectiveness of a home-based Pilates-based core stability training (PBCST) program on lower-limb strength and postural control in individuals with MS, comparing it to the same program conducted under supervision [69]. In this study, 50 individuals with MS were randomly assigned to two groups: a TC group, which performed the training program independently at home, and a control group, which completed the routine training program under supervision in a clinical setting. Both groups followed the training program for 8 weeks, participating in two sessions per week, each lasting approximately 60–75 min. Exercises were performed in different positions, including supine, lateral, prone, quadrupedal, sitting, and standing, and were complemented with self-stretching exercises during the final phase of each session. The primary outcomes of the study included postural oscillation and isokinetic muscle strength of the lower limbs, assessed using the Modified Clinical Test of Sensory Integration of Balance, the Balance Error Scoring System (BESS Test), the Postural Stability Test (PST), and a Biodex Multi-Joint System (isokinetic dynamometer). Secondary outcomes included physical ability and fatigue. Statistically significant improvements were observed in all parameters for both groups, although certain sub-parameters of postural oscillation in the TC group did not reach statistical significance ($p < 0.05$). Overall, the control group demonstrated slightly greater improvements.

Telecoaching and Ataxia

Cabanas Valdés and colleagues (2024) utilized a TC approach to investigate the effectiveness of a home-based core stability exercise (CSE) program on ataxia severity, functional abilities, QoL, and fall rates in individuals with both short- and long-term hereditary ataxia [70]. This randomized controlled trial involved 23 participants, divided into two groups: a TC group that received standard care combined with the home-based CSE program and a control group that received standard care alone. Participants in the TC groups performed the CSE independently, engaging in sessions five days a week for 5 weeks, with each session lasting 60 min. The exercises were designed to strengthen trunk muscles and enhance proprioception, incorporating movements in various positions, including supine, sitting on an unstable surface, prone, and standing. Assessments were conducted at baseline, at the end of the intervention (5 weeks), and at follow-up (10 weeks). The primary outcomes included ataxia severity and trunk function, while secondary outcomes included the following: balance confidence, measured by the ABC Scale; gait speed, assessed with the 4-Meter Walk Test (4-MWT); lower-limb motor function, evaluated by the 30-Second Sit-to-Stand Test; QoL, measured using the EuroQol 5-Dimension 5-Level (EQ-5D-5L); health status, assessed with the EQ-5D Index and fall rates. Although no statistically significant differences were observed between the groups regarding ataxia severity or trunk function, significant improvements were noted in balance confidence, gait speed, QoL, and fall rates. A statistically significant interaction between groups and time was observed for the ABC Scale ($p = 0.007$), the EQ-5D-5L total score ($p = 0.013$), and the EQ-5D index ($p = 0.006$).

Jabri and colleagues (2022) conducted a study investigating how a home TC training program, with and without vibrotactile Sensory Augmentation (SA), influences balance and coordination in individuals affected by hereditary cerebellar ataxia [71]. This crossover study recruited 10 patients who participated in two blocks of training, each lasting six weeks. Participants were instructed to perform balance and coordination exercises five times a week for a total of 12 weeks, with each session lasting 30 min. The exercises were categorized into five groups: Static Standing, standing on a Compliant Surface, Arm Raises, Weight Shifting, and Gait. Regardless of whether they received vibrotactile SA, all participants utilized a smartphone balance trainer during their home training sessions. This balance training system included an Apple iPod, four tactor buds attached to an elastic belt, and a portable Apple iPod. During sessions incorporating vibrotactile SA, the tactors delivered directional vibrotactile feedback corresponding to the navel, lumbar spine, and right and left sides of the trunk. When a participant’s control signal exceeded a predefined threshold, the corresponding tactor was activated to deliver a vibrotactile signal, prompting participants to make postural corrections by “moving away from the vibration”. Participants were instructed to record any step-outs and self-evaluations using the iPod interface, with these data automatically uploaded to a secure cloud server for review by a physical therapist who remained unaware of the participants' identities or group assignments. Each week, the therapist personalized exercises for each participant based on these data. Performance was assessed before, during, and after the training program. Several assessment measurements were used, including the Scale for the Assessment and Rating of Ataxia (SARA), the posture and gait sub-scores of SARA, the Dynamic Gait Index, the modified Clinical Test of Sensory Interaction in Balance, and the TUG Test. Among the seven participants who completed both training blocks, the changes in SARA scores and the SARA posture and gait sub-scores following training with SA were not statistically significant compared to those observed after training without SA ($p > 0.05$). However, a trend toward indicating improved SARA scores and sub-scores for posture and gait was observed with vibrotactile SA. Significantly, participants demonstrated improvements in their SARA scores ($p = 0.02$) and SARA posture and gait sub-scores ($p = 0.01$) when compared to their pre-training evaluations with vibrotactile SA.

Telecoaching and Other Neurological Disorders

The TC approach was employed by Burns and colleagues (2017) to evaluate the safety and effectiveness of progressive resistance exercise for addressing foot dorsiflexion weakness in children with CMT disease [72]. In this randomized, double-blinded, controlled study, 60 children were assigned to either a progressive resistance training group ($n = 30$) or a control group receiving a sham training program ($n = 30$). All participants engaged in training three times a week for six months, focusing on dorsiflexion exercises for each foot, using an adjustable exercise cuff specifically designed to increase load capacity. For the exercise group, the intensity was initially set at 50% of one repetition maximum (1RM) and was gradually increased to 70% over the training period. In the control group, participants followed the same procedure but trained at a very low intensity (less than 10% of 1RM) without any increases throughout the training. The primary outcome was the between-group difference in dorsiflexion strength, expressed as a Z score, assessed using hand-held dynamometry at baseline and at 6 months, 12 months, and 24 months. The ANCOVA-adjusted Z score differences in dorsiflexion strength between groups were as follows: 0 (95% CI −0.37 to 0.42; $p = 0.91$) at 6 months, 0.3 (95% CI −0.23 to 0.81; $p = 0.27$) at 12 months, and 0.6 (95% CI 0.03 to 1.12; $p = 0.041$) at 24 months. Overall, the study concluded that six months of targeted progressive resistance exercise effectively attenuated the long-term progression of dorsiflexion weakness in paediatric patients with CMT disease, with no reported adverse events.

Mehta and colleagues (2021) utilized a TC approach to compare the effectiveness of physical therapy (stretching) and yoga therapy as complementary tools to standard drug treatment in patients with migraine [73]. A total of 61 participants were divided into three groups: a physical therapy group (n = 20), a yoga therapy group (n = 20), and a standard therapy group (n = 21). All participants followed their respective programs for 12 weeks: the physical therapy group practiced relaxation exercises, neck stretching, and cardio-respiratory resistance training; the yoga therapy group performed specific exercises, including the butterfly position (Bhadrasana), cobra position (Bhunjagasana), and foot touch (Padhastasana); and the standard therapy group continued only with drug treatment. The outcome measures assessed included headache frequency, the Short-Form McGill Pain Questionnaire, and the Headache Impact Test-6. These assessments were conducted at recruitment and subsequently at monthly intervals for three months. All three groups demonstrated a significant reduction in headache frequency when comparing baseline measurements with post-intervention assessments at 1 month, 2 months, and 3 months ($p < 0.05$). However, the reduction in headache frequency was significantly greater in the physical therapy group compared to the other two groups. Furthermore, all three groups showed significant differences in sensory and affective pain ratings between pre-intervention and post-intervention at 1 month, 2 months, and 3 months. A one-way ANOVA Test revealed a statistically significant reduction in headache frequency across all groups at 3 months post-intervention.

Menengi and colleagues (2022) evaluated the effectiveness of home-based exercise treatment using a TC approach in patients with AD [74]. The study involved 20 individuals with early to middle-stage AD, who were randomized into two groups: a TC group (n = 10) and a control group (n = 10). Participants in the TC group completed 25 training sessions over 6 weeks, with each session lasting between 15 and 40 min. All sessions included dual-task motor and cognitive exercises, utilizing specific strategies to maintain participant engagement, such as singing and rhythm activities. The progression of exercises was facilitated by introducing new activities throughout the program. Primary outcomes included the Mini-Mental State Examination (MMSE), the TUG Test, and the Five-Times Sit-to-Stand Test. Secondary outcomes included the One-Leg Stance Test (OLST), Katz Activities of Daily Living Scale (Katz-ADL), Functional Independence Measure, Geriatric Depression Scale-Short Form, Beck Anxiety Scale, Zarit Caregiver Burden Inventory (ZCBI), and the Warwick Edinburgh Well-Being Scale. These outcomes were assessed at baseline and post-treatment. Results indicated a significant difference in the mean change between the groups, favouring the TC group for all primary and secondary outcomes ($p < 0.05$), except for the ZCBI and OLST ($p > 0.05$). No significant differences were observed in the comparison of primary outcome measures between the groups in the post-treatment results ($p > 0.05$). However, significant differences in all secondary outcome measures were noted in favour of the TC group ($p < 0.05$), except for the OLST, Katz-ADL, and ZCBI ($p > 0.05$). More information about TC in different neurological disorders can be found in Table 1.

Table 1. Telecoaching Approach in Different Neurological Disorders

	Neurological Disorder	Program (time)	Training	TC Strategies	Main Results
Hoang, 2015	MS	12 weeks of training, 2 times/w	Interactive Exergames	- Digital tools - Supervised training session - Asynchronous TC approach - Interactive exergaming systems - Weekly progress assessment calls	TC program is feasible, safe, and effective in enhancing stepping, standing balance, coordination, and functional performance in individuals with MS.
Yang, 2016	PD	6 weeks of training, 2 times/w	Virtual Reality Balance Training	- Digital tools - Synchronous TC approach	TC is effective in improving balance, gait, and QoL in individuals with PD.
Gandolfi, 2017	PD	7 weeks of training, 2 times/w	Virtual Reality Balance Training	- Logbook - Digital tools - Synchronous TC approach - Supervised training session - Interactive exergaming systems	TC is a feasible alternative to conventional training for reducing postural instability in individuals with PD.
Burns, 2017	CMT	24 weeks of training, 3 times/w	Resistance Strength Training	- Logbook - Digital tools - Supervised training session - Asynchronous TC approach	TC resistance training attenuates the long-term progression of dorsiflexion weakness without adverse effects in children with CMT disease.
Atterbur 2017	PD	8 weeks of training, 2times/w	Dual-Task Balance Training	- Digital tools - Asynchronous TC approach	TC is effective in improving some aspects of gait, such as stride velocity and cadence, in individuals with mild to moderate PD.
Pagliari, 2021	MS	6 weeks of training, 5 times/w	Virtual Reality Dual-Task Training	- Digital tools - Asynchronous TC approach - Offline Remote Monitoring	TC is effective in improving the physical domain of QoL and alleviating motor symptoms in individuals with MS.
Mehta,	MG	12 weeks	Physical	- Logbook	Physical therapy and yoga,

2021		of training, 3 times/w	Therapy or Yoga training	- Digital tools - Supervised training session - Asynchronous TC approach - Weekly progress assessment calls	when added to regular care, improve QoL and reduce the frequency of headaches in individuals with MG.
Güngör, 2022	MS	8 weeks of training, 2 times/w	Pilates-Based Core Stability Training	- Supervised training session - Asynchronous TC approach - Weekly progress assessment calls	Supervised training is more effective than TC in improving strength, postural control, core stability, and fatigue in individuals with MS. However, TC can be recommended for patients with limitations in attending supervised sessions.
Menengi, 2022	AD	6 weeks of training, 25 times/6w	Motor-Cognitive Dual-Task Training	- Digital tools - Synchronous TC approach	TC may significantly enhance cognition and mobility, improve independence, and reduce anxiety and depressive symptoms in individuals with AD.
Jabri, 2022	AT	12 weeks of training, 4 times/w	Balance and Coordination Training	- Digital tools - Synchronous TC approach	TC balance and coordination training improved motor performance in participants.
Cabanas Valdés, 2024	AT	5 weeks of training, 2 times/w	Home-Base Core Stability Training	- Logbook - Digital tools - Supervised training session - Asynchronous TC approach - Weekly progress assessment calls	TC improves balance confidence, gait speed, and QoL, and reduces the fall rate in individuals with AT. No evidence supports its effectiveness in improving AT severity and trunk function.

Legend: (TC) Telecoaching; **(PD)** Parkinson's disease; **(MS)** Multiple Sclerosis; **(CMT)** Charcot-Marie-Tooth; **(MG)** Migraine; **(AD)** Alzheimer's disease; **(AT)** ataxia; **(QoL)** Quality of Life.

DISCUSSION

This narrative review explores the effectiveness of TC and MT in the treatment of neurological disorders, highlighting their potential benefits for individuals. The findings suggest that TC significantly improves physical function, balance, and QoL and reduces fall risk, while MT enhances cognitive function, motor performance, and psychological well-being. Unlike conventional training, which typically takes place in dedicated facilities with direct interaction between trainers and participants, TC leverages digital tools and technologies to remotely manage and deliver training programs [8]. Common TC strategies include the use of wearable devices, mobile applications, and VR systems, often enhanced by gaming consoles. Wearable devices, such as smartwatches, play a crucial role in continuous and non-invasive monitoring of key health data, including heart rate, daily step count, walking speed, and weekly physical activity levels [75,76]. Applications and digital platforms further enhance TC by enabling the creation of personalized exercise plans and facilitating the remote delivery of training programs aimed at improving physical activity and cardiorespiratory fitness [77,78]. One particularly effective TC strategy is VR-based training, which immerses participants in interactive, simulated environments that mimic real-life activities. This approach not only increases physical activity levels but also enhances executive function, short-term memory, and long-term memory [79,80]. Moreover, VR-based TC improves participant engagement by dynamically adjusting difficulty levels based on individual skill levels, helping overcome barriers such as time constraints, geographical distances, and transportation challenges [39]. The effectiveness of TC has been demonstrated across various populations, including older adults [81,82] and individuals with respiratory [83,84], metabolic [85], and cardiovascular diseases [86]. However, further research is needed to precisely determine its long-term effectiveness and clarify its role as both a preventive and therapeutic approach [87,88]. The mechanisms through which TC influences neurological disorders are multifactorial. Firstly, TC provides personalized and flexible interactions, which enhance motivation and adherence to the training programs. Continuous engagement with a coach can strengthens participants' commitment to rehabilitation, fostering a sense of responsibility for their progress. Additionally, TC develops practical and cognitive skills, improving awareness and decision-making related to well-being [89]. Beyond behavioural benefits, TC actively stimulates neuroplasticity, potentially aiding in the recovery of motor and cognitive functions [90]. Research shows that the human brain is highly adaptable and capable of reorganizing itself in response to new demands and environmental influences [91]. Neuroplasticity plays a key role in acquiring new skills and recovering from neurological injuries [92]. Similarly, MT is believed to leverage neuroplasticity. Whether through active participation or passive listening, MT engages multiple neural pathways and sensory modalities in the brain. Structural changes occur at both cortical and subcortical levels, impacting regions responsible for sensorimotor functions [93], auditory perception [94], and white-matter tracts [95]. Additionally, MT has been associated with increased grey matter density in the left anterior hippocampus, a region linked to memory and learning [96] […]. However, the potential limitations and negative effects of these innovative approaches must also be considered. Regarding TC, the main limitations may include low technological ability among some patients and the possible lack of a stable internet connection. These factors could negatively impact patient engagement and reduce adherence to the intervention program. An additional factor to consider when implementing these interventions is the influence of circadian rhythms on both physical and cognitive performance [97]. Circadian rhythms impact not only sleep but also mood, emotional responses, and physical abilities [98,99]. For individuals with neurological disorders, who often experience fatigue and cognitive fluctuations, it is important to schedule therapy sessions during optimal times of day when they are most energetic and alert [100]. Aligning TC and MT interventions with circadian rhythms may also improve sleep quality, which is frequently compromised in these populations [101]. In this context, our review findings suggest that while MT can enhance mood, attention, and QoL in individuals with PD, it does not lead to improvements in dual-task performance or balance ability. The progression of the disease may limit neuronal plasticity, preventing long-term effects on motor and cognitive abilities in this population. Cognitive and motor functions in this condition may require more specific and multi-component interventions to achieve substantial improvements [102]. In addition, the role of patient demographics and the presence of comorbidities may affect the effectiveness of the intervention [80]. Similarly, in patients with MS, the PBCST program has been shown to be more effective when delivered through a traditional method rather than a TC approach. The effectiveness of PBCST may be enhanced by direct interaction with a therapist, highlighting the importance of supervised training in some conditions. Therefore, it is essential to adapt therapeutic approaches to meet the specific needs of the population. Administering these interventions at times when individuals feel most motivated and energized could significantly enhance their effectiveness [99].

Proposed Integrated Intervention Program: Music Therapy and Telecoaching for Neurological Disorders

This proposal presents an integrated program that combines MT and TC to enhance the physical, cognitive, and social well-being of individuals with neurological disorders. The selection of participants for the integrated TC and MT program will be conducted through a rigorous screening process that employs the following inclusion criteria: (a) a confirmed diagnosis of a neurological disorder; (b) age between 18 and 75 years; (c) readiness to engage in a 12-week training program; and (d) signed informed consent. The evaluation of the training program will involve both instrumental assessments and questionnaires specifically designed to assess various aspects of neurological disorders. The assessments will include the State-Trait Anxiety Inventory (STAI) to evaluate emotional function, the

BBS and TUG Test to assess balance and fall risk, the Pittsburgh Sleep Quality Index to measure sleep disturbances, the 36-Item Short Form Survey Instrument (SF-36) to evaluate QoL, and the International Physical Activity Questionnaire (IPAQ) to assess levels of physical activity. These assessments will enable the measurement of changes in physical functioning, cognitive abilities, and emotional well-being throughout the duration of the intervention. The intervention would consist of weekly TC sessions led by sports and exercise science professionals, guiding participants through personalized physical activities. Participants would receive tailored training programs supported by wearable devices that monitor their goals and make necessary adjustments to their training. Additionally, the training program would utilize video calls and dedicated platforms to facilitate ongoing communication between participants and professionals. This approach fosters an engaging and supportive environment, encouraging participants to remain motivated and connected. These strategies will be effective in addressing potential variability in participants' engagement, enabling the collection of objective data and facilitating personalized adjustments to training programs based on individual needs. MT sessions could be conducted online by certified music therapists and would include a variety of activities such as active listening, passive listening, musical improvisation, and group activities. These sessions aim to promote social interaction and the release of positive emotions. The intervention program could last for 12 weeks, with three sessions per week and continuous monitoring. It should commence with an assessment of the participant's physical and cognitive condition using standardized tests and questionnaires. A combined program of TC and MT promotes continuous monitoring, supports the development of a sustainable intervention, enhances motivation and adherence, fosters stronger social relationships, and leads to improvements in cognitive functions and memory. In summary, these integrated TC and MT programs represent a valuable opportunity to enhance well-being among individuals with neurological disorders. This combined approach aims to address cognitive and physical decline while providing emotional support, ultimately contributing to an improved QoL.

Strength and Limitations

One of the primary strengths of this study is its comprehensive examination of TC and MT in the treatment of neurological disorders. The review provides valuable insights into the benefits of both approaches, highlighting potential physical, cognitive, and emotional improvements for patients. Another significant strength is the exploration of the mechanisms of action for both approaches. Understanding these mechanisms, particularly the role of neuroplasticity, establishes a solid theoretical foundation for their application in treatment. Additionally, in today's digital age, the incorporation of technology and wearable devices is an important aspect to consider. These tools help overcome barriers by enhancing motivation, monitoring progress, and ensuring high adherence to intervention programs. However, this study has some limitations. Firstly, as it is a narrative review rather than a systematic review, there was no rigorous methodology for selecting studies, which could introduce bias in the results. Additionally, the variability in intervention programs, along with differences in administration methods and duration, complicates the comparison of results. Finally, while the review analyses the potential impacts of the TC and MT on cognitive, psychological, and emotional well-being, the lack of long-term follow-up limits the ability to comprehensively evaluate the effects of these approaches over time.

CONCLUSION

In conclusion, the findings of this review suggest that TC and MT are effective alternative approaches for treating neurological disorders. Both TC and MT, as well as their combination, enhance physical well-being while also improving the overall QoL by enhancing cognitive abilities and psychological well-being in individuals with neurological disorders. Neuroplasticity emerges as a key mechanism through which these approaches positively influence brain functions. However, the limited number of studies assessing long-term effects highlights the need for further research to explore these interventions in greater depth and to develop practical guidelines for their implementation in clinical practice.

2.2 Telecoaching in Rare Neurological Diseases: Focus on Charcot-Marie-Tooth (CMT)

List of publications/projects discussed within Chapter II:

Leale, I., Di Stefano, V., Costanza, C., Brighina, F., Roccella, M., Palma, A., & Battaglia, G. (2024). *Telecoaching: a potential new training model for Charcot-Marie-Tooth patients: a systematic review. Frontiers in neurology, 15, 1359091. https://doi.org/10.3389/fneur.2024.1359091*

INTRODUCTION

CMT also named hereditary motor and sensory neuropathy (HMSN) [103], encompasses a heterogeneous set of disorders affecting peripheral nerves. CMT is the most common inherited neuromuscular disorder with an estimated prevalence of 1 in 2500 [104,105], caused by mutations in more than 80 genes [106]. In this disease, the most common subtypes are CMT1A, CMT1X, hereditary neuropathy with a predisposition to pressure paralysis (HNPP), CMT1B and CMT2A. The other identified subtypes represent less than 1% [107]. CMT1 is characterized by a slow conduction speed in the motor nerves caused by a high demyelination process. According to Latour, the CMT1A is the most common form (76%), followed by CMT1X (11%), CMT1B (6%), and CMT1C (<6%) [108]. CMT2 is characterized by a mutation in the MFN2 gene, which causes axonal neuropathy with onset in childhood. In general, patients with CMT show a high genetic heterogeneity but with a relatively homogeneous clinical component. Clinically the main symptoms include distal weakness, muscle atrophy, loss of proprioception, sensory loss, reduced reflexes, and skeletal deformities such as hollow foot [109,110]. The combination of these symptoms causes in patients an altered gait associated with difficulty in balance [111,112] . It has also been shown that patients with CMT have anxiety and depression problems [113] with alteration of body composition [114] and low levels of physical activity [113,115,116]. A sedentary lifestyle increases body weight, muscle loss, and musculoskeletal pain, worsening the medical case of patients with CMT [117]; this condition increases the risk of comorbidities such as metabolic syndrome or cardiovascular disease [118]. The optimization of body composition profiles should be one of the main objectives to be achieved in patients with CMT. In fact, in these patients, a strong relationship between lean mass and physical functionality has been demonstrated [114]. In addition, reduced fat mass is related to improved quality of life and reduced symptoms [114]. The current absence of specific medical treatment for several neurological diseases [119], and the need for new evidence for the use of drugs [120] emphasizes the importance of developing sustainable physical activity programs [109]. Indeed, physical exercise might be an effective tool to improve quality of life and improve lifestyle in these patients, as well as slowing the progression of the disease. In particular, aerobic exercises, resistance training, and stretching appear to be the main training methods for CMT patients [121]. However, it could be challenging to investigate new types of exercise in these patients, considering the potential benefits of physical activity but the difficulties in its practice in this population [122]. Therefore, this systematic review aims to analyze the effectiveness and safety of TC training programs for CMT patients. Physical exercise in TC involves the use of technological and digital tools, such as computers and mobile devices, to remotely access training content [39]. Physical exercise in TC may be useful to reverse the sedentary lifestyle of CMT patients, allowing them to gain greater autonomy and independence, and improving their quality of life.

METHODS

Search strategy

This systematic review was developed based on the favoured reporting items for systematic reviews and meta-analyses (PRISMA) guidelines [123]. The studies were selected through a database screening, such as PubMed (NLM) Web of Science (TS), and Scopus. The following keywords have been included to identify the articles: exercise, physical activity, telecoaching, tele-coaching, Charcot–Marie-Tooth, aerobic training, resistance training, and training. Terms were included in three different groups. In Group A the terms “telecoaching” and “tele-coaching” were inserted, in Group B the terms “exercise,” “physical activity,” “aerobic training,” “resistance training” and “training” were inserted. Finally, in Group C has been inserted the “Charcot–Marie-Tooth” term. To analyze the groups, Boolean operators “AND” and “OR” were used. Examples of matching included: Charcot–Marie-Tooth AND aerobic training OR telecoaching; resistance training AND Charcot–Marie-Tooth. All the founded articles were transferred into the Endnote software (Vers. X20 for Windows 11, © Thomson Reuters).

Eligibility criteria

All studies that have the following criteria were included in this systematic review: (1) original research with full text written in the English language; (2) all study designs different than reviews, meta-analyses, letters to editors, and theses; (3) studies with training protocol in TC for patients with CMT. No gender differences between males and females were used for exclusion criteria. Articles from gray literature have not been investigated. The PICOS approach (Population, Intervention, Comparator, Outcomes, Study design) is explained in Table 2.

Table 2. The PICOS framework.
Population
Males and female subjects with Charcot–Marie–Tooth disease
Interventions
Physical endurance, physical fitness, aerobic training, resistance training, and physical therapy performed in telecoaching. Training protocols not performed in TC have been excluded.
Comparator
No restriction.
Outcomes
Muscle strength, aerobic capacity, balance, psychological status, quality of life, physiological adaptations, or functional ability.
Study design
Randomized clinical trials, randomized controlled trials, or clinical trials. Articles that were not published in the last 10 years, systematic reviews, scoping reviews, meta-analyses, letters to editors, and grey literature have been not investigated.

Study selection

The identification and elimination of duplicate studies were carried out by a single researcher. Subsequently, two authors analysed independently the articles. Initially, the authors analysed the title and abstracts of each study. Secondly the authors analysed the full text to assess whether the selected studies agreed with the criteria of inclusion and exclusion. The two authors discussed any dispute regarding their decisions; if the two authors did not agree on the inclusion or exclusion of a study, a third auditor was consulted. A Microsoft Excel spreadsheet (Microsoft Corp, Redmond, Washington) was used to report the following information related to the included studies: year of publication, sample age, gender, the aim of the study, and the TC protocol.

Quality assessment

Two authors evaluated the quality and bias of all the studies included in this review, using a modified version of the checklist to measure the quality of RCTs and not RCTs written by Downs and Black [124]. In the modified version of the checklist, item 27 (power) was changed from 0 to 5 to a score of 0–1, so that a study would receive a score of 0 in case the statistical power was below 80%, a score of 1 if the statistical power was above 80% [125]. As a result, the final checklist score changed from 32 to 28. The quality of the studies was divided into four levels: excellent [123-125], good (20–25), fair (15–19), and poor (<14) [126,127]. The authors' results were compared by an external researcher and discrepancies were resolved in a consensus meeting.

RESULTS

Study identification

A total of 382 studies were identified through electronic databases. The titles and abstracts of 199 studies were analysed after removing 183 duplicates. The full text of 17 studies has been examined of which only 7 articles agree with the inclusion and exclusion criteria. The PRISMA flowchart shows the entire selection process (Figure 1).

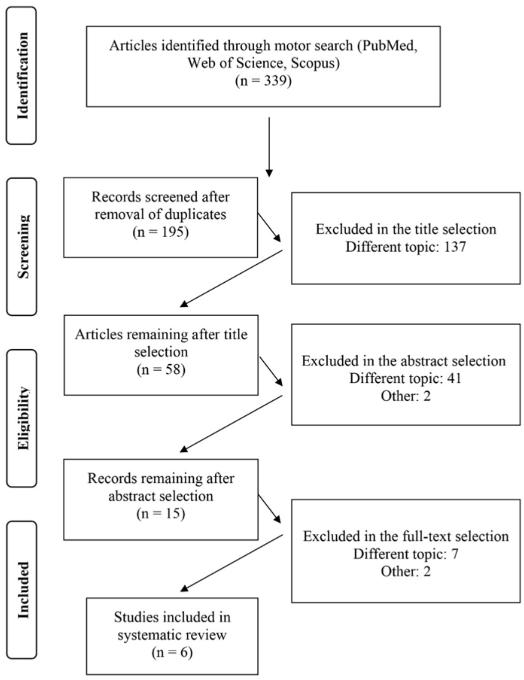

Figure 1. Flow Diagram representing the selection process of manuscripts.

In detail, of the 7 included studies, 5 analysed the effectiveness of a resistance training protocol in patients with CMT [72,128-131], while 2 studies analysed the effectiveness of an interval training protocol on this target population [132,133]. A total of 170 patients with CMT were included in this review with an age between 11 and 45 years. Of the 7 studies, it is possible to identify two studies of El Mhandi et al. [132,133] that included only male participants. The other 5 studies included both male and female participants. More detailed information on each study can be found in Table 3.

Table 3. The aim of the manuscripts and relative characteristics of the sample

1st author, year	Participants [f] [m], Age ± SD	Aim	Telecoaching
Burns, 2017	60 [30] [30], 11,5 ± 3,3	Evaluate the safety and efficacy of progressive resistance exercise for foot dorsiflexion weakness in children with CMT disease.	- 12/72 supervised training sessions. - a demonstration video for each participant. - an exercise diary. - parents as a guide.
Chetlin, 2004	20 [11] [9], 45,2 ± 8,9	Evaluate the effects of a home-based resistance exercise program on strength, body composition, and activities of daily living in patients with CMT disease.	- weekly telephone calls. - a demonstration video for each participant. - an exercise diary.
Chetlin, 2004	20 [11] [9], 45,2 ± 8,9	Evaluate the effects of resistance training with and without creatine supplementation on muscle, strength, and function in patients with CMT disease.	- weekly telephone calls. - a demonstration video for each participant. - an exercise diary.
El Mhandi, 2008	8 [0] [8] 34 ± 11	Evaluate if 24 weeks of interval-training exercise cycling can significantly improve physiological, neuromuscular, and functional capacities and alleviate fatigue in CMT patients.	- weekly telephone calls. - a heart rate monitor for each participant. - an exercise diary.
El Mhandi, 2008	16 [0] [16] 33 ± 8	Evaluate the effects of an interval exercise training program on heart rate variability in CMT patients.	- weekly telephone calls. - a heart rate monitor for each participant. - an exercise diary
Ramdharry, 2014	32 [17] [15] 44 ± 15	Evaluate the effects of a 16-week home-based program of resistance training on hip flexor muscle strength in CMT patients.	- weekly telephone calls. - monthly visits to progress resistance. - an exercise diary.

F: female; M: male; SD: standard deviation; CMT: Charcot-Marie-Tooth disease.

Methodological quality

The methodological quality of the included studies was analysed using the modified version of the Downs and Black checklist. Out of 7 studies, 1 study was evaluated as "good quality" [130], 3 studies as "fair quality" [72,129,131], and 3 studies were evaluated as "poor quality" studies [128,132,133]. Some items of Downs and Black are difficult to use in studies with physical activity protocol, such as the use of a study design in double-blind.

Resistance training

Of the extrapolated studies, five used a TC resistance training protocol in patients with CMT (31–34). Among these, there is the study of Burns and colleagues [72]; a randomized, double-blind, sham-controlled trial, in which the experimental group performed a TC training resistance exercise, while the control group performed a fictitious workout. The treatment team was the only one who knew about group assignment; participants, parents, caregivers, clinical evaluators, and other investigators were not informed of the group allocation. The experimental group, consisting of children, had performed a TC training program that aimed to improve the weakness in the dorsiflexion of the foot. Participants were trained using an adjustable ankle bracelet, designed to prevent slipping, three times a week or non-consecutive days, for 6 months with a protocol that provided an initial intensity of 50% and a progressive increase of up to 70% of 1RM. The control group trained with the same procedure, including the same equipment, the same duration, the same frequency, the same series, and repetitions. However, the participants trained with a very low intensity, never exceeding 10% 1RM. Each parent was asked to help the child with the application of the bracelet and to supervise the training performed in TC. TC included the compilation of an exercise diary, the delivery of a video to be used as a familiarization, and the active participation of parents as a guide, as well as the execution of some supervised training sessions. The results indicated that after a 24-week intervention period, the experimental group had reduced the long-term progression of dorsiflexion weakness without side effects on muscle morphology; there were no signs of overwork fatigue. It has been shown that a TC training program is safe, valid, and effective in a paediatric population affected by CMT disease. A drop-out of 5 patients was detected, demonstrating high adherence to the training mode. Also, Chetlin's study [130] used a home-based resistance training program, for 12 weeks. This study aimed to evaluate the efficacy of resistance training with and without creatine supplementation on muscle strength and activities of daily living (ADL) in patients with CMT disease. ADL included getting up from the chair without using your arms, getting up from a supine position, and going up and down the stairs. The subjects were also timed while performing a lifting and moving test. Each test was performed from 3 to 6 times. In detail, 20 patients with CMT consumed 5 g/day creatine or placebo, while participating in a resistance training program. Resistance training consisted of 12 weeks of exercise performed in TC, divided into three phases (each phase of 4 weeks) with the amount of work increased systematically by adjusting the resistance or repetitions for each of the phases. For example, hand-grip exercises consisted of 3 sets of 4 repetitions, three times per week, with a 1-min rest period between each set. If the subjects failed to perform the number of repetitions, they used a lower resistance to complete the required program. More details can be found in Table 4. TC included the delivery of videos describing in detail the training techniques as well as supervised training sessions in which subjects knew the exercises to be performed.

Table 4. Type of treatment and protocol in telecoaching.

Author, Years	Exercise	Intervention (n)	Treatment (time)	Training protocol
Burns, 2017	RT	TCG (30) vs. CG (30)	24 weeks of training, 3 times/week	**TCG:** exercises with an intensity that is initially at 50% and progressed to 70% of the 1RM. **CG:** participants trained at very low intensity (<10% of one repetition maximum).
Chetlin, 2004	RT	Male TCG (11) vs. Female TCG (9)	2 weeks of training, 3 times/week	**TCGs:** Resistance training was increased as follows: knee flexors and extensors, 40% (phase I), 45% (phase II), 50% (phase III); elbow flexors and extensors, 20% (phase I), 25% (phase II), 30% (phase III). Repetitions: week 1, 4RP; week 2, 6 RP; week 3, 8 RP; and week 4, 10 RP.
Chetlin, 2004	RT	TCG (10) vs. TCG+ integration (10)	12 weeks of training, 3 times/week	**TCGs**: Resistance training was increased as follows: knee flexors and extensors, 40% (phase I), 45% (phase II), 50% (phase III); elbow flexors and extensors, 20% (phase I), 25% (phase II), 30% (phase III). Repetitions: week 1, 4RP; week 2, 6 RP; week 3, 8 RP; and week 4, 10 RP. Integration: 5 g creatine monohydrate fortified with 2 g dextrose (Neotine; Avicena, Cambridge, MA) daily.
El Mhandi, 2008	ITE	TCG group (8)	24 weeks of training, 3 times/week	**TCG:** cycling program adapted; 5-minute warm-up followed by six 5-minute exercise bouts: 4 minutes at 40% of Pmax alternated with 1 minute at 80% of Pmax.
El Mhandi, 2008	ITE	TCG (8) vs. CG (8)	24 weeks of training, 3 times/week	**TCG:** 5-minute warm-up followed by six 5-minute exercise bouts: 4 minutes at 40% of Pmax alternated with 1 minute at 80% of Pmax. **CG:** No intervention.
Ramdharry, 2014	RT	TCG (18) vs. CG (14)	16 weeks of training, 4 times/week	**TCG:** Ankle weights with 0.5 kg increments and progressed from loads at 40% of the maximal voluntary isometric contraction to 60%. Two consecutive sets of 8-12 repetitions. **CG:** No intervention.

The results indicated that for both groups, the type I muscle fiber diameter, and strength, were improved as well as the ADL. Overall, patients with CMT respond to resistance training performed in TC with muscle fibre adaptations, and with improvements in strength, and in the ADL. However, the use of Creatine was not beneficial. No drop-out has been detected. The same research design has been applied by Chetlin and colleagues [128] to determine the effectiveness of a TC resistance training program on body composition, strength, and function of daily activities in men and women with CMT. The women's group consisted of 11 participants while the men's group of 9. At baseline, women had a normal percentage of strength (80%) in 4 out of 10 measurements, while men did not reach 80% of normal force in any measure. After resistance training, women reached 80% of normal strength in 8 out of 10 measurements, while men in 1 measurement. The functions of daily activities were improved after training without gender differences; moreover, men had significantly more fat-free mass ($p < 0.05$) before and after training compared to women. Ramdharry and colleagues [129] used a randomized single-blind crossover design to assess the effectiveness of a physical exercise in TC on hip flexor muscle strength. Randomization was used to assign the subjects to one of two groups: group A with initial training, and group B with initial control period. The training protocol conformed with the guidelines of the American College of Sports Medicine (ACSM) and provided 16 weeks of training with 4 weekly training (38). Weights were used, positioned in the ankle, with periodic increments of 0.5 kg and oscillation from 40 to 60% of the maximum voluntary isometric contraction (MVC). Participants performed 2 sets of 8–12 repetitions, 4 days a week for 16 weeks. The exercise was performed in the supine position with load displacement from 10° in hip extension to 45° in hip flexion. After a period of familiarization, patients were monitored through an exercise diary, weekly phone calls, and monthly visits to improve protocol adherence. The results showed a significant increase in the strength of the hip flexor muscles to the left but not to the right, demonstrating that the resistance training was well-tolerated without evidence of weakness from overload. In addition, no drop-out was recorded, indicating high compliance with this training mode. Finally, Dudziec and colleagues [131] used TC training protocol to assess the effectiveness of resistance training and multisensory balance training, delivered at home, on the ability to balance in patients with CMT. 14 patients were randomized into two groups: the TC group performed 12 weeks of strength training and multisensory balance; the control group performed the daily activities. The results showed high adherence to this training modality with 93% of patients completing the study. Posturography tests showed improvement in postural stability in favour of the intervention group, and the ability to balance and gait showed an improved elevated in the TC group. In the same group, partial improvements have been shown in the strength of the lower limbs.

Interval-training exercise

Only two of the studies analysed have used a TC protocol of interval training. El Mhandi and colleagues [133] have used this training program to assess if 24 weeks of interval training cycles could significantly improve physiological, neuromuscular, and functional abilities, as well as alleviate the perception of fatigue in patients with CMT. The training program included 24 weeks of training of which 12 were supervised and 12 TC-independently at home. The single training session was 45 min and included 5 min of warm-up, 30 min of the middle phase, and 10 min of cool-down. No stretching activity was foreseen. The central phase consisted of 6 exercises of 5 min, of which 4 min at 40% of the maximum aerobic power (Pmax) and 1 min at 80% of Pmax. The exercise was made on stationary cyclo-ergometers. TC period was performed with the same protocol, although several personal cyclo-ergometers were used by subjects in their homes. Subjects were motivated and checked by weekly phone calls. The training period was well tolerated; no subjects reported adverse events or complications during the protocol. The results showed significant improvements in cardiorespiratory abilities, functional ability, and isokinetic strength, as well as in the scale of pain and fatigue during training. Also, benefits obtained at the end of the supervised period were maintained after the home period. However, the results also revealed that there was no effect on the production of isometric strength and indices of fatigue resistance after training. The same training protocol was applied by El Mhandi and colleagues [132] to assess the effectiveness of interval training on heart rate variability (HRV) in patients with CMT. An experimental group and a healthy control group were included in this study. The HRV assessment was conducted at the baseline (T0) and the end of the 24-week study period (T1); in both evaluations, subjects were monitored through 24-h Holter electrocardiographic (ECG). The results showed that at the baseline all HRV indices of the experimental group were lower than the control group with a statistically significant difference for the pNN50 parameter. After the training program, the researchers found improvement in some time and frequency parameters in the experimental group; in some cases, the values of the experimental group at T1 exceeded the values of the control group at baseline (+8% mean R–R interval, +95% pNN50, 52%

reduction in low/high-frequency ratio). These results suggest that interval training might improve dysautonomia in CMT, improving the activity of the parasympathetic nervous system.

DISCUSSION

The present review aimed to analyse the effectiveness of TC programs in patients with CMT disease. The topic is innovative and punctual, but there are still few studies in the literature. It has been found that this modality of exercise training can determine significant improvements in motor strength, functional abilities, heart rate variability, activities of daily life, as well as cardiorespiratory ability. However, due to the low number of randomized controlled trials, the low quality of the studies, the reduced number of participants within each training protocol, and the limited evidence of pre-post differences, the true effectiveness of TC in CMT disease remains unclear. Most of the studies analysed examined the effectiveness of a TC resistance training program, showing positive changes in the indices of strength and muscle weakness, associating them with an increase in physiological abilities, neuromuscular and functional. Similarly, interval training showed significant improvements in HRV and the perception of fatigue, as well as an increase in cardiovascular ability. In detail, Burns and colleagues [72] showed that 6 months of resistance training in TC preserved the strength of the dorsiflexion in the children; while over the weeks, likewise of an adult with CMT [134,135], children have produced through resistance training, an overall gain of strength of 5% compared to a deterioration of 23% for the sedentary children, reflecting the normal course of the disease [136]. Although creatine has not involved any more significant changes, the improvements induced by the training protocol of Chetlin and colleagues [128,130], show the effectiveness of the TC training mode. The results obtained could be the result of muscle adaptation induced by resistance training. Indeed, post-workout, a hypertrophy of type 1 fibres was found, a condition consistent with what happens in healthy people after high-volume training [137]. However, subjects with CMT are not able to train at the same intensities recommended for healthy sedentary subjects (8–12 repetitions to exhaustion or 67–80% of maximum strength) [138]. Considering that the high intensity of training is associated with a decrease in performance and an increased risk of injury in patients with neuromuscular diseases (44), CMT patients needed to perform more repetitions, with less intensity, to equalize the recommended training volume. About creatine, it has been shown that oral intake increases muscle levels of creatine and phosphocreatine in healthy subjects, improving performance and post-exercise recovery [139-141]. In detail, subjects who increase creatine levels by 17–30% get the biggest increases [142], while those who increase by 5% do not get any performance improvement [143]. Conversely, although the initial levels of creatine are within the reference values for subjects with neuropathy [144], the lack of benefits induced by taking it might be caused by a low percentage of intake (5%). Not increasing muscle creatine concentration in patients with CMT may be caused by the non-compliant use of the supplement or an alteration of the creatine transporter. Future studies could analyse the correct functioning of the creatine transporter in patients with CMT. Moreover, the study by Ramdharry and colleagues [129], showed contrasting results, demonstrating a modest improvement in hip strength, but only to the left side. Overall, resistance training performed in TC would seem beneficial for this population, even if in the programming phase it should be considered that the muscles of CMT subjects do not physiologically respond to the training session due to chronic denervation [145]. In addition, the sedentary lifestyle of CMT patients may be the cause of the improvements achieved by resistance training evidenced in other studies, as seen in healthy subjects [146]; hence, it could be useful to extend the protocol administration period. Also, the protocol of El Mhandi and colleagues [132,133] of interval training performed in TC was an effective strategy, aligning with other studies that demonstrate the effectiveness of regular and progressive dynamic activity in neuromuscular diseases [147-149]. The numerous positive results obtained show that the program developed by researchers is perfectly in line with the needs and abilities of patients with CMT. A program that requires high functional abilities may be difficult to integrate into the daily routine, demotivating patients and causing a high risk of abandonment [150]. A physical activity program should consider this aspect, especially if executed in TC; indeed, it has been shown that poor motivation becomes an obstacle to exercise for both the patient and the healthcare professional [151,152] . Moreover, recruitment is one of the main problems of studies conducted on CMT (60), because many patients with neuromuscular diseases do not undertake a physical activity program for lack of motivation and difficulties in shifts and logistics. Indeed, only one of the studies in this review has analysed the sample size to ensure sufficient power in its study, to detect a statistically significant effect [129]; the remaining studies did not use any reference to sample power. From this perspective, TC could be a training mode that helps this population by offering a practical and attainable approach. In addition, physical exercise in TC for patients with CMT should consider the age of participants. All studies included recruited adult participants with an average age of 40 years, except for the study conducted by Burns and colleagues [72], in which participants were children between the ages of 6 and 17 years and an average age of 11.5 years. The age of the participants could influence both recruitment and results obtained; it is more likely that the main benefits induced by physical exercise in TC, are obtained at the disease onset, therefore in the early stages of the disease when the clinical burden is limited, and chronic complications have still not overcome.

Future directions

A training program performed in TC has already been used in many other target populations, resulting in effective and risk-free [86,153]. From the analysis of these studies, it is possible to observe the main strengths and limitations of this new training approach. Indeed, the execution of physical exercise in TC has several advantages, among these we can identify the reduction of economic resources, the reduction of geographical limits, the freedom to train when you want as well as the possibility of training in a family environment and safe. In addition, this mode increases the autonomy and independence of the patient. However, TC has also negative factors, including social isolation, loss of contact between coach and patient, the high risk of abandonment, and the difficulty for the patient to understand the right execution technique of the exercises. For these aspects, physical exercise in TC requires tele-coaches flexible and available to every need of the patient, constant weekly calls in order to supervise and control the progress of the exercise as well as an initial familiarization in order to learn and improve the execution of the exercises. Moreover, to optimize the effectiveness of this training modality, could be useful to provide each patient a clear and concise digital material that explains in detail the exercises to be performed, such as demo videos. Another important tool could be an exercise diary, in which to record when the training is carried out and any personal considerations to optimize PA.

CONCLUSION

Overall, this systematic review has found consistent results regarding the effectiveness and safety of a training protocol performed in TC, resulting in free of adverse events, with high adherence to the training mode and effective on all the variables analysed. However, due to the low number of randomized controlled trials, the low quality of the studies, the reduced number of participants within each training protocol, and the limited evidence of pre-post differences, the true effectiveness of TC in CMT disease is still unclear. The TC training intervention allows researchers to develop new research strategies. Considering this, a multicentre study project involving a larger number of subjects could be the main intervention strategy to reduce these limits. Further research is needed to verify the real benefits of a training protocol in TC and to organize and detail the training parameters such as volume, intensity, and density.

2.3 Telecoaching in Migraine: Principles and Practice

List of publications/projects discussed within Chapter II:

Leale, I., Figlioli, F., Giustino, V., Brusa, J., Barcellona, M., Nocera, V., Canzone, A., Patti, A., Messina, G., Barbagallo, M., Palma, A., Dominguez, L. J., & Battaglia, G. *(2024).* *Telecoaching as a new training method for elderly people: a systematic review.* Aging clinical and experimental research, 36(1), 18. https://doi.org/10.1007/s40520-023-02648-9

INTRODUCTION

Incidence and Impact of Migraine

Migraine is a highly common neurological disorder that affects approximately 15% of the European population [154], resulting in the second most severe disorder in terms of years lived with disability [155], and is the main cause of disability in the 15–49 age group [155]. It is a cyclic disorder characterised by recurrent attacks of moderate-to-severe headaches that may be pulsating in quality and unilateral, accompanied by nausea and intolerance to light or noise [156]. Moreover, one of the characteristics is that the pain usually worsens with physical exercise [156]. Some patients also experience transient focal neurological symptoms (usually lasting up to one hour each) before or during an attack, called aura, which configure the migraine with aura subtype [156]. Migraine creates a debilitating condition that causes work absenteeism or presenteeism (i.e., working with limited efficiency) and reduced participation in social activities [157]. Some consequences are high economic losses [158] and an increased risk of side effects due to overuse or misuse of medications [159].

Pathogenesis and Management of Migraine

In recent decades, much progress has been made in understanding the physiopathology, genetics, and neurophysiology of migraine. There is strong evidence that migraine may depend on alterations in cortical excitability (i.e., increased), which may lead to maladaptive patterns of brain plasticity, especially when the frequency of headache attacks increases (i.e., transformation from episodic to chronic migraine) [160-162]. The progress allowed the creation of new opportunities for the diagnosis and management of this disorder, even in rare familial forms [163,164]. There are two different approaches, which include the use of acute medication to stop a migraine attack, or preventive medication to reduce the frequency, duration, and severity of the pain episodes. The guidelines recommend the use of preventatives in case of debilitating headaches occurring for 2 or more days per month [165]. However, traditional oral prophylaxes may not be well tolerated or accepted by patients due to the possible side effects [166,167].

Non-Pharmacological Treatment of Migraine

For the above-mentioned reasons, non-pharmacological treatments, such as self-management strategies, manual therapy, physical activity, or physical exercise progressively gained interest as valid alternatives to conventional therapies [168-170]. Sport has a controversial role in migraine [171,172]. Although sport has been associated with a worsening of migraine attacks [173,174], there is evidence that regular physical activity or physical exercise could play a primary role in preventing them [175,176]. This phenomenon could be related to the intensity of exercise. High-intensity exercise (mainly present in sport) is a migraine trigger [173,174], while regular and moderate-intensity exercise (mainly present in physical activity) plays a role in attacks prevention [172-176]. Busch and colleagues [176], in their review, showed that regular, planned, and structured physical activity was associated with several benefits in this target population. The beneficial effects of exercise on migraine may be related to better pain modulation. Indeed, several studies demonstrate the analgesic effect of aerobic exercise [177,178]. Despite these findings, it has been shown that patients with migraine are more sedentary than healthy subjects [179]; a sedentary lifestyle that has further increased due to the recent COVID-19 pandemic, in several neurological disorders [115,116]. On the other side, the recent COVID-19 pandemic raised the need and gave impulse for the development of telemedicine.

Aerobic and Resistance Training: Evidence-Based Benefits

Recent literature demonstrated that exercise plays a significant role in the management of migraine. Specifically, aerobic activity has been shown to be particularly effective in reducing both the frequency and intensity of headache episodes, as well as enhancing the overall well-being of patients [180,181]. Indeed, as shown by the current literature, aerobic activity improves not only the specific parameters of migraine (frequency, intensity, and duration), but also the cardiovascular function, the affective discomfort [181], and the quality of life (QoL) of these patients [180]. A recent systematic review highlighted that moderate aerobic training is the most effective approach for reducing migraine-related disability [182]. Furthermore, the findings suggest that combining pharmacological treatment with aerobic training is more effective than drug treatment alone in decreasing both the frequency and intensity of migraine attacks [182]. Resistance training has been shown to positively contribute to migraine management by enhancing overall muscle strength and physical resilience, as well as reducing the frequency of headache attacks [183]. Muscle strengthening and reconditioning, particularly focused on the neck, shoulder, and upper limb muscles, could be the mechanisms responsible for the therapeutic effects of resistance training [183]. Furthermore, resistance training facilitates the increase and preservation of lean muscle mass, which can help reduce sarcopenia [184]. Research indicates that an increase in lean muscle mass is associated with a reduction in the frequency of migraine episodes [185]. These findings highlight the importance of incorporating resistance training into a comprehensive approach to migraine management.

Telecoaching: New Training Approach

A recent study showed the important association between migraine and some neurodegenerative disorders. For example, patients with migraine are more likely to develop Parkinson’s disease (PD) than subjects without migraine [186]. Kim and colleagues also found a relevant association between migraine and Alzheimer’s disease [187]. The authors demonstrated that individuals with a history of migraine had a higher prevalence of Alzheimer’s disease. The association was even stronger in young and obese subjects with migraine [187]. These findings suggest that migraine may be a risk factor for some neurodegenerative diseases, so proper migraine management (as well as an active lifestyle) might help reduce this risk. For these reasons, there is a need to develop new intervention strategies to contrast migraine and increase physical activity levels. This approach could also induce changes in brain plasticity that could have a beneficial effect on headache frequency. A new training modality could be represented by telecoaching (TC). Unlike traditional training, where exercises are performed in specific facilities and coach–athlete communication occurs in person, TC utilises technological and digital tools, such as computers and mobile devices, to deliver and manage training services remotely. This new approach of distance communication offers greater flexibility and facilitates access to the training. Technological tools allow the trainer to send training materials and monitor adherence to the program, while allowing patients to train independently, overcoming obstacles such as time, distances, and transport [39]. This new approach could serve as a primary strategy to increase adherence and engagement of individuals, reducing sedentary lifestyles. The effectiveness of TC in other populations and diseases has already been demonstrated, including its efficacy in the elderly population [81,82], in respiratory diseases [83,84], in patients with metabolic or cardiac diseases [85,86], as well as in patients with other neurological diseases such as Charcot–Marie–Tooth [72,88]. Therefore, TC could be one of the main tools to be used to increase physical activity levels in migraine patients, reducing their sedentary lifestyle and promoting improved QoL, autonomy, and self-esteem [188]. However, potential issues related to internet connection, as well as video and audio quality, should be considered to ensure the effectiveness of this modality [189]. TC aligns well with telemedicine and eHealth, which, despite its various approaches and challenges primarily related to the complexities of app development [190], has been extensively utilised and studied [189], as well as with the use of wearable devices for the benefit of human health [76]. While some patients express a preference for a hybrid care model [190], telemedicine consultations demonstrated a quality of care comparable to that of traditional headache outpatient consultations, offering a more cost-effective solution for patients [189], with also a positive endorsement from neurologists [191]. However, the use of telemedicine is significantly influenced by geographic location [192]. Countries such as the United States, China, and Norway, which benefit from advanced technology, make extensive use of telemedicine [193,194]. In contrast, countries such as Lithuania have not adopted this tool to the same extent. A recent study indicated that only 17% of migraine patients in Lithuania received remote consultations, compared to 57.5% of patients in the United States [192,193]. Positive experiences with telemedicine may encourage wider adoption of this approach.

Aim of the Study

Considering these premises, this scoping review aims to identify the available evidence on the use and feasibility of TC training programs in migraine patients.

MATERIALS AND METHOD

This scoping review was developed according to the PRISMA guidelines for systematic reviews and meta-analysis [123]. The protocol was not recorded in a specific database but was developed before the study.

Eligibility Criteria

Inclusion criteria were: (a) original research with full text written in English; (b) all study designs different than reviews, meta-analyses, letters to editors, and theses; (c) studies with training programs performed in TC for migraine patients; (d) studies published over the last decade, concluding in September 2024. No gender difference between males and females was used as an exclusion criterion. The population, intervention, comparison, outcome, and study design (PICOS) framework was used as shown in Table 5.

Table 5. The PICOS framework.

PICOS components	Details
Population	Migraine individuals.
Intervention	Telecoaching training program (aerobic training, resistance training, stretching and physical therapy)
Comparison	The post-exercise migraine endpoints were compared to pre-exercise migraine endpoints within each study
Outcome	Migraine Endpoints (Migraine days, attack frequency, pain intensity, duration of migraine attacks)
Study design	Original articles

Data Collection

Major databases, including PubMed (NLM), Web of Science (TS), and Scopus, were used to find useful articles for this study. Keywords included: exercise, physical activity, telecoaching, migraine, and headache. The different terms have been divided into 3 groups. In Group A, the terms “migraine” and “headache” were entered; in Group B, the terms “exercise” and “physical activity”; and in Group C, the term “telecoaching” was entered. The Boolean operators ‘AND’ and ‘OR’ were used to analyse the three categories. Matching examples were “migraine” AND “physical activity” AND “telecoaching”. All items found were transferred to Endnote software for the analyses (Version X20 for Windows 11, Thomson Reuters, New York, NY, USA).

Study Selection

Database analysis, identification, and elimination of duplicates were carried out by a single researcher. Subsequently, two authors independently analysed the studies (I.L.; V.D.S.). In detail, in the initial phase, the title and abstract of each study was examined; in the final phase, the researchers double-checked the entire text to confirm that the selected studies met the inclusion and exclusion criteria. In case of disagreements between the two raters on the inclusion or exclusion of a study, a third researcher was consulted (G.B). A Microsoft Excel spreadsheet (Microsoft Corp, Redmond, WA, USA) was used to report the study information including year of publication, age of sample, gender, aim of the study, results, and TC training protocol. The PRISMA flow diagram (Figure 13) illustrates the process by which the articles were selected.

Quality and Risk of Bias Assessment

Two authors (I.L.; V.D.S.) evaluated the quality and BIAS of all the studies included, using a modified version of the “Downs and Black Checklist” [124]. In the modified version of the Downs and Black checklist, the score of item 27 (concerning the power of the study) was changed from 0–5 to 0–1, so that a study would receive a score of 0 in case the statistical power was below 80%, and a score of 1 if the statistical power was above 80% [125]. Taking this into account, the final checklist score changed from 32 to 28. The quality of the studies was divided into four levels: excellent (26–28), good (20–25), fair (15–19), and poor (<14) [126,127]. Another researcher (G.B.) compared the authors’ results for each study and discrepancies were resolved through a consensus meeting.

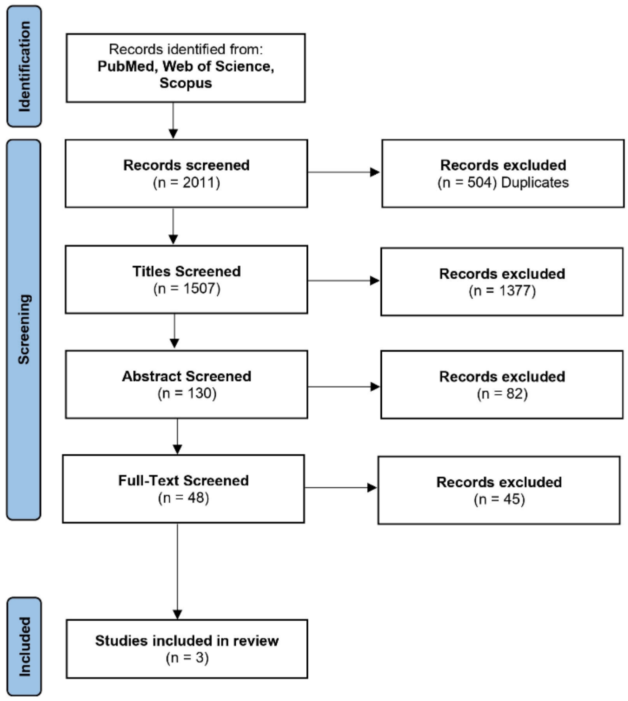

Figure 2. The flow diagram representing the selection process of records

RESULTS

A total of 2011 studies were identified through electronic databases. In total, 504 studies were eliminated because they were duplicates; 1507 titles and 130 abstracts were analysed. The full text of 48 studies was analysed; of these, only 3 studies agreed with the inclusion and exclusion criteria. Specifically, the three included studies analysed the efficacy of a TC aerobic training program [195], a TC resistance training program [196], and a TC physical therapy [197]. A total of 181 participants with migraine were included in this review. All included studies presented data on both males and females, but female sex was prevalent (n = 139, 76.7%). More detailed information about the study selection process and the characteristics of the included studies can be found in Figure 2 and Table 6.

First author, year	Participants [F%], Age ± SD	Aim	Telecoaching strategies	Downs and Black score
Santiago, 2014	60 [88%], 31±9	Compare the preventive treatment benefits of amitriptyline and aerobic exercise in patients with chronic migraine.	- Weekly telephone calls to assess the progress of training. - 1 supervised training session. - Explanatory leaflet about the warm-up exercises.	18
Madsen, 2018	60 [68%], 32 ± Na	Examine the effect of strength training of the shoulder/neck muscles on tension-type headache frequency and duration.	- Weekly telephone calls to assess the progress of training. - Some supervised training sessions. - An exercise diary to monitor adherence and migraine intensity.	19
Mehta, 2021	61 [74%] 39 ± 8.24	Evaluate and compare the effectiveness of physical and yoga therapies in patients with migraine.	- Weekly telephone calls to assess the progress of training. - Some supervised training sessions. - An exercise diary to monitor adherence.	19

Table 6. The aim of the studies and relative characteristics of the samples.

F: female; SD: standard deviation; Na: Not available

Methodological Quality

For each study, the methodological quality was analysed through the modified version of the Downs and Black Checklist. All studies included were rated as "fair quality" [195-197]. These results must consider that some items on the checklist are difficult to use in sport and exercise field. For example, the use of a double-blind study design is difficult due to the presence of a program with physical activity.

Aerobic Training

Among the identified studies that used aerobic training, there is the article by Santiago and colleagues [195]. Researchers evaluated the benefits induced by the association between exercise and medication compared to medication alone in patients with migraine. The inclusion criteria for this study were a diagnosis of chronic migraine, normal cardiac and neurological examination, and being sedentary for at least 3 months. Based on these criteria, 60 patients were included and divided into two groups: a control group receiving pharmacological treatment only, and an experimental group combining pharmacological treatment with a TC training program. The control group was treated with amitriptyline (25 mg/day) for 12 weeks. The experimental group followed the same pharmacological treatment but integrated with an aerobic training program. The aerobic training program, performed via TC, consisted of free outdoor walking of 40 min with a weekly frequency of 3 times for 12 consecutive weeks. TC strategies included weekly phone calls to monitor progress and motivate participants, the flexibility for participants to choose when and where to perform the exercises, a spreadsheet with a detailed training plan to ensure the correct execution of the exercises, and a supervised training session with a movement expert. The following parameters were evaluated: frequency (days/month), intensity, and duration/day of migraine attacks (6 h, 12 h, 18 h, and 24 h), body mass index, Back Depression Inventory, and Beck Anxiety Inventory at baseline and the end of the third month. Both groups showed a decrease in the frequency, intensity, and duration of migraine episodes. However, the efficacy of amitriptyline increased when combined with the TC training program.

Resistance Training

Of the identified studies, Madsen and colleagues [196] used a TC approach to examine the effectiveness of a resistance training program and a postural training program on the frequency and duration of migraine. A total of 60 subjects were randomised into two groups: the control group and the experimental group. The control group was instructed on ergonomic and postural correction and performed postural exercises three times a day for 10 weeks. The experimental group performed a resistance training program, with three sessions per week for 10 weeks. The resistance training program involved the execution of specific shoulder exercises with progressive intensity: initially 70%, and later 80% of 1RM. All exercises were performed with elastic bands. TC approach was applied in both groups and the strategies included a free choice of when and where to perform the exercises, weekly calls to monitor exercise adherence and manage progress and motivate subjects to protocol adherence, and some supervised sessions to manage the correct execution of exercises. In addition, participants were given a migraine diary to record the frequency, duration, and intensity of headache episodes. Although no statistically significant changes were detected between groups, the experimental group reduced the frequency of headache episodes by 11% and the duration by 10%, while the control group showed a 24% reduction in frequency and 27% in duration 27% of headache attacks.

Physical Therapy

Mehta and colleagues [197] used a randomised controlled trial to evaluate and compare the effectiveness of physical therapy (stretching) and yoga therapies, applied with a TC approach, for the adjuvant therapy of standard pharmacologic treatment in patients with migraine. Subjects diagnosed with migraine, over 18 years old, and with at least five headache attacks per month were included in the study. A total of 61 patients were distributed in three groups: physical therapy, yoga therapy, and standard therapy. The physical therapy group practiced relaxation exercises, stretching of the neck muscles, and cardiorespiratory endurance training (30 min of free walking). The yoga therapy group performed several specific exercises, including the position of the butterfly (Bhadrasana), the position of the cobra (Bhunjagasana), and the touch of the feet standing (Padhastasana). The standard treatment group continued the usual medication treatment without any additional physical therapy. Participants performed the specific program for 12 weeks. All subjects received lifestyle advice including obtaining adequate rest, not skipping meals, avoiding bright lights, and using a headache diary to identify headache triggers. TC strategies, both physical therapy and yoga groups, included free choice of when and where to perform the exercises, constant weekly calls to monitor the progress, encouragement for participants, and motivation for them to perform the recommended intervention regularly. All groups showed statistically significant improvements in the frequency and severity of headaches. Additionally, pain assessments revealed improvements in all groups compared to baseline. Table 7 summarises the different types of treatment and the training programs applied to the TC approach.

Table 7. Types of program in telecoaching.

Author, Years	Exercise	Intervention (n)	Treatment (time)	Training protocol	Main results
Santiago, 2014	AT	TCG (30) Vs. CG (30)	12 weeks of training, 3 times/w	**TCG:** 40' free outdoor walk. **CG:** usual daily activities + drug treatment.	The drug was an effective treatment for chronic migraine, but its efficacy was increased when combined with AT.
Madsen, 2018	RT	TCG (30) Vs. CG (30)	10 weeks of training, 3 times/w	**TCG:** shoulder exercises with resistance from the elastic bands. **CG:** ergonomic and posture correction + specific exercise for lumbar lordosis.	Both groups showed a reduction in the frequency and duration of migraine episodes.
Mehta, 2021	PT	TCG (20) Vs. YG (20) Vs. CG (21)	12 weeks of training, 4 times/w	**TCG:** progressive muscle relaxation exercise, self-stretching of neck muscles, isometric exercise of neck muscles, and cardiorespiratory endurance training (30' of free walking). **YG:** Pranayama, and asana followed by Savasana. **CG:** usual daily activities.	Physical therapy and Yoga, added to regular care, improved QoL and reduced the frequency of migraine.

TCG: telecoaching group; CG: control group; YG: yoga group; W: week; TC: telecoaching; QoL: quality of life; AT: aerobic training; RT: resistance training; PT: physical therapy.

DISCUSSION

The primary aim of this scoping review was to investigate the use and feasibility of TC training programs in patients with migraine. The main outcomes assessed included the intensity, frequency, and duration of headache episodes, as well as pain perception and any potential adverse events. The present study showed very interesting results. First, this scoping review comprised more than 60% of women, a distribution that aligns with numerous epidemiological studies reporting a female to male ratio of 3:1 [198]. Second, the review demonstrated that in the analysed studies, an exercise conducted in TC significantly reduced the burden of headache attacks, leading to decreases in their intensity, frequency, and duration.

The Benefits of Physical Exercise in Migraine Management

The relationship between exercise and migraine is very complex [199]. Many studies show how physical exercise may represent a trigger for migraine attacks [171,200]. Nevertheless, for many authors, these negative aspects would depend on the excessive intensity of exercise [173] or performing an inadequate warm-up [201]. We can hypothesise that it may depend on the rise of serum calcitonin gene-related peptide (CGRP) levels occurring during exercise for its cardiovascular role in vasodilation [202,203] in a susceptible subject. In contrast, many studies highlight the positive effects of exercise in this population. Indeed, exercise would seem to significantly reduce the impact of migraine, improving the lifestyle and QoL [204,205]. Moreover, the absence of exercise, which increased during the COVID-19 pandemic and related social restrictions, has been shown to affect sleep quality in migraineurs [206]. The benefits of physical exercise would seem to depend on an increase in the plasma level of β-endorphins [207]; in fact, the β-endorphin level appears to be lower in migraineurs than in healthy subjects [208]. There is evidence that exercise increases the concentration of β-endorphins in healthy individuals [209,210]. Köseoglu and colleagues [211] showed a similar effect on migraine patients both after a single training session and after a prolonged training program. Further studies in the literature highlight additional benefits of exercise in this population, including increased cardiovascular and cerebrovascular capacity, as well as improvements in psychological states such as depression, stress, and anxiety [199,212]. Moreover, exercise has been shown to improve pain perception [213]. After exercise, patients show a reduction in pain-related fear and its perception [213]. In addition, migraine is a risk factor for excessive drug intake [214]. Overuse of medications in migraine patients causes increased disability, depression, anxiety, and fear, as well as increased pain and headache frequency (i.e., medication overuse headache) [215]. Consequently, exercise can be proposed as a useful tool to counteract the high use of drugs. Despite these positive aspects, as shown by Lemmens and colleagues [216], the drop-out rate to exercise is very high in migraineurs, due to the lack of time to perform supervised exercise training sessions/week [216].

Telecoaching: A Digital Approach to Migraine Management

Considering the spread and convenience of telemedicine, the new technological solutions in managing migraine [217], along with the need for structural changes in healthcare [82], TC could represent a valuable approach for this population. By providing personalised guidance and remote support, TC aligns with modern healthcare trends and has the potential to enhance adherence to physical activity programs. This approach could be particularly beneficial for migraine patients, offering accessible and flexible training options that remove common barriers to exercise. However, it is important to acknowledge the psychological variables and the strong association between anxiety, mood disorders, depression, and migraine [218]. Participants' attitudes toward TC may have played a crucial role in their performance in the included studies [219]. Positive attitudes toward this training modality can improve participant engagement, adherence, and overall satisfaction, while negative perceptions may reduce participation and limit the effectiveness of the intervention. This highlights the need to design user-friendly tools and methods that support acceptance of the condition and provide adaptive content and functionality [219]. However, attitudes toward telemedicine and eHealth are rarely reported or analysed as factors influencing participant performance in existing studies [220]. Future research should address this gap by incorporating these attitudes as a variable of interest, both in study design and analysis. To reduce stress, a major trigger of migraine attacks, Varkey and colleagues proposed the implementation of home training programs [221], incorporating TC training modality to enhance physical activity levels. Consistent with Varkey's study [221], the articles included in this review have shown several benefits. Indeed, in every study included in this review, the dropout rate in the TC group did not exceed 30%, with one study that showed a 0% dropout rate for the TC training program [197]. This demonstrates how TC is a sustainable and accepted training methodology in this population. This finding is significant for patients who intend to perform a training protocol and for physicians who intend to advise active participation in a physical activity program for migraine patients. The sustainability of TC and the relative benefits (i.e., training in the preferred place, during the leisure time, breaking down barriers such as costs and structures [39]) make TC one of the main solutions for physical activity intervention. The sustainability of TC in migraine is in line with the scientific literature for other neurological diseases. Burns and colleagues evaluated the effectiveness of a TC resistance training program for the weakness of the dorsiflexion of the foot in children with Charcot–Marie–Tooth polyneuropathy. The intervention program attenuated the progression of weakness in dorsiflexion without side effects and with a low abandonment rate (8%) [72]. Van der Kolk and colleagues evaluated the efficacy of aerobic exercise performed in TC to relieve motor symptoms in patients with mild-severity PD. The reduction in motor symptoms demonstrated in the intervention group showed how TC can be a useful additional tool to manage this disease. Ninety-four percent of the participants completed the study, demonstrating high tolerance to the TC training modality. In agreement with Varkey and colleagues, our study suggests the possible implementation of TC in patients with migraine; although, the few included studies reported in this scoping review do not allow us to evaluate in detail the relationship between TC and migraine in detail. Future studies should analyse and evaluate the efficacy of a fully executed TC training program, using uniform outcome measures for migraine as recommended by the International Headache Society [222], with a randomised controlled trial design based on the guidelines of the American College of Sports Medicine (3–5 days per week, 20–60 min, with an intensity equal to 55/65–90% of maximum heart rate).

Strength and Limitations

The following limitations were identified in this study: firstly, the few studies included and the heterogeneity of the physical activity programs used could alter the generalisation of results, not allowing the correct relationship between migraine and TC to be assessed. Secondly, the quality of the studies was not excellent, a condition that could depend on the researchers' lack of double-blinding (a condition that is difficult to apply with an exercise program to be performed). Additionally, the lack of homogeneity in the evaluation methods did not allow us to conduct a meta-analysis. Finally, the absence of a direct comparison between groups treated with and without TC represents a significant limitation of this review, as it does not allow us to assess in detail the true effects of TC. Thus, the observed benefits may not be exclusively attributed to TC. Future studies should aim to design randomised controlled trials to clarify these effects and to evaluate the participant's attitudes towards the TC, especially considering the absence of psychological component evaluations in the included studies. Despite these limitations, this review has several strengths. It highlights that TC is potentially safe, effective, and risk-free for migraine patients. An additional strength is the dropout rate: no included study showed a dropout exceeding 30% and one study noted a 0% dropout rate. Finally, to our knowledge, this is the first review in the literature to examine the application of TC in migraine patients, as well as the first attempt to evaluate novel treatments for the management of this disease and the exacerbation of symptoms observed during the COVID-19 pandemic.

CONCLUSIONS

The results of this review, based on GRADE guidelines, show low evidence that exercise performed in TC is beneficial in patients with migraine. Further studies are needed to show the efficacy, benefits, and safety of this training modality, as well as to establish guidelines for administering a TC training program in this population. Future research should focus on high-quality randomised controlled trials to clarify and isolate the effects of TC on migraine outcomes. These studies should aim to standardise physical activity programs and standardised outcome measures to enable more comparisons. Additionally, it is essential to assess participants' attitudes toward TC in future studies, as this factor could significantly influence their performance and engagement. Addressing these gaps will help to clarify the role of TC as a treatment modality for migraine and establish evidence-based guidelines for its use.

2.4 Telecoaching in Elderly Populations: Promoting Functional Independence

List of publications/projects discussed within Chapter II:

Leale, I., Figlioli, F., Giustino, V., Brusa, J., Barcellona, M., Nocera, V., Canzone, A., Patti, A., Messina, G., Barbagallo, M., Palma, A., Dominguez, L. J., & Battaglia, G. *(2024). Telecoaching as a new training method for elderly people: a systematic review.* Aging clinical and experimental research, 36(1), 18. https://doi.org/10.1007/s40520-023-02648-9

INTRODUCTION

The world aging process is indisputable, 125 million people are 80 years of age or older, altering the social, economic, and health systems of most countries. Population aging is a problem for the present and especially for the future, and the United Nations estimates that the elderly population will reach 2 billion by 2050. This aging process results from the increase in life expectancy, the decrease in birth rates, and the advances in medical care and technology. The European Commission has recently expressed the need to increase scientific research to ensure healthy aging. Indeed, after the age of 40, it is possible to detect a first involution of the physiological systems, involution that develop at a peak near 65 years of age [223,224]. Aging is a process associated with structural and functional changes in both the physical and mental domains. The mental component is altered due to neurological mechanisms related to aging [225], such as vestibulocochlear degeneration [226], the reduction of cognitive functions [227], and the development of dementia and depression [227], while the physical component is associated with a decreased muscle strength, muscle flexibility, and body balance [226,228]. All these impairments, associated with a sedentary lifestyle, accelerate the decline of bodily functions [229] and increase the risk of falls [230,231]. Consequently, to ensure a healthy aging, it is important to develop appropriate health habits such as sleep management, stress management, balanced nutrition, and physical activity (PA) practice [14]. PA has been shown to be effective in encouraging a healthy aging [232]. For example, a regular outdoor walk seems to generate benefits on body balance ability in elderly people and consequently prevent the risk of falls [233]. The benefits of PA in elderly have also been demonstrated in sarcopenia [230] and osteoporosis diseases [234], as well as to improve physical performance such as the range of motion (ROM) of joints. For example, a flexibility training program has been shown to improve spinal ROM in a population of older women [235]. In consideration of the recent COVID-19 pandemic and the relative restrictive measures, it would be useful to increase the duration of the weekly time of PA practice in elderly people [236,237]. Indeed, the recent COVID-19 pandemic, due to the numerous restrictive measures implemented, has reduced the levels of PA practiced by this population [238,239]. As a consequence, different strategies have been developed and, among these, TC seems to result as an effective training setting for maintaining the recommended levels of PA [153,240]. TC provides the use of information technologies and digital communications, such as computers and mobile devices, to access training services remotely [241]. It is a useful training method for all patients with travel difficulties, who live in different cities, or who prefer to train in a familiar environment such as their own home [39]. Therefore, this systematic review aimed to analyse the application, efficacy, and safety of TC training programs in elderly people.

METHODS

Search strategy

For conducting this systematic review, the PRISMA guidelines were adopted [242]. The studies were searched in electronic databases such as PubMed, Scopus, and Web of Science. To find studies, the following keywords were used in different combinations: telecoaching, exercise, elderly, training protocol, and training program. All the articles found were transferred into Endnote software (vers. X9 for Windows 11, © Thomson Reuters).

Eligibility Criteria

All studies that have the following criteria were included in this systematic review: (1) studies with TC as training program for elderly people; (2) original research with full text written in English language; (3) studies published in the last decade; (4) study designs other than reviews, meta-analysis, letter to editors, and theses. No gender differences between males and females were considered for this study.

Study selection

The search of the studies was performed by one author of the research group (I.L.). After removing duplicates, two authors (F.F. and V.G.) independently analysed the titles and abstracts of all studies. Other two authors (J.B. and M.B.) later analysed the full text for study inclusion according to the inclusion and exclusion criteria. In case of disagreement of the latter two authors, a negotiation process was carried out and, if necessary, a third author (V.N.) was consulted. A Microsoft Excel spreadsheet (Microsoft Corp, Redmond, Washington) was used to record the following information related to the included studies: year of publication, sample age, gender, aim of the study, and TC program.

RESULTS

Study Identification

From the search conducted on these databases, a total of 113 studies analysing the use of TC in elderly were found. 77 were doubled and 33 were eliminated because they did not include elderly subjects, or they analysed a different topic. Only 3 articles were finally included. In detail, 2 studies aimed to evaluate the effects of TC in elderly suffering from respiratory diseases, while 1 study aimed to evaluate the effects of TC in elderly suffering from metabolic disease. The PRISMA flowchart shows the entire selection process (Fig. 2).

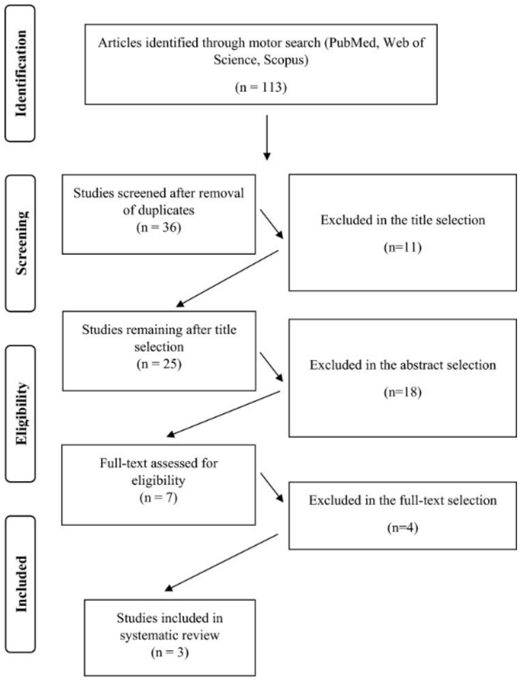

Figure 3. Flow Diagram representing the entire selection process

A total of 194 elderly participants were included and the sample size varied from 12 to 117 while the TC training program lasted from 8 to 12 weeks. Detailed information is provided in Table 8.

Table 8. *Characteristics of the studies included*

1st author, year	Participants [f] [m]	Age (SD)	Weeks	Aim	Tele-coaching
Cameron-Tucker, 2016	65 [36] [29]	68 (8.6)	8	Evaluate the effectiveness of tele-coaching in patients with COPD.	Tele-coaching supported participants' home-based walking through pedometers and two calls weekly.
Hume, 2022	12 [4] [8]	57 (9.0)	12	Evaluate the effectiveness of a tele-coaching program on LTx patients.	Tele-coaching supported physical activity programs through a smartphone app, pedometers, and calls weekly.
Storch, 2019	117 [23] [94]	59 (6.3)	12	Evaluate the effects of tele-coaching in patients with T2DM	Tele-coaching supported a lifestyle intervention through an individual coaching approach.

Table 9 shows details of the training program and the results found in the articles included.

Table 9. *Description of intervention, training program, and results of the studies included*

1st Author, Years	Intervention	Training program	Results
Cameron-Tucker, 2016	Tele-coaching (35) vs. usual care (30) + physical activity	Patients were asked to walk at a moderate intensity (i.e., to breathe more heavily but not to "huff and puff") to accumulate 30 minutes daily, preferably all days of the week.	There were no significant changes between time points or between groups.
Hume, 2022	Tele-coaching (7) vs. usual care (5)	Patients were asked to wear the pedometer during waking hours and interact with the smartphone application every day by reviewing and completing the automated application tasks (free walking + home exercise).	Tele-coaching seems to be a feasible, safe, and well-accepted intervention in LTx.
Storch, 2019	Tele-coaching (60) vs. usual care (55)	Patients were asked to wear a pedometer and walk. Periodically through a telephone meeting, the coach and participant have decided the goals.	Patients with TD2M can benefit from this new type of intervention. Tele-coaching has proven useful in disease management.

Respiratory diseases

The first study included in this review was conducted by Cameron-Tucker and colleagues [84] who applied the TC method to patients with COPD which is a chronic inflammatory disease with non-reversible obstruction of airways. The researchers investigated telephone health mentoring aimed at home-based free walking (TC or experimental group) compared to the usual waiting time (usual care or control group) followed by a training program for each group. Participants were randomized between the two groups (i.e., TC and usual care). TC provided by trained nurse healthcare supported participants' home-based free walking for 8 weeks, to accumulate 30 min of training per day, preferably every day of the week. Data collection was performed at the baseline (T1), after the TC program (T2), and at the end of the training program of both groups (T3). The primary outcome was a change in physical capacity measured by a 6-min walk test, resulting in highly indicative disease status in patients suffering from respiratory diseases [243]. The results demonstrated no significant changes between time points in the TC group. It follows that in patients with COPD, telephone mentoring for home-based walking has not demonstrated any benefit on exercise capacity. The second study included in this review was conducted by Hume and colleagues [83]. The researchers evaluated the feasibility and acceptability of a TC training program for lung transplant recipients (LTx). The program included 12 weeks of TC training program. In detail, patients were recruited and randomized into two groups (i.e., TC and usual care). TC involved the use of a pedometer and a smartphone app, with the latter the researchers established periodic PA goals, monitored the activity performed by patients, and dialogued with them if necessary. 86% of participants rated the TC training program positively. The pedometer was used excellently, being used by the patients for 90% of the study period without any negative events. After 12 weeks, only the TC group showed significant improvements in daily steps and movement intensity, while both groups showed significant changes in quality of life (SF-36). In conclusion, TC in patients with LTx appears to be safe, feasible, and well-accepted.

Metabolic diseases

The third study included in this review was the only one that applied TC in elderly patients suffering from metabolic diseases. In detail, Storch and colleagues [244] applied TC in patients with type 2 diabetes mellitus (T2DM). Participants were recruited and randomized into two groups (i.e., the intervention group with the TC training program and the control group with usual care). The TC training program lasted 12 weeks and, through a tablet, a glucometer, and a pedometer, different measures relating to diet, PA, and stress management were recorded. In each phone-based meeting, the participant and the coach individually decided on the patient's periodic goals to manage the disease. The number of daily steps was monitored continuously through the pedometer and automatically reported each day through Bluetooth. The results showed a greater reduction in glycated hemoglobin (HbA) values in the experimental group compared to the control group. In addition, the analysis conducted on PA demonstrated, although not significant, an increase in terms of average daily steps for the intervention group compared to the control group. However, this increase allowed a significant improvement in the management of the body mass index. It follows that a TC training program could be a new approach to manage disease progression in patients with T2DM.

DISCUSSION

This systematic review aimed to analyse the use of TC training programs in elderly people. Indeed, the average age of the world population is constantly growing and epidemiological studies showed that the number of people aged 60 or more exceeds 11% and is expected to increase reaching 22% in 2050. This aging process causes an increase in the development of age-related diseases and respiratory and metabolic diseases. One of the major respiratory diseases is COPD. This disease is characterized by bronchial obstruction with a progressive increase in dyspnea generating large physical limitations. For this reason, one of the main objectives to contrast this disease is to limit the sedentary lifestyle. This is demonstrated by the fact that physically active people with COPD have a lower risk of hospitalization and death than sedentary ones. Despite the demonstrated benefits of PA, these patients are still largely sedentary [245]. It follows that exercise professionals should counter the misconceptions related to the practice of PA or exercise in order to motivate individuals to train [246]. In this way, Cameron-Tucker and colleagues applied TC to these patients. Although their results demonstrate that the use of a diary with weekly walking plans and 1 h of weekly exercise does not induce benefits, TC can still be considered a useful method to increase daily PA time. The non-significant results found could depend on the reduced duration of the program, the small sample size, and the small number of tests carried out to evaluate physical efficiency. The 8 weeks of duration with 7 calls for single individual does not seem to be sufficient. Indeed, a systematic review of elderly patients with various chronic diseases demonstrated that 12 or more calls in 6–12 months are effective in increasing PA and improving eating behaviour [247]. Moreover, this study agrees with the scientific literature that 1 h of supervised exercise is insufficient to generate improvements in exercise capacity, supporting that at least two weekly sessions are necessary to improve exercise capacity in these patients [248]. A further disease analysed in this review refers to elderly with LTx, i.e., patients with end-stage lung disease who require surgery. In recent years, the disease survival rate has improved significantly and the International Society for Heart and Lung Transplantation Registry reports a 5-year survival rate of 59% [249]. It follows that one of the main objectives is to improve physical functions and the related quality of life in this population [250]. The study by Hume and colleagues demonstrated the effectiveness of TC in these patients. In detail, 86% of the participants evaluated this intervention positively stating that this allowed them to increase PA time. On the contrary one study in COPD patients, with the same intervention program, had a 59% satisfaction level [251]. 47.8% of participants with COPD rated goal progression as “high” or “much too high” compared to only 14% of participants with LTx. These results seem to suggest a greater ambition in choosing physical goals in LTx patients than in COPD patients. This condition could be due to a greater consideration of the role of PA and the clear progress that the practice of PA generates in the symptoms of these patients [252]. The effectiveness of TC in elderly patients was also analyzed in subjects with T2DM. Diabetes is a metabolic disease characterized by chronic hyperglycemia with impairment of carbohydrate metabolism caused by partial or non-secretion of insulin. T2DM is the most common form of diabetes mellitus reaching 90/95% of all patients with diabetes. It is also predicted that patients with this disease could become 439 million by 2030 [253]. The main objective for these patients is to prevent the onset of complications to maintain a high quality of life index [254]. In order to reach this goal, blood sugar levels need to be checked periodically and the American Diabetes Association (ADA) recommends HbA values < 7% [254]. TC program applied by Storch and colleagues allowed a reduction in HbA values from 7% to 6.6%, demonstrating the success of this training method in these patients. In detail, TC intervention has made it possible to increase daily activity with a consequent reduction in a sedentary lifestyle. A further benefit is the prevention of cardiovascular disease and all other complications that lead to death, especially in males with T2DM. It should be noted that high levels of physical fitness are associated with greater insulin sensitivity favouring better management and control of diabetes [255,256]. Although 30% of elderly people suffer at least one fall per year [257], no literature supporting the application of TC as primary method for preventing falls in the elderly was identified. As reported by Lord and colleagues, one-third of older people experience at least one episode of falling each year [258]. The prevention of falls, due to the constant aging of the world population, is one of the main public health problems. Falls, after road accidents, are the main cause of death related to injuries among elderly subjects in the world [259], resulting in one of the main causes of death for people over 65 years of age [260]. In detail, high levels of PA reduce mortality and fall risk in the range of 30–50% [261-263].

CONCLUSION

This systematic review highlighted that few studies have been conducted for evaluating the efficacy of TC training programs in elderly people. Despite this, the few studies included in this systematic review demonstrated that this training method seems to be safe, effective, and injury-free. In detail, the findings suggest that TC can be effective in subjects with metabolic diseases while partial results have been recorded in subjects with respiratory diseases. Considering these results, further studies are needed to analyse the effectiveness of this intervention program. Moreover, future studies should investigate the efficacy of this training method also on different physical performance such as balance ability to evaluate its effects on falls prevention because TC program could increase adherence to the training, thanks to the possibility of overcoming barriers such as costs, time, travel, and facilities.

List of publications/projects discussed within Chapter II:

Leale, I., Giustino, V., Brusa, J., Barcellona, M., Barbagallo, M., Palma, A., Messina, G., Dominguez, L. J., & Battaglia, G. (2024). *Effectiveness of a Sustainable Training Program Combining Supervised Outdoor Exercise with Telecoaching on Physical Performance in Elderly People*. Sustainability, 16(8), 3254. https://doi.org/10.3390/su16083254

INTRODUCTION

The aging process is expanding, and, in fact, 125 million people worldwide are 80 years old or older. In this regard, the WHO predicts an increase in the elderly population which will reach 426 million in 2050. This process is mainly due to social and economic development, which has caused a reduction in births and an increase in life expectancy [264]. For this reason, the WHO and the European Commission have expressed the need to intervene to improve quality of life and ensure the adequate aging of the elderly population [265]. It is well known that aging is a natural and progressive process which is associated with a decline in both the mental and physical spheres [258]. As a matter of fact, decreased cognitive functions, impaired sensory function, and a reduction in strength, body balance, and flexibility can occur at this stage of life [228,266-268]. And it is known that, in this population, a minimal decrease in functional abilities can negatively influence quality of life and autonomy [269]. Although healthy aging is a multifactorial phenomenon, regular physical activity and exercise can contribute to preserve the physical and mental components, consequently improving quality of life [270]. The literature suggests that it is necessary to identify effective methods to increase engagement and maintain high training adherence in this population [271,272]. Several studies have demonstrated the fundamental role played by physical activity and exercise in combating heart disease, diabetes, osteoporosis, the risk of falls, and other common deficits that affect the elderly population [273,274]. Battaglia et al. (2020) showed that regular walking in an outdoor environment leads to beneficial effects on body balance capacity in the elderly and this can, consequently, prevent the risk of falls [233]. Similarly, it has been shown that a flexibility training program leads to an improved spinal RoM in a population of elderly women [235]. The effectiveness of training programs on specific abilities and quality of life has been widely demonstrated not only on the healthy elderly population but also on those suffering from pathologies or musculoskeletal alterations [275,276]. A recent study detected improvements in pain and quality of life and significant functional improvement in Timed Up and Go (TUG) performance after a 7-week program in women with multiple vertebral fragility fractures [277]. Hennig et al. (2015) investigated the effects of home-based hand exercises in women with hand osteoarthritis and found positive clinical difference on activity performance measured through the Patient-Specific Functional Scale (PSFS) and significant difference in physical performance such as grip strength [278]. In a study by Martínez-Velilla et al. (2019) a sample of elderly patients was randomly divided into an exercise group (resistance, balance, and walking exercises) and a control group (usual-care hospital care). Among the findings, the exercise group showed significant benefits over the control group, with an increase of 2.2 points detected on the SPPB [279]. This evidence emphasizes the crucial role played by physical exercise regardless of the type. Among the latter, also due to the COVID-19 pandemic, outdoor exercise and TC are settings that have been widely used [280,281]. In detail, outdoor exercise (also named green exercise) concerns the practice of physical activity or exercise in natural environments; it is characterized by easy accessibility and mainly uses walking as a type of exercise [233]. The benefits of nature exposure on psychophysiological health are documented in the literature, and this exercise setting can also counteract conditions caused by urban living such as air pollution, urban noise, and crowding [282,283]. For example, a recent systematic review has shown that Nordic Walking can represent a safe and accessible outdoor exercise for the elderly population, improving cardiovascular function, balance ability, and quality of life. In detail, this walking program showed benefits on dynamic balance, functional balance, upper and lower limb strength, aerobic capacity, and lipid profile [284]. TC represents a solution for those individuals who are unable to practice physical exercise in sports centres, and, thanks to the remote presence of a sports and exercise science professional and the use of wearable devices, it can be individualized [285]. In fact, TC involves the use of information technology and digital tools such as computers and mobile devices to access training services remotely [39]. However, as demonstrated by our previous systematic review, few studies have used TC, as a training method, in the elderly population and no studies have used a combined training approach (TC and supervised exercise) [81]. In detail, Hume et al. (2022) applied this physical exercise method to elderly patients with lung transplantation and, after 12 weeks, the TC group showed statistically significant improvements in daily steps, movement intensity, and quality of life [83]. Von Storch et al. (2019) used TC in elderly patients with type 2 diabetes, showing, after 12 weeks, a reduction in glycated hemoglobin values, an increase in the number of daily steps, and an improvement in the management of body mass index [244]. Based on this knowledge, the aim of this study was to investigate the effectiveness of a sustainable training program combining supervised outdoor exercise with TC on physical performance in elderly people. This study is part of the project "Walking Leaders", a supervised green exercise program that also includes TC exercises for elderly people. It was developed based on our previous outdoor walking plan in natural environments, named "Passiata Day" model [233].

MATERIAL AND METHODS

Study Design

This study is part of the project "Walking Leaders". This is a project developed for elderly people in which a training program combining supervised outdoor exercise with TC is carried out by sports and exercise science professionals. The project was developed based on our previous project, named "Passiata Day" model [233]. The project "Walking Leaders", currently ongoing and lasting a total of 2 years, involves the recruitment of approximately 150 elderly people from the metropolitan city of Palermo (Italy). Over the two years, participants will be recruited in groups of approximately 30 each for a total of 5 groups. Participants recruited in the study were divided into 2 groups: a trained group (TG), who performed the training program, and an untrained group (UG), who did not complete the established minimum period of the training program (i.e., 75%). As in this study, we did not randomly assign participants to the TG or UG, the present is a quasi-experimental design. The training program was an 8-week sustainable training program combining supervised outdoor exercise with TC. The training program was preceded by a theoretical phase of 6 meetings, lasting 3 h each, in which the topics of physical activity, balanced diet, adequate rest, and stress management were addressed by medical doctors and professionals of these sectors. For this first study, we considered participants from the first 2 groups recruited. The measurements were carried out before (T0, baseline) and at the end of the training program (T1, after 8 weeks) by sports and exercise science professionals of the Sport and Exercise Sciences Research Unit of the Department of Psychology, Educational Science and Human Movement of the University of Palermo (Italy), and took place at the Functional Evaluation Laboratory and the Posturology and Biomechanics Laboratory of the same institution.

Participants

A total of 62 participants were enrolled in this study using the following inclusion criteria: (1) ≥60 years of chronological age; (2) ability to provide informed consent for study participation; (3) medical certificate attesting cognitive and physical suitability for the practice of physical activity; and (4) a declared ability of self-care. The exclusion criteria included the following: (1) inability or high difficulty in walking, as established by a score <18 on the Tinetti scale [286]; (2) participating in less than 75% of the training program. Of these, 2 participants dropped out of the study. Of the 60 participants (32 f, 28 m; age: 71.20 ± 6.01 years; height: 1.60 ± 0.09 m; weight: 70.24 ± 16.29 kg; BMI: 27.31 ± 5.48), 11 did not complete the established minimum period of the training program (i.e., 75%). For this reason, the 60 participants were divided into 2 groups: a trained group (TG) composed of 49 participants and an untrained group (UG) composed of 11 participants, as shown in Figure 4. The characteristics of the two groups' participants are reported in Table 10.

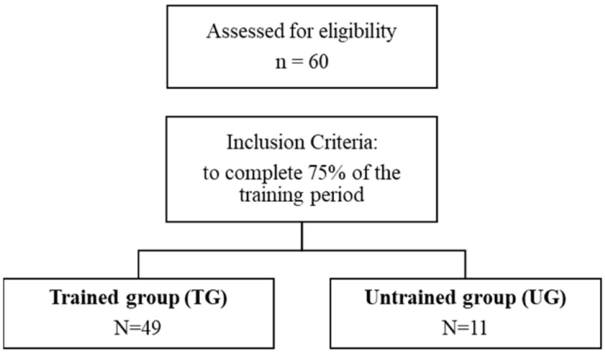

Figure 4. *Division of participants into the two groups.*

Table 10. *Characteristics of the participants.*

	Total sample (mean±SD)	TG (n=49) (mean±SD)	UG (n=11) (mean±SD)
Male/Female	28/32	23/26	5/6
Age (years)	71.20±6.01	71.32±5.98	70.64±6.38
BMI	27.31±5.48	27.22±5.70	27.70±4.61
Weight (kg)	70.24±16.29	71.01±14.41	72.38±14.23
Height (m)	1.60±0.09	1.60±0.09	1.61±0.08

All participants provided informed consent for participation in the study, and they could withdraw at any stage of the study. The study was approved by the Ethics Committee Palermo 1 of the University Hospital “Policlinico di Palermo” (n. 06/2022) and complies with the criteria defined in the Declaration of Helsinki.

Measurements

All the measurements were carried out in random order for all participants. Each measurement is detailed below.

Anthropometric measurements

Anthropometric measurements were performed as follows. Body weight was measured using a Seca electronic scale (maximum weight recordable: 300 kg; resolution: 100 g; Seca, Hamburg, Germany), with the participants standing upright and barefoot, in light clothing, and with arms along the trunk. Body height was measured through a stadiometer (maximum height recordable: 220 cm; resolution: 1 mm), with the participants standing upright and barefoot. BMI was calculated as weight divided by height squared (kg/m2).

Handgrip test

The handgrip test allows to measure the grip capacity, that is, the maximum isometric strength developed by the muscles of the hand and forearm. Each participant performed the test as recommended by the American Society of Hand Therapists [287], that is, with the back leaning against the back of the chair and the elbow joint positioned at 90°. At the signal, each participant performed the test by squeezing the handle of a mechanical dynamometer (Kern Map model 80K1-Kern®, Kern & Sohn GmbH, Balingen, Germany) with maximum isometric grip strength. Each participant performed 3 trials with both the right and left hand, with 1 min of rest between trials. For the statistical analysis, the best results of the 3 trials for each hand were considered.

Timed Up and Go (TUG) test

The TUG is a test used to measure balance capacity, the level of functional mobility, and the associated risk of falls. The test measures the time it takes to get up from a chair without using the hands, walk 3 m, turn around, return, and sit back down on the chair. During the test, the participant can use walking aids. A score of 10 s or less indicates normal mobility; times between 11 and 20 s represent the normal range for elderly individuals with frailty or disabilities; times over 20 s indicate that the individual requires assistance; values above 30 s indicate a high risk of falls [288].

Short physical performance battery (SPPB)

The SPPB is a test developed to measure functional status and physical performance [289]. This battery contains 3 components with the aim of analyzing balance capacity, gait speed, and lower limb function. In detail, for the balance capacity, the following 3 balance tests are included: (1) the “side-by-side stand”, in which each participant was asked to stand with feet together, side-by-side, for 10 s; (2) the “semi-tandem stand”, in which each participant was asked to stand with the side of the heel of one foot placed by the big toe of the other foot for 10 s; and (3) the “full-tandem stand”, in which each participant was asked to stand with the heel of one foot placed in front of the toes of the other foot for 10 s. As for gait speed, each participant was asked to walk 4 m at a normal pace. The starting time was recorded when one foot began to move beyond the starting line and stopped when one foot completely passed the finishing line. Regarding lower limb function, to execute the chair stand test, each participant was asked to sit on a chair with both feet flat on the floor, and then, with arms folded across the chest, to stand up and sit down as quickly as possible 5 times without stopping. The execution time was recorded. The test was considered valid if the participant performed the full movement (knees extended) and was stopped if the participant became too tired, used the arms, or the execution exceeded 1 min. For each component, the maximum total score is 4 and the final maximum score that can be obtained by their sum is 12. A high score indicates a high level of functionality, while a low score indicates a low level of functionality. Low scores on the SPPB have been shown to predict increased fall risk [290], reduced personal autonomy [291], decreased mobility [292], and worsened health [293].

Tinetti Scale

The Tinetti scale allows balance capacity and gait to be measured [294]. The items concerning balance are the following: sitting balance, rising from a chair, attempts to stand, standing balance, standing balance prolonged, Romberg, Romberg with nudge, turning balance (360°), and sitting down. The following items focus on gait: initiation of gait, step length and height, step symmetry, step continuity, path deviation, trunk stability, and walking stance. The scores of all items are combined to develop three measures: an overall balance assessment score, an overall gait assessment score, and a total score. The maximum score for the balance component is 16 points. The maximum score for the gait component is 12 points. The maximum total score is 28 points. A total score of 24 or more indicates a low risk of falling, a total score of 19 to 24 indicates a moderate risk of falling, and a total score of 18 or less indicates a high risk of falling [286,295].

Training Program

The sustainable training program was a combined approach consisting of supervised outdoor exercise and TC. The sustainable training program lasted 8 weeks and consisted of 5 sessions/week, of which 2 sessions/week involved supervised outdoor exercise (walking, as in the study by Battaglia et al. (2020) [233], and balance circuit ~90 min, as in the studies by Battaglia et al. (2010) and Bellafiore et al. (2011) [261,262]) and 3 sessions/week involved TC [2 sessions/week of resistance training (~40 min) and 1 session/week of free-walking (~40 min)]. In accordance with the WHO recommendations for physical activity practice in elderly people (i.e., from 150 to 300 min of moderate physical activity), participants performed a weekly volume of 300 min of physical activity. More details on the weekly distribution of physical activity minutes are shown in Figure 5.

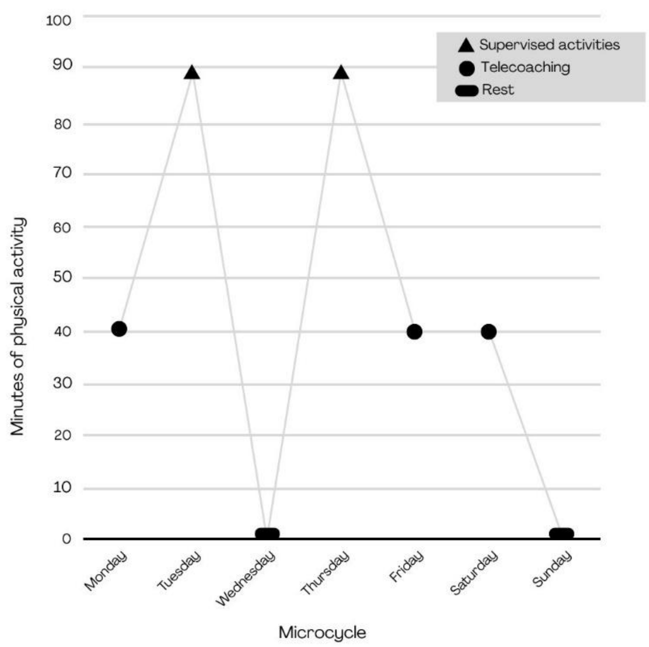

Figure 5. Microcycle training program.

Supervised outdoor exercise

Each session of the supervised outdoor exercise was composed of a warm-up phase (~15 min), a central phase (~60 min), and a cool-down phase (~15 min). In the warm-up phase, from standing posture, participants executed a standard sequence of exercises, including circling movements of the shoulders, pelvis, feet, and trunk rotations. In the central phase of each session, participants were randomly divided into two subgroups, and one subgroup started with the execution of a walking path and subsequently carried out a balance circuit while the other subgroup performed the exercises in reverse order. The supervised walking, carried out in groups, involved the following setting: (1) 1st and 2nd week: slow walk (1.5–3.0 km/h; <3 MET); (2) 3rd week: moderate walk (4.5–6.0 km/h 3–6 MET); (3) 4th and 5th week: slow walk (1.5–3.0 km/h) with axial loading (2% of body weight); (4) 6th and 7th week: moderate walk (4.5–6.0 km/h) with axial loading (2% of body weight); (5) 8th week: moderate walk (4.5–6.0 km/h 3–6 MET). The walking speed was controlled by a sports and exercise science professional (J.B.) who was the leader of the group and by another researcher at the end of the group (I.L.) who wore a smartwatch, as well as by at least 3 other sports and exercise science professionals who were in the group. A representation of the supervised walking is shown in Figure 6.

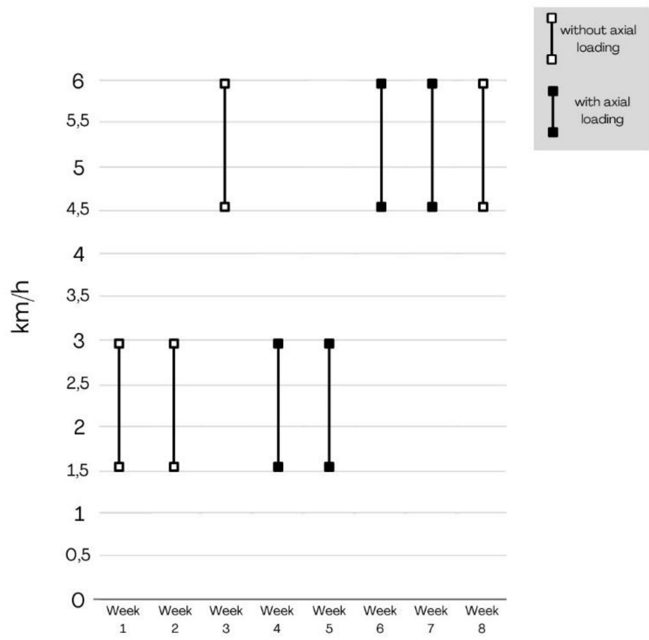

Figure 6. Supervised outdoor walking program. X: axial loading.

The supervised balance circuit was managed by a sports and exercise science professional (M.B.) and predicted a ratio of 3:8 (3 coaches and 8 subjects) in the initial phase of the program, which evolved with a ratio of 2:8 in the final four weeks. The balance circuit involved the following setting: (1) from 1st to 4th week = 2 circuits training/session; (2)

from 5th to 8th week = 3 circuits training/session. For the balance circuit the axial loading adopted from week 4 to week 7 was used. The cool-down phase included free body movements, deep breaths, and isometric contractions of both arms in different positions.

Telecoaching

The TC training, carried out using demonstration videos, consisted of resistance training and free walking. The resistance training (2 sessions/week of about 40 min) consisted of a warm-up phase, a central phase, and a cool-down phase. The warm-up phase included dynamic movements of the neck, shoulders, trunk, and legs (3 series x 8 repetitions). The central phase included 8 exercises (3 series x 8 repetitions): (a) lateral raises with elastic bands; (b) biceps curl with elastic bands; (c) handgrip exercise; (d) front raises with elastic bands; (e) box squat; and (f) calf exercise. The cool-down phase included free body movement, deep breaths, and isometric contractions (2 series of 30 s). The free-walking (1 session/week of about 40 min) was self-managed based on the indications previously received in TC.

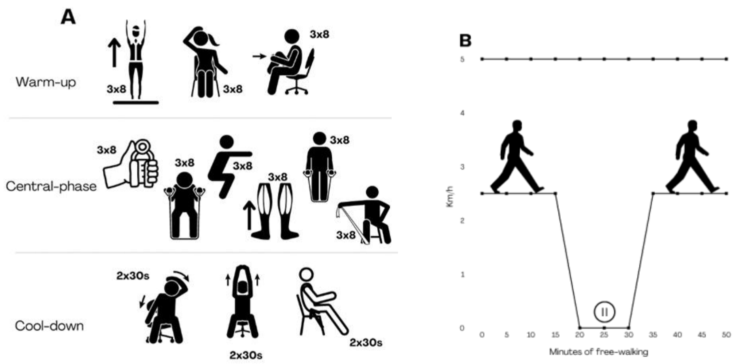

Figure 7. (A). TC: resistance training exercises with series and repetitions. (B). TC: free walking.

The TC training was monitored via weekly calls and through an exercise diary filled out weekly by each participant. Moreover, in order to guarantee the correct execution of the training program, a training manual was created. In addition, sports and exercise science professionals were always available to resolve any doubts regarding the execution of the exercises. The presence of psychologists was useful in maintaining high motivation and adherence to the TC training.

Statistical Analysis

Data are presented as mean ± standard deviation. The data distributions were tested through the Shapiro–Wilk test. Any difference between T0 and T1 within groups was analyzed. Student's T-test or Wilcoxon T-test was used in relation to the results of data distributions of the Shapiro–Wilk test. All analyses were performed using Jamovi software (The Jamovi project (2021). Jamovi (Version 1.8.0.1) [Computer Software]). The significance for all analyses was set at $p < 0.05$. Graphs were created using GraphPad Prism 7 (GraphPad Software Inc., San Diego, CA, USA).

RESULTS

Of the total of 60 participants, 49 performed 75% of the training protocol, resulting in the TG (26 f, 23 m). More information about the TG and UG can be found in Table 1. The results of the Shapiro–Wilk test of each measurement, means and standard deviations, and levels of significance of the comparison between T0 and T1 are reported in Table 8.

	Shapiro-Wilk		T0 (mean±SD)	T1 (mean±SD)	p-value
	W	p-value			
right handgrip°	0.94	0.015	27.47±11.58	28.82±11.06	<0.001***
left handgrip×	0.967	0.176	25.11±10.80	26.39±10.30	<0.001***
TUG°	0.918	0.002	7.19±1.37	6.56±1.36	<0.001***
SPPB°	0.759	<0.001	11.22±0.98	11.5±0.82	0.012*
Gait Speed°	0.838	<0.001	4.90±1.66	4.67±1.43	0.194
Sit To Stand°	0.946	0.025	9.98±2.07	8.05±2.02	<0.001***
Tinetti Scale°	0.871	<0.001	24.92±2.74	26.20±1.38	0.002**
Balance°	0.741	<0.001	15.78±1.53	16.76±0.48	<0.001***
Gait°	0.948	0.03	9.14±1.63	9.45±1.26	0.359

Table 11. Performances at T0 and T1 of the TG.

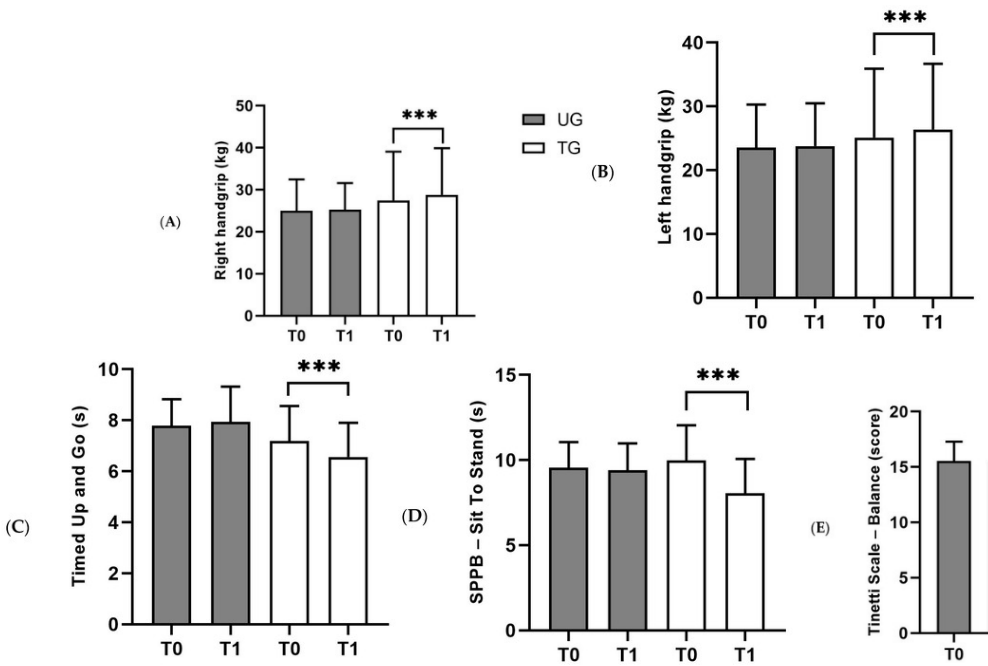

Figure 8. Results of the comparisons between T0 and T1: (A) kg expressed by the right hand in the handgrip test; (B) kg expressed by the left hand in the handgrip test; (C) time to perform the TUG test; (D) seconds for the execution of the Sit To Stand of the SPPB; and (E) score of the balance of the Tinetti scale. ***, $p < 0.001$.

In the TG, we found significant improvements in the following tests: right handgrip ($p < 0.001$); left handgrip ($p < 0.001$); TUG ($p < 0.001$); SPPB ($p = 0.012$); and the Tinetti scale ($p = 0.002$). A detailed analysis showed the lack of significant changes in gait speed ($p > 0.05$) and gait ($p > 0.05$) for the SPPB and the Tinetti scale, respectively. No statistically significant changes were shown in the UG ($p > 0.05$).

DISCUSSION

Few studied have evaluated the effectiveness of TC in elderly people [81], and no study has evaluated the effectiveness of a sustainable training program combining supervised outdoor exercise with TC on physical performance in elderly people. The effectiveness of physical activity and exercise in the elderly population has been demonstrated in numerous studies [296-298]. In fact, beneficial effects have been found on the capacity to balance [261,299] and on the subsequent risk of falls [300], as well as on the contrast of pathologies such as osteoporosis [301] and sarcopenia [302,303]. However, as reported by Furtado et al. (2023), it is necessary to implement new methodologies and intervention strategies to increase the involvement of the elderly population and increase adherence to physical activity, minimizing barriers to participation [271]. Indeed, different types of exercise settings exist and among these, also due to the COVID-19 pandemic, outdoor exercise and TC are increasingly implemented. Our previous study showed that a no-structured outdoor walking plan carried out in natural environments for six-month once a week improved balance capacity in elderly people [233]. These preliminary findings from the “Passiata Day” model led us to develop a further walking program associated with TC named “Walking Leaders”. The results of the present study showed that an 8-week sustainable training program consisting of a supervised outdoor exercise and TC led to significant positive effects on all the outcomes considered. In fact, the TG significantly improved the performances of handgrip, TUG, SPPB, and the Tinetti scale, while no differences were detected in the UG. However, a more detailed analysis highlighted the lack of improvement in walking ability. Indeed, no significant change was found in the component of gait speed and the field gait of the Tinetti scale. This result could depend on the initial choice to exclude individuals with high walking difficulty, which means that, a priori, a sample with a good walking level was recruited. This choice was made because the protocol included the walking exercise. This improvement, as already highlighted in our preliminary study [233], could be induced by carrying out the walking program outdoors, i.e., on non-uniform ground which stimulates proprioception to a greater extent than walking on a regular surface, increasing, therefore, the balance capacity. A fundamental aspect of the walking plan of the present study was the variability of walking speed and axial loading during the program. Indeed, walking speed in elderly people is a topic of interest for researchers, and our results are in line with the existing literature [304]. In this way, in a recent systematic review by Bai et al. (2022), the effect of brisk walking on various outcomes has been studied [305]. The authors demonstrated that brisk walking improves cardiorespiratory fitness, muscular strength, and body composition. Research by Fan et al. (2016) investigated the influence of gait speed (slow, normal, and fast speed of walking) on walking stability in the elderly, showing that stride length and cadence increased at fast speed [306]. Interesting research by Chatutain et al. (2019) emphasizes the importance of walking among elderly [306]. The authors highlight the practice of walking meditation as a mindfulness practice of walking, that is, focusing on the movements of the legs while walking slowly [307]. In line with our results, a recent pilot study involving people with multiple sclerosis demonstrated that axial loading during walking can influence stride length, cadence, and gait speed [308]. Our results are consistent with these studies for supporting the effectiveness of axial loading during walking plan. It should be noted that the scientific literature shows conflicting results regarding the benefits and risks of walking [309,310]. Indeed, Okubo et al. (2016) showed that, in the elderly without risk of falling, walking improves balance and is therefore a useful strategy for preventing falls

[311]. In contrast, Gillespie et al. (2003) found that walking should not be recommended to the elderly population with great difficulties in walking and therefore at high risk of falling [312]. Based on this previous research, walking may have negative effects on populations at risk of falling. In accordance with these studies, we checked this aspect by recruiting older adults who had no history of falls and who were not at risk of falling. Another important result of our study is related to the resistance training carried out in TC. Many studies have shown the effectiveness of resistance training in terms of strength improvement and to counteract some pathologies in this population [313,314]. In a recent study, Otsuka et al. (2022) reported that a resistance training program of 24 weeks improved muscle quantity and quality in older people [315]. Similar results were found by the study of Seo et al. (2021), in which after 16 weeks of resistance training, older adult women with sarcopenia improved functional fitness, grip strength, gait speed, and isometric muscle strength [316]. Among the findings by Hennig et al. (2015) on the effects of home-based hand exercises in women with hand osteoarthritis, there was a significant difference in grip strength [278], in line with our results. The evidence for the effectiveness of TC training is growing. For example, in a sample of breast cancer survivors, TC improved adherence and retention among participants [317]. A study by Demeyer et al. (2017) showed that a 12-week semiautomated TC program, including a step counter and a smartphone app, increased the amount and the intensity of physical activity in patients with COPD [285]. In our study, the improvements in the handgrip test and the absence of adverse events highlight the effectiveness and the safety and feasibility of a resistance training program carried out in TC. Thus, considering that TC is a safe and accessible training modality used in other populations [85,128,129,318], this can represent an innovative setting that can also be administered to the elderly in order to achieve the WHO recommendations on physical activity practice for this population.

Strengths and Limitations

The main strength of our study is the adherence to the project. In fact, 81.66% of the participants completed the training program. Other strengths are represented by the fact that this exercise setting is easily accessible, economical, and free of adverse events. In fact, no accidents occurred during the entire training program. Among the strengths, it should be noted that the training program was developed and supervised by sports and sports science professionals, with the collaboration of geriatric doctors and psychologists. Indeed, as demonstrated by Furtado and colleagues, a comprehensive and targeted approach is needed to promote overall well-being in older individuals [319]. One of the main limitations is related to the small sample size of this study. However, this is a first study of the "Walking Leaders" project which, as described above, is ongoing and has a duration of 2 years, and intends to recruit a total sample of approximately 150 elderly people from the metropolitan city of Palermo (Italy). Among the limitations of the study, we should note the failure to include, by choice, individuals with a high risk of falls, which does not allow for the generalization of the results. Another limitation is represented by the absence of a follow-up that aims to highlight any change in the practice of physical activity and exercise of the elderly who participated in the project. The absence of a random assignment of participants to the two groups, a process that makes our study quasi-experimental, may represent a further limitation of the study.

Practical Implications

This study could have a broad practical application for the elderly population who wants to practice physical activity and exercise, given the easy accessibility to outdoor physical exercise, even in urban areas, and its economic convenience. Likewise, the convenience of practicing exercise from one's own home, such as using TC, could help to achieve the physical activity levels recommended by the WHO. These physical exercise settings could also have an interesting implication for sports and exercise science professionals. In fact, by using both green exercise and TC, they could more easily reach the elderly population who wants to practice physical exercise. Moreover, these exercise settings allow greater flexibility, and do not imply the use of a sports building or specific tools, emphasizing their cost-effectiveness. Furthermore, as regards the outdoor exercise, the possibility of grouping elderly people with similar characteristics (after measuring their physical and functional abilities) would Favor adherence to the training program and the possibility of creating new social relationships for those who participate.

CONCLUSIONS

In conclusion, based on our results, we suggest that a sustainable training program combining supervised outdoor exercise and TC could be effective in the elderly population for improving balance capacity and strength. In addition, this combined method could be an effective intervention strategy to increase the levels of physical activity in the elderly population, maintaining high adherence to training and being safe, effective, and risk-free. Further studies should also evaluate the effectiveness of this type of training on body composition, body posture, and psychological components. Furthermore, we recommend that walking programs are carried out by a sports and exercise science professional and in groups, since physical activity carried out in groups has been shown to be associated with high levels of enjoyment, improving adherence to the training program [320].

2.5 Challenges and Future Directions in Telecoaching

Despite growing evidence supporting the efficacy of TC interventions, several critical challenges remain that may hinder their large-scale adoption, clinical effectiveness, and long-term public health impact. One of the most significant barriers is technological limitations, including unequal access to high-speed internet, limited digital literacy, and the lack of appropriate devices. These issues are particularly pronounced among rural populations, older adults, and individuals from socioeconomically disadvantaged backgrounds, exacerbating existing health disparities and limiting the equitable dissemination of digital health solutions. Another critical challenge involves user engagement and adherence. Compared to traditional face-to-face coaching, TC interventions are often associated with higher dropout rates and lower participation. The absence of in-person accountability, along with increased opportunities for distraction in virtual environments, can compromise the development of a strong coach–athlete or coach–client alliance, an essential component of effective and lasting behavioural change. Future research should focus on the implementation of adaptive intervention models and the integration of artificial intelligence (AI)-driven personalization strategies to enhance user motivation, adherence, and long-term engagement.

Data privacy and ethical considerations also represent key concerns in the development of TC interventions. These platforms frequently collect and process sensitive personal data, including biometric markers, lifestyle behaviours, and mental health information. Ensuring robust data protection protocols, a secure storage system, and strict compliance with relevant regulatory frameworks, such as the General Data Protection Regulation (GDPR) and the Health Insurance Portability and Accountability Act (HIPAA), is essential to uphold user confidentiality. In parallel, the increasing reliance on automated decision-making tools and AI-driven coaching systems calls for updated ethical guidelines. These technologies may introduce algorithmic bias, reduce transparency, and reduce human oversight, raising important issues related to autonomy, accountability, and informed consent. From a professional perspective, there is a clear need to standardize training pathways and certification frameworks for tele-coaches. Historically, the coaching profession has lacked uniform regulation; the transition to digital platforms further increases the risk of inconsistent service quality and the involvement of unqualified practitioners. The development of internationally recognized guidelines and competency standards, ideally endorsed by professional coaching associations, would improve the credibility, consistency, and reliability of TC practices, supporting its integration into broader healthcare and wellness systems. Looking forward, interdisciplinary collaborations offer a direction for the advancement of TC. Collaborations with behavioural science, digital health, AI, and human–computer interaction could foster the creation of more sophisticated, adaptive, and effective coaching models. Additionally, hybrid approaches that combine digital platforms with periodic in-person interactions may provide an optimal balance between scalability, personalization, and the relational depth required for sustained behaviour change. In conclusion, TC represents a promising modality for promoting personal development, health, and performance across a range of populations. However, realizing its full potential will require coordinated efforts among researchers, practitioners, technologists, and policymakers to overcome current limitations. Future developments should emphasize inclusivity, scientific rigor, and ethical integrity to ensure that TC delivers meaningful, equitable, and sustainable outcomes within an increasingly digital and dynamic health ecosystem

2.6 Telecoaching: Guidelines and Practical Applications

List of publications/projects discussed within Chapter II:

Leale Ignazio; Giustino Valerio; Alesi Marianna; Gómez-López Manuel; Battaglia Giuseppe. *Enhancing Physical Activity in Health-Impaired Individuals Through Telecoaching: A Systematic Review of Evidence and Practical Applications. American Journal of Physical Medicine & Rehabilitation ():10.1097/PHM.0000000000002850, August 28, 2025. | DOI: 10.1097/PHM.0000000000002850*

[…]

Although the requirement for basic technological skills, internet access, and digital devices may limit the applicability of TC, particularly among individuals from lower socioeconomic backgrounds, its flexibility and adaptability make it a valuable tool for sports and exercise science professionals. Importantly, TC does not require specialized facilities or equipment, offering a versatile and easily implementable approach.

Research Skills

When implementing TC programs, researchers should provide clear, simple, and accessible instructions. Video tutorials and written manuals are recommended to help participants correctly perform and manage the training program, as well as to review exercises independently. During the initial phase, a familiarization session can enhance participants' understanding and adherence. Furthermore, informing patients about the expected benefits of TC may increase motivation, while setting predefined objectives can improve program effectiveness.

Technological Skills

Prior to initiating the program, researchers should determine the digital tools and features required for TC delivery. This includes selecting between synchronous TC (real-time interaction) and asynchronous TC (flexible, time-independent interaction). Web platforms and mobile applications represent accessible solutions to deliver content, share information, and monitor adherence. Additional motivational strategies—such as regular contact via e-mail, phone calls, or online communities—can support participant engagement and provide timely assistance.

Communication Skills

Effective communication is a critical determinant of patient experience and should remain professional, timely, and concise. Instructional materials (e.g., videos, technique tutorials, and manuals) should be designed to minimize cognitive overload and avoid vague or unnecessary content. Weekly calls and text reminders can reinforce adherence and motivation. The use of exercise diaries allows participants to track progress and adverse events, facilitating feedback between patients and telecoaches. While TC reduces barriers related to cost, geography, and access, it may also decrease direct interpersonal contact and increase the risk of dropout. To mitigate this, programs should integrate: (a) an initial supervised session; (b) accessible online platforms with multimedia resources; (c) written guidelines on exercise technique; (d) self-maintained training diaries; (e) weekly motivational calls; (f) reminder messages; (g) clear communication channels; and (h) flexible, responsive telecoaches.

CONCLUSION

Considering these factors, TC emerges as an effective intervention to maintain physical activity and improve quality of life, particularly by enhancing exercise capacity and tolerance in health-impaired individuals. Future research should investigate the key variables influencing the success of digital training in primary prevention, as well as determine the optimal duration, frequency, and intensity of TC programs. Furthermore, direct comparisons between synchronous and asynchronous TC modalities are needed to clarify their differential impact across diverse populations.

Chapter III – Wearable Devices for Monitoring and Support

3.0 Chapter III Overview

In recent years, wearable technology has had a significant impact on sports and athletic performance [321]. These devices are changing the way athletes train, compete, and recover by providing real-time data and insights that were not previously available. Wearable tools can monitor vital signs, track movement patterns, and support the evaluation of training loads. For these reasons, wearable technology is now considered an important instrument for optimizing sports training and improving individual performance. The primary contribution of wearable technology in sports lies in its ability to improve performance through real-time data collection and analysis [321]. These devices provide detailed information that allows coaches and athletes to make evidence-based decisions aimed at optimizing training programs, enhancing performance efficiency, and reducing the risk of injury. As a result, wearable technology is becoming increasingly indispensable for those seeking to gain a competitive advantage in modern sport. The term *wearable technology* in sports refers to electronic devices designed to be worn by athletes with the purpose of collecting data related to different aspects of performance and physical condition. Common examples include GPS trackers, heart rate monitors, and motion sensors. The primary objective of these technologies is to provide accurate and timely information that can support both the improvement of individual performance and the development of more effective and safer training methodologies [322-324]. In *football*, wearable devices are commonly used to monitor player movements, heart rate, and overall workload during both training sessions and competitive matches [325]. GPS trackers and heart rate monitors allow for the collection of data on speed, distance covered, and exercise intensity, enabling coaches to tailor training programs and manage muscle fatigue more effectively. The use of wearable technology is also becoming increasingly common in basketball [326]. These devices monitor jumps, movements, and exertion levels, providing essential information for assessing both individual and team workloads. Such data is critical for designing personalized training programs and targeted recovery strategies, with the goal of optimizing overall team performance. The range of wearable devices used in sports is broad and continuously evolving. Among the most common are [327,328]:

- **GPS trackers:** These devices monitor athletes' movements during training and competition, providing data on speed, distance covered, and positioning. Such information is useful for performance analysis, fatigue management, and tactical planning.
- **Heart rate monitors**: These devices measure heart rate in real time, allowing assessment of exercise intensity, cardiovascular load, and recovery.
- **Accelerometers**: Sensors that detect changes in movement speed, enabling analysis of acceleration and deceleration patterns.
- **Smartwatches and fitness bands:** Multifunctional devices that track heart rate, physical activity, energy expenditure, and sleep quality. These tools are useful for both professional and recreational athletes.

These wearable technologies offer objective data that support personalized training, optimize performance, and reduce the risk of injury, making them increasingly important in modern sports practice. In summary, wearable technology is transforming training and sports performance management by providing objective data that can improve efficiency, safety, and athlete outcomes. These tools allow for personalized training, optimized recovery, and informed decision-making, making them increasingly essential in modern sports.

3.1 GPS Technology: Applications in Sport and Functional Monitoring

The GPS is a satellite-based navigation technology initially developed by the United States Department of Defense for military applications and later made available for civilian use.

The system comprises a constellation of 27 satellites equipped with atomic clocks, which orbit the Earth and continuously transmit signals to GPS receivers. By processing these signals, the receivers calculate their distance from each satellite [329]. Determining the distance from at least four satellites enables the computation of the receiver's precise geographic coordinates, latitude, longitude, and altitude, with high accuracy [329]. In the sports context, a GPS tracker is a wearable device designed to capture real-time data on an athlete's movement patterns and performance metrics, including speed, distance covered, acceleration, and intensity of effort. Typically worn in a compact vest or integrated into sports equipment, these devices are widely employed across various sports disciplines to monitor training loads, optimize performance, and reduce the risk of injury through informed workload management. GPS-based athlete monitoring was first introduced in 1997 and has since seen widespread adoption, particularly in team sports such as rugby league, rugby union, soccer, field hockey, and Australian football [330]. From a performance management perspective, it is essential for strength and conditioning coaches and sports scientists to understand the relationship between an athlete's external and internal training loads, as this interaction provides valuable insight for monitoring fatigue, managing recovery, and optimizing performance [331]. GPS technology has been extensively employed by coaches in team sports to assess external load, enabling time–motion analysis of on-field performance during both technical–tactical drills and official matches [332-334]. Through this approach, GPS systems capture key components of athletes' movement profiles, including derived metrics such as speed, distance covered, acceleration, and estimates of metabolic power [330,335]. Compared to other athlete-tracking methods, GPS technology offers time efficiency and the capacity for real-time feedback, which is particularly advantageous in team sports. While video-based motion analysis can only track the movements of a single athlete at a time, GPS systems enable the simultaneous monitoring of multiple athletes [336]. The use of GPS facilitates several performance and management benefits, including: a) reducing injury risk through continuous workload monitoring; b) enhancing tactical decision-making via precise positional data; maintaining optimal performance throughout the season; c) providing objective feedback on player output; d) establishing benchmarks for performance development and progress tracking and e) supporting athlete recruitment by generating quantifiable performance data. Despite its advantages, GPS technology presents both technological and practical limitations. Satellite signals may be disrupted by atmospheric conditions and local environmental obstructions, such as stadium structures or tall buildings, resulting in measurement errors [331]. The number of satellites communicating with the GPS receiver is also a key determinant of positional accuracy [337]. Although four satellites represent the theoretical minimum required to triangulate a receiver's position, evidence suggests a moderate negative correlation between total distance error, defined as the difference between the recorded and actual distance, and the number of satellites transmitting signals to the receiver [332]. Similarly, velocity measurements are also susceptible to increased error when the number of satellites interacting with the receiver decreases [338]. In addition, the spatial configuration of the satellites relative to the receiver, commonly referred to as satellite geometry, is a critical factor influencing the accuracy of the measurements obtained [338].

3.2 Wearable Inertial Sensor: Applications in Sport and Functional Monitoring

List of publications/projects discussed within Chapter III:

Pillitteri, G., Giustino, V., Petrucci, M., Rossi, A., Leale, I., Bellafiore, M., Thomas, E., Iovane, A., Palma, A., & Battaglia, G. (2023). *Match Load Physical Demands in U-19 Professional Soccer Players Assessed by a Wearable Inertial Sensor.* Journal of functional morphology and kinesiology, 8(1), 22. https://doi.org/10.3390/jfmk8010022

INTRODUCTION

Soccer is a situational team sport in which players are interconnected in a complex system characterized by technical–tactical components that are supported by physical and physiological factors [339]. In soccer, the physical performance consists of intermittent cyclic and acyclic activities characterized by aerobic and anaerobic demands [336,340]. The need to know the physical demands required during a soccer match is of fundamental importance for coaches and athletic trainers in order to properly plan the training program with the aim of increasing the training effect and reducing the risk of injury [341-344]. High-speed running, acceleration, and deceleration characteristics are considered determinant factors for physical performance and should be taken into consideration when designing the training program [345]. As a matter of fact, players usually perform 150–250 different actions and 1100 changes of direction during a match [346]. Moreover, players' physical activity characteristics change every 4–6 s based on the different player's positions on the pitch [346,347], resulting in a high rate of change in speed (i.e., acceleration). Studies have shown that professional players travel a total distance of between 10 and 13 km during a match [348]. Most of the total distance is covered at low intensities, whereas 22–24% is spent at intensities above 15 km/h, 8–9% above 20 km/h, and 2–3% above 25 km/h. Additionally, it has been found that players can perform between 600 and 650 accelerations during a match. To improve performance while reducing the risk of injury, practitioners should assess match loads in relation to playing positions on the pitch to optimize training planning [349,350]. Specifically, the external load (EL) is usually described by the total distance, range of speed covered, accelerations, metabolic power [335], and other derived measures. Global position systems (GPS) technology has been largely used by practitioners to assess EL allowing for time-motion analysis in technical–tactical tasks [334,343,351,352]. However, in the last few years, several microelectromechanical systems (MEMS) have been developed and are available and these include triaxial accelerometers, triaxial gyroscopes, magnetometers, and pressure sensors. These devices, defined as inertial sensors devices (ISDs) or inertial measurement units (IMUs), can measure acceleration and angular velocity, among other parameters. ISD technology was developed specifically for the assessment in indoor sports where GPS devices cannot be used [353]. The literature suggests that this technology has not yet been fully used in professional soccer for EL monitoring. It should be mentioned that physical demand is highly related to playing positions on the pitch due to the fact that roles have specific technical–tactical requests strictly related to different physical, physiological, energetic, and biomechanical components [336,350,354,355]. For example, the literature has reported that the total high-intensity distance is covered by central midfielders, wide defenders, and wide midfielders, whereas strikers and central defenders travel lower distances [356]. Moreover, wide defenders and wide midfielders perform the highest sprinting distance, whereas central midfielders and central backs cover the lowest in elite soccer players [356-360]. Moreover, significant differences were found between the various playing positions for all measures of EL in amateur soccer players [361]. Authors reported that central midfielders covered the longest distance during a match, which is in line with recent literature followed by the forwards, the full-backs, and the wide midfielders. As in adult professional soccer players, physical performance is affected by playing position also in youth elite players. In young male elite players (8–18 years), center backs covered the shortest high-intensity running and sprinting distances and wide midfielders the longest [362]. Additionally, in young soccer players (mean age 16.0 years), center defenders covered the shortest very high-speed ($\geq$19.8 km·h−1) and sprint ($\geq$25.2 km·h−1) distances, whereas wide players and center forwards covered the longest distances in these speed zones [363], which is in line with other studies [364]. It is worth noting that the GPS may have some signal issues due to adverse weather conditions or being used indoors compared to ISD. In fact, being that this technology is based on (inertial) movement, it allows for evaluating the EL considering the same parameters relating to distance, speed, and metabolic power with greater precision than GPS at 10 Hz [365]. Indeed, the better applicability of ISD technology is due to its small size, lower cost, and the possibility of using the device indoors, avoiding possible connection problems between GPS and satellite [365]. To the best of our knowledge, there are no studies that have investigated, through ISD technology, differences in EL indicators in young professional soccer players during official matches (OMs) considering the different playing positions on the pitch. We hypothesized that there may be differences in EL indicators in young professional soccer players during OMs depending on playing position. Hence, the aim of this study was to investigate any differences in EL indicators, specifically cinematic, mechanical, and metabolic indicators, measured through a wearable inertial sensor during the first half time of four OMs, considering the different playing positions in young professional soccer players (U19).

MATERIALS AND METHODS

Study Design

In this cross-sectional study, young players from a professional Italian soccer club were monitored using a wearable inertial sensor during the first half time of four OMs during the season 2021–2022. Soccer players were categorized into five groups according to their playing position on the pitch as follows: central back (CB), external striker (ES), fullback (FB), midfielder (MD), and wide midfielder (WM).

Participants

Thirteen young professional soccer players (age: 18.5 ± 0.4 years; height: 177 ± 6 cm; weight: 67 ± 4.8 kg) competing in the Italian U19 Championship were included. Participants' playing positions were the following: CB (n = 2), ES (n = 3), FB (n = 5), MD (n = 1), and WM (n = 2). The following inclusion criteria were considered: (1) professional male soccer players belonging to the Under-19; (2) no injury in the previous six months. Based on the exclusion criteria, only goalkeepers were not eligible for the study. All participants signed an informed consent form before taking part in the study. The study, which complies with the principles of the Declaration of Helsinki, was approved by the Bioethics Committee of the University of Palermo (n. 68/2021).

Procedures

Participants were monitored during four OMs in a regular pitch with a theoretical match density (m2/player) referred to ~320 m2 according to Riboli et al. [366,367]. OMs were played on a third-generation artificial pitch or natural grass. All participants performed a typical 25-min pre-match warm-up before each OM. The ISD was started 5 min prior to the assessment. Data were collected through a wearable inertial sensor (TalentPlayers TPDev, firmware version 1.3) [365]. To avoid interunit errors, each participant was assigned the same ISD for each OM. Among the available devices, TalentPlayers was chosen as it provides very similar data compared to traditional GPS systems (i.e., instantaneous speed and distance, change of directions, and metabolic data) and it is already used by various Italian soccer teams (https://talentplayers.com (accessed on 16 December 2016)). This ISD is a small wearable device integrating a six degrees of freedom MEMS inertial sensor, capable of providing real-time acceleration and rotation data along three orthogonal axes at a frequency of 100 Hz per channel. It is designed to be worn on the lower leg using an elastic band. The validity and reliability of the ISD have been previously reported [365]. All data were acquired by the TalentPlayer mobile app (software version 1.0.7) and uploaded to the TalentPlayers cloud. EL indicators considered for this study were classified as cinematic, mechanical, and metabolic. All indicators assess the volume of OMs (except the metabolic power indicator) although some parameters represent intensity performance indicators. These are detailed in Table 12.

Table 12. Descriptions of the external load indicators.

Indicators	Type	Description (Unit of Measure)
TD	Cinematic/volume	Total distance covered (m)
MS *	Cinematic/intensity	Maximum speed reached (even for <1 s)
N°INTACC *	Mechanical/volume	Number of intense accelerations >2 m/s^2
N°INTDEC *	Mechanical/volume	Number of intense decelerations >2 m/s^2
TDA	Mechanical/volume	Distance traveled with positive acceleration (i.e., with speed increase) (m)
TDD	Mechanical/volume	Distance traveled with negative acceleration (i.e., with speed decrease) (m)
N°HSR *	Cinematic/volume	Number of high-intensity running at >20 km/h
WT	Cinematic/volume	Time spent in the various speed zones (<6 km/h) (s)
THSR *	Cinematic/volume	Time spent in the various speed zones (>20 km/h) (s)
WD	Cinematic/volume	Distance traveled in the various speed zones (<6 km/h) (m)
DHSR *	Cinematic/volume	Distance traveled in the various speed zones (>20 km/h) (m)
MP *	Metabolic/intensity	Metabolic Power ($w \cdot kg^{-1}$) was calculated by multiplying EC (in $J \cdot kg^{-1} \cdot m^{-1}$) by running speed (v; in $m \cdot s^{-1}$) at any given moment (i.e., every 0.2 s): P met = EC·v.In order to assess metabolic power, considering the energy expenditure and derived, the equation developed by di Prampero et al. [33] established on previously studies by Minetti et al. [34] and Osgnach et al. [14] was adopted. (Watt = w)
TLMP	Metabolic/volume	Time spent in various metabolic power zones (<10 w) (s)
THMP *	Metabolic/volume	Time spent in various metabolic power zones (20–35 w) (s)
TEMP *	Metabolic/volume	Time spent in various metabolic power zones (35–55 w) (s)
TMMP *	Metabolic/volume	Time spent in various metabolic power zones (>55 w) (s)
DLMP	Metabolic/volume	Distance traveled in the various metabolic power zones (<10 w) (m)
DHMP *	Metabolic/volume	Distance traveled in the various metabolic power zones (20–35 w) (m)
DEMP *	Metabolic/volume	Distance traveled in the various metabolic power zones (35–55 w) (m)
DMMP *	Metabolic/volume	Distance traveled in the various metabolic power zones (>55 w) (m)
N°CoDR *	Mechanical/volume	Number of direction changes to the right >30° and with speed >2 m/s
N°CoDL *	Mechanical/volume	Number of direction changes to the left >30° and with speed >2 m/s

Legend: TD, Total Distance; MS, Maximal Speed; N_INTACC, Number of Accelerations; N_INTDEC, Number of Decelerations; TDA, Total Distance Acceleration; TDD, Total Distance deceleration; N_HSR, Number of High-Speed Running; WT, Walking Time; THSR, Time High-Speed Running; WD, Walking Distance; DHSR, Distance High-Speed Running; MP, Metabolic Power; TLMP, Time Low Metabolic Power; THMP, Time High Metabolic Power; TEMP, Time Elevated Metabolic Power; TMMP, Time Max Metabolic Power; DLMP, Distance Low Metabolic Power; DHMP, Distance High Metabolic Power; DEMP, Distance Elevated Metabolic Power; DMMP, Distance Max Metabolic Power; N_CoDR, Number of Direction Changes to the Right; N_CoDL, Number of Direction Changes to the Left; * Intensity indicator.

Statistical Analysis

Normality distribution was calculated through the Shapiro–Wilk test. Means and standard deviations of all the EL indicators for OMs and for each playing position (CB, ES, FB, MD, WM) were provided. A one-way analysis of variance (ANOVA) test on one factor (OM) was performed to detect differences for each EL indicator. The Tukey post hoc test was used for pairwise comparisons for each EL indicator between playing positions. Statistical significance was set at $p < 0.05$. The Statistical Package jamovi (The jamovi project—jamovi Version 1.8.0.1) was used to perform data analysis. Graphs were created through Graph Pad Prism 8 (Version 8.0.2).

RESULTS

Descriptive statistics of EL indicators (i.e., TD, MS, N°INTACC, N°INTDEC, TDA, TDD, N°HSR, WT, THSR, WD, DHSR, MP, TLMP, THMP, TEMP, TMMP, DLMP, DHMP, DEMP, DMMP, N°CoDR, N°CoDL) for each playing position (i.e., CB, ES, FB, MD, WM) are reported in Table 13, Table 13, Table 15 and Table 16.

Table 13. Descriptive statistics of the external load indicators

					Cinematic				
	TD (m)	**MS (km/h)**	**N°HSR (Total)**	**WT (s)**	**THSR (s)**	**WD (m)**	**DHSR (m)**		
MEAN	5620	26.5	29.4	1451	54.7	1226	335		
SD	537	2.58	10.3	179	24.5	155	152		
MIN	4714	20.6	10	1106	13	987	76.5		
MAX	6557	30.8	58	1780	143	1539	880		
					Mechanical				
	N°INTACC (total)	N°INTDEC (total)	TDA (m)	TDD (m)	N°CoDR (total)	N°CoDL (total)			
MEAN	25.5	24.9	3018	2582	143	139			
SD	6.35	7.09	309	239	15.9	31.6			
MIN	16	9	2466	2161	105	76			
MAX	37	38	3569	3071	173	220			
					Metabolic				
	MP (w)	TLMP (s)	THMP (s)	TEMP (s)	TMMP (s)	DLMP (m)	DHMP (m)	DEMP (m)	DMMP (m)
MEAN	10.7	1739	250	80.3	30.8	1883	998	399	179
SD	1.12	139	46.3	21.5	10.6	120	207	119	67.5
MIN	8.7	1502	172	33	14	1668	628	136	77.4
MAX	13	2004	337	133	56	2197	1398	711	329

Legend: TD, Total Distance; MS, Maximal Speed; N°INTACC, Number of Intense Accelerations; N°INTDEC, Number of Intense Decelerations; TDA, Total Distance Acceleration; TDD, Total Distance deceleration; N ° HSR, Number of High-Speed Running; WT, Walking Time; THSR, Time High-Speed Running; WD, Walking Distance; DHSR, Distance High-Speed Running; MP, Metabolic Power; TLMP, Time Low Metabolic Power; THMP, Time High Metabolic Power; TEMP, Time Elevated Metabolic Power; TMMP, Time Max Metabolic Power; DLMP, Distance Low Metabolic Power; DHMP, Distance High Metabolic Power; DEMP, Distance Elevated Metabolic Power; DMMP, Distance Max Metabolic Power; N°CoDR, Number of Change of Direction Right; N°CoDL, Number of Change of Direction Left; SD, standard deviation.

Table 14. Descriptive statistics of the external load indicators for each official match.

					Cinematic			
	MATCH	**TD (m)**	**MS (km/h)**	**N°HSR (Total)**	**WT (s)**	**THSR (s)**	**WD (m)**	**DHSR (m)**
MEAN	1	5708	26.8	29.8	1428	53.7	1248	328
	2	5673	25.7	31.6	1330	60.3	1151	369
	3	5456	26.8	26.6	1595	49.6	1325	303
	4	5625	26.8	29.3	1469	54.8	1187	335
SD	1	594	2.77	12.1	164	23.4	124	146
	2	625	1.97	12.4	163	35.0	109	216
	3	515	2.68	7.69	192	18.7	195	117
	4	444	3.14	8.86	96.8	19.3	153	119
MIN	1	4714	21.9	10	1177	13	1119	76.5
	2	4728	22.4	14	1106	20	987	120
	3	4936	23.3	14	1267	22	1079	131
	4	4740	20.6	11	1318	13	1026	77.4
MAX	1	6557	29.1	48	1705	81	1444	504
	2	6544	28.4	58	1575	143	1343	880
	3	6338	30.8	38	1780	82	1539	505
	4	6162	30.2	41	1571	78	1409	477

	MATCH	N°INTACC (total)	N°INTDEC (total)	TDA (m)	TDD (m)	N°CoDR (total)	N°CoDL (total)
					Mechanical		
MEAN	1	26.3	27.6	3097	2592	148	139
	2	24.8	23.1	3038	2616	138	146
	3	24.4	22.9	2903	2532	134	125
	4	26.4	25.9	3023	2581	150	145
SD	1	5.74	7.11	345	265	12.5	30.9
	2	6.89	7.94	356	275	18.3	33.3
	3	5.60	4.97	305	215	15.8	39.2
	4	7.93	7.97	229	228	12.8	21.8
MIN	1	18	18	2485	2206	124	101
	2	16	13	2466	2248	105	117
	3	19	15	2581	2280	108	76
	4	16	9	2557	2161	137	117
MAX	1	35	36	3569	2970	164	198
	2	35	38	3476	3071	162	220
	3	35	28	3476	2845	153	184
	4	37	35	3357	2904	173	188

	MATCH	MP (w)	TLMP (s)	THMP (s)	TEMP (s)	TMMP (s)	DLMP (m)	DHMP (m)	DEMP (m)	DMMF (m)
					Metabolic					
MEAN	1	10.9	1711	257	85.6	31.0	1896	1028	423	181
	2	11.1	1646	252	80.9	32.0	1867	1009	408	183
	3	10.1	1850	236	71.9	28.9	1907	938	356	168
	4	10.6	1766	254	82.0	31.1	1862	1012	406	182
SD	1	1.22	137	50.1	19.8	11.6	114	223	111	77.1
	2	1.26	122	46.6	29.1	10.9	152	219	163	69.0
	3	0.964	138	52.6	11.1	11.8	116	219	59.8	76.4
	4	0.884	80.7	41.1	23.0	9.46	106	190	126	57.3
MIN	1	8.88	1511	181	56	15	1738	690	254	79.5
	2	9.15	1502	172	48	21	1668	628	213	106
	3	9.05	1659	178	50	15	1743	688	242	81.8
	4	8.70	1641	187	33	14	1763	685	136	77.4
MAX	1	12.6	1958	321	107	48	2060	1319	559	289
	2	13.0	1857	337	133	56	2197	1398	711	329
	3	11.8	2004	327	87	52	2068	1324	450	312
	4	11.6	1864	327	101	44	2069	1330	511	261

Legend: TD, Total Distance; MS, Maximal Speed; N◦INTACC, Number of Intense Accelerations; N◦INTDEC, Number of Intense Decelerations; TDA, Total Distance Acceleration; TDD, Total Distance Deceleration; N◦ HSR, Number of High-Speed Running; WT, Walking Time; THSR, Time High-Speed Running; WD, Walking Distance; DHSR, Distance High-Speed Running; MP, Metabolic Power; TLMP, Time Low Metabolic Power; THMP, Time High Metabolic Power; TEMP, Time Elevated Metabolic Power; TMMP, Time Max Metabolic Power; DLMP, Distance Low Metabolic Power; DHMP, Distance High Metabolic Power; DEMP, Distance Elevated Metabolic Power; DMMP, Distance Max Metabolic Power; N◦CoDR, Number of Change of Direction Right; N◦CoDL, Number of Change of Direction Left; SD, standard deviation.

Table 15. External load indicator differences among playing positions (central back, external striker, full back, midfielder, wide midfielder).

	Midfielder (M ± SD)	Central Back (M ± SD)	External Striker (M ± SD)	Full Back (M ± SD)	Wide Midfielder (M ± SD)
			Cinematic		
TD (m)	5963 ± 74	5240 ± 340 ^{1,5}	5723 ± 438 ^{4}	5087 ± 344 ^{1,5}	6161 ± 316
MS (km/h)	25.7 ± 1.88	24.3 ± 2.66 ^{3,5}	28.4 ± 1.34 ^{4}	25 ± 2.61 ^{5}	28.2 ± 1.31
N°HSR	29.8 ± 3.5	18.7 ± 7.89 ^{3,5}	38.8 ± 8.88 ^{4}	22.9 ± 6.53 ^{5}	34.4 ± 7.03
WT (s)	1303 ± 78.5	1490 ± 60.5	1476 ± 205	1578 ± 187 ^{5}	1345 ± 151

THSR (s)	56 ± 5.72	29.7 ± 15.6 ^{3,5}	80.4 ± 26.3 ^{4}	39.9 ± 12.4	62.1 ± 13.5
WD (m)	1071 ± 53.9	1191 ± 161	1260 ± 137	1308 ± 186	1214 ± 129
DHSR (m)	342 ± 36.3	179 ± 95.2 ^{3,5}	494 ± 163 ^{4}	242 ± 77.3	381 ± 84.6
			Mechanical		
N°INTACC (total)	21.8 ± 4.35 ^{3}	22.5 ± 5.21 ^{3}	32.3 ± 3.99 ^{5}	25.4 ± 6.55	22.9 ± 5.3
N°INTDEC (total)	22.5 ± 6.86	21.7 ± 8.21	29.9 ± 3.91	21.9 ± 5	26.5 ± 8.64
TDA (m)	3136 ± 59.1 ^{3}	2818 ± 197 ^{5}	3067 ± 251 ^{4}	2732 ± 234 ^{5}	3348 ± 202
TDD (m)	2810 ± 64.4 ^{2,4}	2404 ± 159 ^{3,5}	2639 ± 206 ^{4}	2336 ± 117 ^{5}	2789 ± 125
N°CoDR (total)	139 ± 5.74	143 ± 8.99	146 ± 18.9	131 ± 19.1 ^{5}	153 ± 9.92
N°CoDL (total)	165 ± 6.08	152 ± 25.1	122 ± 25.1	149 ± 44.4	123 ± 15.4
			Metabolic		
MP (w)	11.1 ± 0.233	9.9 ± 0.792 ^{5}	11.1 ± 1.07 ^{4}	9.68 ± 0.771 ^{5}	11.7 ± 0.812
TLMP (s)	1625 ± 87.6 ^{4}	1793 ± 54	1754 ± 135	1856 ± 128 ^{5}	1626 ± 103
THMP (s)	286 ± 9.54 ^{2,4}	221 ± 32.7 ^{5}	245 ± 32.3 ^{5}	209 ± 23.7 ^{5}	301 ± 36.6
TEMP (s)	76.5 ± 17.7	67.2 ± 22.2 ^{3}	97.4 ± 16.6 ^{4}	66 ± 15.6	89.1 ± 19.2
TMMP (s)	25.3 ± 4.72 ^{3}	21.8 ± 7.25 ^{3,5}	42 ± 9.87 ^{4}	25 ± 7.98	34.9 ± 5.67
DLMP (m)	1790 ± 90.8	1888 ± 153	1894 ± 148	1934 ± 98.3	1863 ± 86.5
DHMP (m)	1139 ± 46.8 ^{2,4}	860 ± 151 ^{5}	999 ± 150 ^{5}	811 ± 110 ^{5}	1281 ± 164
DEMP (m)	382 ± 92	316 ± 111 ^{3}	502 ± 94.3 ^{4}	316 ± 82.9	450 ± 98.2
DMMP (m)	144 ± 31.4 ^{3}	120 ± 42.1 ^{3,5}	247 ± 59.5 ^{4}	140 ± 48.4	212 ± 43.9

Legend: TD, Total Distance; MS, Maximal Speed; N◦INTACC, Number of Intense Accelerations; N◦INTDEC, Number of Intense Decelerations; TDA, Total Distance Acceleration; TDD, Total Distance Deceleration; N◦HSR, Number of High-Speed Running; WT, Walking Time; THSR, Time High-Speed Running; WD, Walking Distance; DHSR, Distance High-Speed Running; MP, Metabolic Power; TLMP, Time Low Metabolic Power; THMP, Time High Metabolic Power; TEMP, Time Elevated Metabolic Power; TMMP, Time Max Metabolic Power; DLMP, Distance Low Metabolic Power; DHMP, Distance High Metabolic Power; DEMP, Distance Elevated Metabolic Power; DMMP, Distance Max Metabolic Power; N◦CoDR, Number of Change of Direction Right; N◦CoDL, Number of Change of Direction Left. $p < 0.05$ for differences between playing positions (1 difference with midfielder; 2 difference with central back; 3 difference with external striker; 4 difference with full back; 5 difference with wide midfielder); M, mean; SD, standard deviation.

Table 16. Highest and lowest external load indicator differences among playing positions (central back, external striker, full back, midfielder, wide midfielder).

Cinematic

	TD (m)	MS (km/h)	N° HSR (Total)	WT (s)	THSR (s)	WD (m)	DHSR (m)
Highest (M ± SD)	WM (6161 ± 316) MD (5963 ± 74)	ES (28.4 ± 1.34) WM (28.2 ± 1.31)	ES (38.8 ± 8.88) WM (34.4 ± 7.03)	FB (1578 ± 187) CB (1490 ± 60.5)	ES (80.4 ± 26.3) WM (62.1 ± 13.5)	FB (1308 ± 186) ES (1260 ± 137)	ES (494 ± 163) WM (381 ± 84.6)
Lowest (M ± SD)	FB (5087 ± 344) CB (5240 ± 340)	CB (24.3 ± 2.66) FB (25 ± 2.61)	CB (18.7 ± 7.89) FB (22.9 ± 6.53)	MD (1303 ± 78.5) WM (1345 ± 151)	CB (29.7 ± 15.6) FB (39.9 ± 12.4)	MD (1071 ± 53.9) CB (1191 ± 161)	CB (179 ± 95.2) FB (242 ± 77.3)

Mechanical

	N° INTACC (total)	N° INTDEC (total)	TDA (m)	TDD (m)	N° CoDR (total)	N° CoDL (total)
Highest (M ± SD)	ES (32.3 ± 3.99) FB (25.4 ± 6.55)	ES (29.9 ± 3.91) WM (26.5 ± 8.64)	WM (3348 ± 202) MD (3136 ± 59.1)	MD (2810 ± 64.4) WM (2789 ± 125)	WM (153 ± 9.92) ES (146 ± 18.9)	MD (165 ± 6.08) CB (152 ± 25.1)
Lowest (M ± SD)	MD (21.8 ± 4.35) CB (22.5 ± 5.21)	CB (21.7 ± 8.21) FB (21.9 ± 5)	FB (2732 ± 234) CB (2818 ± 197)	FB (2336 ± 117) CB (2404 ± 159)	FB (131 ± 19.1) MD (139 ± 5.74)	ES (122 ± 25.1) WM (123 ± 15.4)

Metabolic

	MP (w)	TLMP (s)	THMP (s)	TEMP (s)	TMMP (s)	DLMP (m)	DHMP (m)	DEMP (m)	DMMP (m)
Highest (M ± SD)	WM (11.7 ± 0.812) MD (11.1 ± 0.233)	FB (1856 ± 128) CB (1793 ± 54)	WM (301 ± 36.6) MD (286 ± 9.54)	ES (97.4 ± 16.6) WM (89.1 ± 19.2)	ES (42 ± 9.87) WM (34.9 ± 5.67)	FB (1934 ± 98.3) ES (1894 ± 148)	WM (1281 ± 164) MD (1139 ± 46.8)	ES (502 ± 94.3) WM (450 ± 98.2)	ES (247 ± 59.5) WM (212 ± 43.9)
Lowest (M ± SD)	FB (9.68 ± 0.771) CB (9.9 ± 0.792)	MD (1625 ± 87.6) WM (1626 ± 103)	FB (209 ± 23.7) CB (221 ± 32.7)	FB (66 ± 15.6) CB (67.2 ± 22.2)	CB (21.8 ± 7.25^{3}) FB (25 ± 7.98)	MD (1790 ± 90.8) WM (1863 ± 86.5)	FB (811 ± 110) CB (860 ± 151)	FB (316 ± 82.9) CB (316 ± 111)	CB (120 ± 42.1) FB (140 ± 48.4)

Legend: TD, Total Distance; MS, Maximal Speed; N°INTACC, Number of Intense Accelerations; N°INTDEC, Number of Intense Decelerations; TDA, Total Distance Acceleration; TDD, Total Distance Deceleration; N°HSR, Number of High-Speed Running; WT, Walking Time; THSR, Time High-Speed Running; WD, Walking Distance; DHSR, Distance High-Speed Running; MP, Metabolic Power; TLMP, Time Low Metabolic Power; THMP, Time High Metabolic Power; TEMP, Time Elevated Metabolic Power; TMMP, Time Max Metabolic Power; DLMP, Distance Low Metabolic Power; DHMP, Distance High Metabolic Power; DEMP, Distance Elevated Metabolic Power; DMMP, Distance Max Metabolic Power; N°CoDR, Number of Change of Direction Right; N°CoDL, Number of Change of Direction Left; M, mean; SD, standard deviation.

As reported in Table 17, results from the one-way ANOVA tests showed significant differences in all the EL indicators between playing positions (TD: $F(4,13,9) = 16.59$, p <

0.001; MS: $F(4,11,8) = 5.54$, $p = 0.009$; N°INTACC: $F(4,12,5) = 6.22$, $p = 0.005$; N°INTDEC: $F(4,11,7) = 3.43$, $p = 0.045$; TDA: $F(4,14,2) = 9.99$, $p < 0.001$; TDD: $F(4,13,7) = 23.29$, $p < 0.001$; N°HSR: $F(4,13,7) = 6.94$, $p = 0.003$; WT: $F(4,13,1) = 5.21$, $p = 0.01$; THSR: $F(4,14) = 7.82$, $p = 0.002$; WD: $F(4,14) = 4.76$, $p = 0.012$; DHSR: $F(4,14) = 7.89$, $p = 0.002$; MP: $F(4,14,2) = 8.83$, $p < 0.001$; TLMP: $F(4,12,6) = 6.22$, $p = 0.005$; THMP: $F(4,14,1) = 18.75$, $p < 0.001$; TEMP: $F(4,12,2) = 4.1$, $p = 0.025$; TMMP: $F(4,13,1) = 7.04$, $p = 0.003$; DHMP: $F(4,14,1) = 15.51$, $p < 0.001$; DEMP: $F(4,12,3) = 5.00$, $p = 0.013$; DMMP: $F(4,13,2) = 7.6$, $p = 0.002$; N°CoDL: $F(4,14) = 13.03$, $p < 0.001$) except for DLMP: $F(4,12,4) = 1.43$, $p = 0.28$ and N°CoDR: $F(4,13,9) = 2.93$, $p = 0.06$.

Table 17. One-way ANOVA test results.

Indicators	F	df1	df2	*p*
TD	16.59	4	13.9	<0.001
MS	5.54	4	11.8	0.009
N°INTACC	6.22	4	12.5	0.005
N°INTDEC	3.43	4	11.7	0.045
TDA	9.99	4	14.2	<0.001
TDD	23.29	4	13.7	<0.001
N°HSR	6.94	4	13.7	0.003
WT	5.21	4	13.1	0.01
THSR	7.82	4	14	0.002
WD	4.76	4	14	0.012
DHSR	7.89	4	14	0.002
MP	8.83	4	14.2	<0.001
TLMP	6.22	4	12.6	0.005
THMP	18.75	4	14.1	<0.001
TEMP	4.1	4	12.2	0.025
TMMP	7.04	4	13.1	0.003
DLMP	1.43	4	12.4	0.28
DHMP	15.51	4	14.1	<0.001
DEMP	5	4	12.3	0.013
DMMP	7.6	4	13.2	0.002
N°CoDR	2.93	4	13.9	0.06
N°CoDL	13.03	4	14	<0.001

Legend: TD, Total Distance; MS, Maximal Speed; N◦INTACC, Number of Intense Accelerations; N◦INTDEC, Number of Intense Decelerations; TDA, Total Distance Acceleration; TDD, Total Distance deceleration; N◦HSR, Number of High-Speed Running; WT, Walking Time; THSR, Time High-Speed Running; WD, Walking Distance; DHSR, Distance High-Speed Running; MP, Metabolic Power; TLMP, Time Low Metabolic Power; THMP, Time High Metabolic Power; TEMP, Time Elevated Metabolic Power; TMMP, Time Max Metabolic Power; DLMP, Distance Low Metabolic Power; DHMP, Distance High Metabolic Power; DEMP, Distance Elevated Metabolic Power; DMMP, Distance Max Metabolic Power; N◦CoDR, Number of Change of Direction Right; N◦CoDL, Number of Change of Direction Left. $p < 0.05$ for differences between playing positions.

Details of the Tukey post hoc analysis reporting the pairwise comparisons between playing positions are provided in Table 17 and Table 18. The data show that all the EL indicators differ for each playing position except for N°INTDEC, WD, DLMP, and N°CoDL.

Table 18. Multiple comparison test results.

	Cinematic Indicators
TD	* significant difference between MD and CB ($p < 0.05$), between CM and FB ($p < 0.01$), between CB and WM ($p < 0.001$), and between FB and WM ($p < 0.001$).
MS	* significant difference between CB and ES ($p < 0.01$), between CB and WM ($p < 0.01$), between ES and FB ($p < 0.05$), and between FB and WM ($p < 0.05$).
N°HSR	* significant difference between CB and ES ($p < 0.001$), between CB and WM ($p < 0.01$), between ES and FB ($p < 0.01$), and between FB and WM ($p < 0.05$).
WT	* significant difference between FB and WM ($p < 0.05$).
THSR	* significant between CB and ES ($p < 0.001$), between CB and WM ($p < 0.05$), and between ES and FB ($p < 0.001$).
WD	no significant difference between playing positions.
DHSR	* significant between CB and ES ($p < 0.001$), between CB and WM ($p < 0.05$), and between ES and FB ($p < 0.001$).
	Mechanical Indicators
N°INTACC	* significant difference between MD and ES ($p < 0.05$), between CB and ES ($p < 0.05$), and between ES and WM ($p < 0.05$).
N°INTDEC	no significant difference between playing positions.
TDA	* significant difference between FB and MD ($p < 0.05$), between CB and MD ($p < 0.001$), between FB and ES ($p < 0.05$), and between WM and FB ($p < 0.001$)
TDD	* significant difference between MD and CB ($p < 0.01$), between MD and FB ($p < 0.001$), between CB and ES ($p < 0.05$), between CB and WM ($p < 0.001$), between ES and FB ($p < 0.01$), and between FB and WM ($p < 0.001$).
N°CoDR	* significant difference between FB and WM ($p < 0.05$).
N°CoDL	no significant difference between playing positions.
	Metabolic Indicators
MP	* significant difference between CB and WM ($p < 0.01$), between ES and FB ($p < 0.05$), and between FB and WM ($p < 0.001$).
TLMP	* significant difference between MD and FB ($p < 0.05$), and between FB and WM ($p < 0.001$).
THMP	* significant difference between MD and CB ($p < 0.05$), between MD and FB ($p < 0.01$), between CB and WM ($p < 0.001$), between ES and WM ($p < 0.01$), and between FB and WM ($p < 0.001$).
TEMP	* significant difference between CB and ES ($p < 0.05$), and between ES and FB ($p < 0.05$).
TMMP	* significant difference between ES and MD ($p < 0.01$), between ES and CB ($p < 0.001$), between CB and WM ($p < 0.05$), and between ES and FB ($p < 0.001$).
DLMP	no significant difference between playing positions.
DHMP	* significant difference between MD and CB ($p < 0.05$), between MD and FB ($p < 0.01$), between CB and WM ($p < 0.001$), between ES and WM ($p < 0.05$), and between FB and WM ($p < 0.001$).
DEMP	* significant difference between CB and ES ($p < 0.01$), and between ES and FB ($p < 0.001$).
DMMP	* significant difference between MD and ES ($p < 0.05$), between CB and ES ($p < 0.001$), between CB and WM ($p < 0.05$), between ES and FB ($p < 0.001$), and between FB and WM ($p < 0.05$).

Legend: TD, Total Distance; MS, Maximal Speed; N◦INTACC, Number of Intense Accelerations; N◦INTDEC, Number of Intense Decelerations; TDA, Total Distance Acceleration; TDD, Total Distance deceleration; N◦HSR, Number of High-Speed Running; WT, Walking Time; THSR, Time High-Speed Running; WD, Walking Distance; DHSR, Distance High-Speed Running; MP, Metabolic Power; TLMP, Time Low Metabolic Power; THMP, Time High Metabolic Power; TEMP, Time Elevated Metabolic Power; TMMP, Time Max Metabolic Power; DLMP, Distance Low Metabolic Power; DHMP, Distance High Metabolic Power; DEMP, Distance Elevated Metabolic Power; DMMP, Distance Max Metabolic Power; N◦CoDR, Number of Change of Direction Right; N◦CoDL, Number of Change of Direction Left. * $p < 0.05$ for differences between playing positions.

Figure 9, Figure 10 and Figure 11 show cinematic, mechanical, and metabolic indicators performed during OMs, respectively.

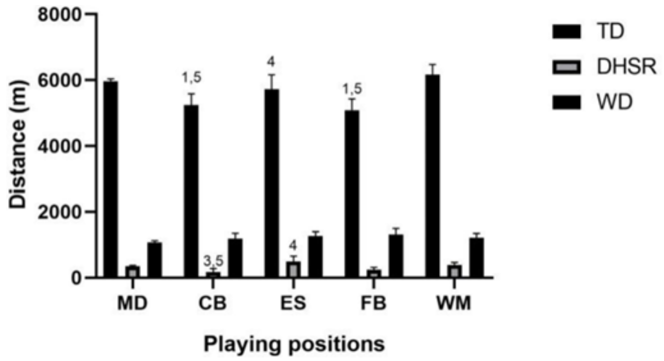

Figure 9. Playing position's cinematic indicators (TD, DHSR, WD) during the first half of official matches. Legend: TD, Total Distance; MS, WD, Walking Distance; DHSR, Distance High-Speed Running; MD, midfielder; CB, central back, ES, external striker, FB, fullback, WM, wide midfielder; $p < 0.05$ for differences between playing positions (1 difference with midfielder; 3 difference with external striker; 4 difference with full back; 5 difference with wide midfielder).

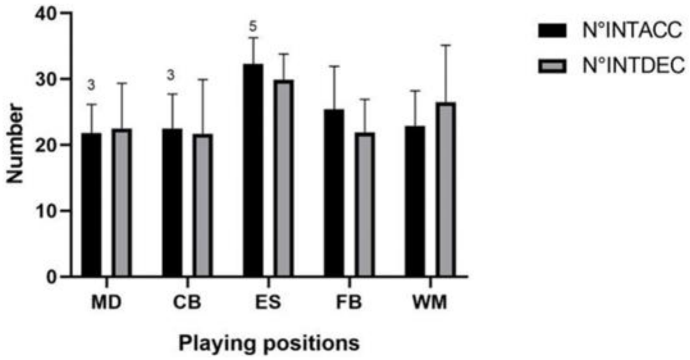

Figure 10. Playing position's mechanics indicators (N°INTACC, N°INTDEC) during the first half of official matches. Legend: N°INTACC, Number of Intense Accelerations; N°INTDEC, Number of Intense Decelerations; $p < 0.05$ for differences between playing positions (3 difference with external striker; 5 difference with wide midfielder).

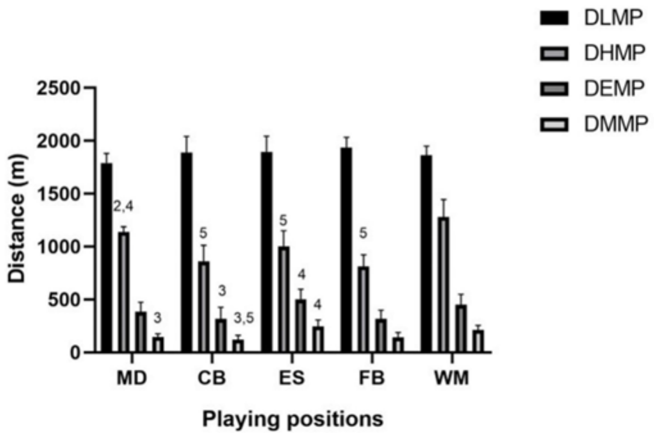

Figure 11. Playing position's metabolic indicators (DLMP, DHMP, DEMP, DMMP) during the first half of official matches. Legend: DLMP, Distance Low Metabolic Power; DHMP, Distance High Metabolic Power; DEMP, Distance Elevated Metabolic Power; DMMP, Distance Max Metabolic Power; $p < 0.05$ for differences between playing positions (2 difference with central back; 3 difference with external striker; 4 difference with full back; 5 difference with wide midfielder).

DISCUSSION

The aim of this study was to investigate any differences in EL indicators during the first half time of four OMs between young professional soccer players based on their playing position. The EL indicators were assessed using a wearable inertial sensor device. This technology allows us to assess EL considering several indicators similar to GPS avoiding signal issues and connection problems. Moreover, Coutts et al. [368] have demonstrated that GPS devices are reliable in assessing total distance and peak speed during high-intensity intermittent exercise but are less reliable for high-intensity activities such as accelerations. In contrast, the ISD device tracks activity information using inertial technology that captures acceleration and rotation data in real time at a rate of 100 Hz per channel, resulting in more accuracy for detecting acceleration and high-intensity effort than GPS. As we hypothesized, the main findings of our study showed significant differences in EL indicators between playing positions during OMs. The scientific literature shows that physical demand in soccer players has been largely studied using GPS technology [334,369,370]. The main studies that assessed external load performance during matches found that physical performance is highly specific according to the role of the players. These results are in line with our findings, although we measured the EL indicators through an ISD. Indeed, considering cinematic, mechanical, and metabolic external load indicators, the ES, WM, and MD performed the highest level of physical performance during the first half of the matches, whereas the CB and FB had the lowest level.

Cinematic External Load Indicators

In our study, significant differences in cinematic EL indicators between playing positions during the first half time of an OM were detected. Several previous studies have found differences in EL as distance, speed, and accelerations [371-373] between playing positions during both training and competition including both elite and amateur soccer players [361]. Moreover, considering physiological characteristics (i.e., HR and derived indices) [374,375] similar results have been found. The literature reports that the longest distance covered at high intensity has been achieved by the WM and FB [373-376]. In our study, we found that the WM and MD covered the highest TD during the first half time of an OM (6161 ± 316 and 5963 ± 74 m, respectively), whereas the CB (5240 ± 340 m) and FB (5087 ± 344 m) the lowest. Our results are in agreement with Ingebrigtsen et al., (2014) in which authors reported that, during the first half time of the match, WM traveled the highest TD and CB the lowest [377]. Concerning intensity indicators (i.e., N°HSR, THSR, and DHSR), ES and WM showed the highest results, whereas CB and FB showed the lowest. In line with these results, we found that FB and CB showed the highest amount of WT whereas MD and WM the lowest. However, there was no significant difference between the roles for the WD even though the FB and ES showed highest and the MD and CB the lowest values. Studies reported that CB showed the longest recoveries between consecutive high-intensity efforts [378] and spent the most time in low intensity efforts [372], in line with our results. Moreover, the MD spent less time in very low activity [379] and stand for much less time than other playing positions [380]. Indeed, MDs perform low to moderate-intensity activity more frequently showing shorter recovery bouts between high intensity efforts [379,380]. It is worth noting that when speed intensity increases, the MD exhibits low results. In fact, MDs play in very dense central spaces that limit the performance of intense actions such as high-speed running. However, when expressed as metabolic power, the central MD showed higher volume of high-intensity activity compared to attackers due to the accelerations [381]. The literature reports that FB perform more high intensity running than other playing positions. Specifically, Bangsbo et al., reported that MDs, FBs, and attackers covered a greater distance in high intensity running than the defenders [380-382]. Our results indicated that FB performed less intensity activity than other playing positions, showing similar performance to CB. Probably, in our sample, FB were required to have more defensive tactical function (i.e., 4:3:3 system) than offensive ones that requires a more intense effort during an OM. Indeed, some contextual factors such as tactics, game location, opponent quality, congested period, or match status could influence physical performance [383,384]. A study carried out by Altmann et al., (2021) [385] have demonstrated that FB (e.g., 4:4:2 or 4:2:3:1 system) displayed lower total and high-intensity distances compared to FB (e.g., 5:3:2 system), which is a new finding that emphasizes the need of differentiating between these two positions based on tactical system used. Moreover, WM, FB (in 3:5:2), and FB followed by forwards showed the greatest sprinting distance, whereas MD and CB showed shorter distances while sprinting. These findings are generally supported by previous literature [356,357,359,360]. Previous research indicates that FB, attackers, and MD players (both central and wide) covered the highest amounts of HSR and sprinting distance [360,386]. Dalen et al., (2016) reported that the FB and WM covered the highest whereas the CB the lowest HSR distance in an OM [387]. Ingebrigtsen et al., (2014) showed a greater HSR for the WM and FB and less for the CB in the first half of the match [377]. Additionally, authors reported the same results considering sprinting and distance [377]. In the same way, Dalen et al., (2016) reported highest sprinting distance for the FB and WM and less for the CB [387]. Moreover, Oliva Lozano et al., (2020) detected a sprinting distance greater for the WM and lower for the MD during an OM [345]. A high requirement for such running patterns in attacking players (e.g., WM) it may be necessary to cope with tactical demands related to overcoming defensive strategies to set up scoring situations. The MD plays in dense zones of the pitch that limit sprinting (i.e., speed >25.2 km/h) performance. We also found that the players who reached the highest speed peaks were the ES and the WM, whereas CB and FB the lowest. These findings are in contrast with a previous study carried out by Rampinini et al., (2007) that reported a peak speed significantly higher for fullbacks than central backs during an OM [386]. Our results are in line with Oliva Lozano et al., (2020) [345] that indicate the highest peak speed for the WM and the lowest for the MD. The bigger space available for the WM compared to the CB and MD can explain these results.

Mechanical External Load Indicators

A determining factor in soccer performance is the acceleration profile [377,388]. Given the rate of change in speed performed by the players [389], the acceleration profile can be considered as a group of acceleration-based variables that requires a high neuromuscular physical demand [390]. Indeed, high-intensity accelerations and decelerations have a considerable impact on soccer players' mechanical load and can be counted as markers of muscle damage post-match [391]. Specifically, accelerations have a high metabolic cost [392], whereas decelerations increase the mechanical load [387]. Oliva Lozano et al., (2020) [345] have considered high intensity (i.e., >3 m/s2) and low intensity (i.e., <3 m/s2) accelerations. Authors reported that WM performed the highest and CB the lowest number of intense accelerations during an OM. However, different results have been found with a lower intensity threshold (i.e., low intensity accelerations). Indeed, the MD achieved the highest and WM the lowest number of accelerations. This result may be explained by the fact that density increases (reduced m2 per player) as the ball is closer to the central zones of the pitch in match play resulting in a decrease in the intensity of play [367,393]. In our study, ES and FB performed a greater number of intense accelerations than other playing positions whereas the MD and CB are the lowest. The literature reported that in the first half of an OM, the highest number of accelerations have been showed by WM whereas the CB showed the lowest [387]. In this way, Ingebrigtsen et al., (2014) detected similar results. Authors reported that the WM and FB demonstrated a higher amount than the MD and CB [377]. Furthermore, our results confirm the findings of previous research which reported that the WM performed a higher number of intense accelerations than the CB [345]. Although the ES and WM showed the highest number of decelerations, there is no significant difference between the roles in our study. Our results are in line with previous research where was reported that the WM performed higher number of intense decelerations than the CB [345]. Moreover, Oliva Lozano et al., (2020) found that the WM performed the highest number of intense decelerations and the CB the lowest during an OM, whereas the MD attained the highest and the WM the lowest number of low decelerations [345]. Moreover, Dalen et al., (2016) reported that the FB and WM performed a higher number of decelerations than the CB in the first half time of an OM [387]. We found that the WM and ES covered the highest TDA and FB and CB the lowest. This means that the FB performed shorter accelerations, similar to the CB, compared to the ES and WM. In general, previous studies revealed that players in wide positions accelerated significantly more than central players [371,387]. Indeed, Oliva-Lozano et al., (2020) found that players covered longer acceleration distances in external positions (i.e., WM and FB) than the central MD and CB [345]. It is worth noting that Dalen et al., (2016) reported that the FB and WM covered the highest acceleration distance in the first half of the match whereas the CB was the lowest [387]. In addition, Abbott et al., (2018) found the highest intensity acceleration distances in wide positions (i.e., attackers and wide defenders) producing the highest distances due to the frequent tactical requirement of wide positions to reach high speeds [371]. In our study, whereas the MD and WM showed the highest decelerations distance, the FB and CB recorded the lowest. This result is in contrast with Dalen et al., (2016) in which a higher deceleration distance for CB and FB compared to WM in the first half of an OM was found [387]. However, there is a difference between the acceleration and deceleration thresholds used between the studies that do not allow us to compare them. Additionally, Oliva Lozano et al., (2020) reported that WM and forward covered the highest deceleration distance whereas the MD and CB were the lowest, accordingly to our results (except for the MD) [345]. However, different methods, MEMS technology, and thresholds used for classifying accelerations and decelerations make it difficult to draw conclusions about this difference. In field-based intermittent sports such as soccer, it is proposed that the ability to execute rapid changes in direction is a critical factor in relation to match outcomes [394]. Therefore, the ability to make a quick change of direction is related to the ability to produce a large amount of force in a short time . Research has shown that soccer players undertake approximately 700 direction changes of varying intensity during a match, and 600 of these changes in direction are 0–90° turns [336]. Around 50 of the direction changes are performed at maximal intensity during a match [336]. Approximately 700 direction changes per match were made by defenders, 500 by midfielders, and 600 by strikers. However, midfielders and strikers performed more turns of 270° to 360°. This could be due to specific tactical requirements such as playing position in midfield. The amount of 90° to 180° turns is relatively uniformly distributed with all positions performing roughly between 90 and 100 in official matches [336]. In our study, we considered a change of direction >30° and performed at a speed >2 m/s, classifying them in right and left changes of direction. Regarding N°CoDR, we found that the difference appears to be significant only between the FB and WM. Specifically, the WM and ES performed the highest amount of CoDR, whereas the FB and MD the lowest. It is worth noting that, considering N°CoDL, there is no significant difference between the roles, even if the MD and CB performed the highest number whereas ES and WM were the lowest.

Metabolic External Load Indicators

Metabolic power, defined as the product of the energetic cost of acceleration running (EC, $J \cdot kg^{-1} \cdot m^{-1}$) and speed (v, $m \cdot s^{-1}$), has been considered for EL monitoring as it considers both speed and acceleration factors [335]. Studies that assessed the performance considering only the speed category have underestimated the amount of high-intensity activity performed by players. Indeed, when expressed as metabolic power, Gaudino et al., (2013) indicated that the MD showed a higher volume of high-intensity activity compared to attackers [381]. Our study confirms previous findings showing that midfielders showed higher metabolic power during an OM compared to other playing positions. Specifically, our results show that the playing positions that recorded the highest MP average values were the WM, followed by the MD and ES, whereas the FB and CB were the lowest. In line with our results, Manzi et al., (2022) [395] reported that central backs covered less high-metabolic power distance and performed lower power events than players in the other playing positions, a finding likely related to the tactical role. Furthermore, midfielders covered both a substantial distance at high metabolic power and the largest number of power events compared to other playing positions. This result could be supported by the fact that midfielders play in very dense central spaces of midfield that limit the performance of intense actions such as high-speed running and possibly increase the number of accelerations. It is worth noting that metabolic power increases because of speed or accelerations [335], consequently, since the MDs do not reach high distances at high intensity, their metabolic power increases more due to the numerous accelerations and decelerations. Furthermore, these results are in line with the results of a previous study showing that midfielders spend most of their time in medium and high-intensity activity during a match [372]. We also found that the MD and WM performed the highest distance per minute, whereas the CB and FB showed the lowest values. This result could be explained by the low recovery time and distance (i.e., TLMP and DLMP) among the actions detected in midfielders. In addition, supporting our results, a study reported that midfielders had greater power recovery than central backs and forwards and lower recovery time after power events than central back, full back, and forward players [395]. Our study provided a detailed analysis of metabolic power as different metabolic intensity thresholds were reported for each playing position. In line with previous findings, we found that the CB showed the lowest high, elevated, and maximum MP (expressed as both time and distance), whereas the MD and WM showed the highest THMP. However, considering the "intense" power thresholds (i.e., TEMP, TMMP, DEMP, and DMMP), the highest results were found in the ES and WM. In order to reach elevated and maximal metabolic power, players have to reach high speeds. This is possible by having space available as in the case of wide players such as the ES and WM. Indeed, Di Pampero et al., (2005) showed that the peak power output, of about 100 W/kg, is attained after about 0.5 s and that the average power over the first 4 s is on the order of 65 W/kg during 30 m running [396]. This means that players have to do a large number of intense long straight intense runs to achieve high and maximum metabolic power.

Strengths and Limitations of the Study

In this study, we considered cinematic, mechanical, and metabolic EL indicators that provide a complete overview of match performance and permit the evaluation of differences between playing positions. Furthermore, it is worth mentioning that a different tactical requirement, the score of the match, the quality of the opponent, and the fact that the present study is based on only four official matches considering only thirteen participants represent the limitations of this study.

Practical Implications

In this study, we used a wearable inertial sensor (ISD technology) that provides several EL indicators useful to assess training and match performance in soccer. Compared to GPS, ISD can also be used for indoor sports without the need of coupling with external signals. Moreover, data sampling takes place differently. ISD measures movement in real time through limb swing, whereas GPS uses the Doppler effect of satellite signals which could increase the distortion of related signals. In summary, these devices can be useful for practitioners in assessing soccer players' EL during training or competitions in order to prevent injuries and improve sports performance.

CONCLUSION

The present study provides a useful and novel insight into sprint and acceleration profiles of young Italian professional soccer players during OMs showing a difference in EL indicators between playing positions. In particular, considering cinematic, mechanical, and metabolic EL indicators, the ES, WM, and MD performed the highest level of physical performance during a match, whereas the CB and FB performed the lowest. However, there is high variability in physical performance during a match between players of the same position [359] (e.g., FB) and a possible explanation for this observation could be that the match performance depends not only on playing position but also to some extent on individual players themselves [385]. This study reveals some new findings concerning the physical demand for each playing position during OMs. To design role-specific soccer training, coaches need a clear view of how different players and positions meet physical requirements. The principle of specificity (SAID) suggests that the training process should be designed to emphasize certain physical components to cope with match demands. Wide players exhibit greater sprinting distances than central players. Finally, as with sprinting, wide players seem to perform more accelerations than central players [349].

3.3 Smartwatch and Other Wearables: Health and Activity Tracking in Re-Education and Daily Life

List of publications/projects discussed within Chapter III:

Giustino V, Leale I, Cicero L, Petrigna L, Nigro ML, Fontana V, Mignosi E, Cataldo P, Macaluso A, Gómez-López M, Cassata G, Battaglia G. *Acute effects of a dog sport on fitness parameters in young adults: a randomised controlled crossover study.* Hum Mov. 2024;25(4):138-146; doi: https://doi.org/10.5114/hm/196835.

INTRODUCTION

The scientific literature has amply demonstrated the beneficial effects of physical activity (PA) on health-related physical fitness parameters in all ages [397-399]. In this line, to increase participation in PA for psychophysical well-being, the prevention of pathologies, and the reduction of sedentary behaviours, it has been suggested that governments adopt various strategies and also promote alternative and feasible programs [400]. these include green exercise and the use of technological and digital tools [81,88]. Among the types of PA, walking is the most common and easiest form, accessible to the general population, and does not require equipment, economic investments, and pre-existing sports skills [401,402]. From this perspective, several research groups have long investigated the effectiveness of walking on physical health [42,403,404]. Although walking can differ widely in terms of frequency, intensity, and volume, evidence suggests that even recreational walking can induce health benefits on cardiovascular function, body mass index, and body balance [233,405-407]. In turn, considering the large number of families who own a dog, encouraging walks with the dog (i.e., dog walking) could be an effective strategy for increasing the level of PA in the general population [408]. As a matter of fact, there is a growing body of evidence suggesting that dog walking is a practice that induces dog owners to have higher levels of PA and lower measures of sedentary behaviour than non-dog owners [409-411]. In a seminal work on this topic, Coleman et al. [412] reported that dog walking is associated with a higher level of moderate to vigorous PA (MVPA) compared to both dog owners who do not walk their dogs and non-dog owners. this can be attributed, in part, to the fact that owning a dog provides the motivation to walk with them [413,414]. Moreover, participating in PA with the dog seems to positively affect many psychophysical and social domains as body weight, cardiovascular function, social interactions, and emotional health [408,413]. Although previous studies have shown that owning a dog, as well as walking a dog, increases the level of PA and improves health-related physical fitness compared to non-dog owners [415-417] . Very few studies have investigated the impact of dog sports on people [418]. Dog sports have increasingly been practised in the world over the years and include all those disciplines that dog owners (specifically referred to as dog handlers) practice with their dogs. Among these, dog agility is a sport that consists of an obstacle course that includes jumps and tunnels that the dog, guided by the handler, must perform in a specific order, in the shortest possible time, and with the least number of penalties. Although studies have investigated the effects of dog walking on humans, as far as we are aware, few research groups have studied the aspects of dog handlers who practice dog agility [418,419], and no studies have investigated the impact of dog agility on a dog handler's fitness parameters. Hence, this pilot study aimed to (a) evaluate the acute effects of a dog agility course on fitness parameters (such as number of steps, walking time, distance covered, average pace, energy expenditure, average and maximum heart rate (HR), and perceived exertion level) in physically active young adults and (b) determine any acute differences in these fitness parameters after the execution of the dog agility course with and without the dog. We hypothesise that a dog agility course can increase all of the aforementioned parameters in dog handlers except for walking time.

MATERIALS AND METHODS

Study design

This study used a randomised controlled crossover design. All participants performed a dog agility course in two different conditions (i.e., with and without the dog), with a washout period of one week between the two conditions [420].

Participants

Participants were recruited from a dog sports club in Palermo, Italy. the research was presented to the staff of the dog sports club and the invitation to participate was spread among the members of the dog sports club. the participation was on a voluntary basis by providing written informed consent. To participate, the inclusion criteria were (1) age between 18 and 35 years, (2) normal weight, (3) level of PA sufficiently active, and (4) one year of dog agility background. Although thirteen participants were recruited, two of them were not eligible for inclusion (> 35 years), and one participant dropped out of the study. thus, 10 young female participants (age: 24.3 ± 3.66 years; height: 1.63 ± 0.07 m; weight: 55.6 ± 7.05 kg; BMI: 20.93 ± 1.34 kg/m2), who had been practising dog agility for at least one year, were enrolled for the study.

Eligibility assessment

Age classification

Considering the 5 following age categories: young (25 years), young adults (25 < years 35), adults (35 < years 55), senior adults (55 < years 65), and elderly (> 65 years) [421-423]; we included only young (excluding minors) and young adults in the study.

Anthropometric measures

An electronic scale (maximum recordable weight: 300 kg; resolution: 100 g; Seca; Hamburg, Germany) was used to measure body weight, and a standard stadiometer (maximum recordable height: 220 cm; resolution: 1 mm) to determine height. Body mass index (BMI) was computed as body weight divided by height squared (kg/m2). Based on the following standard BMI categories: underweight (BMI < 18.5), normal weight (18.5 BMI < 25), overweight (25 BMI < 30), and obesity (BMI 30) [424]; we only considered people with normal weight.

Physical activity level assessment

The International Physical Activity Questionnaire – Short Form (IPAQ-SF), an instrument to detect the level of PA during the last 7 days or a usual week, was administered to all participants [425]. through the frequency (days) and the duration (minutes) spent for each PA intensity (i.e., vigorous activities, moderate activities, walking, and sitting), we calculated the total weekly PA as reported in the "Guidelines for Data Processing and Analysis of the International Physical Activity Questionnaire (IPAQ) – Short and Long Forms" (http://www.ipaq.ki.se). In detail, we used the corresponding metabolic equivalent task (MEt) assigned to each type of PA (i.e., 3.3 for walking, 4.0 for moderate-intensity physical activities, and 8.0 for vigorous-intensity physical activities) [426]. Hence, to calculate the total weekly energy expenditure, we multiplied the MEt of each type of PA for the minutes of practice over the last seven days and then we summed the results (i.e., for walking, moderate-intensity physical activities, and vigorous-intensity physical activities). According to the abovementioned IPAQ scoring protocol, participants were classified into the 3 following categories of PA: low active, moderate active, and high active. For the study, we only considered moderately active people.

Procedure

Participants were randomised in a crossover design between two conditions for performing the dog agility course: with and without the dog. Five participants performed the dog agility course first with the dog and then, after a washout period of one week, without the dog; the other five participants performed the same dog agility course in reverse order. Figure 12 shows the flow diagram of the study.

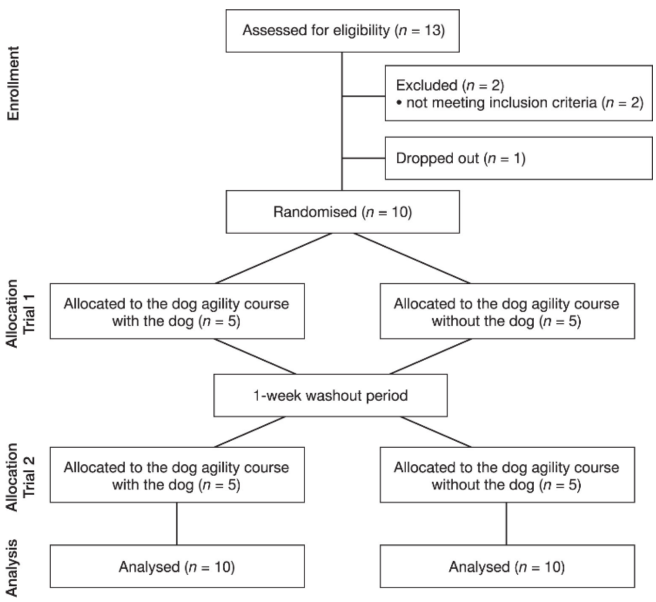

Figure 12. *Flow diagram*

The dog agility course was 56.87 m long and consisted of 12 obstacles: 10 jumps and 2 tunnels. the course was designed with a minimum and maximum distance between obstacles of 5 and 8 m, respectively (Figure 13). For the jumps, the bar was 50 cm high and 120 cm wide; for the tunnels, the diameter was 60 cm and the length was 525 cm.

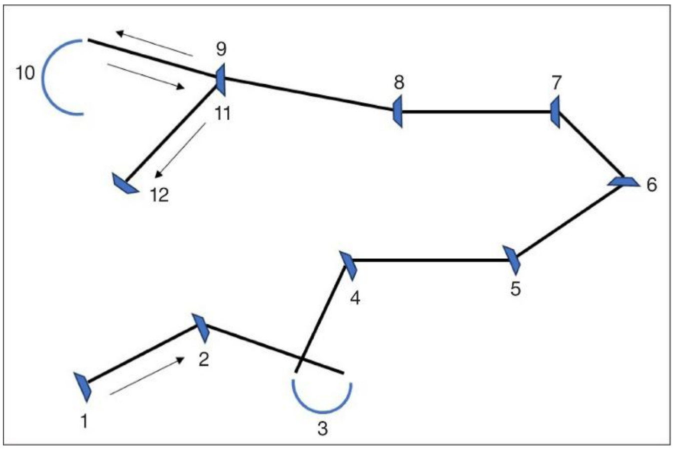

Figure 13. *Dog agility course*

Prior to the dog agility course, a 10-minute warm-up phase consisting of exercises aimed at improving joint mobility and engaging the major muscle groups was conducted. Following the dog agility course, a 10-minute cool-down phase, which included leisure exercises and walking, was carried out. three time points of measurement were included: before the dog agility course (t0), immediately after the dog agility course (t1), and 10 minutes after the end of the cool-down phase (t2). At t0 and t2, the average HR (bpm) and the perceived exertion level were measured; whereas at t1, the number of steps, walking time (s), distance covered (km), average pace (min/km), energy expenditure (cal), average and maximum HR (bpm), and perceived exertion were assessed. Parameters were recorded using a fitness smartwatch (Fitbit Blaze, San Francisco, CA, USA) selected based on the validity and reliability of the device [427,428]. Participants were asked to wear the instrument on the non-dominant wrist at all three time points (i.e., t0, t1, and t2) for both conditions (i.e., with and without the dog). the subjective level of perceived exertion during exercise was assessed using the Borg category-ratio scale (Borg CR10) [429]. this scale from 0 (no perceived exertion) to 10 (maximum perceived exertion) allows individuals to report the internal intensity of the exercise [429].

Statistical analysis

Statistical analysis was conducted using R (R Core team; Vienna, Austria) with a significance level set to < 0.05. Considering the small sample recruited, a non-parametric analysis was performed. For ordinal data, a Wilcoxon matched-pairs signed ranks test was used to compare medians between each set of matched pairs (i.e., with and without the dog) for all the parameters (i.e., number of steps, walking time, distance covered, average pace, energy expenditure, average and maximum HR, and perceived exertion). the Friedman test for randomised complete block designs was adopted to detect any differences between the variables considered (i.e., average HR and perceived exertion) in the two conditions (i.e., with and without the dog) measured at the different time points (t0, t1, t2).

RESULTS

The Wilcoxon matched-pairs signed ranks test revealed significant differences in the number of steps ($p = 0.011$), walking time ($p = 0.006$), average HR ($p = 0.004$), maximum HR ($p = 0.003$), and perceived exertion ($p = 0.007$) between the two conditions immediately after (t1) the dog agility course. In particular, for all these parameters, higher values were found in the execution of the dog agility course with the dog. No significant differences were found in distances covered ($p = 0.104$), average pace ($p = 0.348$), and energy expenditure ($p = 0.102$), between the two conditions, as reported in table 19.

Table 19. Statistical analysis of parameters considered using the Wilcoxon matched-pairs signed ranks test.

Parameter	Mean	Standard deviation	p-value (Wilcoxon)
	Dog condition No-dog condition	Dog condition No-dog condition	
Number of steps	62.8 41.5	27.93 10.27	0.011
Walking time (s)	36.5 21.3	16.35 2.76	0.006
Distance covered (km)	0.03 0.02	0.02 0.01	n.s.
Average pace (min/km)	15.61 14.33	4.15 5.25	n.s.
Energy expenditure (cal)	3 1.3	3.07 1.62	n.s.
Average HR (bpm)	99.7 79.8	10.31 10.18	0.004
Maximum HR (bpm)	107.6 85.7	10.22 9.65	0.003
Perceived exertion	4.1 2.2	1.04 1.17	0.007

Furthermore, among the parameters considered, the comparison of both the average HR and the perceived exertion (which were measured at t0, t1, and t2) showed significant increases in all three measurement times (t0, t1, t2) in the condition with the dog compared to without the dog. As reported in table 17, the Friedman test for randomised complete block design analysis showed significant differences for the average HR and the perceived exertion parameters for both conditions in the three time points (t0, t1, t2). In detail, the values found for the average HR in the condition with ($p = 0.0004$) and without a dog ($p = 0.0001$) and for the perceived exertion in the condition with ($p = 0.0003$) and without a dog ($p = 0.0001$) at t0, t1, and t2 were not equivalent to each other.

Table 20. Statistical analysis of parameters considered using the Friedman test.

Parameter	Condition	Mean and Standard Deviation	T0	T1	T2	p-value (Friedman)
Average HR (bpm)	No-dog condition	Mean	65.1	79.8	68.5	0.0001
		SD	3.81	10.18	8.66	
Average HR (bpm)	Dog condition	Mean	72.8	99.7	81.7	0.0004
		SD	6.37	10.31	12.28	
Average perceived exertion	Dog condition	Mean	1	4.1	1.2	0.0003
		SD	1	1.04	0.75	
Average perceived exertion	No-dog condition	Mean	0.6	2.2	0.7	0.0001
		SD	1.02	1.17	0.78	

DISCUSSION

The purpose of this study was to examine the acute effects on fitness parameters such as number of steps, walking time, distance covered, average pace, energy expenditure, average and maximum HR, and perceived exertion level in young adults who performed the same dog agility course in two different conditions, i.e., with and without the dog. Our hypothesis was to detect, after the execution of the course with a dog, an increase in the number of steps, distance covered, average pace, energy expenditure, average and maximum HR, and perceived exertion level, and a decrease in walking time. Our hypothesis was based on the fact that the dog could have increased the intensity of the physical exercise because (a) the participants were pushed to motivate the dogs to perform the course in the shortest possible time; (b) the participants could have indicated the course to the dogs and given indications on overcoming obstacles. Results showed a significant increase in the number of steps ($p = 0.011$), walking time ($p = 0.006$), average HR ($p = 0.004$), maximum HR ($p = 0.003$), and perceived exertion ($p = 0.007$) during the execution of the course with a dog. In contrast with our hypothesis, we found a significant increase in walking time and no significant difference in distance covered, average pace, and energy expenditure. Although a growing body of evidence suggests that dog walking has positive effects on several physical characteristics in dog handlers [409,410], no studies have focused on the benefits of dog sports on dog handlers. As for the increase in the number of steps we found, this could be partially explained because, to stay as close as possible to the dogs, participants took shorter steps or even approached the obstacle to indicate it to the dogs. this could also be related to the increase in walking time found. Powell et al. [430] showed that dog ownership is associated with a higher daily number of steps and higher weekly time spent walking, with results suggesting dog acquisition increases PA levels in a short time. Here, we also found that these parameters can increase after a single session of a dog sport performed with the dog than without. Although the number of steps increased, the distance covered, and the average pace did not change significantly, and this outcome could be related to the length of the course, which was the same in both conditions. A recent study by Machová et al. [431] showed that dog owners spent more time in PA during a week and reported higher energy expenditure levels compared with non-dog owners. However, no previous studies have investigated the impact on energy expenditure in dog handlers after a session of any dog sport. We found no difference in calories burned after a dog agility course between the conditions with and without a dog. this could be explained due to the type and intensity of the dog sport we examined. However, in contrast with our findings, Engelberg et al. [409] detected that dog owners showed 4–5 more minutes/day of MVPA than non-dog owners. Performing the course with the dog resulted in greater perceived exertion than executing the course without a dog. this finding can be explained by the increase in cardiovascular function (increase in average HR and maximum HR) found. Indeed, it is known that the perceived exertion level measured by the Borg scale is strongly correlated with the HR detected during exercise [432]. Although the cardiovascular benefits of dog walking have been reported by many research groups, no studies have so far examined the effects on the cardiovascular function of a dog sport [408,413]. Based on our outcomes, increased HR responses to exercise seem to be associated with the presence of the dog. Among other outcomes, Sirard et al. [433] found that dog ownership increases the metabolic equivalent per minute/week, and calorie expenditure. the greater perceived exertion could also be explained by the attention that owners must pay to their dogs [434]. Indeed, the owner-dog relationship of gaze average length and gaze frequency may have played a primary role as dog agility shifts the gaze to the owners more frequently than assistance dogs or untrained dogs. Although no study has investigated the effectiveness of dog sports, which are increasingly practised, on owners' physical characteristics, previous studies have already reported that dog owners engage more in the practice of walking and PA, and these findings align with our results. Indeed, in recent years, the research has focused more on the beneficial effects of owning a dog on the practice of PA. A recent scoping review aimed to investigate the association between

PA in young people and the presence of a dog in the family demonstrated that walking and playing with the dog increased the level of PA in dog owners [435]. the authors concluded that suggesting and promoting awareness campaigns on the importance of owning dogs to increase the practice of PA in young people, emphasising the importance of walking and playing with them daily to achieve this goal [435]. Similarly, in the scoping review by Chase et al. [436], the authors stated that walking and playing with a dog are favourable strategies for increasing the level of PA in young people by detecting this positive association in the majority of the articles included. A previous review summarized the articles that compared the level of PA of dog owners and non-dog owners, showing that dog owners reported higher walking and PA practice than non-dog owners, with effect sizes from small to moderate [437]. the above-reported findings are in agreement with our preliminary results suggesting that practising sports with the dog could be as effective as other sports. However, due to the lack of studies, more research is needed on this topic to confirm the contribution of any dog sport on fitness parameters in dog handlers. Of interest is a study by Krøger et al. [438] in which authors explored the effectiveness of agility activity with dogs to motivate less active children to participate in PA. this research highlighted that dog agility appeared to motivate less active children to engage in challenging PA [438]. the main limitation of the present pilot study is the lack of literature on this topic. However, this could also be the major strength of the study which, in this regard, intends to provide a fundamental contribution to this field of research. Moreover, a limitation of the study is the small sample size which may not be representative of the general population. Among the limitations of the study, it is necessary to mention the IPAQ as an eligibility instrument for the sample which, being self-reported, increases the risk of self-reporting bias. Moreover, it should be mentioned that this study explored the acute effects of the practice of a dog sport. thus, longitudinal studies could be useful to provide stronger causal evidence on the relationship between PA and dog ownership.

CONCLUSIONS

Considering the already known effectiveness of all animal-assisted activities, dog sports such as dog agility, could be useful also for populations with disorders/disabilities [439-441]. Having a dog could increase the physical level of people. Doing sports with the dog could be an effective alternative strategy to increase the practice of PA and reduce sedentary behaviours with consequent beneficial effects on psychophysical health. Furthermore, since it is an outdoor exercise, it could also be recommended in particular socio-sanitary conditions, such as during the most recent pandemic [442]. As a matter of fact, in a study that investigated dog walking before and during the COVID-19 pandemic lockdown, the authors highlighted that this could be a public health strategy in cases of lockdowns/disasters/emergencies that may occur in the future [443]. Moreover, dog sports are accessible to the general population, and do not require equipment, economic investments, and pre-existing sports skills.

3.4 Privacy and Ethical Considerations in Technology

AI and technology-based systems continuously collect and process large volumes of sensitive data, including biometric markers, physiological parameters, and personal information, raising significant concerns regarding data security, storage, and sharing [444]. Data ownership and accessibility are critical factors influencing the adoption of these technologies in sports, as athletes' confidential information may be vulnerable to unauthorized access, potentially resulting in misuse or exploitation aimed at obtaining unfair competitive advantages. To ensure responsible integration of technology, the development and enforcement of specific legal and regulatory frameworks are essential to guarantee data confidentiality and ethical use. Regulations such as the General Data Protection Regulation (GDPR) in Europe, alongside other privacy laws, play a pivotal role in protecting sensitive information and ensuring compliance within the sports domain [445]. Another challenge associated with technology integration is the risk of over-reliance, which may diminish the role of human expertise, particularly among coaches and sports analysts. While technology provides substantial benefits in data collection, analysis, and decision-making, it is essential to maintain a balanced approach that preserves the critical value of human judgment and contextual understanding. A relevant issue in this context concerns the use of technology in officiating and dispute resolution. Technological and artificial intelligence tools should function as aids to referees rather than replacements, ensuring that ultimate decision-making authority remains with match officials. Preserving this balance is critical in sports, particularly given the dynamic and unpredictable nature of team competitions. In this context, technologies such as the Video Assistant Referee (VAR) system in football, Goal Line Technology, and the Challenge system in sports like tennis and American football exemplify how technology can reduce officiating errors and enhance decision accuracy [446]. For instance, Goal Line Technology provides precise determination of whether the ball has fully crossed the goal line, thereby resolving contentious goal situations. Similarly, VAR enables referees to review potentially erroneous decisions through video replay, allowing intervention in cases of clear errors or significant oversights [447]. In rugby, the Television Match Official (TMO) serves a comparable function, supporting the on-field referee in the evaluation of complex game situations, including tries and foul tackles. Additionally, the Challenge system enables teams to request real-time video reviews, thereby enhancing the fairness and accuracy of officiating decisions. However, despite these tools becoming integral to modern sport, it is essential that their application remains subordinate to the human discretion of referees, who must retain the ability to assess subjective elements such as intent and contextual factors within the game. This approach ensures that technology serves as an effective aid without compromising the fluidity and intrinsic spirit of the sport.

Chapter IV – Personal Contributions and Research Experience

4.0 Research Activities and Skill Development

Within the local unit where the main activities of the doctoral program were conducted, research projects constituted a fundamental component of the training experience and were complemented by a wide range of practical activities. Multiple functional assessment protocols were employed, including handgrip dynamometry for strength evaluation; push-up and pull-up tests to exhaustion for muscular endurance; baropodometric footplate, Tinetti Scale, Berg Balance Scale, and the Short Physical Performance Battery (SPPB) for balance assessment. Jump performance was evaluated using both the standing long jump and the Optojump system, while range of motion (ROM) was measured via a Gyko inertial sensor. Body composition analysis was performed using bioelectrical impedance analysis (BIA; AKERN 101, AKERN SRL, RJL Systems, Detroit, USA). Heart rate variability (HRV) was assessed using a Polar H10 sensor, with data subsequently analyzed through Kubios software. Additionally, validated questionnaires were administered, including the SF-36 for health-related quality of life and the International Physical Activity Questionnaire (IPAQ) for physical activity levels. All protocols were first studied and practiced, then tested during a dedicated training phase, and only implemented in research projects following an adequate period of familiarization to ensure measurement reliability. I actively contributed to several studies, including the application of TC in diverse contexts such as elderly populations, Charcot–Marie–Tooth disease (CMT), migraine, and epilepsy. Moreover, I participated in the European AMIS project, which also provided the opportunity to present as a speaker at a national congress. Throughout the three years of the doctoral program, I contributed to the development of systematic reviews and scoping reviews, activities requiring in-depth knowledge of research methodologies, review protocols, and risk-of-bias assessment. These competencies were progressively refined as part of my training, providing advanced methodological expertise to support the production of high-quality research outputs. The research activities further encompassed statistical analysis and graphical data representation. To this end, I explored and applied various software platforms, including JASP, Jamovi, GraphPad Prism, and R, with primary analyses for submitted projects conducted using JASP and GraphPad Prism. Utilizing multiple analytical tools allowed for the exploitation of each software's specific strengths, thereby enhancing accuracy and robustness of results. Additionally, I obtained two certifications in statistical competence: "*Formazione e certificazione in Statistica per le Scienze Motorie e Sportive"*, both awarded by the Italian Society of Sport and Exercise Sciences (SISMES). Beyond research and technical expertise, I also served as co-supervisor for several undergraduate and master's theses. This role provided an opportunity to expand my academic and scientific competencies, refine my mentoring skills, and strengthen my ability to guide students through the various stages of research development, from study design to data analysis and final presentation. In addition, I carried out teaching support activities as a tutor for a total of four years. This experience significantly contributed to my professional growth, enhancing my didactic abilities and consolidating my subject-matter knowledge, while fostering effective communication and knowledge transfer within academic settings.

4.1 Collaborations with Clinical and Sport Institutions

During the three years of my doctoral program, I had the opportunity to establish and consolidate collaborations with both clinical and sports institutions, which proved essential for the development and implementation of several research projects. In the clinical setting, I collaborated with the Policlinico Hospital of Palermo, specifically with the Geriatrics and Neurology Departments, where multiple studies were conducted involving diverse patient populations and research protocols. These collaborations provided valuable clinical expertise, facilitated access to specific participant groups, and enabled the integration of research activities within a real-world healthcare context.

In the sports field, I had the privilege of working with Dr. Guglielmo Pillitteri, athletic trainer of Palermo Football Club, contributing to the design and implementation of physical assessment and training protocols within professional sports environments. Additionally, my collaboration with CUS Palermo allowed me to extend research activities into broader sporting contexts, supporting participant recruitment and the testing of performance evaluation methodologies in both competitive and recreational athletes. These experiences significantly enriched the scope of my doctoral research, fostering an interdisciplinary approach that integrated clinical perspectives, sports science principles, and applied performance analysis.

4.2 International Research Period

During my three-year PhD program in Health Promotion and Cognitive Sciences, I had the opportunity to undertake a six-month research period abroad, from September 2024 to March 2025, at the University of Murcia, Faculty of Sport Sciences. Within this research environment, my primary focus was the application of technological tools in sport, with particular emphasis on the utilization of artificial intelligence and mathematical algorithms in the sporting context. Concurrently, I investigated additional relevant topics, including the role of chronotype and its influence on individual lifestyle and quality of life. Furthermore, I explored the application of specific field tests within the Paralympic context, with particular attention to wheelchair tennis, an area I had previously studied, as well as wheelchair fencing and sitting volleyball. Under the supervision of Professor Manuel Gómez-López, this research experience culminated in the completion of two scientific manuscripts, with additional articles currently in preparation and under revision.

The ongoing exchange of ideas within the research team, combined with the consistent support from supervisors, fostered significant professional and personal development. I greatly valued the expertise, accessibility, and humility demonstrated by the research group, which facilitated the enhancement of my analytical and critical thinking skills. This experience enabled me to undertake a complex and multidisciplinary project, further strengthening my commitment to applied research within the fields of motor sciences and sports technology.

4.3 Publications and Dissemination

During the three years of the PhD program, I actively contributed to the dissemination of research findings through participation in national and international scientific events, oral and poster presentations, academic publications, and the receipt of scientific awards. I participated in two national congresses organized by the Società Italiana di Scienze Motorie e Sportive (SISMES), where I presented my doctoral research through both oral communications and poster sessions. At the international level, I attended the European Congress on Sports Science (ECSS), where I presented a poster on my research activities related to Telecoaching interventions. I also served as a speaker at a national congress and attended several additional scientific conferences, which provided valuable opportunities for academic exchange, networking, and interdisciplinary collaboration. As part of the dissemination strategy, I conducted a lunch seminar designed to present and promote my research project to a broader scientific and professional audience. A significant achievement was the receipt of the Premio Miglior Poster awarded by the Associazione Italiana Sistema Nervoso Periferico, obtained together with my research group for the work entitled “Tele-Coaching Physical Exercise for Patients with Charcot–Marie–Tooth Disease: An Italian Multicentric Study – EFTELCMT23”. In addition to conference participation, I contributed to the preparation of a scientific book, playing an active role in both its conceptual framework and the drafting of specific chapters, thereby extending the dissemination of research outputs beyond traditional peer-reviewed journal publications.

4.4 Other Articles Published

Some of the published papers that were not included or discussed in the previous chapters are presented in the following section. These works, although not directly addressed earlier, are relevant to the research activity carried out during the doctoral program and contribute to providing a more complete overview of the scientific output achieved. They include studies developed in parallel to the main projects described above, and their inclusion here aims to ensure that the overall research contribution is fully represented.

Leale, I., Pillitteri, G., Giustino, V., Scarpa, O., Cataldo, P., Gómez-López, M., & Battaglia, G. (2025). *Acute effects of overload strength training on vertical jump performance in young female volleyball players.* The Journal of sports medicine and physical fitness, 65(7), 891–899. https://doi.org/10.23736/S0022-4707.25.16497-9

ABSTRACT

Background: The vertical jump performance is one of the most used parameters for the evaluation of lower limb strength in volleyball. Indeed, vertical jumps are frequently performed by volleyball players during the match both in defensive and offensive actions. This study aimed to evaluate the acute effects of a 90-minute strength training session (STS) with different overload intensities on vertical jump performance and on rating of perceived exertion (RPE) in young female volleyball players.

Methods: Ten young female volleyball players (14.00±1.01 years; 165±0.03 cm; 58.33±10.25 kg; 21.52±3.84 kg/m2) were included in this randomized crossover study. The participants were subjected to the three following STS: STS-A without overload; STS-B with 10% body weight (BW) overload; and STS-C with 20% BW overload. The RPE for the three sessions was recorded using the modified 20-point Borg Scale. For the evaluation of lower limb strength, the following tests were used: squat jump (SJ), countermovement jump with hands on the hips (CMJ), and countermovement jump with arm swing (CMJ-AS).

Results: Although a significant interaction was detected after the STS, no significant changes were observed among the three sessions (i.e., STS-A, STS-B, and STS-C). No differences were detected in the Borg Scale across the three sessions.

Conclusions: This study showed that a STS administered without load or with an overload of 10% or 20% of BW, does not lead to significant changes on vertical jump performance in young volleyball players.

Leale, I., Giustino, V., Trapani, P., Alonge, P., Rini, N., Cutrò, I., Leone, O., Torrente, A., Lupica, A., Palma, A., Roccella, M., Brighina, F., Di Stefano, V., & Battaglia, G. (2024). *Physical Activity in Patients with Neuromuscular Disease Three Years after COVID-19, a Longitudinal Survey: The After-Effects of the Quarantine and the Benefits of a Return to a Healthier Life-Style.* Journal of clinical medicine, 13(1), 265. https://doi.org/10.3390/jcm13010265.

ABSTRACT

Background: Quarantine was one of the strategies adopted by governments against the spread of COVID-19. This restriction has caused an increase in sedentary behaviors and a decrease in the practice of physical activity (PA), with a consequent negative impact on lifestyle both in healthy people and in those who need constant practice of PA to combat diseases, such as patients suffering from neuromuscular diseases (NMDs). Hence, this study aimed to compare PA levels among patients with NMD during and after quarantine.
Methods: An adapted version of the International Physical Activity Questionnaire Short-Form and the Short-Form Health Survey were administered during COVID-19 quarantine (T0) and after 3 years (T1) to 91 Italian patients with NMDs.
Results: We found a significant increase in the total PA level at T1, with no significant changes in vigorous-intensity PA. Moreover, a significant decrease in the PA level was found among the patients with different NMDs. No significant changes in physical component scores and mental component scores were detected.
Conclusions: Our results suggest that it would be necessary to provide alternative indoor exercise settings to prevent the adoption of sedentary behaviors.

Leale, I., Petrigna, L., Giustino, V., Pillitteri, G., Barbieri, R. A., Palma, A., Musumeci, G., & Battaglia, G. (2023). *A standard operating procedure for the physical performance analysis of wheelchair fencer: a scoping review.* The Journal of sports medicine and physical fitness, 63(11), 1175–1181. https://doi.org/10.23736/S0022-4707.23.14998-X

ABSTRACT

Introduction: Wheelchair fencing (WF) is a very practiced sport within the Paralympic world. A careful analysis of the characteristics and data of a WF athlete can be useful for coaches and movement experts to better plan a training program. The objective of the study was to evaluate physical fitness assessment methods adopted in WF and to propose a standard operating procedures (SOP).

Evidence acquisition: Original articles written in English were included in this review, and the population studied was composed of athletes who practiced WF. Studies were searched from PubMed, Web of Science, and Scopus databases using keywords and Boolean operators. Eight studies were included in this review.

Evidence synthesis: Most of the studies converge and agree on the physical, physiological, and technical characteristics of a WF athlete.

Conclusions: The scientific literature referring to this sport is very scarce, hence the need for new original studies to optimize the SOP proposed.

Inguglia, C., Ingoglia, S., Leale, I., Iannello, N. M., Gennaro, A., Manzano-Sánchez, D., Gómez-López, M., & Battaglia, G. (2023). *Psychological Antecedents of Italian Sport Coaches' Coaching Behaviors: The Role of Basic Psychological Needs, Motivation and Subjective Vitality*. Healthcare (Basel, Switzerland), 11(20), 2797. https://doi.org/10.3390/healthcare11202797

ABSTRACT

The extant literature has identified some variables that are associated with sport coaches' coaching style, like their basic psychological need satisfaction, their motivation for coaching, and their psychological well-being. Framed from a conceptual framework based on Self-Determination Theory applied to sport coaches, the current study explored how sport coaches' basic psychological needs are associated with their motivation (intrinsic vs. external), subjective vitality, and coaching behaviors (autonomy-supporting vs. need-thwarting). Participants were 184 Italian sport coaches (males = 65%, Mage = 40.22, SD = 11.55, age range 19-74 years) from the "Centro CONI" project. They were requested to fill out online self-report questionnaires assessing the study variables. Structural equation modeling analyses suggested that sport coaches' satisfaction of basic psychological needs was associated with higher levels of intrinsic motivation to train as well as with higher levels of vitality that, in turn, were associated with coaching behaviors supporting athletes' autonomy. Moreover, sport coaches' frustration of basic psychological needs was associated with higher levels of external motivation to train that, in turn, were associated

with higher levels of a need-thwarting coaching style. Overall, the findings provided additional support for understanding how sport coaches' basic psychological needs relate to their coaching styles.

Pillitteri, G., Rossi, A., Simonelli, C., Leale, I., Giustino, V., & Battaglia, G. (2023). *Association between internal load responses and recovery ability in U19 professional soccer players: A machine learning approach*. Heliyon, 9(4), e15454. https://doi.org/10.1016/j.heliyon.2023.e15454

ABSTRACT

Background: The objective of soccer training load (TL) is enhancing players' performance while minimizing the possible negative effects induced by fatigue. In this regard, monitoring workloads and recovery is necessary to avoid overload and injuries. Given the controversial results found in literature, this study aims to better understand the complex relationship between internal training load (IL) by using rating of perceived exertion (RPE), recovery, and availability (i.e., subjective players' readiness status).

Methods: In this cross-sectional study, twenty-two-professional soccer players (age: 18.5 ± 0.4 years, height: 177 ± 6 cm, weight: 67 ± 6.7 kg) competing in the U19 Italian Championship were monitored using RPE scale to assess IL, and TreS scale to detect information about recovery and training/match availability during an entire season (2021-2022).

Results: Autocorrelation analysis showed a repeated pattern with 7 days lag (weekly microcycle pattern) for all the variables considered (i.e., TL, recovery, and availability). For recovery ($r = 0.64$, $p < 0.001$) and availability ($r = 0.63$, $p < 0.001$) the best lag for both of them is 1 day. It indicates that recovery and availability are related to the past day value. Moreover, TL was found to be negatively affected by recovery and availability of the current day (lag = 0 day). Cross-correlation analysis indicates that TL is negatively affected by recovery ($r = 0.46$, $p < 0.001$) and availability ($r = 0.42$, $p < 0.001$) of the current day (lag = 0 day). In particular, lower recovery and availability will result in following lower TL. Furthermore, we found that TL negatively affects recovery ($r = 0.52$, $p < 0.001$) and availability ($r = 0.39$, $p < 0.01$) of the next day (lag = 1 day). In fact, the higher the TL in a current day is, the lower the recovery and availability in the next day will be.

Conclusion: In conclusion, this study highlights that there is a relationship between TL and recovery and that these components influence each other both on the same day and on the next one. The use of RPE and TreS scale to evaluate TL and recovery/availability of players allows practitioners to better adjust and schedule training within the microcycle to enhance performance while reducing injury risk.

Petrigna, L., Petta, A., Giustino, V., Leale, I., Pillitteri, G., Palma, A., Zangla, D., & Battaglia, G. (2023). *A scoping review on how physical fitness is evaluated in sitting volleyball players*. The Journal of sports medicine and physical fitness, 63(3), 430–435. https://doi.org/10.23736/S0022-4707.22.13982-4

ABSTRACT

Introduction: Sitting volleyball is a widely practiced paralympic sport. A correct and standardized physical evaluation helps coaches to plan and manage the training. It is also important to evaluate physical fitness accurately and adopt standardized protocols to compare and normalize the data. The aim of the study was to evaluate physical fitness evaluation methods adopted in sitting volleyball and to eventually propose standard operating procedures.

Evidence acquisition: English-written and peer-reviewed original articles were included in this review. The population studied was composed only of athletes practicing sitting volleyball. Articles were searched on the electronic databases PubMed, Web of Science, and Scopus using keywords matched with Boolean operators. Two independent investigators collected and screened the studies against the eligibility criteria. Data were analyzed narratively.

Evidence synthesis: Only 7 studies were eligible and included in this review, but a wide testing methodology exists. There are some tests commonly adopted in the studies included and these are the handgrip test, the agility t-test, the speed, and endurance test. These tests with the 2-site skinfold thickness evaluation, the modified push-ups, the shoulder-stretch test, the chest throw test and the simple reaction time task were included in the standard operating procedure.

Conclusions: The literature on the topic is poor and standardization of the testing procedure to evaluate the physical fitness of people practicing SV has been provided.

Di Stefano, V., Thomas, E., Alonge, P., Giustino, V., Pillitteri, G., Leale, I., Torrente, A., Pignolo, A., Norata, D., Iacono, S., Lupica, A., Palma, A., Battaglia, G., & Brighina, F. (2022). *Patisiran Enhances Muscle Mass after Nine Months of Treatment in ATTRv Amyloidosis: A Study with Bioelectrical Impedance Analysis and Handgrip Strength*. Biomedicines, 11(1), 62. https://doi.org/10.3390/biomedicines11010062

ABSTRACT

Background and aims: Hereditary transthyretin amyloidosis with polyneuropathy (ATTRv) is caused by mutations in the TTR gene, leading to misfolded monomers that aggregate generating amyloid fibrils. The clinical phenotype is heterogeneous, characterized by a multisystemic disease affecting the sensorimotor, autonomic functions along with other organs. Patisiran is a small interfering RNA acting as a TTR silencer approved for the treatment of ATTRv. Punctual and detailed instrumental biomarkers are on demand for ATTRv to measure the severity of the disease and monitor progression and response to treatment.

Methods: Fifteen patients affected by ATTRv amyloidosis (66.4 ± 7.8 years, six males) were evaluated before the start of therapy with patisiran and after 9-months of follow-up. The clinical and instrumental evaluation included body weight and height; Coutinho stage; Neuropathy Impairment Score (NIS); Karnofsky performance status (KPS); Norfolk QOL Questionnaire; Six-minute walking test (6 MWT); nerve conduction studies; handgrip strength (HGS); and bioimpedance analysis (BIA).

Results: Body composition significantly changed following the 9-months pharmacological treatment. In particular, the patients exhibited an increase in fat free mass, body cell mass, and body weight with a decrease in fat mass. A significant increase after 9 months of treatment was observed for the 6 MWT. Coutinho stage, KPS, NIS, NIS-W, nerve conduction studies, Norfolk, COMPASS-31 scale, and HGS remained unchanged.

Conclusions: BIA might represent a useful tool to assess the effects of multiorgan damage in ATTRv and to monitor disease progression and response to treatments. More evidence is still needed for HGS. Patisiran stabilizes polyneuropathy and preserves motor strength by increasing muscle mass after 9 months of treatment.

Chapter V – Conclusions

The use of technology represents a key and continuously evolving element in both re-education and sports settings. Evidence shows that training with TC is an effective strategy to maintain high levels of physical activity and improve quality of life. This approach can enhance exercise capacity and tolerance in individuals with various health conditions, as well as in vulnerable populations, such as older adults. At the same time, wearable devices have proven to be effective tools for monitoring athletes, allowing the identification of differences between players based on their specific roles and individual characteristics. Such information is essential for optimizing training programs and designing personalized performance strategies. The main strengths of these approaches lie in their innovation and versatility. The ability to collect objective data in real time allows for the customization of training programs, improved workload management, and support for secondary prevention, thereby reducing the risk of complications associated with chronic diseases or a sedentary lifestyle. However, despite these clear advantages, several limitations remain. The effectiveness of such interventions largely depends on the correct use of devices and the quality of the data collected; technical issues or measurement errors may affect the results. Moreover, many studies have included small or highly specific samples, which may limit the generalizability of the findings. The relatively short duration of most interventions also prevents a full evaluation of their long-term effectiveness, and external factors such as individual motivation, social support, and lifestyle may influence outcomes, yet are not always adequately considered. Future research should focus on identifying the key variables that determine the effectiveness of digital training interventions, expanding the current evidence base and integrating insights from advancements in artificial intelligence. This approach will enable the development of increasingly targeted, safe, and effective strategies for both secondary and, potentially, primary prevention. Overall, the integration of wearable technologies with digital training programs represents a promising avenue for health management, enhancement of athletic performance, and optimization of wellness in the general population.

Glossary of Key Concepts

Telecoaching: A remote coaching approach that uses digital technologies to provide guidance, feedback, and motivation to individuals engaged in physical activity or rehabilitation programs. Telecoaching emphasizes personalized support, goal-setting, and continuous monitoring of progress.

Telehealth: A broad term encompassing all health-related services delivered remotely via digital technologies, including prevention, education, monitoring, and clinical care.

Telemedicine: A subset of telehealth focused specifically on the diagnosis, treatment, and clinical management of medical conditions through remote communication tools

REFERENCE

1. Ratten, V. Sports technology and innovation. *Cham: Springer Books* **2019**, 95-111.
2. Ratten, V. Sport-based entrepreneurship: towards a new theory of entrepreneurship and sport management. *International entrepreneurship and management journal* **2011**, *7*, 57-69.
3. Balmer, N.; Pleasence, P.; Nevill, A. Evolution and revolution: Gauging the impact of technological and technical innovation on Olympic performance. *Journal of Sports Sciences* **2012**, *30*, 1075-1083.
4. Dyer, B. The controversy of sports technology: a systematic review. *SpringerPlus* **2015**, *4*, 524.
5. Evans, R.; McNamee, M.; Guy, O. Ethics, nanobiosensors and elite sport: The need for a new governance framework. *Science and engineering ethics* **2017**, *23*, 1487-1505.
6. Karkazis, K.; Fishman, J.R. Tracking US professional athletes: The ethics of biometric technologies. *The American Journal of Bioethics* **2017**, *17*, 45-60.
7. Loland, S. The varieties of cheating—comments on ethical analyses in sport. *Sport in Society* **2005**, *8*, 11-26.
8. Miah, A. From anti-doping to a 'performance policy'sport technology, being human, and doing ethics. *European Journal of Sport Science* **2005**, *5*, 51-57.
9. Guppy, F.; Muniz-Pardos, B.; Angeloudis, K.; Grivas, G.V.; Pitsiladis, A.; Bundy, R.; Zelenkova, I.; Tanisawa, K.; Akiyama, H.; Keramitsoglou, I.; et al. Technology Innovation and Guardrails in Elite Sport: The Future is Now. *Sports Med* **2023**, *53*, 97-113, doi:10.1007/s40279-023-01913-1.
10. Rebelo, A.; Martinho, D.V.; Valente-Dos-Santos, J.; Coelho, E.S.M.J.; Teixeira, D.S. From data to action: a scoping review of wearable technologies and biomechanical assessments informing injury prevention strategies in sport. *BMC Sports Sci Med Rehabil* **2023**, *15*, 169, doi:10.1186/s13102-023-00783-4.
11. Russell, J.L.; McLean, B.D.; Stolp, S.; Strack, D.; Coutts, A.J. Quantifying Training and Game Demands of a National Basketball Association Season. *Front Psychol* **2021**, *12*, 793216, doi:10.3389/fpsyg.2021.793216.
12. Mikołajec, K.; Maszczyk, A.; Zając, T. Game Indicators Determining Sports Performance in the NBA. *J Hum Kinet* **2013**, *37*, 145-151, doi:10.2478/hukin-2013-0035.
13. Sitton, Z.; Swisher, J.; Davis, S.; Thornton, H. A Retrospective Analysis of Major League Baseball Hit-by-Pitch Rates before and after the Crackdown on Foreign Substance Use. *Clin J Sport Med* **2024**, *34*, 381-385, doi:10.1097/jsm.0000000000001200.
14. Yunchao, M.; Mengyao, R.; Xingman, L. Application of virtual simulation technology in sports decision training: a systematic review. *Front Psychol* **2023**, *14*, 1164117, doi:10.3389/fpsyg.2023.1164117.
15. Dawson, L.; McErlain-Naylor, S.A.; Devereux, G.; Beato, M. Practitioner Usage, Applications, and Understanding of Wearable GPS and Accelerometer Technology in Team Sports. *J Strength Cond Res* **2024**, *38*, e373-e382, doi:10.1519/jsc.0000000000004781.
16. Işın, A.; Yi, Q. Does video assistant referee technology change the magnitude and direction of home advantages and referee bias? A proof-of-concept study. *BMC Sports Sci Med Rehabil* **2024**, *16*, 21, doi:10.1186/s13102-024-00813-9.
17. Burkett, B. Technology in Paralympic sport: performance enhancement or essential for performance? *Br J Sports Med* **2010**, *44*, 215-220, doi:10.1136/bjsm.2009.067249.
18. Howe, P.D. Cyborg and Supercrip: The Paralympics Technology and the (Dis)empowerment of Disabled Athletes. *Sociology* **2011**, *45*, 868-882, doi:10.1177/0038038511413421.
19. Control, C.f.D.; Prevention. Physical activity for people with disability. *Centers for Disease Control and Prevention* **2022**.

20. Carroll, D.D.; Courtney-Long, E.A.; Stevens, A.C.; Sloan, M.L.; Lullo, C.; Visser, S.N.; Fox, M.H.; Armour, B.S.; Campbell, V.A.; Brown, D.R. Vital signs: disability and physical activity—United States, 2009–2012. *MMWR Morb Mortal Wkly Rep* **2014**, *63*, 407-413.
21. Ginis, K.A.M.; van der Ploeg, H.P.; Foster, C.; Lai, B.; McBride, C.B.; Ng, K.; Pratt, M.; Shirazipour, C.H.; Smith, B.; Vásquez, P.M. Participation of people living with disabilities in physical activity: a global perspective. *The Lancet* **2021**, *398*, 443-455.
22. Jetha, A.; Faulkner, G.; Gorczynski, P.; Arbour-Nicitopoulos, K.; Ginis, K.A.M. Physical activity and individuals with spinal cord injury: accuracy and quality of information on the Internet. *Disability and Health Journal* **2011**, *4*, 112-120.
23. Gelaw, A.Y.; Janakiraman, B.; Gebremeskel, B.F.; Ravichandran, H. Effectiveness of Home-based rehabilitation in improving physical function of persons with Stroke and other physical disability: A systematic review of randomized controlled trials. *Journal of Stroke and Cerebrovascular Diseases* **2020**, *29*, 104800.
24. Rimmer, J.H.; Wilroy, J.; Galea, P.; Jeter, A.; Lai, B.W. Retrospective evaluation of a pilot eHealth/mHealth telewellness program for people with disabilities: Mindfulness, Exercise, and Nutrition To Optimize Resilience (MENTOR). *Mhealth* **2022**, *8*, 15.
25. Fiuza-Luces, C.; Santos-Lozano, A.; Joyner, M.; Carrera-Bastos, P.; Picazo, O.; Zugaza, J.L.; Izquierdo, M.; Ruilope, L.M.; Lucia, A. Exercise benefits in cardiovascular disease: beyond attenuation of traditional risk factors. *Nature Reviews Cardiology* **2018**, *15*, 731-743.
26. Henriksson, H.; Henriksson, P.; Tynelius, P.; Ekstedt, M.; Berglind, D.; Labayen, I.; Ruiz, J.R.; Lavie, C.J.; Ortega, F.B. Cardiorespiratory fitness, muscular strength, and obesity in adolescence and later chronic disability due to cardiovascular disease: a cohort study of 1 million men. *European heart journal* **2020**, *41*, 1503-1510.
27. Edwards, T.; Pilutti, L.A. The effect of exercise training in adults with multiple sclerosis with severe mobility disability: a systematic review and future research directions. *Multiple sclerosis and related disorders* **2017**, *16*, 31-39.
28. Kwok, J.Y.Y.; Choi, K.C.; Chan, H.Y.L. Effects of mind–body exercises on the physiological and psychosocial well-being of individuals with Parkinson's disease: a systematic review and meta-analysis. *Complementary therapies in medicine* **2016**, *29*, 121-131.
29. Mandolesi, L.; Polverino, A.; Montuori, S.; Foti, F.; Ferraioli, G.; Sorrentino, P.; Sorrentino, G. Effects of physical exercise on cognitive functioning and wellbeing: biological and psychological benefits. *Frontiers in psychology* **2018**, *9*, 347071.
30. Bombardier, C.H.; Dyer, J.R.; Burns, P.; Crane, D.A.; Takahashi, M.M.; Barber, J.; Nash, M.S. A tele-health intervention to increase physical fitness in people with spinal cord injury and cardiometabolic disease or risk factors: a pilot randomized controlled trial. *Spinal Cord* **2021**, *59*, 63-73.
31. Martin Ginis, K.A.; Ma, J.K.; Latimer-Cheung, A.E.; Rimmer, J.H. A systematic review of review articles addressing factors related to physical activity participation among children and adults with physical disabilities. *Health psychology review* **2016**, *10*, 478-494.
32. Rimmer, J.H. Equity in active living for people with disabilities: less talk and more action. *Prev Med* **2017**, *95*, S154-S156.
33. Richardson, E.V.; Smith, B.; Papathomas, A. Crossing boundaries: The perceived impact of disabled fitness instructors in the gym. *Psychology of Sport and Exercise* **2017**, *29*, 84-92.
34. Lai, B.; Young, H.-J.; Bickel, C.S.; Motl, R.W.; Rimmer, J.H. Current trends in exercise intervention research, technology, and behavioral change strategies for people with disabilities: a scoping review. *American journal of physical medicine & rehabilitation* **2017**, *96*, 748-761.

35. Rimmer, J.; Lai, B. Framing new pathways in transformative exercise for individuals with existing and newly acquired disability. *Disability and rehabilitation* **2017**, *39*, 173-180.
36. Nikolajsen, H.; Richardson, E.V.; Sandal, L.F.; Juul-Kristensen, B.; Troelsen, J. Fitness for all: how do non-disabled people respond to inclusive fitness centres? *BMC Sports Science, Medicine and Rehabilitation* **2021**, *13*, 81.
37. Costa, R.R.G.; Dorneles, J.R.; Veloso, J.H.; Gonçalves, C.W.; Neto, F.R. Synchronous and asynchronous tele-exercise during the coronavirus disease 2019 pandemic: Comparisons of implementation and training load in individuals with spinal cord injury. *Journal of Telemedicine and Telecare* **2021**, 1357633X2098273.
38. Rimmer, J.H.; Padalabalanarayanan, S.; Malone, L.A.; Mehta, T. Fitness facilities still lack accessibility for people with disabilities. *Disability and health journal* **2017**, *10*, 214-221.
39. Colorado-State-University. Telecoaching emerges as tool in nutrition and medicine. Available online: https://source.colostate.edu/telecoaching-emerges-as-tool-in-nutrition-and-medicine/ (accessed on
40. Haleem, A.; Javaid, M.; Singh, R.P.; Suman, R. Telemedicine for healthcare: Capabilities, features, barriers, and applications. *Sens Int* **2021**, *2*, 100117, doi:10.1016/j.sintl.2021.100117.
41. Setiawan, I.M.A.; Zhou, L.; Alfikri, Z.; Saptono, A.; Fairman, A.D.; Dicianno, B.E.; Parmanto, B. An adaptive mobile health system to support self-management for persons with chronic conditions and disabilities: usability and feasibility studies. *JMIR formative research* **2019**, *3*, e12982.
42. Leale, I.; Vinciguerra, C.; Di Stefano, V.; Brighina, F.; Battaglia, G. Effectiveness of Telecoaching and Music Therapy in Neurological Disorders: A Narrative Review and Proposal for a New Interventional Approach. *Healthcare* **2025**, *13*, doi:10.3390/healthcare13070826.
43. Tuckson, R.V.; Edmunds, M.; Hodgkins, M.L. Telehealth. *New England Journal of Medicine* **2017**, *377*, 1585-1592, doi:doi:10.1056/NEJMsr1503323.
44. What Is Telehealth? *Catalyst Carryover* **2018**, *4*, doi:doi:10.1056/CAT.18.0268.
45. Monaghesh, E.; Hajizadeh, A. The role of telehealth during COVID-19 outbreak: a systematic review based on current evidence. *BMC Public Health* **2020**, *20*, 1193, doi:10.1186/s12889-020-09301-4.
46. George, M.D.; Danila, M.I.; Watrous, D.; Reddy, S.; Alper, J.; Xie, F.; Nowell, W.B.; Kallich, J.; Clinton, C.; Saag, K.G.; et al. Disruptions in Rheumatology Care and the Rise of Telehealth in Response to the COVID-19 Pandemic in a Community Practice–Based Network. *Arthritis Care & Research* **2021**, *73*, 1153-1161, doi:https://doi.org/10.1002/acr.24626.
47. Harris, E. Neurological Conditions Are Leading Cause of Disability Worldwide. *JAMA* **2024**, *331*, 1440-1440, doi:10.1001/jama.2024.5160.
48. Santos, M.; Sousa, C.; Pereira, M.; Pereira, M.G. Quality of life in patients with multiple sclerosis: A study with patients and caregivers. *Disabil Health J* **2019**, *12*, 628-634, doi:10.1016/j.dhjo.2019.03.007.
49. Zhao, N.; Yang, Y.; Zhang, L.; Zhang, Q.; Balbuena, L.; Ungvari, G.S.; Zang, Y.F.; Xiang, Y.T. Quality of life in Parkinson's disease: A systematic review and meta-analysis of comparative studies. *CNS Neurosci Ther* **2021**, *27*, 270-279, doi:10.1111/cns.13549.
50. Grisold, W.; Freedman, M.; Gouider, R.; Guekht, A.; Lewis, S.; Medina, M.; Meshram, C.; Rouleau, G.; Stark, R. The Intersectoral Global Action Plan (IGAP): A unique opportunity for neurology across the globe. *J Neurol Sci* **2023**, *449*, 120645, doi:10.1016/j.jns.2023.120645.
51. León-Salas, B.; González-Hernández, Y.; Infante-Ventura, D.; de Armas-Castellano, A.; García-García, J.; García-Hernández, M.; Carmona-Rodríguez, M.; Olazarán, J.; Dobato, J.L.; Rodríguez-Rodríguez, L.; et al. Telemedicine for neurological diseases: A

systematic review and meta-analysis. *Eur J Neurol* **2023**, *30*, 241-254, doi:10.1111/ene.15599.
52. Ohannessian, R.; Duong, T.A.; Odone, A. Global Telemedicine Implementation and Integration Within Health Systems to Fight the COVID-19 Pandemic: A Call to Action. *JMIR Public Health Surveill* **2020**, *6*, e18810, doi:10.2196/18810.
53. Leubner, D.; Hinterberger, T. Reviewing the Effectiveness of Music Interventions in Treating Depression. *Front Psychol* **2017**, *8*, 1109, doi:10.3389/fpsyg.2017.01109.
54. Wang, S.; Agius, M. The use of Music Therapy in the treatment of Mental Illness and the enhancement of Societal Wellbeing. *Psychiatr Danub* **2018**, *30*, 595-600.
55. Garza-Villarreal, E.A.; Pando, V.; Vuust, P.; Parsons, C. Music-Induced Analgesia in Chronic Pain Conditions: A Systematic Review and Meta-Analysis. *Pain Physician* **2017**, *20*, 597-610.
56. Association, A.M.T. Definition and quotes about music therapy. *American Music Therapy Association*. https://www. *musictherapy. org/about/quotes* **2020**.
57. Vinciguerra, C.; Federico, A. Neurological music therapy during the COVID-19 outbreak: updates and future challenges. *Neurol Sci* **2022**, *43*, 3473-3478, doi:10.1007/s10072-022-05957-5.
58. Sihvonen, A.J.; Särkämö, T.; Leo, V.; Tervaniemi, M.; Altenmüller, E.; Soinila, S. Music-based interventions in neurological rehabilitation. *Lancet Neurol* **2017**, *16*, 648-660, doi:10.1016/s1474-4422(17)30168-0.
59. Wise, M.G.; Rundell, J.R. Anxiety and neurological disorders. *Semin Clin Neuropsychiatry* **1999**, *4*, 98-102, doi:10.1053/scnp00400098.
60. Salas, C.E.; Rojas-Líbano, D.; Castro, O.; Cruces, R.; Evans, J.; Radovic, D.; Arévalo-Romero, C.; Torres, J.; Aliaga, Á. Social isolation after acquired brain injury: Exploring the relationship between network size, functional support, loneliness and mental health. *Neuropsychol Rehabil* **2022**, *32*, 2294-2318, doi:10.1080/09602011.2021.1939062.
61. Busse, M.E.; Wiles, C.M.; van Deursen, R.W. Community walking activity in neurological disorders with leg weakness. *J Neurol Neurosurg Psychiatry* **2006**, *77*, 359-362, doi:10.1136/jnnp.2005.074294.
62. Baethge, C.; Goldbeck-Wood, S.; Mertens, S. SANRA—a scale for the quality assessment of narrative review articles. *Research Integrity and Peer Review* **2019**, *4*, 5, doi:10.1186/s41073-019-0064-8.
63. Lavorgna, L.; Maida, E.; Reinhard, C.; Cras, P.; Reetz, K.; Molnar, M.J.; Nonnekes, J.; Medijainen, K.; Summa, S.; Diserens, K.; et al. The Growing Role of Telerehabilitation and Teleassessment in the Management of Movement Disorders in Rare Neurological Diseases: A Scoping Review. *Telemed J E Health* **2024**, *30*, 2419-2430, doi:10.1089/tmj.2023.0702.
64. Gandolfi, M.; Geroin, C.; Dimitrova, E.; Boldrini, P.; Waldner, A.; Bonadiman, S.; Picelli, A.; Regazzo, S.; Stirbu, E.; Primon, D.; et al. Virtual Reality Telerehabilitation for Postural Instability in Parkinson's Disease: A Multicenter, Single-Blind, Randomized, Controlled Trial. *Biomed Res Int* **2017**, *2017*, 7962826, doi:10.1155/2017/7962826.
65. Yang, W.-C.; Wang, H.-K.; Wu, R.-M.; Lo, C.-S.; Lin, K.-H. Home-based virtual reality balance training and conventional balance training in Parkinson's disease: A randomized controlled trial. *Journal of the Formosan Medical Association* **2016**, *115*, 734-743, doi:https://doi.org/10.1016/j.jfma.2015.07.012.
66. Atterbury, E.M.; Welman, K.E. Balance training in individuals with Parkinson’s disease: Therapist-supervised vs. home-based exercise programme. *Gait & Posture* **2017**, *55*, 138-144, doi:https://doi.org/10.1016/j.gaitpost.2017.04.006.
67. Pagliari, C.; Di Tella, S.; Jonsdottir, J.; Mendozzi, L.; Rovaris, M.; De Icco, R.; Milanesi, T.; Federico, S.; Agostini, M.; Goffredo, M.; et al. Effects of home-based virtual reality telerehabilitation system in people with multiple sclerosis: A randomized controlled

trial. *Journal of Telemedicine and Telecare* **2021**, *30*, 344-355, doi:10.1177/1357633X211054839.

68. Hoang, P.; Schoene, D.; Gandevia, S.; Smith, S.; Lord, S.R. Effects of a home-based step training programme on balance, stepping, cognition and functional performance in people with multiple sclerosis – a randomized controlled trial. *Multiple Sclerosis Journal* **2015**, *22*, 94-103, doi:10.1177/1352458515579442.
69. Güngör, F.; Tarakci, E.; Özdemir-Acar, Z.; Soysal, A. The effects of supervised versus home Pilates-based core stability training on lower extremity muscle strength and postural sway in people with multiple sclerosis. *Mult Scler* **2022**, *28*, 269-279, doi:10.1177/13524585211012202.
70. Cabanas-Valdés, R.; Fernández-Lago, H.; Peláez-Hervás, S.; Serra-Rusiñol, L.; López-de-Celis, C.; Masbernat-Almenara, M. Effect of a Home-Base Core Stability Exercises in Hereditary Ataxia. A Randomized Controlled Trial. A Pilot Randomized Controlled Trial. *Mov Disord Clin Pract* **2024**, *11*, 666-675, doi:10.1002/mdc3.14036.
71. Jabri, S.; Bushart, D.D.; Kinnaird, C.; Bao, T.; Bu, A.; Shakkottai, V.G.; Sienko, K.H. Preliminary Study of Vibrotactile Feedback during Home-Based Balance and Coordination Training in Individuals with Cerebellar Ataxia. *Sensors (Basel)* **2022**, *22*, doi:10.3390/s22093512.
72. Burns, J.; Sman, A.D.; Cornett, K.M.D.; Wojciechowski, E.; Walker, T.; Menezes, M.P.; Mandarakas, M.R.; Rose, K.J.; Bray, P.; Sampaio, H.; et al. Safety and efficacy of progressive resistance exercise for Charcot-Marie-Tooth disease in children: a randomised, double-blind, sham-controlled trial. *Lancet Child Adolesc Health* **2017**, *1*, 106-113, doi:10.1016/s2352-4642(17)30013-5.
73. Mehta, J.N.; Parikh, S.; Desai, S.D.; Solanki, R.C.; Pathak, A.G. Study of Additive Effect of Yoga and Physical Therapies to Standard Pharmacologic Treatment in Migraine. *JOURNAL OF NEUROSCIENCES IN RURAL PRACTICE* **2021**, *12*, 60-66, doi:10.1055/s-0040-1718842.
74. Menengi Ç, K.N.; Yeldan, İ.; Çınar, N.; Şahiner, T. Effectiveness of motor-cognitive dual-task exercise via telerehabilitation in Alzheimer's disease: An online pilot randomized controlled study. *Clin Neurol Neurosurg* **2022**, *223*, 107501, doi:10.1016/j.clineuro.2022.107501.
75. Kristoffersson, A.; Lindén, M. A systematic review of wearable sensors for monitoring physical activity. *Sensors* **2022**, *22*, 573.
76. Giustino, V.; Leale, I.; Cicero, L.; Petrigna, L.; Lo Nigro, M.; Fontana, V.; Mignosi, E.; Cataldo, P.; Macaluso, A.; Gómez-López, M.; et al. Acute effects of a dog sport on fitness parameters in young adults: a randomised controlled crossover study. *Human Movement* **2024**, *25*, 138-146, doi:10.5114/hm/196835.
77. Romeo, A.; Edney, S.; Plotnikoff, R.; Curtis, R.; Ryan, J.; Sanders, I.; Crozier, A.; Maher, C. Can Smartphone Apps Increase Physical Activity? Systematic Review and Meta-Analysis. *J Med Internet Res* **2019**, *21*, e12053, doi:10.2196/12053.
78. Muntaner-Mas, A.; Martinez-Nicolas, A.; Lavie, C.J.; Blair, S.N.; Ross, R.; Arena, R.; Ortega, F.B. A Systematic Review of Fitness Apps and Their Potential Clinical and Sports Utility for Objective and Remote Assessment of Cardiorespiratory Fitness. *Sports Medicine* **2019**, *49*, 587-600, doi:10.1007/s40279-019-01084-y.
79. Gentile, A.; Ficarra, S.; Thomas, E.; Bianco, A. Nature Through Virtual Reality as a Stress-Reduction Tool: A Systematic Review. *International Journal of Stress Management* **2023**, *30*, doi:10.1037/str0000300.
80. Wu, J.; Ma, Y.; Ren, Z. Rehabilitative Effects of Virtual Reality Technology for Mild Cognitive Impairment: A Systematic Review With Meta-Analysis. *Frontiers in Psychology* **2020**, *11*, doi:10.3389/fpsyg.2020.01811.
81. Leale, I.; Figlioli, F.; Giustino, V.; Brusa, J.; Barcellona, M.; Nocera, V.; Canzone, A.; Patti, A.; Messina, G.; Barbagallo, M.; et al. Telecoaching as a new training method for

elderly people: a systematic review. *Aging Clin Exp Res.* **2024**, *36*, 18, doi:10.1007/s40520-023-02648-9.
82. Leale, I.; Giustino, V.; Brusa, J.; Barcellona, M.; Barbagallo, M.; Palma, A.; Messina, G.; Dominguez, L.J.; Battaglia, G. Effectiveness of a Sustainable Training Program Combining Supervised Outdoor Exercise with Telecoaching on Physical Performance in Elderly People. *Sustainability* **2024**, *16*, 3254.
83. Hume, E.; Muse, H.; Wallace, K.; Wilkinson, M.; Heslop Marshall, K.; Nair, A.; Clark, S.; Vogiatzis, I. Feasibility and acceptability of a physical activity behavioural modification tele-coaching intervention in lung transplant recipients. *Chron Respir Dis* **2022**, *19*, 14799731221116588, doi:10.1177/14799731221116588.
84. Cameron-Tucker, H.L.; Wood-Baker, R.; Joseph, L.; Walters, J.A.; Schüz, N.; Walters, E.H. A randomized controlled trial of telephone-mentoring with home-based walking preceding rehabilitation in COPD. *Int J Chron Obstruct Pulmon Dis* **2016**, *11*, 1991-2000, doi:10.2147/copd.S109820.
85. De Vasconcelos, H.C.A.; Lira Neto, J.C.G.; De Araújo, M.F.M.; Carvalho, G.C.N.; De Souza Teixeira, C.R.; De Freitas, R.W.J.F.; Damasceno, M.M.C. Telecoaching programme for type 2 diabetes control: A randomised clinical trial. *Br J Nurs.* **2018**, *27*, 1115-1120, doi:10.12968/bjon.2018.27.19.1115.
86. Snoek, J.A.; Meindersma, E.P.; Prins, L.F.; van't Hof, A.W.J.; de Boer, M.J.; Hopman, M.T.; Eijsvogels, T.M.H.; de Kluiver, E.P. The sustained effects of extending cardiac rehabilitation with a six-month telemonitoring and telecoaching programme on fitness, quality of life, cardiovascular risk factors and care utilisation in CAD patients: The TeleCaRe study. *Journal of Telemedicine and Telecare* **2021**, *27*, 473-483, doi:10.1177/1357633X19885793.
87. Leale, I.; Di Stefano, V.; Torrente, A.; Alonge, P.; Monastero, R.; Roccella, M.; Brighina, F.; Giustino, V.; Battaglia, G. Telecoaching and Migraine: Digital Approach to Physical Activity in Migraine Management. A Scoping Review. *Journal of Clinical Medicine* **2025**, *14*, doi:10.3390/jcm14030861.
88. Leale, I.; Di Stefano, V.; Costanza, C.; Brighina, F.; Roccella, M.; Palma, A.; Battaglia, G. Telecoaching: a potential new training model for Charcot-Marie-Tooth patients: a systematic review. *Frontiers in Neurology* **2024**, *15*, doi:10.3389/fneur.2024.1359091.
89. Hartasanchez, S.A.; Heen, A.F.; Kunneman, M.; García-Bautista, A.; Hargraves, I.G.; Prokop, L.J.; May, C.R.; Montori, V.M. Remote shared decision making through telemedicine: A systematic review of the literature. *Patient Educ Couns* **2022**, *105*, 356-365, doi:10.1016/j.pec.2021.06.012.
90. Aderinto, N.; AbdulBasit, M.O.; Olatunji, G.; Adejumo, T. Exploring the transformative influence of neuroplasticity on stroke rehabilitation: a narrative review of current evidence. *Annals of Medicine and Surgery* **2023**, *85*.
91. Pascual-Leone, A.; Torres, F. Plasticity of the sensorimotor cortex representation of the reading finger in Braille readers. *Brain* **1993**, *116 (Pt 1)*, 39-52, doi:10.1093/brain/116.1.39.
92. Bavelier, D.; Neville, H.J. Cross-modal plasticity: where and how? *Nat Rev Neurosci* **2002**, *3*, 443-452, doi:10.1038/nrn848.
93. Schlaug, G. The brain of musicians. A model for functional and structural adaptation. *Ann N Y Acad Sci* **2001**, *930*, 281-299.
94. Kraus, N.; Chandrasekaran, B. Music training for the development of auditory skills. *Nat Rev Neurosci* **2010**, *11*, 599-605, doi:10.1038/nrn2882.
95. Reybrouck, M.; Vuust, P.; Brattico, E. Music and brain plasticity: how sounds trigger neurogenerative adaptations. *Neuroplasticity Insights of Neural Reorganization* **2018**, *85*.
96. Groussard, M.; La Joie, R.; Rauchs, G.; Landeau, B.; Chételat, G.; Viader, F.; Desgranges, B.; Eustache, F.; Platel, H. When music and long-term memory interact:

effects of musical expertise on functional and structural plasticity in the hippocampus. *PLoS One* **2010**, *5*, doi:10.1371/journal.pone.0013225.
97. Rubio-Sastre, P.; Gómez-Abellán, P.; Martinez-Nicolas, A.; Ordovás, J.M.; Madrid, J.A.; Garaulet, M. Evening physical activity alters wrist temperature circadian rhythmicity. *Chronobiol Int* **2014**, *31*, 276-282, doi:10.3109/07420528.2013.833215.
98. Antúnez, J.M. Circadian typology is related to emotion regulation, metacognitive beliefs and assertiveness in healthy adults. *PLoS One* **2020**, *15*, e0230169, doi:10.1371/journal.pone.0230169.
99. Ayala, V.; Martínez-Bebia, M.; Latorre, J.A.; Gimenez-Blasi, N.; Jimenez-Casquet, M.J.; Conde-Pipo, J.; Bach-Faig, A.; Mariscal-Arcas, M. Influence of circadian rhythms on sports performance. *Chronobiol Int* **2021**, *38*, 1522-1536, doi:10.1080/07420528.2021.1933003.
100. Penner, I.-K.; Paul, F. Fatigue as a symptom or comorbidity of neurological diseases. *Nature Reviews Neurology* **2017**, *13*, 662-675, doi:10.1038/nrneurol.2017.117.
101. de Bergeyck, R.; Geoffroy, P.A. Insomnia in neurological disorders: Prevalence, mechanisms, impact and treatment approaches. *Revue Neurologique* **2023**, *179*, 767-781, doi:https://doi.org/10.1016/j.neurol.2023.08.008.
102. Popescu, B.O.; Batzu, L.; Ruiz, P.J.G.; Tulbă, D.; Moro, E.; Santens, P. Neuroplasticity in Parkinson's disease. *J Neural Transm (Vienna)* **2024**, *131*, 1329-1339, doi:10.1007/s00702-024-02813-y.
103. Dyck, P.J.; Lambert, E.H. Lower Motor and Primary Sensory Neuron Diseases With Peroneal Muscular Atrophy: I. Neurologic, Genetic, and Electrophysiologic Findings in Hereditary Polyneuropathies. *Archives of Neurology* **1968**, *18*, 603-618, doi:10.1001/archneur.1968.00470360025002.
104. Saporta, M.A.; Shy, M.E. Inherited peripheral neuropathies. *Neurol Clin* **2013**, *31*, 597-619, doi:10.1016/j.ncl.2013.01.009.
105. Barreto, L.C.L.S.; Oliveira, F.S.; Nunes, P.S.; de França Costa, I.M.P.; Garcez, C.A.; Goes, G.M.; Neves, E.L.A.; de Souza Siqueira Quintans, J.; de Souza Araújo, A.A. Epidemiologic Study of Charcot-Marie-Tooth Disease: A Systematic Review. *Neuroepidemiology* **2016**, *46*, 157-165, doi:10.1159/000443706.
106. Braathen, G.; Zelano, J. Long-term seizure and psychosocial outcome in childhood epilepsy of unknown cause. *Acta Neurol Scand* **2021**, *143*, 653-660, doi:10.1111/ane.13414.
107. Saporta, A.S.; Sottile, S.L.; Miller, L.J.; Feely, S.M.; Siskind, C.E.; Shy, M.E. Charcot-Marie-Tooth disease subtypes and genetic testing strategies. *Ann Neurol* **2011**, *69*, 22-33, doi:10.1002/ana.22166.
108. Latour, P.; Gonnaud, P.-M.; Ollagnon, E.; Chan, V.; Perelman, S.; Stojkovic, T.; Stoll, C.; Vial, C.; Ziegler, F.; Vandenberghe, A.; et al. SIMPLE mutation analysis in dominant demyelinating Charcot-Marie-Tooth disease: three novel mutations. *J Peripher Nerv Syst.* **2006**, *11*, 148-155, doi:https://doi.org/10.1111/j.1085-9489.2006.00080.x.
109. Pareyson, D.; Marchesi, C. Diagnosis, natural history, and management of Charcot-Marie-Tooth disease. *Lancet Neurol* **2009**, *8*, 654-667, doi:10.1016/s1474-4422(09)70110-3.
110. Reilly, M.M.; Shy, M.E. Diagnosis and new treatments in genetic neuropathies. *J Neurol Neurosurg Psychiatry* **2009**, *80*, 1304-1314, doi:10.1136/jnnp.2008.158295.
111. Ong, C.F.; Geijtenbeek, T.; Hicks, J.L.; Delp, S.L. Predicting gait adaptations due to ankle plantarflexor muscle weakness and contracture using physics-based musculoskeletal simulations. *PLoS Comput Biol* **2019**, *15*, doi:10.1371/journal.pcbi.1006993.
112. Kennedy, R.A.; McGinley, J.L.; Paterson, K.L.; Ryan, M.M.; Carroll, K. Gait and footwear in children and adolescents with Charcot-Marie-Tooth disease: A cross-sectional, case-controlled study. *Gait Posture* **2018**, *62*, 262-267, doi:10.1016/j.gaitpost.2018.03.029.

113. Thomas, F.P.; Saporta, M.A.; Attarian, S.; Sevilla, T.; Sivera, R.; Fabrizi, G.M.; Genovese, F.; Gray, A.J.; Bull, S.; Tanesse, D.; et al. Patient-Reported Symptom Burden of Charcot-Marie-Tooth Disease Type 1A: Findings From an Observational Digital Lifestyle Study. *J Clin Neuromuscul Dis* **2022**, *24*, 7-17, doi:10.1097/cnd.0000000000000426.
114. Hackett, D.; Roberts-Clarke, D.; Jain, N.; Mavros, Y.; Wilson, G.C.; Halaki, M.; Burns, J.; Nicholson, G.; Fiatarone Singh, M.; Fornusek, C. Body composition and its association with physical performance, quality of life, and clinical indictors in Charcot-Marie-Tooth disease: a pilot study. *Disabil Rehabil* **2019**, *41*, 405-412, doi:10.1080/09638288.2017.1395083.
115. Di Stefano, V.; Battaglia, G.; Giustino, V.; Gagliardo, A.; D'Aleo, M.; Giannini, O.; Palma, A.; Brighina, F. Significant reduction of physical activity in patients with neuromuscular disease during COVID-19 pandemic: the long-term consequences of quarantine. *J Neurol* **2021**, *268*, 20-26, doi:10.1007/s00415-020-10064-6.
116. Leale, I.; Giustino, V.; Trapani, P.; Alonge, P.; Rini, N.; Cutrò, I.; Leone, O.; Torrente, A.; Lupica, A.; Palma, A.; et al. Physical Activity in Patients with Neuromuscular Disease Three Years after COVID-19, a Longitudinal Survey: The After-Effects of the Quarantine and the Benefits of a Return to a Healthier Life-Style. *J Clin Med* **2024**, *13*, doi:10.3390/jcm13010265.
117. Tremblay, M.S.; Colley, R.C.; Saunders, T.J.; Healy, G.N.; Owen, N. Physiological and health implications of a sedentary lifestyle. *Appl Physiol Nutr Metab* **2010**, *35*, 725-740, doi:10.1139/h10-079.
118. Aitkens, S.; Kilmer, D.D.; Wright, N.C.; McCrory, M.A. Metabolic syndrome in neuromuscular disease. *Arch Phys Med Rehabil* **2005**, *86*, 1030-1036, doi:10.1016/j.apmr.2004.09.012.
119. Pareyson, D.; Saveri, P.; Pisciotta, C. New developments in Charcot-Marie-Tooth neuropathy and related diseases. *Curr Opin Neurol* **2017**, *30*, 471-480, doi:10.1097/wco.0000000000000474.
120. Di Stefano, V.; Thomas, E.; Alonge, P.; Giustino, V.; Pillitteri, G.; Leale, I.; Torrente, A.; Pignolo, A.; Norata, D.; Iacono, S.; et al. Patisiran Enhances Muscle Mass after Nine Months of Treatment in ATTRv Amyloidosis: A Study with Bioelectrical Impedance Analysis and Handgrip Strength. *Biomedicines* **2023**, *11*, doi:10.3390/biomedicines11010062.
121. Sman, A.D.; Hackett, D.; Fiatarone Singh, M.; Fornusek, C.; Menezes, M.P.; Burns, J. Systematic review of exercise for Charcot-Marie-Tooth disease. *J Peripher Nerv Syst* **2015**, *20*, 347-362, doi:10.1111/jns.12116.
122. Menotti, F.; Felici, F.; Damiani, A.; Mangiola, F.; Vannicelli, R.; Macaluso, A. Charcot-Marie-Tooth 1A patients with low level of impairment have a higher energy cost of walking than healthy individuals. *Neuromuscul Disord* **2011**, *21*, 52-57, doi:10.1016/j.nmd.2010.09.008.
123. Shamseer, L.; Moher, D.; Clarke, M.; Ghersi, D.; Liberati, A.; Petticrew, M.; Shekelle, P.; Stewart, L.A. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015: elaboration and explanation. *Bmj* **2015**, *350*, g7647, doi:10.1136/bmj.g7647.
124. Downs, S.H.; Black, N. The feasibility of creating a checklist for the assessment of the methodological quality both of randomised and non-randomised studies of health care interventions. *J Epidemiol Community Health* **1998**, *52*, 377-384, doi:10.1136/jech.52.6.377.
125. Chuter, V.; Spink, M.; Searle, A.; Ho, A. The effectiveness of shoe insoles for the prevention and treatment of low back pain: a systematic review and meta-analysis of randomised controlled trials. *BMC Musculoskelet Disord* **2014**, *15*, 140, doi:10.1186/1471-2474-15-140.

126. Pas, H.I.; Reurink, G.; Tol, J.L.; Weir, A.; Winters, M.; Moen, M.H. Efficacy of rehabilitation (lengthening) exercises, platelet-rich plasma injections, and other conservative interventions in acute hamstring injuries: an updated systematic review and meta-analysis. *Br J Sports Med* **2015**, *49*, 1197-1205, doi:10.1136/bjsports-2015-094879.
127. Hooper, P.; Jutai, J.W.; Strong, G.; Russell-Minda, E. Age-related macular degeneration and low-vision rehabilitation: a systematic review. *Can J Ophthalmol* **2008**, *43*, 180-187, doi:10.3129/i08-001.
128. Chetlin, R.D.; Gutmann, L.; Tarnopolsky, M.; Ullrich, I.H.; Yeater, R.A. Resistance training effectiveness in patients with Charcot-Marie-Tooth disease: recommendations for exercise prescription. *Arch Phys Med Rehabil* **2004**, *85*, 1217-1223, doi:10.1016/j.apmr.2003.12.025.
129. Ramdharry, G.M.; Pollard, A.; Anderson, C.; Laurá, M.; Murphy, S.M.; Dudziec, M.; Dewar, E.L.; Hutton, E.; Grant, R.; Reilly, M.M. A pilot study of proximal strength training in Charcot-Marie-Tooth disease. *J Peripher Nerv Syst* **2014**, *19*, 328-332, doi:10.1111/jns.12100.
130. Chetlin, R.D.; Gutmann, L.; Tarnopolsky, M.A.; Ullrich, I.H.; Yeater, R.A. Resistance training exercise and creatine in patients with Charcot-Marie-Tooth disease. *Muscle Nerve* **2004**, *30*, 69-76, doi:10.1002/mus.20078.
131. Dudziec, M.M.; Lee, L.E.; Massey, C.; Tropman, D.; Skorupinska, M.; Laurá, M.; Reilly, M.M.; Ramdharry, G.M. Home-based multi-sensory and proximal strengthening program to improve balance in Charcot–Marie–Tooth disease Type 1A: A proof of concept study. *Muscle & Nerve* **2024**, *69*, 354-361, doi:https://doi.org/10.1002/mus.28032.
132. El Mhandi, L.; Pichot, V.; Calmels, P.; Gautheron, V.; Roche, F.; Féasson, L. Exercise training improves autonomic profiles in patients with Charcot-Marie-Tooth disease. *Muscle Nerve* **2011**, *44*, 732-736, doi:10.1002/mus.22150.
133. El Mhandi, L.; Millet, G.Y.; Calmels, P.; Richard, A.; Oullion, R.; Gautheron, V.; Féasson, L. Benefits of interval-training on fatigue and functional capacities in Charcot-Marie-Tooth disease. *Muscle Nerve* **2008**, *37*, 601-610, doi:10.1002/mus.20959.
134. Lindeman, E.; Leffers, P.; Spaans, F.; Drukker, J.; Reulen, J.; Kerckhoffs, M.; Köke, A. Strength training in patients with myotonic dystrophy and hereditary motor and sensory neuropathy: a randomized clinical trial. *Arch Phys Med Rehabil* **1995**, *76*, 612-620, doi:10.1016/s0003-9993(95)80629-6.
135. Smith, C.A.; Chetlin, R.D.; Gutmann, L.; Yeater, R.A.; Alway, S.E. Effects of exercise and creatine on myosin heavy chain isoform composition in patients with Charcot-Marie-Tooth disease. *Muscle Nerve* **2006**, *34*, 586-594, doi:10.1002/mus.20621.
136. Burns, J.; Ouvrier, R.; Estilow, T.; Shy, R.; Laurá, M.; Pallant, J.F.; Lek, M.; Muntoni, F.; Reilly, M.M.; Pareyson, D.; et al. Validation of the Charcot-Marie-Tooth disease pediatric scale as an outcome measure of disability. *Ann Neurol* **2012**, *71*, 642-652, doi:10.1002/ana.23572.
137. Taaffe, D.R.; Pruitt, L.; Pyka, G.; Guido, D.; Marcus, R. Comparative effects of high- and low-intensity resistance training on thigh muscle strength, fiber area, and tissue composition in elderly women. *Clin Physiol* **1996**, *16*, 381-392, doi:10.1111/j.1475-097x.1996.tb00727.x.
138. American College of Sports Medicine Position Stand. The recommended quantity and quality of exercise for developing and maintaining cardiorespiratory and muscular fitness, and flexibility in healthy adults. *Med Sci Sports Exerc* **1998**, *30*, 975-991, doi:10.1097/00005768-199806000-00032.
139. Wang, C.C.; Fang, C.C.; Lee, Y.H.; Yang, M.T.; Chan, K.H. Effects of 4-Week Creatine Supplementation Combined with Complex Training on Muscle Damage and Sport Performance. *Nutrients* **2018**, *10*, doi:10.3390/nu10111640.

140. Wax, B.; Kerksick, C.M.; Jagim, A.R.; Mayo, J.J.; Lyons, B.C.; Kreider, R.B. Creatine for Exercise and Sports Performance, with Recovery Considerations for Healthy Populations. *Nutrients* **2021**, *13*, doi:10.3390/nu13061915.
141. Hall, M.; Trojian, T.H. Creatine supplementation. *Curr Sports Med Rep* **2013**, *12*, 240-244, doi:10.1249/JSR.0b013e31829cdff2.
142. Persky, A.M.; Brazeau, G.A. Clinical pharmacology of the dietary supplement creatine monohydrate. *Pharmacol Rev* **2001**, *53*, 161-176.
143. Greenhaff, P.L. Creatine and its application as an ergogenic aid. *Int J Sport Nutr* **1995**, *5 Suppl*, S100-110, doi:10.1123/ijsn.5.s1.s100.
144. Tarnopolsky, M.A.; Parise, G. Direct measurement of high-energy phosphate compounds in patients with neuromuscular disease. *Muscle Nerve* **1999**, *22*, 1228-1233, doi:10.1002/(sici)1097-4598(199909)22:9<1228::aid-mus9>3.0.co;2-6.
145. Lewis, R.A.; Li, J.; Fuerst, D.R.; Shy, M.E.; Krajewski, K. Motor unit number estimate of distal and proximal muscles in Charcot-Marie-Tooth disease. *Muscle Nerve* **2003**, *28*, 161-167, doi:10.1002/mus.10419.
146. Deschenes, M.R.; Kraemer, W.J. Performance and physiologic adaptations to resistance training. *Am J Phys Med Rehabil* **2002**, *81*, S3-16, doi:10.1097/00002060-200211001-00003.
147. Florence, J.M.; Hagberg, J.M. Effect of training on the exercise responses of neuromuscular disease patients. *Med Sci Sports Exerc* **1984**, *16*, 460-465, doi:10.1249/00005768-198410000-00007.
148. Voorn, E.L.; Koopman, F.S.; Nollet, F.; Brehm, M.A. Individualized Aerobic Exercise in Neuromuscular Diseases: A Pilot Study on the Feasibility and Preliminary Effectiveness to Improve Physical Fitness. *Phys Ther* **2021**, *101*, doi:10.1093/ptj/pzaa213.
149. Oorschot, S.; Brehm, M.A.; van Groenestijn, A.C.; Koopman, F.S.; Verhamme, C.; Eftimov, F.; Jelsma, J.G.M.; Jorstad, H.T.; Nollet, F.; Voorn, E.L. Efficacy of a physical activity programme combining individualized aerobic exercise and coaching to improve physical fitness in neuromuscular diseases (I'M FINE): study protocol of a randomized controlled trial. *BMC Neurol* **2020**, *20*, 184, doi:10.1186/s12883-020-01725-0.
150. Bakker, M.; Schipper, K.; Koopman, F.S.; Nollet, F.; Abma, T.A. Experiences and perspectives of patients with post-polio syndrome and therapists with exercise and cognitive behavioural therapy. *BMC Neurol* **2016**, *16*, 23, doi:10.1186/s12883-016-0544-0.
151. Phillips, M.; Flemming, N.; Tsintzas, K. An exploratory study of physical activity and perceived barriers to exercise in ambulant people with neuromuscular disease compared with unaffected controls. *Clin Rehabil* **2009**, *23*, 746-755, doi:10.1177/0269215509334838.
152. Voorn, E.L.; Koopman, F.; Nollet, F.; Brehm, M.A. Aerobic exercise in adult neuromuscular rehabilitation: A survey of healthcare professionals. *J Rehabil Med* **2019**, *51*, 518-524, doi:10.2340/16501977-2567.
153. de Vasconcelos, H.C.A.; Lira Neto, J.C.G.; de Araújo, M.F.M.; Carvalho, G.C.N.; de Souza Teixeira, C.R.; de Freitas, R.; Damasceno, M.M.C. Telecoaching programme for type 2 diabetes control: a randomised clinical trial. *Br J Nurs* **2018**, *27*, 1115-1120, doi:10.12968/bjon.2018.27.19.1115.
154. Stovner, L.J.; Andree, C. Prevalence of headache in Europe: a review for the Eurolight project. *J Headache Pain* **2010**, *11*, 289-299, doi:10.1007/s10194-010-0217-0.
155. Steiner TJ.; Stovner LJ.; Vos T.; Jensen R.; Z., K. Migraine is first cause of disability in under 50s: will health politicians now take notice? *J Headache Pain* **2018**, *19*, 17, doi:10.1186/s10194-018-0846-2.
156. The International Classification of Headache Disorders, 3rd edition (beta version). *Cephalalgia* **2013**, *33*, 629-808, doi:10.1177/0333102413485658.

157. Leonardi, M.; Raggi, A.; Ajovalasit, D.; Bussone, G.; D'Amico, D. Functioning and disability in migraine. *Disabil Rehabil* **2010**, *32 Suppl 1*, S23-32, doi:10.3109/09638288.2010.511687.
158. Linde, M.; Gustavsson, A.; Stovner, L.J.; Steiner, T.J.; Barré, J.; Katsarava, Z.; Lainez, J.M.; Lampl, C.; Lantéri-Minet, M.; Rastenyte, D.; et al. The cost of headache disorders in Europe: the Eurolight project. *Eur J Neurol* **2012**, *19*, 703-711, doi:10.1111/j.1468-1331.2011.03612.x.
159. Evers, S.; Afra, J.; Frese, A.; Goadsby, P.J.; Linde, M.; May, A.; Sándor, P.S. EFNS guideline on the drug treatment of migraine--revised report of an EFNS task force. *Eur J Neurol* **2009**, *16*, 968-981, doi:10.1111/j.1468-1331.2009.02748.x.
160. Brighina, F.; Palermo, A.; Daniele, O.; Aloisio, A.; Fierro, B. High-frequency transcranial magnetic stimulation on motor cortex of patients affected by migraine with aura: a way to restore normal cortical excitability? *Cephalalgia* **2010**, *30*, 46-52, doi:10.1111/j.1468-2982.2009.01870.x.
161. Viganò, A.; Toscano, M.; Puledda, F.; Di Piero, V. Treating Chronic Migraine With Neuromodulation: The Role of Neurophysiological Abnormalities and Maladaptive Plasticity. *Front Pharmacol* **2019**, *10*, 32, doi:10.3389/fphar.2019.00032.
162. Cosentino, G.; Fierro, B.; Vigneri, S.; Talamanca, S.; Paladino, P.; Baschi, R.; Indovino, S.; Maccora, S.; Valentino, F.; Fileccia, E.; et al. Cyclical changes of cortical excitability and metaplasticity in migraine: evidence from a repetitive transcranial magnetic stimulation study. *Pain* **2014**, *155*, 1070-1078, doi:10.1016/j.pain.2014.02.024.
163. Di Stefano, V.; Rispoli, M.G.; Pellegrino, N.; Graziosi, A.; Rotondo, E.; Napoli, C.; Pietrobon, D.; Brighina, F.; Parisi, P. Diagnostic and therapeutic aspects of hemiplegic migraine. *J Neurol Neurosurg Psychiatry* **2020**, *91*, 764-771, doi:10.1136/jnnp-2020-322850.
164. Brighina, F.; Cosentino, G.; Vigneri, S.; Talamanca, S.; Palermo, A.; Giglia, G.; Fierro, B. Abnormal facilitatory mechanisms in motor cortex of migraine with aura. *Eur J Pain* **2011**, *15*, 928-935, doi:10.1016/j.ejpain.2011.03.012.
165. Eigenbrodt, A.K.; Ashina, H.; Khan, S.; Diener, H.C.; Mitsikostas, D.D.; Sinclair, A.J.; Pozo-Rosich, P.; Martelletti, P.; Ducros, A.; Lantéri-Minet, M.; et al. Diagnosis and management of migraine in ten steps. *Nat Rev Neurol* **2021**, *17*, 501-514, doi:10.1038/s41582-021-00509-5.
166. Marmura, M.J.; Silberstein, S.D.; Schwedt, T.J. The acute treatment of migraine in adults: the american headache society evidence assessment of migraine pharmacotherapies. *Headache* **2015**, *55*, 3-20, doi:10.1111/head.12499.
167. Kowacs, P.A.; Piovesan, E.J.; Tepper, S.J. Rejection and acceptance of possible side effects of migraine prophylactic drugs. *Headache* **2009**, *49*, 1022-1027, doi:10.1111/j.1526-4610.2009.01431.x.
168. Koseoglu, E.; Yetkin, M.F.; Ugur, F.; Bilgen, M. The role of exercise in migraine treatment. *J Sports Med Phys Fitness* **2015**, *55*, 1029-1036.
169. Chaibi, A.; Tuchin, P.J.; Russell, M.B. Manual therapies for migraine: a systematic review. *J Headache Pain* **2011**, *12*, 127-133, doi:10.1007/s10194-011-0296-6.
170. Probyn, K.; Bowers, H.; Mistry, D.; Caldwell, F.; Underwood, M.; Patel, S.; Sandhu, H.K.; Matharu, M.; Pincus, T. Non-pharmacological self-management for people living with migraine or tension-type headache: a systematic review including analysis of intervention components. *BMJ Open* **2017**, *7*, e016670, doi:10.1136/bmjopen-2017-016670.
171. Amin, F.M.; Aristeidou, S.; Baraldi, C.; Czapinska-Ciepiela, E.K.; Ariadni, D.D.; Di Lenola, D.; Fenech, C.; Kampouris, K.; Karagiorgis, G.; Braschinsky, M.; et al. The association between migraine and physical exercise. *J Headache Pain* **2018**, *19*, 83, doi:10.1186/s10194-018-0902-y.

172. Pilati, L.; Battaglia, G.; Di Stefano, V.; Di Marco, S.; Torrente, A.; Raieli, V.; Firenze, A.; Salemi, G.; Brighina, F. Migraine and Sport in a Physically Active Population of Students: Results of a Cross-Sectional Study. *Headache* **2020**, *60*, 2330-2339, doi:10.1111/head.14015.
173. Hougaard, A.; Amin, F.M.; Hauge, A.W.; Ashina, M.; Olesen, J. Provocation of migraine with aura using natural trigger factors. *Neurology* **2013**, *80*, 428-431, doi:10.1212/WNL.0b013e31827f0f10.
174. Hauge, A.W.; Kirchmann, M.; Olesen, J. Trigger factors in migraine with aura. *Cephalalgia* **2010**, *30*, 346-353, doi:10.1111/j.1468-2982.2009.01930.x.
175. Varkey, E.; Cider, A.; Carlsson, J.; Linde, M. Exercise as migraine prophylaxis: a randomized study using relaxation and topiramate as controls. *Cephalalgia* **2011**, *31*, 1428-1438, doi:10.1177/0333102411419681.
176. Busch, V.; Gaul, C. Exercise in migraine therapy--is there any evidence for efficacy? A critical review. *Headache* **2008**, *48*, 890-899, doi:10.1111/j.1526-4610.2007.01045.x.
177. Borisovskaya, A.; Chmelik, E.; Karnik, A. Exercise and Chronic Pain. *Adv Exp Med Biol* **2020**, *1228*, 233-253, doi:10.1007/978-981-15-1792-1_16.
178. Fernández-Rodríguez, R.; Álvarez-Bueno, C.; Cavero-Redondo, I.; Torres-Costoso, A.; Pozuelo-Carrascosa, D.P.; Reina-Gutiérrez, S.; Pascual-Morena, C.; Martínez-Vizcaíno, V. Best Exercise Options for Reducing Pain and Disability in Adults With Chronic Low Back Pain: Pilates, Strength, Core-Based, and Mind-Body. A Network Meta-analysis. *J Orthop Sports Phys Ther* **2022**, *52*, 505-521, doi:10.2519/jospt.2022.10671.
179. Varkey, E.; Hagen, K.; Zwart, J.A.; Linde, M. Physical activity and headache: results from the Nord-Trøndelag Health Study (HUNT). *Cephalalgia* **2008**, *28*, 1292-1297, doi:10.1111/j.1468-2982.2008.01678.x.
180. Narin, S.O.; Pinar, L.; Erbas, D.; Oztürk, V.; Idiman, F. The effects of exercise and exercise-related changes in blood nitric oxide level on migraine headache. *Clin Rehabil* **2003**, *17*, 624-630, doi:10.1191/0269215503cr657oa.
181. Lockett, D.M.; Campbell, J.F. The effects of aerobic exercise on migraine. *Headache* **1992**, *32*, 50-54, doi:10.1111/j.1526-4610.1992.hed3201050.x.
182. Reina-Varona, Á.; Madroñero-Miguel, B.; Fierro-Marrero, J.; Paris-Alemany, A.; La Touche, R. Efficacy of various exercise interventions for migraine treatment: A systematic review and network meta-analysis. *Headache: The Journal of Head and Face Pain* **2024**, *64*, 873-900, doi:https://doi.org/10.1111/head.14696.
183. Woldeamanuel, Y.W.; Oliveira, A.B.D. What is the efficacy of aerobic exercise versus strength training in the treatment of migraine? A systematic review and network meta-analysis of clinical trials. *The Journal of Headache and Pain* **2022**, *23*, 134, doi:10.1186/s10194-022-01503-y.
184. Zhao, H.; Cheng, R.; Song, G.; Teng, J.; Shen, S.; Fu, X.; Yan, Y.; Liu, C. The Effect of Resistance Training on the Rehabilitation of Elderly Patients with Sarcopenia: A Meta-Analysis. *Int J Environ Res Public Health* **2022**, *19*, doi:10.3390/ijerph192315491.
185. Caverni, C.N.; da Costa, A.T.; Simioni, C.G.; Fukue, R.R.; Tengan, C.H.; Villa, T.R. Evaluation of body composition in patients with migraine on prophylactic treatment with topiramate. *Heliyon* **2021**, *7*, e06865, doi:10.1016/j.heliyon.2021.e06865.
186. Ha, W.S.; Kim, J.; Hwang, H.W.; Lee, S.H.; Kim, J.I.; Hong, J.Y.; Park, S.H.; Han, K.D.; Baek, M.S. The association between migraine and Parkinson's disease: a nationwide cohort study. *Epidemiol Health* **2024**, *46*, e2024010, doi:10.4178/epih.e2024010.
187. Kim, J.; Ha, W.S.; Park, S.H.; Han, K.; Baek, M.S. Association between migraine and Alzheimer's disease: a nationwide cohort study. *Front Aging Neurosci* **2023**, *15*, 1196185, doi:10.3389/fnagi.2023.1196185.
188. Irby, M.B.; Bond, D.S.; Lipton, R.B.; Nicklas, B.; Houle, T.T.; Penzien, D.B. Aerobic Exercise for Reducing Migraine Burden: Mechanisms, Markers, and Models of Change Processes. *Headache* **2016**, *56*, 357-369, doi:10.1111/head.12738.

189. Clausen, T.C.; Greve, N.K.; Müller, K.I.; Kristoffersen, E.S.; Schytz, H.W. Telemedicine in headache care: A systematic review. *Cephalalgia* **2022**, *42*, 1397-1408, doi:10.1177/03331024221111554.
190. Noutsios, C.D.; Boisvert-Plante, V.; Perez, J.; Hudon, J.; Ingelmo, P. Telemedicine Applications for the Evaluation of Patients with Non-Acute Headache: A Narrative Review. *J Pain Res* **2021**, *14*, 1533-1542, doi:10.2147/jpr.S309542.
191. Kristoffersen, E.S.; Sandset, E.C.; Winsvold, B.S.; Faiz, K.W.; Storstein, A.M. Experiences of telemedicine in neurological out-patient clinics during the COVID-19 pandemic. *Ann Clin Transl Neurol* **2021**, *8*, 440-447, doi:10.1002/acn3.51293.
192. Andruskevicius, S.; Petrosian, D.; Dapkute, A.; Jokubaitis, M.; Ryliskiene, K. Evolving migraine management: Lithuania's telemedicine experience. *Frontiers in Neurology* **2024**, *15*, doi:10.3389/fneur.2024.1388100.
193. Chiang, C.C.; Halker Singh, R.; Lalvani, N.; Shubin Stein, K.; Henscheid Lorenz, D.; Lay, C.; Dodick, D.W.; Newman, L.C. Patient experience of telemedicine for headache care during the COVID-19 pandemic: An American Migraine Foundation survey study. *Headache* **2021**, *61*, 734-739, doi:10.1111/head.14110.
194. Müller, K.I.; Alstadhaug, K.B.; Bekkelund, S.I. Acceptability, Feasibility, and Cost of Telemedicine for Nonacute Headaches: A Randomized Study Comparing Video and Traditional Consultations. *J Med Internet Res* **2016**, *18*, e140, doi:10.2196/jmir.5221.
195. Santiago, M.D.; Carvalho Dde, S.; Gabbai, A.A.; Pinto, M.M.; Moutran, A.R.; Villa, T.R. Amitriptyline and aerobic exercise or amitriptyline alone in the treatment of chronic migraine: a randomized comparative study. *Arq Neuropsiquiatr* **2014**, *72*, 851-855, doi:10.1590/0004-282x20140148.
196. Madsen, B.K.; Søgaard, K.; Andersen, L.L.; Tornøe, B.; Jensen, R.H. Efficacy of strength training on tension-type headache: A randomised controlled study. *Cephalalgia* **2018**, *38*, 1071-1080, doi:10.1177/0333102417722521.
197. Mehta, J.N.; Parikh, S.; Desai, S.D.; Solanki, R.C.; A, G.P. Study of Additive Effect of Yoga and Physical Therapies to Standard Pharmacologic Treatment in Migraine. *J Neurosci Rural Pract* **2021**, *12*, 60-66, doi:10.1055/s-0040-1718842.
198. Moens, G.J., K. Verbeek, C. Bulterys, S. The prevalence and characteristics of migraine among the Belgian working population. *Acta Neurol Belg* **2007**, *107*, 84-90.
199. Darling, M. Exercise and migraine. A critical review. *J Sports Med Phys Fitness* **1991**, *31*, 294-302.
200. Annalisa, G.; Davide, B.; Marco, A. Sport and migraine-a dynamic relationship. *Neurol Sci* **2022**, *43*, 5749-5751, doi:10.1007/s10072-022-06273-8.
201. Lambert, R.W., Jr.; Burnet, D.L. Prevention of exercise induced migraine by quantitative warm-up. *Headache* **1985**, *25*, 317-319, doi:10.1111/j.1526-4610.1985.hed2506317.x.
202. Lind, H.; Brudin, L.; Lindholm, L.; Edvinsson, L. Different levels of sensory neuropeptides (calcitonin gene-related peptide and substance P) during and after exercise in man. *Clin Physiol* **1996**, *16*, 73-82, doi:10.1111/j.1475-097x.1996.tb00557.x.
203. Onuoha, G.N.; Nicholls, D.P.; Patterson, A.; Beringer, T. Neuropeptide secretion in exercise. *Neuropeptides* **1998**, *32*, 319-325, doi:10.1016/s0143-4179(98)90054-3.
204. Hagen, K.; Wisløff, U.; Ellingsen, Ø.; Stovner, L.J.; Linde, M. Headache and peak oxygen uptake: The HUNT3 study. *Cephalalgia* **2015**, *36*, 437-444, doi:10.1177/0333102415597528.
205. La Touche, R.; Fernández Pérez, J.J.; Proy Acosta, A.; González Campodónico, L.; Martínez García, S.; Adraos Juárez, D.; Serrano García, B.; Angulo-Díaz-Parreño, S.; Cuenca-Martínez, F.; Suso-Martí, L.; et al. Is aerobic exercise helpful in patients with migraine? A systematic review and meta-analysis. *Scand J Med Sci Sports* **2020**, *30*, 965-982, doi:10.1111/sms.13625.

206. Di Stefano, V.; Ornello, R.; Gagliardo, A.; Torrente, A.; Illuminato, E.; Caponnetto, V.; Frattale, I.; Golini, R.; Di Felice, C.; Graziano, F.; et al. Social Distancing in Chronic Migraine during the COVID-19 Outbreak: Results from a Multicenter Observational Study. *Nutrients* **2021**, *13*, doi:10.3390/nu13041361.
207. Pertovaara, A.; Huopaniemi, T.; Virtanen, A.; Johansson, G. The influence of exercise on dental pain thresholds and the release of stress hormones. *Physiol Behav* **1984**, *33*, 923-926, doi:10.1016/0031-9384(84)90230-0.
208. Misra, U.K.; Kalita, J.; Tripathi, G.M.; Bhoi, S.K. Is β endorphin related to migraine headache and its relief? *Cephalalgia* **2013**, *33*, 316-322, doi:10.1177/0333102412473372.
209. Pierce, E.F.; Eastman, N.W.; Tripathi, H.L.; Olson, K.G.; Dewey, W.L. Beta-endorphin response to endurance exercise: relationship to exercise dependence. *Percept Mot Skills* **1993**, *77*, 767-770, doi:10.2466/pms.1993.77.3.767.
210. Grossman, A.; Sutton, J.R. Endorphins: what are they? How are they measured? What is their role in exercise? *Med Sci Sports Exerc* **1985**, *17*, 74-81.
211. Köseoglu, E.; Akboyraz, A.; Soyuer, A.; Ersoy, A. Aerobic Exercise and Plasma Beta Endorphin Levels in Patients with Migrainous Headache Without Aura. *Cephalalgia* **2003**, *23*, 972-976, doi:10.1046/j.1468-2982.2003.00624.x.
212. Ledwidge, B. Run for your mind: Aerobic exercise as a means of alleviating anxiety and depression. *Canadian Journal of Behavioural Science / Revue canadienne des sciences du comportement* **1980**, *12*, 126-140, doi:10.1037/h0081048.
213. Smith, B.E.; Hendrick, P.; Bateman, M.; Holden, S.; Littlewood, C.; Smith, T.O.; Logan, P. Musculoskeletal pain and exercise-challenging existing paradigms and introducing new. *Br J Sports Med* **2019**, *53*, 907-912, doi:10.1136/bjsports-2017-098983.
214. Hagen, K.L., Mattias Steiner, Timothy J. Stovner, Lars Jacob Zwart, John-Anker. Risk factors for medication-overuse headache: An 11-year follow-up study. The Nord-Trøndelag Health Studies. *PAIN* **2012**, *153*, 56-61, doi:https://doi.org/10.1016/j.pain.2011.08.018.
215. Peck, K.R.; Roland, M.M.; Smitherman, T.A. Factors Associated With Medication-Overuse Headache in Patients Seeking Treatment for Primary Headache. *Headache: The Journal of Head and Face Pain* **2018**, *58*, 648-660, doi:https://doi.org/10.1111/head.13294.
216. Lemmens, J.D.P., J. Van Soom, T. Michiels, S. Versijpt, J. van Breda, E. Castien, R. De Hertogh, W. The effect of aerobic exercise on the number of migraine days, duration and pain intensity in migraine: a systematic literature review and meta-analysis. *J Headache Pain* **2019**, *20*, 16, doi:10.1186/s10194-019-0961-8.
217. Liu, Q.; Liu, F.; Yu, X.; Zang, J.; Tan, G. Telemedicine efficacy and satisfaction of patients and headache specialists in migraine management. *Front Mol Neurosci* **2023**, *16*, 1093287, doi:10.3389/fnmol.2023.1093287.
218. Peres, M.F.P.; Mercante, J.P.P.; Tobo, P.R.; Kamei, H.; Bigal, M.E. Anxiety and depression symptoms and migraine: a symptom-based approach research. *J Headache Pain* **2017**, *18*, 37, doi:10.1186/s10194-017-0742-1.
219. Brzeskot Ganning, E. Designing Migraine Applications : A Qualitative Interview Study on Migraine Patients' Motivation of using Mhealth Applications. Student thesis, 2023.
220. Giannouli, V.; Giannoulis, K. Better Understand to Better Predict Subjective Well-Being Among Older Greeks in COVID-19 Era: Depression, Anxiety, Attitudes Towards eHealth, Religiousness, Spiritual Experience, and Cognition. In Proceedings of the GeNeDis 2022, Cham, 2023//, 2023; pp. 359-364.
221. Varkey, E.C., A. Carlsson, J. Linde, M. A study to evaluate the feasibility of an aerobic exercise program in patients with migraine. *Headache* **2009**, *49*, 563-570, doi:10.1111/j.1526-4610.2008.01231.x.
222. Tassorelli, C.D., H. C., Dodick, D. W., Silberstein, S. D., Lipton, R. B., Ashina, M.; Becker, W.J.F., M. D. Goadsby, P. J. Pozo-Rosich, P. Wang, S. J. Guidelines of the

International Headache Society for controlled trials of preventive treatment of chronic migraine in adults. *Cephalalgia* **2018**, *38*, 815-832, doi:10.1177/0333102418758283.
223. Boss, G.R.; Seegmiller, J.E. Age-related physiological changes and their clinical significance. *West J Med* **1981**, *135*, 434-440.
224. Kendrick, D.; Kumar, A.; Carpenter, H.; Zijlstra, G.R.; Skelton, D.A.; Cook, J.R.; Stevens, Z.; Belcher, C.M.; Haworth, D.; Gawler, S.J. Exercise for reducing fear of falling in older people living in the community. *Cochrane database of systematic reviews* **2014**.
225. Bishop, N.A.; Lu, T.; Yankner, B.A. Neural mechanisms of ageing and cognitive decline. *Nature* **2010**, *464*, 529-535.
226. Benavent-Caballer, V.; Rosado-Calatayud, P.; Segura-Ortí, E.; Amer-Cuenca, J.; Lisón, J. Effects of three different low-intensity exercise interventions on physical performance, muscle CSA and activities of daily living: a randomized controlled trial. *Experimental Gerontology* **2014**, *58*, 159-165.
227. Zecevic, A.A.; Salmoni, A.W.; Speechley, M.; Vandervoort, A.A. Defining a fall and reasons for falling: comparisons among the views of seniors, health care providers, and the research literature. *The Gerontologist* **2006**, *46*, 367-376.
228. Daley, M.J.; Spinks, W.L. Exercise, mobility and aging. *Sports medicine* **2000**, *29*, 1-12.
229. Inouye, S.K.; Studenski, S.; Tinetti, M.E.; Kuchel, G.A. Geriatric Syndromes: Clinical, Research, and Policy Implications of a Core Geriatric Concept: (See Editorial Comments by Dr. William Hazzard on pp 794–796). *Journal of the American Geriatrics Society* **2007**, *55*, 780-791.
230. Zhao, H.; Cheng, R.; Song, G.; Teng, J.; Shen, S.; Fu, X.; Yan, Y.; Liu, C. The effect of resistance training on the rehabilitation of elderly patients with sarcopenia: a meta-analysis. *International journal of environmental research and public health* **2022**, *19*, 15491.
231. Kramarow, E.A. *Deaths from unintentional injury among adults aged 65 and over, United States, 2000-2013*; US Department of Health and Human Services, Centers for Disease Control and ...: 2015.
232. Spruit, M.A.; Singh, S.J.; Garvey, C.; ZuWallack, R.; Nici, L.; Rochester, C.; Hill, K.; Holland, A.E.; Lareau, S.C.; Man, W.D.-C. An official American Thoracic Society/European Respiratory Society statement: key concepts and advances in pulmonary rehabilitation. *American journal of respiratory and critical care medicine* **2013**, *188*, e13-e64.
233. Battaglia, G.; Giustino, V.; Messina, G.; Faraone, M.; Brusa, J.; Bordonali, A.; Barbagallo, M.; Palma, A.; Dominguez, L.-J. Walking in natural environments as geriatrician's recommendation for fall prevention: preliminary outcomes from the "passiata day" model. *Sustainability* **2020**, *12*, 2684.
234. Wietlisbach, M.; Benden, C.; Koutsokera, A.; Jahn, K.; Soccal, P.M.; Radtke, T. Perceptions towards physical activity in adult lung transplant recipients with cystic fibrosis. *PLoS One* **2020**, *15*, e0229296.
235. Battaglia, G.; Bellafiore, M.; Caramazza, G.; Paoli, A.; Bianco, A.; Palma, A. Changes in spinal range of motion after a flexibility training program in elderly women. *Clinical interventions in aging* **2014**, 653-660.
236. Chambonniere, C.; Lambert, C.; Tardieu, M.; Fillon, A.; Genin, P.; Larras, B.; Melsens, P.; Baker, J.; Pereira, B.; Tremblay, A. Physical activity and sedentary behavior of elderly populations during confinement: results from the FRENCH COVID-19 ONAPS survey. *Experimental Aging Research* **2021**, *47*, 401-413.
237. Genin, P.M.; Lambert, C.; Larras, B.; Pereira, B.; Toussaint, J.-F.; Baker, J.S.; Tremblay, A.; Thivel, D.; Duclos, M. How did the COVID-19 confinement period affect our physical activity level and sedentary behaviors? Methodology and first results from

the French national ONAPS survey. *Journal of Physical Activity and Health* **2021**, *18*, 296-303.
238. Giustino, V.; Parroco, A.M.; Gennaro, A.; Musumeci, G.; Palma, A.; Battaglia, G. Physical activity levels and related energy expenditure during COVID-19 quarantine among the Sicilian active population: a cross-sectional online survey study. *Sustainability* **2020**, *12*, 4356.
239. Gjaka, M.; Feka, K.; Bianco, A.; Tishukaj, F.; Giustino, V.; Parroco, A.M.; Palma, A.; Battaglia, G. The effect of COVID-19 lockdown measures on physical activity levels and sedentary behaviour in a relatively young population living in Kosovo. *Journal of clinical medicine* **2021**, *10*, 763.
240. Owino, V.; Yang, S.Y.; Goldspink, G. Age-related loss of skeletal muscle function and the inability to express the autocrine form of insulin-like growth factor-1 (MGF) in response to mechanical overload. *FEBS Lett* **2001**, *505*, 259-263, doi:10.1016/s0014-5793(01)02825-3.
241. Field, M.J. Telemedicine: A guide to assessing telecommunications for health care. **1996**.
242. Moher, D.; Liberati, A.; Tetzlaff, J.; Altman, D.G. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS Med* **2009**, *6*, e1000097, doi:10.1371/journal.pmed.1000097.
243. Guyatt, G.H.; Sullivan, M.J.; Thompson, P.J.; Fallen, E.L.; Pugsley, S.O.; Taylor, D.W.; Berman, L.B. The 6-minute walk: a new measure of exercise capacity in patients with chronic heart failure. *Canadian medical association journal* **1985**, *132*, 919.
244. von Storch, K.; Graaf, E.; Wunderlich, M.; Rietz, C.; Polidori, M.C.; Woopen, C. Telemedicine-Assisted Self-Management Program for Type 2 Diabetes Patients. *Diabetes Technology & Therapeutics* **2019**, *21*, 514-521, doi:10.1089/dia.2019.0056.
245. Bernard, P.; Hains-Monfette, G.; Atoui, S.; Moullec, G. Daily objective physical activity and sedentary time in adults with COPD using spirometry data from Canadian measures health survey. *Canadian respiratory journal* **2018**, *2018*, 9107435.
246. Costello, E.; Kafchinski, M.; Vrazel, J.; Sullivan, P. Motivators, barriers, and beliefs regarding physical activity in an older adult population. *Journal of geriatric physical therapy* **2011**, *34*, 138-147.
247. Eakin, E.G.; Lawler, S.P.; Vandelanotte, C.; Owen, N. Telephone interventions for physical activity and dietary behavior change: a systematic review. *American journal of preventive medicine* **2007**, *32*, 419-434.
248. Bolton, C.E.; Bevan-Smith, E.F.; Blakey, J.D.; Crowe, P.; Elkin, S.L.; Garrod, R.; Greening, N.J.; Heslop, K.; Hull, J.H.; Man, W.D. British Thoracic Society guideline on pulmonary rehabilitation in adults: accredited by NICE. *Thorax* **2013**, *68*, ii1-ii30.
249. Bos, S.; Vos, R.; Van Raemdonck, D.E.; Verleden, G.M. Survival in adult lung transplantation: where are we in 2020? *Current opinion in organ transplantation* **2020**, *25*, 268-273.
250. Loeckx, M.; Rabinovich, R.A.; Demeyer, H.; Louvaris, Z.; Tanner, R.; Rubio, N.; Frei, A.; De Jong, C.; Gimeno-Santos, E.; Rodrigues, F.M. Smartphone-based physical activity telecoaching in chronic obstructive pulmonary disease: mixed-methods study on patient experiences and lessons for implementation. *JMIR mHealth and uHealth* **2018**, *6*, e9774.
251. Lord, S.R.; Ward, J.A.; Williams, P.; Anstey, K.J. An epidemiological study of falls in older community-dwelling women: the Randwick falls and fractures study. *Australian and New Zealand Journal of Public Health* **1993**, *17*, 240-245.
252. Sherrington, C.; Whitney, J.C.; Lord, S.R.; Herbert, R.D.; Cumming, R.G.; Close, J.C. Effective exercise for the prevention of falls: a systematic review and meta-analysis. *Journal of the American Geriatrics Society* **2008**, *56*, 2234-2243.

253. Chen, L.; Magliano, D.J.; Zimmet, P.Z. The worldwide epidemiology of type 2 diabetes mellitus—present and future perspectives. *Nature reviews endocrinology* **2012**, *8*, 228-236.
254. Davies, M.J.; D'Alessio, D.A.; Fradkin, J.; Kernan, W.N.; Mathieu, C.; Mingrone, G.; Rossing, P.; Tsapas, A.; Wexler, D.J.; Buse, J.B. Management of hyperglycemia in type 2 diabetes, 2018. A consensus report by the American Diabetes Association (ADA) and the European Association for the Study of Diabetes (EASD). *Diabetes care* **2018**, *41*, 2669.
255. Balkau, B.; Mhamdi, L.; Oppert, J.-M.; Nolan, J.; Golay, A.; Porcellati, F.; Laakso, M.; Ferrannini, E.; Group, E.-R.S. Physical activity and insulin sensitivity: the RISC study. *Diabetes* **2008**, *57*, 2613-2618.
256. Helmrich, S.P.; Ragland, D.R.; Leung, R.W.; Paffenbarger Jr, R.S. Physical activity and reduced occurrence of non-insulin-dependent diabetes mellitus. *New England journal of medicine* **1991**, *325*, 147-152.
257. Gillespie, L.; Gillespie, W.; Robertson, M.; Lamb, S.; Cumming, R.; Rowe, B. Interventions for preventing falls in elderly people (Cochrane Review). Cochrane Library. *Issue* **2003**, *3*, 2001.
258. Merchant, R.; Morley, J.; Izquierdo, M. Exercise, aging and frailty: guidelines for increasing function. *The journal of nutrition, health & aging* **2021**, *25*, 405-409.
259. Langer, D. Addressing the changing rehabilitation needs of patients undergoing thoracic surgery. *Chronic Respiratory Disease* **2021**, *18*, 1479973121994783.
260. Stevens, J.; Ryan, G.; Kresnow, M. Fatalities and injuries from falls among older adults--United States, 1993-2003 and 2001-2005. *MMWR: Morbidity & Mortality Weekly Report* **2006**, *55*.
261. Battaglia, G.; Bellafiore, M.; Bianco, A.; Paoli, A.; Palma, A. Effects of a dynamic balance training protocol on podalic support in older women. Pilot Study. *Aging clinical and experimental research* **2010**, *22*, 406-411.
262. Bellafiore, M.; Battaglia, G.; Bianco, A.; Paoli, A.; Farina, F.; Palma, A. Improved postural control after dynamic balance training in older overweight women. *Aging clinical and experimental research* **2011**, *23*, 378-385.
263. Bembom, O.; van der Laan, M.; Haight, T.; Tager, I. Leisure-time physical activity and all-cause mortality in an elderly cohort. *Epidemiology* **2009**, *20*, 424-430, doi:10.1097/EDE.0b013e31819e3f28.
264. Peters, E.; Pritzkuleit, R.; Beske, F.; Katalinic, A. [Demographic change and disease rates: a projection until 2050]. *Bundesgesundheitsblatt Gesundheitsforschung Gesundheitsschutz* **2010**, *53*, 417-426, doi:10.1007/s00103-010-1050-y.
265. Rudnicka, E.; Napierała, P.; Podfigurna, A.; Męczekalski, B.; Smolarczyk, R.; Grymowicz, M. The World Health Organization (WHO) approach to healthy ageing. *Maturitas* **2020**, *139*, 6-11.
266. Benavent-Caballer, V.; Rosado-Calatayud, P.; Segura-Ortí, E.; Amer-Cuenca, J.J.; Lisón, J.F. Effects of three different low-intensity exercise interventions on physical performance, muscle CSA and activities of daily living: a randomized controlled trial. *Exp Gerontol* **2014**, *58*, 159-165, doi:10.1016/j.exger.2014.08.004.
267. de Oliveira, L.; Souza, E.C.; Rodrigues, R.A.S.; Fett, C.A.; Piva, A.B. The effects of physical activity on anxiety, depression, and quality of life in elderly people living in the community. *Trends Psychiatry Psychother* **2019**, *41*, 36-42, doi:10.1590/2237-6089-2017-0129.
268. Andreescu, C.; Lee, S. Anxiety Disorders in the Elderly. *Adv Exp Med Biol* **2020**, *1191*, 561-576, doi:10.1007/978-981-32-9705-0_28.
269. Rikli, R.E.; Jones, C.J. Assessing Physical Performance in Independent Older Adults: Issues and Guidelines. *Journal of Aging and Physical Activity* **1997**, *5*, 244-261, doi:10.1123/japa.5.3.244.

270. Seah, B.; Kowitlawakul, Y.; Jiang, Y.; Ang, E.; Chokkanathan, S.; Wang, W. A review on healthy ageing interventions addressing physical, mental and social health of independent community-dwelling older adults. *Geriatric Nursing* **2019**, *40*, 37-50.
271. Furtado, G.E.; Letieri, R.V.; Carballeira, E. Exercise Evaluation and Prescription in Older Adults. *Healthcare* **2023**, *11*, doi:10.3390/healthcare11010042.
272. Patti, A.; Bianco, A.; Karsten, B.; Montalto, M.A.; Battaglia, G.; Bellafiore, M.; Cassata, D.; Scoppa, F.; Paoli, A.; Iovane, A. The effects of physical training without equipment on pain perception and balance in the elderly: A randomized controlled trial. *Work* **2017**, *57*, 23-30.
273. Cunningham, C.; O'Sullivan, R.; Caserotti, P.; Tully, M.A. Consequences of physical inactivity in older adults: A systematic review of reviews and meta-analyses. *Scandinavian journal of medicine & science in sports* **2020**, *30*, 816-827.
274. Guirguis-Blake, J.; Calonge, N.; Miller, T.; Siu, A.; Teutsch, S.; Whitlock, E. Current processes of the U.S. Preventive Services Task Force: refining evidence-based recommendation development. *Ann Intern Med* **2007**, *147*, 117-122, doi:10.7326/0003-4819-147-2-200707170-00170.
275. Hoffmann, K.; Sobol, N.A.; Frederiksen, K.S.; Beyer, N.; Vogel, A.; Vestergaard, K.; Brændgaard, H.; Gottrup, H.; Lolk, A.; Wermuth, L.; et al. Moderate-to-High Intensity Physical Exercise in Patients with Alzheimer's Disease: A Randomized Controlled Trial. *J Alzheimers Dis* **2016**, *50*, 443-453, doi:10.3233/jad-150817.
276. Koevoets, E.W.; Schagen, S.B.; de Ruiter, M.B.; Geerlings, M.I.; Witlox, L.; van der Wall, E.; Stuiver, M.M.; Sonke, G.S.; Velthuis, M.J.; Jobsen, J.J.; et al. Effect of physical exercise on cognitive function after chemotherapy in patients with breast cancer: a randomized controlled trial (PAM study). *Breast Cancer Res* **2022**, *24*, 36, doi:10.1186/s13058-022-01530-2.
277. Scaturro, D.; Rizzo, S.; Sanfilippo, V.; Giustino, V.; Messina, G.; Martines, F.; Falco, V.; Cuntrera, D.; Moretti, A.; Iolascon, G.; et al. Effectiveness of Rehabilitative Intervention on Pain, Postural Balance, and Quality of Life in Women with Multiple Vertebral Fragility Fractures: A Prospective Cohort Study. *J Funct Morphol Kinesiol* **2021**, *6*, doi:10.3390/jfmk6010024.
278. Hennig, T.; Hæhre, L.; Hornburg, V.T.; Mowinckel, P.; Norli, E.S.; Kjeken, I. Effect of home-based hand exercises in women with hand osteoarthritis: a randomised controlled trial. *Ann Rheum Dis* **2015**, *74*, 1501-1508, doi:10.1136/annrheumdis-2013-204808.
279. Martínez-Velilla, N.; Casas-Herrero, A.; Zambom-Ferraresi, F.; Sáez de Asteasu, M.L.; Lucia, A.; Galbete, A.; García-Baztán, A.; Alonso-Renedo, J.; González-Glaría, B.; Gonzalo-Lázaro, M.; et al. Effect of Exercise Intervention on Functional Decline in Very Elderly Patients During Acute Hospitalization: A Randomized Clinical Trial. *JAMA Intern Med* **2019**, *179*, 28-36, doi:10.1001/jamainternmed.2018.4869.
280. Sahin, H.; Naz, I.; Karadeniz, G.; Süneçli, O.; Polat, G.; Ediboglu, O. Effects of a home-based pulmonary rehabilitation program with and without telecoaching on health-related outcomes in COVID-19 survivors: a randomized controlled clinical study. *Jornal Brasileiro De Pneumologia* **2023**, *49*, doi:10.36416/1806-3756/e20220107.
281. Fraser, M.; Munoz, S.A.; MacRury, S. Does the Mode of Exercise Influence the Benefits Obtained by Green Exercise? *Int J Environ Res Public Health* **2019**, *16*, doi:10.3390/ijerph16163004.
282. Li, H.; Liu, H.; Yang, Z.; Bi, S.; Cao, Y.; Zhang, G. The Effects of Green and Urban Walking in Different Time Frames on Physio-Psychological Responses of Middle-Aged and Older People in Chengdu, China. *Int J Environ Res Public Health* **2020**, *18*, doi:10.3390/ijerph18010090.
283. Greco, G.; Centrone, C.; Poli, L.; Silva, A.F.; Russo, L.; Cataldi, S.; Giustino, V.; Fischetti, F. Impact of Coastal Walking Outdoors and Virtual Reality Indoor Walking on

Heart Rate, Enjoyment Levels and Mindfulness Experiences in Healthy Adults. *J Funct Morphol Kinesiol* **2023**, *9*, doi:10.3390/jfmk9010011.
284. Bullo, V.; Gobbo, S.; Vendramin, B.; Duregon, F.; Cugusi, L.; Di Blasio, A.; Bocalini, D.S.; Zaccaria, M.; Bergamin, M.; Ermolao, A. Nordic Walking Can Be Incorporated in the Exercise Prescription to Increase Aerobic Capacity, Strength, and Quality of Life for Elderly: A Systematic Review and Meta-Analysis. *Rejuvenation Res* **2018**, *21*, 141-161, doi:10.1089/rej.2017.1921.
285. Demeyer, H.; Louvaris, Z.; Frei, A.; Rabinovich, R.A.; de Jong, C.; Gimeno-Santos, E.; Loeckx, M.; Buttery, S.C.; Rubio, N.; Van der Molen, T.; et al. Physical activity is increased by a 12-week semiautomated telecoaching programme in patients with COPD: a multicentre randomised controlled trial. *Thorax* **2017**, *72*, 415-423, doi:10.1136/thoraxjnl-2016-209026.
286. Scura, D.; Munakomi, S. Tinetti gait and balance test. **2022**.
287. Spijkerman, D.C.; Snijders, C.J.; Stijnen, T.; Lankhorst, G.J. Standardization of grip strength measurements. Effects on repeatability and peak force. *Scand J Rehabil Med* **1991**, *23*, 203-206.
288. Bohannon, R.W. Reference values for the timed up and go test: a descriptive meta-analysis. *Journal of geriatric physical therapy* **2006**, *29*, 64-68.
289. Welch, S.A.; Ward, R.E.; Beauchamp, M.K.; Leveille, S.G.; Travison, T.; Bean, J.F. The short physical performance battery (SPPB): a quick and useful tool for fall risk stratification among older primary care patients. *Journal of the American Medical Directors Association* **2021**, *22*, 1646-1651.
290. Veronese, N.; Bolzetta, F.; Toffanello, E.D.; Zambon, S.; De Rui, M.; Perissinotto, E.; Coin, A.; Corti, M.-C.; Baggio, G.; Crepaldi, G. Association between short physical performance battery and falls in older people: the Progetto Veneto Anziani study. *Rejuvenation research* **2014**, *17*, 276-284.
291. Volpato, S.; Cavalieri, M.; Sioulis, F.; Guerra, G.; Maraldi, C.; Zuliani, G.; Fellin, R.; Guralnik, J.M. Predictive value of the Short Physical Performance Battery following hospitalization in older patients. *Journals of gerontology series a: biomedical sciences and medical sciences* **2011**, *66*, 89-96.
292. Vasunilashorn, S.; Coppin, A.K.; Patel, K.V.; Lauretani, F.; Ferrucci, L.; Bandinelli, S.; Guralnik, J.M. Use of the Short Physical Performance Battery Score to predict loss of ability to walk 400 meters: analysis from the InCHIANTI study. *Journals of Gerontology Series A: Biomedical Sciences and Medical Sciences* **2009**, *64*, 223-229.
293. Studenski, S.; Perera, S.; Wallace, D.; Chandler, J.M.; Duncan, P.W.; Rooney, E.; Fox, M.; Guralnik, J.M. Physical performance measures in the clinical setting. *Journal of the American Geriatrics Society* **2003**, *51*, 314-322.
294. Tinetti, M.E. Performance-oriented assessment of mobility problems in elderly patients. *Journal of the American Geriatrics Society* **1986**.
295. Rivolta, M.W.; Aktaruzzaman, M.; Rizzo, G.; Lafortuna, C.L.; Ferrarin, M.; Bovi, G.; Bonardi, D.R.; Caspani, A.; Sassi, R. Evaluation of the Tinetti score and fall risk assessment via accelerometry-based movement analysis. *Artificial intelligence in medicine* **2019**, *95*, 38-47.
296. An, H.Y.; Chen, W.; Wang, C.W.; Yang, H.F.; Huang, W.T.; Fan, S.Y. The Relationships between Physical Activity and Life Satisfaction and Happiness among Young, Middle-Aged, and Older Adults. *Int J Environ Res Public Health* **2020**, *17*, doi:10.3390/ijerph17134817.
297. F, M.S.; Petrica, J.; Serrano, J.; Paulo, R.; Ramalho, A.; Lucas, D.; Ferreira, J.P.; Duarte-Mendes, P. The Sedentary Time and Physical Activity Levels on Physical Fitness in the Elderly: A Comparative Cross Sectional Study. *Int J Environ Res Public Health* **2019**, *16*, doi:10.3390/ijerph16193697.

298. Valenzuela, P.L.; Castillo-García, A.; Morales, J.S.; Izquierdo, M.; Serra-Rexach, J.A.; Santos-Lozano, A.; Lucia, A. Physical Exercise in the Oldest Old. *Compr Physiol* **2019**, *9*, 1281-1304, doi:10.1002/cphy.c190002.
299. Low, D.C.; Walsh, G.S.; Arkesteijn, M. Effectiveness of Exercise Interventions to Improve Postural Control in Older Adults: A Systematic Review and Meta-Analyses of Centre of Pressure Measurements. *Sports Med* **2017**, *47*, 101-112, doi:10.1007/s40279-016-0559-0.
300. Eckardt, N. Lower-extremity resistance training on unstable surfaces improves proxies of muscle strength, power and balance in healthy older adults: a randomised control trial. *BMC Geriatr* **2016**, *16*, 191, doi:10.1186/s12877-016-0366-3.
301. Watson, S.L.; Weeks, B.K.; Weis, L.J.; Harding, A.T.; Horan, S.A.; Beck, B.R. High-Intensity Resistance and Impact Training Improves Bone Mineral Density and Physical Function in Postmenopausal Women With Osteopenia and Osteoporosis: The LIFTMOR Randomized Controlled Trial. *J Bone Miner Res* **2018**, *33*, 211-220, doi:10.1002/jbmr.3284.
302. Vikberg, S.; Sörlén, N.; Brandén, L.; Johansson, J.; Nordström, A.; Hult, A.; Nordström, P. Effects of Resistance Training on Functional Strength and Muscle Mass in 70-Year-Old Individuals With Pre-sarcopenia: A Randomized Controlled Trial. *J Am Med Dir Assoc* **2019**, *20*, 28-34, doi:10.1016/j.jamda.2018.09.011.
303. Osuka, Y.; Fujita, S.; Kitano, N.; Kosaki, K.; Seol, J.; Sawano, Y.; Shi, H.; Fujii, Y.; Maeda, S.; Okura, T.; et al. Effects of Aerobic and Resistance Training Combined with Fortified Milk on Muscle Mass, Muscle Strength, and Physical Performance in Older Adults: A Randomized Controlled Trial. *J Nutr Health Aging* **2017**, *21*, 1349-1357, doi:10.1007/s12603-016-0864-1.
304. Harwood, R.H.; Conroy, S.P. Slow walking speed in elderly people. *Bmj* **2009**, *339*, b4236, doi:10.1136/bmj.b4236.
305. Bai, X.; Soh, K.G.; Omar Dev, R.D.; Talib, O.; Xiao, W.; Cai, H. Effect of Brisk Walking on Health-Related Physical Fitness Balance and Life Satisfaction Among the Elderly: A Systematic Review. *Front Public Health* **2021**, *9*, 829367, doi:10.3389/fpubh.2021.829367.
306. Fan, Y.; Li, Z.; Han, S.; Lv, C.; Zhang, B. The influence of gait speed on the stability of walking among the elderly. *Gait Posture* **2016**, *47*, 31-36, doi:10.1016/j.gaitpost.2016.02.018.
307. Chatutain, A.; Pattana, J.; Parinsarum, T.; Lapanantasin, S. Walking meditation promotes ankle proprioception and balance performance among elderly women. *J Bodyw Mov Ther* **2019**, *23*, 652-657, doi:10.1016/j.jbmt.2018.09.152.
308. Little, C.; Moore, C.; Bean, E.; Peters, D.M.; McGinnis, R.S.; Kasser, S.L. Acute effects of axial loading on postural control during walking and turning in people with multiple sclerosis: A pilot study. *Gait Posture* **2022**, *94*, 102-106, doi:10.1016/j.gaitpost.2022.02.031.
309. Madureira, M.M.; Takayama, L.; Gallinaro, A.L.; Caparbo, V.F.; Costa, R.A.; Pereira, R.M. Balance training program is highly effective in improving functional status and reducing the risk of falls in elderly women with osteoporosis: a randomized controlled trial. *Osteoporos Int* **2007**, *18*, 419-425, doi:10.1007/s00198-006-0252-5.
310. Okubo, Y.; Osuka, Y.; Jung, S.; Figueroa, R.; Tsujimoto, T.; Aiba, T.; Kim, T.; Tanaka, K. Effects of walking on physical and psychological fall-related factors in community-dwelling older adults: Walking versus balance program. *The Journal of Physical Fitness and Sports Medicine* **2014**, *3*, 515-524, doi:10.7600/jpfsm.3.515.
311. Okubo, Y.; Osuka, Y.; Jung, S.; Rafael, F.; Tsujimoto, T.; Aiba, T.; Kim, T.; Tanaka, K. Walking can be more effective than balance training in fall prevention among community-dwelling older adults. *Geriatr Gerontol Int* **2016**, *16*, 118-125, doi:10.1111/ggi.12444.

312. Gillespie, L.D.; Robertson, M.C.; Gillespie, W.J.; Sherrington, C.; Gates, S.; Clemson, L.M.; Lamb, S.E. Interventions for preventing falls in older people living in the community. *Cochrane Database Syst Rev* **2012**, *2012*, Cd007146, doi:10.1002/14651858.CD007146.pub3.
313. Lopez, P.; Pinto, R.S.; Radaelli, R.; Rech, A.; Grazioli, R.; Izquierdo, M.; Cadore, E.L. Benefits of resistance training in physically frail elderly: a systematic review. *Aging Clin Exp Res* **2018**, *30*, 889-899, doi:10.1007/s40520-017-0863-z.
314. Borde, R.; Hortobágyi, T.; Granacher, U. Dose-Response Relationships of Resistance Training in Healthy Old Adults: A Systematic Review and Meta-Analysis. *Sports Med* **2015**, *45*, 1693-1720, doi:10.1007/s40279-015-0385-9.
315. Otsuka, Y.; Yamada, Y.; Maeda, A.; Izumo, T.; Rogi, T.; Shibata, H.; Fukuda, M.; Arimitsu, T.; Miyamoto, N.; Hashimoto, T. Effects of resistance training intensity on muscle quantity/quality in middle-aged and older people: a randomized controlled trial. *J Cachexia Sarcopenia Muscle* **2022**, *13*, 894-908, doi:10.1002/jcsm.12941.
316. Seo, M.W.; Jung, S.W.; Kim, S.W.; Lee, J.M.; Jung, H.C.; Song, J.K. Effects of 16 Weeks of Resistance Training on Muscle Quality and Muscle Growth Factors in Older Adult Women with Sarcopenia: A Randomized Controlled Trial. *Int J Environ Res Public Health* **2021**, *18*, doi:10.3390/ijerph18136762.
317. Wagner, L.I.; Tooze, J.A.; Hall, D.L.; Levine, B.J.; Beaumont, J.; Duffecy, J.; Victorson, D.; Gradishar, W.; Leach, J.; Saphner, T.; et al. Targeted eHealth Intervention to Reduce Breast Cancer Survivors' Fear of Recurrence: Results From the FoRtitude Randomized Trial. *J Natl Cancer Inst* **2021**, *113*, 1495-1505, doi:10.1093/jnci/djab100.
318. Maggi, G.; Monti Bragadin, M.; Padua, L.; Fiorina, E.; Bellone, E.; Grandis, M.; Reni, L.; Bennicelli, A.; Grosso, M.; Saporiti, R.; et al. Outcome measures and rehabilitation treatment in patients affected by Charcot-Marie-Tooth neuropathy: a pilot study. *Am J Phys Med Rehabil* **2011**, *90*, 628-637, doi:10.1097/PHM.0b013e31821f6e32.
319. Furtado, G.E.; Reis, A.; Braga-Pereira, R.; Caldo-Silva, A.; Teques, P.; Sampaio, A.R.; Santos, C.; Bachi, A.L.L.; Campos, F.; Borges, G.F.; et al. Impact of Exercise Interventions on Sustained Brain Health Outcomes in Frail Older Individuals: A Comprehensive Review of Systematic Reviews. *Healthcare (Basel)* **2023**, *11*, doi:10.3390/healthcare11243160.
320. Trott, M.; Smith, L. What are the associations between extroversion, enjoyment, and wellness in group vs non-group physical activity? A pilot study. **2019**.
321. Li, R.T.; Kling, S.R.; Salata, M.J.; Cupp, S.A.; Sheehan, J.; Voos, J.E. Wearable Performance Devices in Sports Medicine. *Sports Health* **2016**, *8*, 74-78, doi:10.1177/1941738115616917.
322. Loader, J.; Montgomery, P.G.; Williams, M.D.; Lorenzen, C.; Kemp, J.G. Classifying training drills based on movement demands in Australian football. *International Journal of Sports Science & Coaching* **2012**, *7*, 57-67.
323. Mooney, M.G.; Hunter, J.R.; O'Brien, B.J.; Berry, J.T.; Young, W.B. Reliability and validity of a novel intermittent peak running speed test for Australian football. *J Strength Cond Res* **2011**, *25*, 973-979, doi:10.1519/JSC.0b013e3181d09dde.
324. Noonan, B.; Bancroft, R.W.; Dines, J.S.; Bedi, A. Heat- and cold-induced injuries in athletes: evaluation and management. *J Am Acad Orthop Surg* **2012**, *20*, 744-754, doi:10.5435/jaaos-20-12-744.
325. Tierney, P.; Clarke, N.; Roberts, S. Use and application of wearable technology in football further education settings in the UK. *Sport, Education and Society*, 1-14, doi:10.1080/13573322.2024.2404896.
326. Wu, Z.; Xu, M.; Qu, C. The use of wearable devices in the assessment of basketball players' athletic performance. *Applied Mathematics and Nonlinear Sciences* **2025**, *10*, doi:10.2478/amns-2025-0754.
327. Pearson, A.L.; Tribby, C.; Brown, C.D.; Yang, J.A.; Pfeiffer, K.; Jankowska, M.M. Systematic review of best practices for GPS data usage, processing, and linkage in

health, exposure science and environmental context research. *BMJ Open* **2024**, *14*, e077036, doi:10.1136/bmjopen-2023-077036.
328. Henriksen, A.; Haugen Mikalsen, M.; Woldaregay, A.Z.; Muzny, M.; Hartvigsen, G.; Hopstock, L.A.; Grimsgaard, S. Using Fitness Trackers and Smartwatches to Measure Physical Activity in Research: Analysis of Consumer Wrist-Worn Wearables. *J Med Internet Res* **2018**, *20*, e110, doi:10.2196/jmir.9157.
329. Larsson, P. Global positioning system and sport-specific testing. *Sports Med* **2003**, *33*, 1093-1101, doi:10.2165/00007256-200333150-00002.
330. Cummins, C.; Orr, R.; O'Connor, H.; West, C. Global positioning systems (GPS) and microtechnology sensors in team sports: a systematic review. *Sports Med* **2013**, *43*, 1025-1042, doi:10.1007/s40279-013-0069-2.
331. Impellizzeri, F.M.; Rampinini, E.; Marcora, S.M. Physiological assessment of aerobic training in soccer. *J Sports Sci* **2005**, *23*, 583-592, doi:10.1080/02640410400021278.
332. Rossi, A.; Pappalardo, L.; Cintia, P.; Iaia, F.M.; Fernàndez, J.; Medina, D. Effective injury forecasting in soccer with GPS training data and machine learning. *PLoS One* **2018**, *13*, e0201264, doi:10.1371/journal.pone.0201264.
333. Rago, V.; Brito, J.; Figueiredo, P.; Costa, J.; Barreira, D.; Krustrup, P.; Rebelo, A. Methods to collect and interpret external training load using microtechnology incorporating GPS in professional football: a systematic review. *Res Sports Med* **2020**, *28*, 437-458, doi:10.1080/15438627.2019.1686703.
334. Varley, M.C.; Fairweather, I.H.; Aughey1, Robert J. Validity and reliability of GPS for measuring instantaneous velocity during acceleration, deceleration, and constant motion. *Journal of sports sciences* **2012**, *30*, 121-127.
335. Osgnach, C.; Poser, S.; Bernardini, R.; Rinaldo, R.; Di Prampero, P.E. Energy cost and metabolic power in elite soccer: a new match analysis approach. *Med Sci Sports Exerc* **2010**, *42*, 170-178.
336. Bloomfield, J.; Polman, R.; O'Donoghue, P. Physical demands of different positions in FA Premier League soccer. *Journal of sports science & medicine* **2007**, *6*, 63.
337. Akenhead, R.; Hayes, P.R.; Thompson, K.G.; French, D. Diminutions of acceleration and deceleration output during professional football match play. *J Sci Med Sport* **2013**, *16*, 556-561, doi:10.1016/j.jsams.2012.12.005.
338. Ade, J.D.; Harley, J.A.; Bradley, P.S. Physiological response, time-motion characteristics, and reproducibility of various speed-endurance drills in elite youth soccer players: small-sided games versus generic running. *Int J Sports Physiol Perform* **2014**, *9*, 471-479, doi:10.1123/ijspp.2013-0390.
339. Mota, T.; Silva, R.; Clemente, F. Holistic soccer profile by position: a theoretical framework. *Human movement* **2021**, *24*, 4-20.
340. Dolci, F.; Hart, N.H.; Kilding, A.E.; Chivers, P.; Piggott, B.; Spiteri, T. Physical and energetic demand of soccer: a brief review. *Strength & Conditioning Journal* **2020**, *42*, 70-77.
341. Jeffries, A.C.; Marcora, S.M.; Coutts, A.J.; Wallace, L.; McCall, A.; Impellizzeri, F.M. Development of a revised conceptual framework of physical training for use in research and practice. *Sports Medicine* **2022**, *52*, 709-724.
342. Buchheit, M. i Laursen, PB (2013a). High-intensity interval training, solutions to the programming puzzle: Part II: anaerobic energy, neuromuscular load and practical applications. *Sports medicine 43*, 927-954.
343. Rossi, A.; Pappalardo, L.; Cintia, P.; Iaia, F.M.; Fernández, J.; Medina, D. Effective injury forecasting in soccer with GPS training data and machine learning. *PloS one* **2018**, *13*, e0201264.
344. Gabbett, T.J.; Nassis, G.P.; Oetter, E.; Pretorius, J.; Johnston, N.; Medina, D.; Rodas, G.; Myslinski, T.; Howells, D.; Beard, A. The athlete monitoring cycle: a practical guide to interpreting and applying training monitoring data. **2017**, *51*, 1451-1452.

345. Oliva-Lozano, J.M.; Fortes, V.; Krustrup, P.; Muyor, J.M. Acceleration and sprint profiles of professional male football players in relation to playing position. *PloS one* **2020**, *15*, e0236959.
346. Krustrup, P.; Mohr, M.; Ellingsgaard, H.; Bangsbo, J. Physical demands during an elite female soccer game: importance of training status. *Medicine & Science in Sports & Exercise* **2005**, *37*, 1242-1248.
347. Chmura, P.; Konefał, M.; Chmura, J.; Kowalczuk, E.; Zając, T.; Rokita, A.; Andrzejewski, M. Match outcome and running performance in different intensity ranges among elite soccer players. *Biology of sport* **2018**, *35*, 197-203.
348. Stølen, T.; Chamari, K.; Castagna, C.; Wisløff, U. Physiology of soccer: an update. *Sports medicine* **2005**, *35*, 501-536.
349. Baptista, I.; Johansen, D.; Figueiredo, P.; Rebelo, A.; Pettersen, S.A. Positional differences in peak-and accumulated-training load relative to match load in elite football. *Sports* **2019**, *8*, 1.
350. Brito, Â.; Roriz, P.; Duarte, R.; Garganta, J. Match-running performance of young soccer players in different game formats. *International Journal of Performance Analysis in Sport* **2018**, *18*, 410-422.
351. Ehrmann, F.E.; Duncan, C.S.; Sindhusake, D.; Franzsen, W.N.; Greene, D.A. GPS and injury prevention in professional soccer. *The Journal of Strength & Conditioning Research* **2016**, *30*, 360-367.
352. Van Eetvelde, H.; Mendonça, L.D.; Ley, C.; Seil, R.; Tischer, T. Machine learning methods in sport injury prediction and prevention: a systematic review. *Journal of experimental orthopaedics* **2021**, *8*, 27.
353. Falbriard, M.; Meyer, F.; Mariani, B.; Millet, G.P.; Aminian, K. Accurate estimation of running temporal parameters using foot-worn inertial sensors. *Frontiers in physiology* **2018**, *9*, 610.
354. Al Haddad, H.; Méndez-Villanueva, A.; Torreño, N.; Munguía-Izquierdo, D.; Suárez-Arrones, L. Variability of GPS-derived running performance during official matches in elite professional soccer players. *The Journal of sports medicine and physical fitness* **2017**, *58*, 1439-1445.
355. Hands, D.E.; Janse de Jonge, X. Current time-motion analyses of professional football matches in top-level domestic leagues: a systematic review. *International Journal of Performance Analysis in Sport* **2020**, *20*, 747-765.
356. Di Salvo, V.; Baron, R.; Tschan, H.; Montero, F.C.; Bachl, N.; Pigozzi, F. Performance characteristics according to playing position in elite soccer. *International journal of sports medicine* **2007**, *28*, 222-227.
357. Sarmento, H.; Clemente, F.M.; Harper, L.D.; Costa, I.T.d.; Owen, A.; Figueiredo, A.J. Small sided games in soccer–a systematic review. *International journal of performance analysis in sport* **2018**, *18*, 693-749.
358. Di Salvo, V.; Baron, R.; González-Haro, C.; Gormasz, C.; Pigozzi, F.; Bachl, N. Sprinting analysis of elite soccer players during European Champions League and UEFA Cup matches. *Journal of sports sciences* **2010**, *28*, 1489-1494.
359. Gregson, W.; Drust, B.; Atkinson, G.; Salvo, V. Match-to-match variability of high-speed activities in premier league soccer. *International journal of sports medicine* **2010**, *31*, 237-242.
360. Mohr, M.; Krustrup, P.; Bangsbo, J. Match performance of high-standard soccer players with special reference to development of fatigue. *Journal of sports sciences* **2003**, *21*, 519-528.
361. Miguel, M.; Oliveira, R.; Brito, J.P.; Loureiro, N.; García-Rubio, J.; Ibáñez, S.J. External match load in amateur soccer: the influence of match location and championship phase. In Proceedings of the Healthcare, 2022; p. 594.

362. Saward, C.; Morris, J.; Nevill, M.E.; Nevill, A.M.; Sunderland, C. Longitudinal development of match-running performance in elite male youth soccer players. *Scandinavian journal of medicine & science in sports* **2016**, *26*, 933-942.
363. Varley, M.C.; Gregson, W.; McMillan, K.; Bonanno, D.; Stafford, K.; Modonutti, M.; Di Salvo, V. Physical and technical performance of elite youth soccer players during international tournaments: influence of playing position and team success and opponent quality. *Science and Medicine in Football* **2017**, *1*, 18-29.
364. Buchheit, M.-v.; Mendez-Villanueva, A.; Simpson, B.; Bourdon, P. Repeated-sprint sequences during youth soccer matches. *International journal of sports medicine* **2010**, *31*, 709-716.
365. Pillitteri, G.; Thomas, E.; Battaglia, G.; Navarra, G.A.; Scardina, A.; Gammino, V.; Ricchiari, D.; Bellafiore, M. Validity and reliability of an inertial sensor device for specific running patterns in soccer. *Sensors* **2021**, *21*, 7255.
366. Riboli, A.; Coratella, G.; Rampichini, S.; Cé, E.; Esposito, F. Area per player in small-sided games to replicate the external load and estimated physiological match demands in elite soccer players. *PloS one* **2020**, *15*, e0229194.
367. Riboli, A.; Olthof, S.B.; Esposito, F.; Coratella, G. Training elite youth soccer players: area per player in small-sided games to replicate the match demands. *Biology of Sport* **2022**, *39*, 579-598.
368. Coutts, A.J.; Duffield, R. Validity and reliability of GPS devices for measuring movement demands of team sports. *Journal of science and Medicine in Sport* **2010**, *13*, 133-135.
369. Impellizzeri, F.M.; Marcora, S.M.; Coutts, A.J. Internal and external training load: 15 years on. *Int J Sports Physiol Perform* **2019**, *14*, 270-273.
370. Ravé, G.; Granacher, U.; Boullosa, D.; Hackney, A.C.; Zouhal, H. How to use global positioning systems (GPS) data to monitor training load in the “real world” of elite soccer. *Frontiers in physiology* **2020**, *11*, 944.
371. Abbott, W.; Brickley, G.; Smeeton, N.J. Physical demands of playing position within English Premier League academy soccer. **2018**.
372. Ademović, A. Differences in the quantity and intensity of playing in elite soccer players of different position in the game. *J Sports Sci Med* **2016**, *18*, 26-31.
373. Andrzejewski, M.; Konefał, M.; Chmura, P.; Kowalczuk, E.; Chmura, J. Match outcome and distances covered at various speeds in match play by elite German soccer players. *International Journal of Performance Analysis in Sport* **2016**, *16*, 817-828.
374. Aslan, A.; Acikada, C.; Güvenç, A.; Gören, H.; Hazir, T.; Özkara, A. Metabolic demands of match performance in young soccer players. *Journal of sports science & medicine* **2012**, *11*, 170.
375. Mendez-Villanueva, A.; Buchheit, M.; Simpson, B.; Bourdon, P.C. Match play intensity distribution in youth soccer. *International journal of sports medicine* **2013**, *34*, 101-110.
376. Di Salvo, V.; Gregson, W.; Atkinson, G.; Tordoff, P.; Drust, B. Analysis of high intensity activity in Premier League soccer. *Int J Sports Med* **2009**, *30*, 205-212, doi:10.1055/s-0028-1105950.
377. Ingebrigtsen, J.; Dalen, T.; Hjelde, G.H.; Drust, B.; Wisløff, U. Acceleration and sprint profiles of a professional elite football team in match play. *Eur J Sport Sci* **2015**, *15*, 101-110, doi:10.1080/17461391.2014.933879.
378. Ade, J.; Fitzpatrick, J.; Bradley, P.S. High-intensity efforts in elite soccer matches and associated movement patterns, technical skills and tactical actions. Information for position-specific training drills. *J Sports Sci* **2016**, *34*, 2205-2214, doi:10.1080/02640414.2016.1217343.
379. Orendurff, M.S.; Walker, J.D.; Jovanovic, M.; Tulchin, K.L.; Levy, M.; Hoffmann, D.K. Intensity and duration of intermittent exercise and recovery during a soccer match. *J Strength Cond Res* **2010**, *24*, 2683-2692, doi:10.1519/JSC.0b013e3181bac463.

380. Bangsbo, J. Energy demands in competitive soccer. *J Sports Sci* **1994**, *12 Spec No*, S5-12.
381. Gaudino, P.; Iaia, F.M.; Alberti, G.; Strudwick, A.J.; Atkinson, G.; Gregson, W. Monitoring training in elite soccer players: systematic bias between running speed and metabolic power data. *Int J Sports Med* **2013**, *34*, 963-968, doi:10.1055/s-0033-1337943.
382. Bangsbo, J.; Nørregaard, L.; Thorsø, F. Activity profile of competition soccer. *Can J Sport Sci* **1991**, *16*, 110-116.
383. Aquino, R.; Carling, C.; Palucci Vieira, L.H.; Martins, G.; Jabor, G.; Machado, J.; Santiago, P.; Garganta, J.; Puggina, E. Influence of Situational Variables, Team Formation, and Playing Position on Match Running Performance and Social Network Analysis in Brazilian Professional Soccer Players. *J Strength Cond Res* **2020**, *34*, 808-817, doi:10.1519/jsc.0000000000002725.
384. Trewin, J.; Meylan, C.; Varley, M.; Cronin, J. The influence of situational and environmental factors on match-running in soccer: a systematic review. *Science and Medicine in Football* **2017**, *1*, 183-194, doi:10.1080/24733938.2017.1329589.
385. Altmann, S.; Neumann, R.; Woll, A.; Härtel, S. Endurance Capacities in Professional Soccer Players: Are Performance Profiles Position Specific? *Front Sports Act Living* **2020**, *2*, 549897, doi:10.3389/fspor.2020.549897.
386. Rampinini, E.; Coutts, A.J.; Castagna, C.; Sassi, R.; Impellizzeri, F.M. Variation in top level soccer match performance. *Int J Sports Med* **2007**, *28*, 1018-1024, doi:10.1055/s-2007-965158.
387. Dalen, T.; Ingebrigtsen, J.; Ettema, G.; Hjelde, G.H.; Wisløff, U. Player Load, Acceleration, and Deceleration During Forty-Five Competitive Matches of Elite Soccer. *J Strength Cond Res* **2016**, *30*, 351-359, doi:10.1519/jsc.0000000000001063.
388. Buchheit, M.; Samozino, P.; Glynn, J.A.; Michael, B.S.; Al Haddad, H.; Mendez-Villanueva, A.; Morin, J.B. Mechanical determinants of acceleration and maximal sprinting speed in highly trained young soccer players. *J Sports Sci* **2014**, *32*, 1906-1913, doi:10.1080/02640414.2014.965191.
389. Little, T.; Williams, A.G. Specificity of acceleration, maximum speed, and agility in professional soccer players. *J Strength Cond Res* **2005**, *19*, 76-78, doi:10.1519/14253.1.
390. Varley, M.C.; Aughey, R.J. Acceleration profiles in elite Australian soccer. *Int J Sports Med* **2013**, *34*, 34-39, doi:10.1055/s-0032-1316315.
391. Vanrenterghem, J.; Nedergaard, N.J.; Robinson, M.A.; Drust, B. Training Load Monitoring in Team Sports: A Novel Framework Separating Physiological and Biomechanical Load-Adaptation Pathways. *Sports Med* **2017**, *47*, 2135-2142, doi:10.1007/s40279-017-0714-2.
392. Hader, K.; Mendez-Villanueva, A.; Palazzi, D.; Ahmaidi, S.; Buchheit, M. Metabolic Power Requirement of Change of Direction Speed in Young Soccer Players: Not All Is What It Seems. *PLoS One* **2016**, *11*, e0149839, doi:10.1371/journal.pone.0149839.
393. Riboli, A.; Esposito, F.; Coratella, G. Small-Sided Games in Elite Football: Practical Solutions to Replicate the 4-min Match-Derived Maximal Intensities. *J Strength Cond Res* **2023**, *37*, 366-374, doi:10.1519/jsc.0000000000004249.
394. Gamble, P.; McGuigan, M.; Gill, N. Bourgeois et al., 2017 - Physical characteristics and performance in change of direction tasks a brief review and training considerations. **2020**.
395. Manzi, V.; Annino, G.; Savoia, C.; Caminiti, G.; Padua, E.; Masucci, M.; D'Onofrio, R.; Iellamo, F. Relationship between aerobic fitness and metabolic power metrics in elite male soccer players. *Biol Sport* **2022**, *39*, 599-606, doi:10.5114/biolsport.2022.106389.

396. di Prampero, P.E.; Fusi, S.; Sepulcri, L.; Morin, J.B.; Belli, A.; Antonutto, G. Sprint running: a new energetic approach. *J Exp Biol* **2005**, *208*, 2809-2816, doi:10.1242/jeb.01700.
397. Smith, J.J.; Eather, N.; Morgan, P.J.; Plotnikoff, R.C.; Faigenbaum, A.D.; Lubans, D.R. The health benefits of muscular fitness for children and adolescents: a systematic review and meta-analysis. *Sports Med* **2014**, *44*, 1209-1223, doi:10.1007/s40279-014-0196-4.
398. Warburton, D.E.R.; Bredin, S.S.D. Health benefits of physical activity: a systematic review of current systematic reviews. *Curr Opin Cardiol* **2017**, *32*, 541-556, doi:10.1097/hco.0000000000000437.
399. Marzetti, E.; Calvani, R.; Tosato, M.; Cesari, M.; Di Bari, M.; Cherubini, A.; Broccatelli, M.; Savera, G.; D'Elia, M.; Pahor, M.; et al. Physical activity and exercise as countermeasures to physical frailty and sarcopenia. *Aging Clin Exp Res* **2017**, *29*, 35-42, doi:10.1007/s40520-016-0705-4.
400. Klepac Pogrmilovic, B.; Ramirez Varela, A.; Pratt, M.; Milton, K.; Bauman, A.; Biddle, S.J.H.; Pedisic, Z. National physical activity and sedentary behaviour policies in 76 countries: availability, comprehensiveness, implementation, and effectiveness. *Int J Behav Nutr Phys Act* **2020**, *17*, 116, doi:10.1186/s12966-020-01022-6.
401. Lee, I.M.; Buchner, D.M. The importance of walking to public health. *Med Sci Sports Exerc* **2008**, *40*, S512-518, doi:10.1249/MSS.0b013e31817c65d0.
402. Bassett, D.R., Jr.; Mahar, M.T.; Rowe, D.A.; Morrow, J.R., Jr. Walking and measurement. *Med Sci Sports Exerc* **2008**, *40*, S529-536, doi:10.1249/MSS.0b013e31817c699c.
403. Hanson, S.; Jones, A. Is there evidence that walking groups have health benefits? A systematic review and meta-analysis. *Br J Sports Med* **2015**, *49*, 710-715, doi:10.1136/bjsports-2014-094157.
404. Oja, P.; Kelly, P.; Murtagh, E.M.; Murphy, M.H.; Foster, C.; Titze, S. Effects of frequency, intensity, duration and volume of walking interventions on CVD risk factors: a systematic review and meta-regression analysis of randomised controlled trials among inactive healthy adults. *Br J Sports Med* **2018**, *52*, 769-775, doi:10.1136/bjsports-2017-098558.
405. Murphy, M.H.; Nevill, A.M.; Murtagh, E.M.; Holder, R.L. The effect of walking on fitness, fatness and resting blood pressure: a meta-analysis of randomised, controlled trials. *Prev Med* **2007**, *44*, 377-385, doi:10.1016/j.ypmed.2006.12.008.
406. Richardson, C.R.; Newton, T.L.; Abraham, J.J.; Sen, A.; Jimbo, M.; Swartz, A.M. A meta-analysis of pedometer-based walking interventions and weight loss. *Ann Fam Med* **2008**, *6*, 69-77, doi:10.1370/afm.761.
407. He, L.I.; Wei, W.R.; Can, Z. Effects of 12-week brisk walking training on exercise blood pressure in elderly patients with essential hypertension: a pilot study. *Clin Exp Hypertens* **2018**, *40*, 673-679, doi:10.1080/10641963.2018.1425416.
408. Christian, H.; Bauman, A.; Epping, J.N.; Levine, G.N.; McCormack, G.; Rhodes, R.E.; Richards, E.; Rock, M.; Westgarth, C. Encouraging Dog Walking for Health Promotion and Disease Prevention. *Am J Lifestyle Med* **2018**, *12*, 233-243, doi:10.1177/1559827616643686.
409. Engelberg, J.K.; Carlson, J.A.; Conway, T.L.; Cain, K.L.; Saelens, B.E.; Glanz, K.; Frank, L.D.; Sallis, J.F. Dog walking among adolescents: Correlates and contribution to physical activity. *Preventive Medicine* **2016**, *82*, 65-72, doi:https://doi.org/10.1016/j.ypmed.2015.11.011.
410. Dall, P.M.; Ellis, S.L.H.; Ellis, B.M.; Grant, P.M.; Colyer, A.; Gee, N.R.; Granat, M.H.; Mills, D.S. The influence of dog ownership on objective measures of free-living physical activity and sedentary behaviour in community-dwelling older adults: a longitudinal case-controlled study. *BMC Public Health* **2017**, *17*, 496, doi:10.1186/s12889-017-4422-5.

411. Garcia, D.O.; Wertheim, B.C.; Manson, J.E.; Chlebowski, R.T.; Volpe, S.L.; Howard, B.V.; Stefanick, M.L.; Thomson, C.A. Relationships between dog ownership and physical activity in postmenopausal women. *Prev Med* **2015**, *70*, 33-38, doi:10.1016/j.ypmed.2014.10.030.
412. Coleman, K.J.; Rosenberg, D.E.; Conway, T.L.; Sallis, J.F.; Saelens, B.E.; Frank, L.D.; Cain, K. Physical activity, weight status, and neighborhood characteristics of dog walkers. *Prev Med* **2008**, *47*, 309-312, doi:10.1016/j.ypmed.2008.05.007.
413. Cutt, H.; Giles-Corti, B.; Knuiman, M.; Burke, V. Dog ownership, health and physical activity: a critical review of the literature. *Health Place* **2007**, *13*, 261-272, doi:10.1016/j.healthplace.2006.01.003.
414. Westgarth, C.; Christley, R.M.; Christian, H.E. How might we increase physical activity through dog walking?: A comprehensive review of dog walking correlates. *International Journal of Behavioral Nutrition and Physical Activity* **2014**, *11*, 83, doi:10.1186/1479-5868-11-83.
415. Mičková, E.; Machová, K.; Daďová, K.; Svobodová, I. Does Dog Ownership Affect Physical Activity, Sleep, and Self-Reported Health in Older Adults? *Int J Environ Res Public Health* **2019**, *16*, doi:10.3390/ijerph16183355.
416. Westgarth, C.; Christley, R.M.; Jewell, C.; German, A.J.; Boddy, L.M.; Christian, H.E. Dog owners are more likely to meet physical activity guidelines than people without a dog: An investigation of the association between dog ownership and physical activity levels in a UK community. *Sci Rep* **2019**, *9*, 5704, doi:10.1038/s41598-019-41254-6.
417. Lentino, C.; Visek, A.J.; McDonnell, K.; DiPietro, L. Dog walking is associated with a favorable risk profile independent of moderate to high volume of physical activity. *J Phys Act Health* **2012**, *9*, 414-420, doi:10.1123/jpah.9.3.414.
418. Kerr, Z.Y.; Fields, S.; Comstock, R.D. Epidemiology of injury among handlers and dogs competing in the sport of agility. *J Phys Act Health* **2014**, *11*, 1032-1040, doi:10.1123/jpah.2012-0236.
419. Buttner, A.P.; Thompson, B.; Strasser, R.; Santo, J. Evidence for a synchronization of hormonal states between humans and dogs during competition. *Physiol Behav* **2015**, *147*, 54-62, doi:10.1016/j.physbeh.2015.04.010.
420. Sibbald, B.; Roland, M. Understanding controlled trials. Why are randomised controlled trials important? *Bmj* **1998**, *316*, 201, doi:10.1136/bmj.316.7126.201.
421. Rosina, A.; Sorgi, S. *Il futuro che (non) c'è: Costruire un domani migliore con la demografia*; Egea: 2016.
422. Minello, A. Alessandro Rosina, Sergio Sorgi: Il futuro che (non) c'è. Costruire un domani migliore con la demografia. The future that is(n't). Building a better future with demography. *Genus* **2018**, *74*, 8, doi:10.1186/s41118-018-0034-x.
423. Paroli, R.; Consonni, G.; Rosina, A. The Measure of Population Aging in Different Welfare Regimes: A Bayesian Dynamic Modeling Approach. *Eur J Popul* **2020**, *36*, 363-385, doi:10.1007/s10680-019-09531-2.
424. Flegal, K.M.; Kit, B.K.; Orpana, H.; Graubard, B.I. Association of all-cause mortality with overweight and obesity using standard body mass index categories: a systematic review and meta-analysis. *Jama* **2013**, *309*, 71-82, doi:10.1001/jama.2012.113905.
425. Craig, C.L.; Marshall, A.L.; Sjöström, M.; Bauman, A.E.; Booth, M.L.; Ainsworth, B.E.; Pratt, M.; Ekelund, U.; Yngve, A.; Sallis, J.F.; et al. International physical activity questionnaire: 12-country reliability and validity. *Med Sci Sports Exerc* **2003**, *35*, 1381-1395, doi:10.1249/01.Mss.0000078924.61453.Fb.
426. Ainsworth, B.E.; Haskell, W.L.; Herrmann, S.D.; Meckes, N.; Bassett, D.R., Jr.; Tudor-Locke, C.; Greer, J.L.; Vezina, J.; Whitt-Glover, M.C.; Leon, A.S. 2011 Compendium of Physical Activities: a second update of codes and MET values. *Med Sci Sports Exerc* **2011**, *43*, 1575-1581, doi:10.1249/MSS.0b013e31821ece12.
427. Etiwy, M.; Akhrass, Z.; Gillinov, L.; Alashi, A.; Wang, R.; Blackburn, G.; Gillinov, S.M.; Phelan, D.; Gillinov, A.M.; Houghtaling, P.L.; et al. Accuracy of wearable heart rate

monitors in cardiac rehabilitation. *Cardiovasc Diagn Ther* **2019**, *9*, 262-271, doi:10.21037/cdt.2019.04.08.
428. Coughlin, S.S.; Hatzigeorgiou, C.; Anglin, J.; Xie, D.; Besenyi, G.M.; De Leo, G.; Stewart, J.; Wilkins, T. Healthy lifestyle intervention for adult clinic patients with type 2 diabetes mellitus. *Diabetes Manag (Lond)* **2017**, *7*, 197-204.
429. Borg, G. Perceived exertion as an indicator of somatic stress. *Scand J Rehabil Med* **1970**, *2*, 92-98.
430. Powell, L.; Edwards, K.M.; Bauman, A.; McGreevy, P.; Podberscek, A.; Neilly, B.; Sherrington, C.; Stamatakis, E. Does dog acquisition improve physical activity, sedentary behaviour and biological markers of cardiometabolic health? Results from a three-arm controlled study. *BMJ Open Sport Exerc Med* **2020**, *6*, e000703, doi:10.1136/bmjsem-2019-000703.
431. Machová, K.; Daďová, K.; Chaloupková, H.; Svobodová, I. Does having a pet influence the physical activity of their young female owners? *BMC Public Health* **2019**, *19*, 1672, doi:10.1186/s12889-019-7962-z.
432. Scherr, J.; Wolfarth, B.; Christle, J.W.; Pressler, A.; Wagenpfeil, S.; Halle, M. Associations between Borg's rating of perceived exertion and physiological measures of exercise intensity. *Eur J Appl Physiol* **2013**, *113*, 147-155, doi:10.1007/s00421-012-2421-x.
433. Sirard, J.R.; Patnode, C.D.; Hearst, M.O.; Laska, M.N. Dog ownership and adolescent physical activity. *Am J Prev Med* **2011**, *40*, 334-337, doi:10.1016/j.amepre.2010.11.007.
434. Ohkita, M.; Nagasawa, M.; Kazutaka, M.; Kikusui, T. Owners' direct gazes increase dogs' attention-getting behaviors. *Behavioural Processes* **2016**, *125*, 96-100, doi:https://doi.org/10.1016/j.beproc.2016.02.013.
435. Pajaujiene, S.; Petrigna, L. Walking and Playing with the Dog to Improve the Physical Activity Level of Adolescents: A Scoping Review. *Healthcare (Basel)* **2024**, *12*, doi:10.3390/healthcare12060631.
436. Chase, C.J.; Mueller, M.K.; Garvey, C.; Potter, K. Family Dog Ownership and Youth Physical Activity Levels: A Scoping Review. *Curr Sports Med Rep* **2022**, *21*, 18-27, doi:10.1249/jsr.0000000000000927.
437. Christian, H.E.; Westgarth, C.; Bauman, A.; Richards, E.A.; Rhodes, R.E.; Evenson, K.R.; Mayer, J.A.; Thorpe, R.J., Jr. Dog ownership and physical activity: a review of the evidence. *J Phys Act Health* **2013**, *10*, 750-759, doi:10.1123/jpah.10.5.750.
438. Krøger, E.; Slettebø, Å.; Fossum, M. Agility activities for children in a municipality in Norway. *J Community Health Nurs* **2015**, *32*, 53-67, doi:10.1080/07370016.2015.992265.
439. Charry-Sánchez, J.D.; Pradilla, I.; Talero-Gutiérrez, C. Animal-assisted therapy in adults: A systematic review. *Complement Ther Clin Pract* **2018**, *32*, 169-180, doi:10.1016/j.ctcp.2018.06.011.
440. Moretti, F.; De Ronchi, D.; Bernabei, V.; Marchetti, L.; Ferrari, B.; Forlani, C.; Negretti, F.; Sacchetti, C.; Atti, A.R. Pet therapy in elderly patients with mental illness. *Psychogeriatrics* **2011**, *11*, 125-129, doi:10.1111/j.1479-8301.2010.00329.x.
441. Giustino, V.; Messina, G.; Alesi, M.; Mantia, L.; Palma, A.; Battaglia, G. Study of postural control and body balance in subjects with Down syndrome. *Human Movement* **2020**, *22*, 66-71, doi:10.5114/hm.2021.98466.
442. Woods, J.A.; Hutchinson, N.T.; Powers, S.K.; Roberts, W.O.; Gomez-Cabrera, M.C.; Radak, Z.; Berkes, I.; Boros, A.; Boldogh, I.; Leeuwenburgh, C.; et al. The COVID-19 pandemic and physical activity. *Sports Med Health Sci* **2020**, *2*, 55-64, doi:10.1016/j.smhs.2020.05.006.
443. Owczarczak-Garstecka, S.C.; Graham, T.M.; Archer, D.C.; Westgarth, C. Dog Walking before and during the COVID-19 Pandemic Lockdown: Experiences of UK Dog Owners. *Int J Environ Res Public Health* **2021**, *18*, doi:10.3390/ijerph18126315.

444. Ash, G.I.; Stults-Kolehmainen, M.; Busa, M.A.; Gaffey, A.E.; Angeloudis, K.; Muniz-Pardos, B.; Gregory, R.; Huggins, R.A.; Redeker, N.S.; Weinzimer, S.A. Establishing a global standard for wearable devices in sport and exercise medicine: perspectives from academic and industry stakeholders. *Sports Medicine* **2021**, *51*, 2237-2250.
445. EPaCotE, U. *Regulation (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data, and repealing Directive 95/46/EC (General Data Protection Regulation).* 2016; p. 2016.
446. Spitz, J.; Wagemans, J.; Memmert, D.; Williams, A.M.; Helsen, W.F. Video assistant referees (VAR): The impact of technology on decision making in association football referees. *J Sports Sci* **2021**, *39*, 147-153, doi:10.1080/02640414.2020.1809163.
447. Tamir, I.; Bar-Eli, M. The Moral Gatekeeper: Soccer and Technology, the Case of Video Assistant Referee (VAR). *Front Psychol* **2020**, *11*, 613469, doi:10.3389/fpsyg.2020.613469.

Appendix

1) ***Articles under review***

Manuel Gómez-López, Salvador Angosto, Sergio Sánchez-López, Ignazio Leale, Giuseppe Battaglia, Iván González-García - *Comparative Study by Gender of the Defensive Efficiency Indicators of the National Teams in the World Handball Championship* – Human Movement

Ignazio Leale, Vincenzo Di Stefano, Fabio Tiziano Orlando, Giuseppe Piscosquito, Claudia Vinciguerra, Giammarco Milella, Stefano Tozza5, Nicasio Rini, Valerio Giustino, Chiara Rizza, Enrica La Rosa, Marzia Leone, Filippo Brighina, Giuseppe Battaglia - *Effects of a Telecoaching Home-Based Training Program on Physical Function and Quality of Life in Charcot-Marie-Tooth (EFTELCMT23): Preliminary Data* – Acta Neurological Scandinavica

Ignazio Leale Angelo Torrente, Vincenzo Di Stefano, Francesco Cutaia, Salvatore Maria Lima, Paolo Alonge, Cecilia Camarda, Filippo Brighina, Giuseppe Battaglia - *Impact of a 12-Week Telecoaching Aerobic Training Program in a Green Environment on Quality of Life and Migraine Frequency: a Pilot Study* – Acta Neurological Scandinavica

Ignazio Leale, Manuel Gómez-López, Luisa Estriga, Giuseppe Battaglia - *A Systematic Review on Artificial Intelligence in Handball: Current Applications, Challenges, and Future Research Directions* - Apunts. Educacion Fisica y Deportes

Ignazio Leale, Anna Maria Parroco, Valerio Giustino, Manuel Gómez-López, Giuseppe Musumeci, Giuseppe Battaglia - *The Influence of Audience in Sports: Differences between Rio 2016 and Tokyo 2020 Paralympic Games* - E-Balonmano.com: Revista de Ciencias del Deporte

Iván González-García, Ignazio Leale, Giuseppe Battaglia, Manuel Gómez-López - *Assessing Fair Play in Elite Handball: A Comparative Study of Men's and Women's World Championship Teams* - Journal of Human Sport and Exercise

2) Attended Conferences

"*XIV National Congress SISMES Naples, 2–4 November, 2023*"

"XV National Congress SISMES Chieti, 19–21 September, 2024"

"30th ECSS Annual Congress ECSS, Rimini, 1–4 July, 2025"

"XXXIII Congreso Internacional FOD, Nuevo Leòn, Mexico, 2025"

"XVI National Congress SISMES Parma, 6–8 November, 2025"

"V Congreso Internacional de Balonmano - COINBA 2025, Zaragoza, November 2025"

3) Co-authored abstracts

I. Leale, A. M. Parroco, M. Gómez-López, G. Pillitteri, V. Giustino and G. Battaglia (2023). The Influence of audience absence on “Sports Performance Share” in the Summer Paralympic Games. Abstract presented at the XIV National Congress SISMES Naples, Italy. (Poster Teaser).

II. M. Petrucci, G. Pillitteri, I. Leale, A. Rossi, A. Bianco, A. Palma, G. Battaglia (2024). Match Load Physical Demands in U-19 Professional Soccer Players Assessed by a Wearable Inertial Sensor Abstract presented at the XV National Congress SISMES, Chieti, Italy. (Poster)

III. Guglielmo Pillitteria, Marco Petrucci, Ignazio Leale, Alessio Rossi, Tindaro Bongiovanni, Giuseppe Puleo, Antonino Bianco, Antonio Palma, Giuseppe Battaglia (2024). Relationship between external and internal load indicators for injury prediction using machine learning in professional soccer: A systematic review and Meta-Analysis. Abstract presented at the XV National Congress SISMES, Chieti, Italy. (Poster)

IV. Ignazio Leale, Vincenzo Di Stefano, Fabio Tiziano Orlando, Enrica La Rosa, Chiara Rizza, Marzia Leone, Filippo Brighina, Giuseppe Battaglia (2024). Effectiveness of a Telecoaching Training Program on Physical Performance and Quality of Life in people with Charcot-Marie-Tooth: A preliminary Results. Abstract presented at the XV National Congress SISMES, Chieti, Italy. (Oral Presentation).

V. Ignazio Leale, Valerio Giustino, Jessica Brusa, Alberto Canzone, Giovanni Boca, Stefano Ciriminna, Valentina Petralia, Candela Iommi, Eleonora Santangelo, Salvatore Maria Baio, Anna Renda, Antonino Patti, Mario Barbagallo, Antonio Palma, Giuseppe Messina, Ligia-Juliana Dominguez, Giuseppe Battaglia (2024). Effectiveness of a Telecoaching Training Program Combined with Supervised Exercise on Physical Functions in Elderly People. Abstract presented at the XV National Congress SISMES, Chieti, Italy. (Short Communication).

VI. Ignazio Leale, Vincenzo Di Stefano, Valerio Giustino, Filippo Brighina, Giuseppe Battaglia. Effectiveness of a 3-Month Telecoaching Training Program on Functional Mobility and Quality of Life in Individuals with Charcot-Marie-Tooth Disease: Preliminary Results. Abstract presented at the 30th ECSS Annual Congress, Rimini, Italy. (Poster).

8) Co-supervised master thesis

I. “IL NUOTO PARALIMPICO: ANALISI DI UN CASO STUDIO DI UN ATLETA DI ALTO LIVELLO” – Student: *Gianluca Criscì*

II. “EFFETTI DI UN PROGRAMMA DI ALLENAMENTO “OUTDOOR” E “INDOOR” SUL CONTROLLO POSTURALE NELLE POPOLAZIONI ANZIANE” – Student: *Giovanni Boca*

III. “EFFETTI DI UN PROTOCOLLO DI ATTIVITA’ MOTORIA COMBIANATA SULLA FORZA E SULL’EQUILIBRIO IN UNA POPOLAZIONE DI ANZIANI” – Student: *Francesco Gentile*

IV. “EFFICACIA DI UN PROTOCOLLO DI RESISTANCE TRAINING ESEGUITO IN TELECOACHING IN UNA POPOLAZIONE ANZIANA” – Student: *Antonina Gaiezza*

V. “ALLENAMENTO IN AMBIENTE NATURALE COME RACCOMANDAZIONE PER UN CORRETTO INVECCHIAMENTO: RISULTATI PRELIMINARI DEL MODELLO “WALKING LEADERS” – Student: *Davide Arena*

VI. “EFFETTI DI UN PROOCOLLO DI ALLENAMENTO PER L'EQUILIBRIO SU UNA POPOLAZIONE DI ANZIANI → TUG – TINETTI EQUILIBRIO – SPPB EQUILIBRIO” – Student: *Giovanni Buzzotta*

VII. “BENEFICI E MODIFICAZIONI A SEGUITO DI UN PROTOCOLLO DI ALLENAMENTO STRUTTURATO NEI PARAMETRI DI FORZA, EQUILIBRIO E DEAMBULAZIONE NELLA POPOLAZIONE ANZIANA.” – Student: *Alessandro Lo Varco*

VIII. “EFFETTI DI UN PROTOCOLLO DI ALLENAMENTO SULLA POPOLAZIONE ANZIANA: RISULTATI PRELIMINARI DEL PROGETTO “Walking Leaders”. – Student: *Claudio Friscia*

IX. “IL TELE-COACHING COME NUOVO METODO PER LE PERSONE ANZIANE: UNA REVISIONE SISTEMATICA” – Student: *Luigi Maria Raciti*

X. “IL PROGETTO WALKING LEADERS: NUOVI PARADIGMI PER IL MIGLIORAMENTO DEL PROFILO PRESTATIVO E DELL’EQUILIBRIO NELLA POPOLAZIONE ANZIANA” – Student: *Francesca Zito*

XI. “GLI EFFETTI DELL’ALLENAMENTO DELLA FORZA CON SOVRACCARICHI SULLA PERFORMANCE DI SALTO VERTICALE IN GIOVANI PALLAVOLISTE” – Student: *Fabrizio Pipitone*

XII. “EFFETTI DI UN PROGRAMMA IN TELECOACHING SULLA QUALITA’ DI VITA E STATO FUNZIONALE DI PERSONE AFFETTE DA CHARCOT-MARIE-TOOTH” – Student: *Marzia Leone*

XIII. “TELECOACHING: UN PARADIGMA INNOVATIVO PER MIGLIORARE EQUILIBRIO E FORZA IN SOGGETTI CON MALATTIA DI CHARCOT-MARIE-TOOTH” – Student: *Giorgio Parrinello*

XIV. “ANALISI DELLE IMPLICAZIONI DELL’ATTIVITA’ FISICA E SPORTIVA IN SOGGETTI CON EMICRANIA: UNO STUDIO SPERIMENTALE IN TELECOACHING” – Student: *Sandro Cucco*

XV. “ESERCIZIO FISICO E TELECOACHING: ANALISI DELLE DIFFERENZE DI GENERE NELL’EMICRANIA” – Student: *Bianca Maria Castelli*

XVI. “CORPO, MENTE E MOVIMENTO: STRATEGIE DI ADATTAMENTO E INCLUSIONE NELL'ATLETICA LEGGERA PER LE DISABILITÀ INTELLETTIVE”– Student: *Emilia Presentato*

XVII. “L’EVOLUZIONE DELLE PARALIMPIADI DA SPORT PIONIERISTICO A SPORT DI ALTO LIVELLO. ANALISI CARICO ALLENANTE DI UN ATLETA DI ELITE” – Student: *Gabriele Muratore*

XVIII. *“"FATICA E RECUPERO NEGLI ATLETI: OTTIMIZZAZIONE DEL CARICO* DI LAVORO PER LA PERFORMANCE" – Student: *Riccardo Spicuzza*

XIX. GLI EFFETTI BENEFICI DELL'ATTIVITÀ FISICA NEI BAMBINI CON SINDROME DI DOWN: UNA REVISIONE SISTEMATICA – Student: *Martina Macaluso*