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DIN TÂRGU MUREȘ



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SCIENTIFIC FIELD: INFORMATICS

UNIVERSITY OF MALAGA
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SCIENTIFIC FIELD: HEALTH SCIENCES

PHD THESIS SUMMARY

**ADVANCED DISTANT DIAGNOSTICS
TECHNIQUES AND SENSORS IN SPORTS
SAFETY AND HEALTH CONDITION
PREDICTION**

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Abstract

The rise of competitive sports has made sports safety a prominent topic. Integrating distance and wearable sensors with innovative recovery or rehabilitation methods has revolutionized training cycles, accelerated progress, and altered fatigue and recovery trends in performance sports. Advances in artificial intelligence (AI) and rapid detection methods can help reduce cases of underdiagnosis. Sports ecosystems or platforms can forecast injury-related data by merging daily metadata with vital and players' health data to generate customized habit-related data analytics.

The multilayered and multidisciplinary thesis is focused on finding/adopting emerging technologies with artificial intelligence to enhance distant diagnostics and methods in performance sports and sports safety to prevent injuries or speed recovery periods. In addition, it applies technology-enabled pipelines, techniques, and models to provide collaborative, real-time, remote consultancies, and diagnosis in sports. The thesis presents a conceptualization to manage a safer and faster future sports ecosystem, minimize risk factors, control them, and emphasize best practices. Telemedicine-related approaches, as part of burnout or neurodegenerative diseases or anomaly detection from voices and text combined with sentiment analysis, will also be highlighted in the research, along with the adaptation of machine learning (ML) and deep learning (DL) algorithms. Providing real-time injury predictions with data analysis reports is a practical and innovative tool for sports physicians to assess injury risks in a preventive way. The three main pillars of the thesis are (1) AI used in remote consulting to provide adequate cross-domain services, which studies collaborative tools that facilitate direct contact between individuals using AI-enhanced, nearly real-time technological pipelines; (2) research the relationship between AI algorithms and fatigue prediction, injury prevention in high-performance sports, and early detection of diseases or abnormalities; (3) research on Sports Safety indicators such as Metabolic Equivalent of Task (MET), Session Rating of Perceived Exertion (sRPE), Acute: Chronic work load ratio (ACWR), injury, fatigue, regeneration cycles, aggregation of health conditions and forecasts using advanced algorithms and AI to enhance performance sports and sports safety. The results prove the scientific value of the thesis. They comprise data collection and integration, pre-processing and feature extraction, model development and training, validation and improvement, deployment and real-time monitoring, tailored suggestions and interventions, and process evaluation and self-improvement. By analyzing behaviors and activities with AI and predictive analytics, this field of study can improve sports safety, performance, and conditioning.

List of publications

The evaluation of the author's publications is in accordance with the standards set by CNATDCU in Romania (National Council for the Accreditation of University Degrees, Diplomas and Certificates), applicable to doctoral students enrolled after October 1, 2018. The rankings are presented based on the classification of conferences¹ and journals² in the field of computer science.

1. **A. Biró**, A.I. Cuesta-Vargas, L. Szilágyi, “*SRPE and ACWR to control fatigue levels and minimize injuries in performance sports*”, IEEE International Conference on Systems, Man, and Cybernetics (SMC), Special Section Cyber, p.2808–2813, Honolulu, Oahu, USA, **2023**, *IEEE Xplore*, [P13]³.
Conference Paper, Rank¹: B, Points: 4.0.
2. **A. Biró**, A.I. Cuesta-Vargas, S.M. Szilágyi, “*Real-time disease and COVID-19 detection pipeline from voice for performance sports*”, IEEE International Conference on Systems, Man, and Cybernetics (SMC), Special Section Cyber, p.2309–2314, Honolulu, Oahu, USA, **2023**, *IEEE Xplore*, [P16].
Conference Paper, Rank¹: B, Points: 4.0.
3. **A. Biró**, A.I. Cuesta-Vargas, L. Szilágyi, “*Enhanced Spatial-Temporal Analysis for EEG-Based Microsleep Detection: Integrating Kalman Filtering with Voronoi Tessellation and Adaptive Coverage Control*”, IEEE International Conference on Systems, Man, and Cybernetics, Special Section Cybernetics (SMC), Special Section Cybernetics, Kuching, Sarawak, Malaysia, **2024**, [**Accepted**], *IEEE Xplore*, [P12].
Conference Paper, Rank¹: B, Points: 4.0.
4. A.I. Cuesta-Vargas, **A. Biró**, A. Escriche-Escuder, et al. “*Effectiveness of a gamified digital intervention based on lifestyle modification (iGame) in secondary prevention: a protocol for a randomised controlled trial*”, *BMJ Open*, 13, **2023**, [P11].
Journal Paper, Rank AIS²: Q2 (A)⁴, Impact Factor (IF)⁵: 3.007, Points: 0.70.

¹Source CORE Conference Ranking Portal: <http://portal.core.edu.au/conf-ranks>

²Source UEFISCDI: <https://uefiscdi.gov.ro/premierea-rezultatelor-cercetarii-articole> (October, 2022)

³The [P1]..[P17] the order number used in the Scientific Results Section 2.1

⁴BMJ Open placed 6th; according to policy, it be considered and calculated as a higher (A) Rank

⁵Source 2022 Journal Impact Factors, Journal Citation Reports TM (Clarivate, 2023)

5. **A. Biró**, A.I. Cuesta-Vargas, L. Szilágyi, “*AI-assisted fatigue and stamina control for performance sports on IMU-generated multivariate times series datasets*”, MDPI, *Sensors*, 24(1): 132, **2024**, [P7].
Journal Paper, Rank AIS²: Q2 (B), IF⁵: 3.9, Points: 4.0.
6. **A. Biró**, S.M. Szilágyi, L. Szilágyi, J. Martin-Martin, A.I. Cuesta-Vargas, “*Machine learning on prediction of relative physical activity intensity using medical radar sensor and 3D accelerometer*”, MDPI, *Sensors*, 23(3595), **2023**, [P4].
Journal Paper, Rank AIS²: Q2 (B), IF⁵: 3.9, Points: 1.33.
7. J. Martin-Martin, L. Wang, **A. Biró**, et al, “*The validity of the energy expenditure criteria based on open source code through two inertial sensors*”, MDPI, *Sensors*, 22(2552), **2022**, [P5].
Journal Paper, Rank AIS²: Q2 (B), IF⁵: 3.9, Points: 0.33.
8. J. Martin-Martin, A. Jimenez-Partinen, **A. Biró**, I. De-Torres, A. Escriche-Escuder, M. Gonzalez-Sanchez, A. Muro-Culebras, C. Roldan-Jimenez, M. Ruiz-Munoz, F. Mayoral-Cleries, et al, “*Reliability study of inertial sensors LIS2DH12 compared to Actigraph GT9X: Based on free code*”, MDPI, *Journal of Personalized Medicine*, 12(749), **2022**, [P6].
Journal Paper, Rank AIS²: Q2 (B), IF⁵: 3.4, Points: 0.33.
9. **A. Biró**, S.M. Szilágyi, L. Szilágyi, “*Optimal training dataset preparation for AI-supported multi-language real-time OCRs using visual methods*”, MDPI, *Applied Sciences*, 13(24): 13107, **2023**, [P3].
Journal Paper, Rank AIS²: Q3 (C), IF⁵: 2.7, Points: 2.0.
10. **A. Biró**, A.I. Cuesta-Vargas, J. Martin-Martin, L. Szilágyi, S.M. Szilágyi “*Synthesized multilanguage OCR using CRNN and SVTR models for realtime collaborative tools*”, MDPI, *Appl. Sciences*, 13(4419), **2023**, [P2].
Journal Paper, Rank AIS²: Q3 (C), IF⁵: 2.7, Points: 0.67.
11. **A. Biró**, K.T. Jánosi-Rancz, L. Szilágyi, A.I. Cuesta-Vargas, J. Martin-Martin, S.M. Szilágyi, “*Visual object detection with DETR to support video-diagnosis using conference tools*”, MDPI, *Appl. Sciences*, 12(5977), **2022**, [P1].
Journal Paper, Rank AIS²: Q3 (C), IF⁵: 2.7, Points: 0.5.
12. **A. Biró**, “*Gamification, GenAI and reinforcement learning as motivational assets in performance sports*”, IEEE 18th International Symposium on Applied Computational Intelligence and Informatics (SACI), Timisoara, Romania, **2024**, p.315–320, *IEEE Xplore*, [P17].
Conference Paper, Rank¹: National (D), Points: 1.0.

13. **A. Biró**, A.I. Cuesta-Vargas, L. Szilágyi, “*Applied AI for real-time detection of lesions and tumors following severe head injuries*”, IEEE 21st International Symposium on Intelligent Systems and Informatics (SISY), p.653–658, Pula, Croatia, **2023**, *IEEE Xplore*, [P9].
Conference Paper, Rank¹: National (D), Points: 1.0.
14. **A. Biró**, A.I. Cuesta-Vargas, L. Szilágyi, “*AI-controlled training method for performance hardening or injury recovery in sports*”, IEEE 22nd World Symposium on Applied Machine Intelligence and Informatics (SAMI), p.259–264, Stara Lesna, Slovakia, **2024**, *IEEE Xplore*, [P8].
Conference Paper, Rank¹: National (D), Points: 0.
15. **A. Biró**, A.I. Cuesta-Vargas, S.M. Szilágyi, “*Predictive sports strategy approach using YOLO and YOLO-NAS in performance sports*”, IEEE 21st International Symposium on Intelligent Systems and Informatics (SISY), p.303–308, Pula, Croatia, **2023**, *IEEE Xplore*, [P10].
Conference Paper, Rank¹: National (D), Points: 0.
16. **A. Biró**, K.T. Jánosi-Rancz, L. Szilágyi, “*Real-time artificial intelligence text analysis for identifying burnout syndromes in high-performance athletes*”, IEEE 22nd World Symposium on Applied Machine Intelligence and Informatics (SAMI), p.253–258, Stara Lesna, Slovakia, **2024**, *IEEE Xplore*, [P14].
Conference Paper, Rank¹: National (D), Points: 0.
17. **A. Biró**, A.I. Cuesta-Vargas, L. Szilágyi, “*Precognition of mental health and neurogenerative disorders using AI-parsed text and sentiment analysis*”, *Acta Universitatis Sapientiae, Informatica*, 15(2): p.359–403, **2023**, [P15].
Journal Paper, Rank AIS²: D, IF⁵: 0.3, Points: 0.

Publication scores per rank:

- **Rank A: 0.70 points,**
- **Rank B: 18.00 points,**
- **Rank C: 3.17 points,**
- **Rank D: 2.00 points.**

Total publication score: 23.87 points.

Total publication IF⁵ score: 26.51 points.

Introduction

Remote diagnosis embraces DX, ML, and DL models in the data age. Data science brings new perspectives to many areas. The COVID-19 pandemic has expanded DX and introduced new collaboration tools such as remote work and social distancing, encouraging new global attitudes. Remote diagnostics, especially video analysis, employs AI to prevent injuries and fatigue. It also informs clinicians of potential diseases and risk factors before action. AI helps healthcare providers monitor athletes or patients. Healthcare generates huge data that would be squandered without Data Science. AI creates innovative drug therapies and individualized medicine, and robots support other professions. Sports safety has improved due to COVID-19. With the rise of competitive sports, safety is a concern. Distance sensors like medical radar, wearable sensors such as 3-axial accelerometers, and revolutionary recovery or rehabilitation approaches have revolutionized training cycles, speeding evolution, and modifying fatigue and recovery patterns. AI and rapid detection reduce underdiagnosis. By combining injury-related day-to-day metadata with vital data, sports ecosystems and platforms can predict injury-related data and analyze and create habit-related data analytics with player health data. Multilayered and multidisciplinary thesis studies used AI-based technologies to improve remote diagnostics, sports performance, and safety to prevent injuries and speed recovery. Technology-enabled pipelines, techniques, and models enable collaborative, real-time, remote sports consultations, and diagnostics. The concept suggests limiting risk variables, regulating them, and encouraging best practices for a faster, safer sports ecosystem. COVID-19 voice disease detection methods are highlighted in the thesis. I also considered ML and DL. Real-time injury projections and data analysis help sports physicians prevent injuries.

Justifications: the thesis' methodologies may transform sports safety and performance. AI can use personalized data-driven real-time insights to prevent injuries, boost performance, and improve athlete health. It can prevent or predict SCD, burnout, and neurodegenerative disorders. The thesis experiments also cover important topics like injury prevention, fatigue control, performance optimization, real-time monitoring and feedback, personalized recommendations, early health issue detection, rehabilitation and recovery control, data-driven decision making, multilingual remote diagnosis, and cost-effectiveness models with AI-supported remote diagnosis,

Necessity: adopting the thesis subjects can greatly impact society and sports safety and performance enthusiasts. These technologies can improve public health, empower

sports performance resources, inform decision-making, boost economic growth, and raise knowledge of best sports safety and health practices. The needs are multifaceted and focus on public health, sports safety, athlete quality of life, healthier lifestyles, economic benefits, informed decision making for staff/coaches/health professionals, equity and accessibility in sports, and education and awareness. These facts demonstrate the importance of these technologies for society and sports safety and performance enthusiasts,

Future-tech insights and new research lines: biomechanics and movement analysis driven by artificial intelligence, mental health and well-being diagnostics powered by AI, genomics and personalized sports medicine, predictive analytics, telemedicine and remote coaching, and rehabilitation enhanced by AI have the potential to stimulate innovation and create new avenues of research. These advancements have the capacity to revolutionize sports safety, performance, and medicine,

Remote sensing: Continuous remote monitoring of vital signs through the use of sensors and targeted questionnaires, such as those for COVID-19 and sRPE, is crucial for promptly identifying and predicting issues that may impact the health and performance of athletes. This monitoring also displays the Acute Chronic Workload Ratio. Artificial intelligence plays a crucial role in predicting health problems, recovery periods, and illnesses with great speed and accuracy, making it an essential tool for ensuring sports safety. This will establish a secure and rapidly expanding sports ecosystem. Once medical radar sensors and wearable sensors reach a high level of accuracy, non-contact remote sensing and mobile technologies will open up a new field of remote monitoring and diagnosis. I conducted an analysis on the correlations between acceleration and tiredness, (post) COVID-19 and fatigue, fatigue and injuries, and COVID-19 and ACWR/sRPE in order to establish preventive measures for performance sports.

The thesis explores the integration of advanced artificial intelligence (AI) and sensor technologies into modern remote diagnostic tools. Its aim is to foresee and address sports safety and health issues in several disciplines and technological domains. New models explain: (1) the next-generation development of remote diagnostics procedures using multilingual collaboration tools and algorithms to accurately analyze players' health and performance; (2) AI-supported condition, sRPE, METs, ACWR study provides insights into injury prevention, performance optimization, and training program development or regeneration for dama; (3) Telemedicine and remote diagnostics technology like medical radar sensors allow real-time athlete health monitoring and assessment regardless of location; (4) Noise reduction and normalization are needed to process and filter raw sensor data (e.g., radar sensors, 3-axial accelerometers, IMUs) for accurate and trustworthy analysis; (5) Large-scale data and data analytics in sports are needed to identify patterns, trends, and connections; (6) Applied AI techniques including supervised, unsupervised, and RL models have helped analyze complicated information and generate actionable insights for sports safety and performance to predict fatigue and prevent accidents.

1.1 Overview

1.1.1 Context

Currently, the topic spans engineering, computer science, physiology, psychology, and more. Our goal is to improve athlete safety and health outcomes by using advanced diagnostic tools and predictive algorithms. Technology such as medical radars, 3D accelerometers and IMU sensors, AI and data analysis in sports science enable this. As technology evolves and we learn more about the complicated relationship between physical, mental, and social aspects in sports performance and health, this discipline evolves. Next-generation sensor and diagnostic technologies are the focus of this thesis. Wearable gadgets such as accelerometers, medical radar sensors, and IMUs collect an extensive amount of athlete data in real time. These sensors gather complex data, from heart rate variability (HR) through pulse to movement patterns related to speed and acceleration, that require advanced analytical methods to interpret. Beyond technology and science, it includes psychology, sociology, and linguistics. Using sentiment and language analysis to identify an athlete’s mental state helps assess their overall health.

Distant diagnostics in health and sports

Multilingual translation has become increasingly important due to the COVID-19 pandemic. DX in medicine has increased due to Visual Object Detection (VOD) and Textual Object Detection, which are essential topics of remote diagnosis and consulting via video conferences. The issue creates a new ”real-time multilingual data processing” market to overcome communication difficulties in multilingual video conferencing. VOD in health-care will improve remote diagnosis and reduce response time to consultations. OCR is also increasingly popular because it underpins several advanced technologies, especially real-time object detection. To synthesize and provide reliable results for a new collaborative working model, the Textual and Visual Object Detection (TVOD) method analyzed popular object detection algorithms and models, such as Fast R-CNN, Faster R-CNN, Region-Based Convolutional Neural Networks (CNNs), Region-Based Fully Convolutional Networks, and real-time object detectors like YOLO, DETECTRON, and DETR. Video conference platforms can simply apply the thesis findings to sports safety.

1.1.2 Research motivation

Motivation is driven by IT, science, technology, and athlete welfare as follow: (1) enhancing athlete safety and health of athletes; (2) optimizing stamina and performance; (3) adoption of technological innovations; (4) interdisciplinary research and collaboration; (5) understanding the economic potential; (6) localization of global health trends and public interest and (7) understanding the ethical and legal considerations of applied AI.

1.1.3 Significance

The multidisciplinary approach fosters innovation by combining diverse expertise (navigating the ethical, legal and societal dimensions of modern sports science and technology) and ensures that technological advancements are ethically sound, culturally sensitive, economically viable, and beneficial to athletes and the community. The thesis' comprehensive approach to sports safety challenges, including performance optimizations of individual athletes or groups/teams, provides a holistic and thorough understanding of athlete health (by identifying risks and possible upcoming anomalies or disease) and performance indexes. This field combines engineering, computer science, medicine, physiology, psychology, and data science to improve athlete health and performance.

1.1.4 Ethics

Scientific rigor, participant rights, and ethical norms guide the ethical research strategy of the multidisciplinary thesis. The thesis implemented these key factors: (1) Each thesis experiment related to the objectives was conducted to answer a specific RQ, and the conclusions correspond to these requirements; (2) The selected research methods fit the research, with all relevant risks investigated and declared before adopting the specific methods; (3) When humans were involved in the research, such as measuring the MET, detailed information was presented. They could quit the study or research at any time; (6) Participants' anonymity was crucial and I took into account global data privacy regulations; (7) Directors and tutors discussed the sampling strategy, ensuring that it was appropriate for the research objectives and methodologies; (8) Only relevant information was collected and controlled; and (9) All potential conflicts were prevented. The validity of the thesis, the suitability of the methodology, the consent of the participants, the confidentiality, the management of the risk, the privacy of the data, the sampling tactics, the usefulness, integrity, and transparency of the information set a high standard for future postdoctoral research on the subject.

1.1.5 Limitations

Although the approaches in the thesis offer considerable advantages, they have limitations. These constraints are inherent in the complexity and scope of integrating multiple disciplines, each with its methodologies, theories, and paradigms. These include integration complexity, data management issues, ethical and privacy concerns, economic disparities, cultural acceptance, generalizability issues, educational gaps, and regulatory challenges.

1.2 Research questions

The central research questions (RQs) revolve around effective leveraging emerging technologies and AI to improve athlete safety, optimize performance, and prevent injuries by predicting anomalies and / or diseases related to performance sports and sports safety. Addressing these questions requires an integrated approach that incorporates the expertise of various disciplines to create innovative, ethical, and practical solutions in sports science.

Table 1.1: Research questions (RQs) and their connectivity with the IT and health the domains

ID	IT	Health	Research question
RQ1	✓	✓	How can cross-disciplinary collaboration be enhanced to foster innovation and comprehensive understanding in sports diagnostics and prediction?
RQ2	✓		How can advanced diagnostic techniques and sensor technologies be effectively integrated into sports practice to enhance real-time monitoring and prediction of athletes' health and performance?
RQ3	✓	✓	How can these advanced diagnostics and sensor technologies be integrated into existing sports training and healthcare infrastructures?
RQ4	✓	✓	How can advanced sensor technologies be optimized for real-time monitoring of athletes' physiological and biomechanical data?
RQ5	✓		What are the optimal algorithms and AI models to interpret data from sports-related sensors to predict health risks and performance outcomes?
RQ6		✓	How can these technologies be tailored to accommodate the various physiological, psychological, and biomechanical profiles of individual athletes?
RQ7	✓	✓	What are the ethical implications and privacy considerations in using advanced diagnostic technologies (sensors, radars) and artificial intelligence in sports, particularly with respect to data privacy and athlete consent?
RQ8		✓	How can these diagnostic techniques be used to develop injury prevention strategies and improve overall athlete well-being?
RQ9	✓		What are the most effective AI and ML algorithms to predict injuries and health conditions in athletes?
RQ10		✓	How can these technologies be tailored to individual athletes, considering their unique physiological and psychological profiles?
RQ11		✓	What are the long term effects of using these technologies on the physical and mental health of athletes?

These RQs (see Table 1.1) collectively define, in general, the problems of the experiments behind the thesis to harness technological advances to improve the health, safety, and performance of athletes while considering factors of individual, economic, and ethical variability. They address technological development, data analysis, personalized medicine, ethical considerations, practical implementation, long-term impacts, and cultural and economic influences. Answering these questions requires a multidisciplinary approach that integrates insights from engineering, computer science, sports medicine, ethics, psychology, and sociology.

1.3 Research objectives

To address the various interdisciplinary focal points, three main pillars were established for the thesis: (S1) **Thesis Group I** – *Advanced Distance Diagnostics Techniques and Sensors*; (S2) **Thesis Group II** – *Sports safety and injury prevention*; (S3) **Thesis Group III** – *Prediction of health conditions*. Based on the research questions defined in Chapter 1.2 and the thesis pillars, specific research objectives (RO) have been established to address these pillars, which are the research directions. These ROs (see Table 1.2) aim to harness the power of AI, machine learning (ML) and advanced data analytics to improve diagnostics, training, rehabilitation, and mental health support for athletes, ultimately improving performance, safety, and well-being in sports.

Table 1.2: Research objectives (ROs)

ID	Objective	Description
RO1	Enhancement of real-time diagnostics and monitoring	Develop and refine near real-time diagnostic and monitoring systems using advanced AI models and sensor-based pipelines to support athletes' health, performance, and safety across various sports disciplines.
RO2	AI-based health and performance prediction	Investigate and create AI-driven prediction models for assessing and enhancing athletes' health conditions, stamina, and performance, incorporating comprehensive data sources such as physiological markers or psychological factors.
RO3	Development of multilingual and multimodal collaboration tools	Investigate AI-assisted tools (real-time OCR solutions) for visual and textual data recognition and translation in multilingual, multiuser collaborative environments, thereby boosting the efficacy of distance diagnosis and communication in sports and other fields.
RO4	Optimization of training and rehabilitation processes	Formulate and implement AI-controlled technological pipelines, frameworks, and methodologies for optimizing training regimens, rehabilitation processes, and performance hardening, ensuring personalized, adaptive, and effective approaches to athlete development and recovery.
RO5	Integration of AI in strategic sports analysis	Develop methods using AI technologies such as YOLO and YOLO-NAS, or OpenCV for real-time player and object tracking, strategy extraction, and performance analysis, facilitating data-driven decision-making and strategic development in sports.
RO6	Innovative approaches to disease detection and prevention	Investigate and develop non-invasive, AI-supported pipelines for early detection and monitoring of diseases and health anomalies using advanced feature extraction methods, with an emphasis on voice-based detection and prevention of cross-contamination in sports events.
RO7	Psychological and mental health monitoring	Formulate and develop AI and NLP techniques for early identification and intervention of psychological and mental health disorders, including burnout and neurodegenerative disorders, ensuring comprehensive support for athletes' mental well-being.
RO8	Gamification and adaptive training enhancements	Investigate and formulate methods combining gamification, generative AI, and reinforcement learning to create engaging and adaptive training environments, enhancing athlete motivation, performance, and psychological involvement.
RO9	Comprehensive data analysis for performance improvement	Develop AI-supported retrospective learning methods with historical data analysis to identify performance trends, evaluate strategies, and set realistic goals, thus enhancing the effectiveness of training programs and overall development of the athlete.

1.4 Research methodology

Taking into account the multidisciplinary type of the thesis, Mixed Method Research (MMR), integrating both qualitative and quantitative techniques with the help of the

universities involved (UMA¹, UMFST², SAPIENTIA³, OBUDA⁴) and performance sports professionals (e.g., coaches, trainers, physiotherapists) from Hungary and Japan (Toyo University), was used with sports strategy developers as follows:

1.4.1 Qualitative techniques

Qualitative research used multiple methods to investigate and improve the prediction of health issues and safety in sports, focusing on the well-being of the players. Focus groups focused on the Toyo University ice hockey team in Tokyo but expanded to other university sports teams. Testing these algorithms against publicly available validated datasets ensured their validity. On-site and conceptual investigations were used to provide a comprehensive understanding of the sports safety environment. The proposed system architectures, algorithms, machine learning models, hyperparameters, and remote sensing solutions were thoroughly examined. These observations covered theoretical and practical applications, including feedback from coaches, strength and fitness trainers, mental coaches, and strategy coaches. The document analysis comprised a thorough evaluation of sports and health reports, including sRPE/ACWR, burnout, mood, and the influence of COVID-19. This document analysis laid the groundwork for systematic reviews and meta-analysis, which were published in academic journals and conferences.

1.4.2 Quantitative techniques

The thesis uses many quantitative methods to improve sports technology, specifically safety and performance of athletes. Surveys and questionnaires were essential for designing remote sensor systems, especially wearable devices and guards. Although revolutionary, these sensors posed certain challenges for players in many sports, which required thorough input. Experiments using 3-axial accelerometers and inertial measuring devices supplemented the surveys. These tools provided quantifiable data to create and distribute new sports monitoring and analysis methods. Diagnostic algorithms were refined using systematic observations during various phases of investigation. The research converted qualitative sports field observations into quantitative data. This data helped learning systems recognize and anticipate field events. Focus group insights and quantitative observations were used to develop these algorithms, ensuring accurate and realistic models for real-world use. Experiments were crucial in testing hypotheses made during research. Both controlled laboratory and natural circumstances on site were used to construct and test PoT, PoC, and MVPs. Ice hockey, running, futsal, and soccer were used to test cause-and-effect correlations in real life. These trials were published, expanding sports technology and player safety knowledge.

¹UMA - University of Malaga

²UMFST - G.E. Palade University of Medicine, Pharmacy, Science, and Technology of Targu Mures

³SAPIENTIA - Sapientia Hungarian University of Transylvania, Targu Mures

⁴OBUDA - Physiological Controls Research Center, Óbuda University, Budapest

Conclusions

All research objectives of Chapter 1.3 were achieved, and the results were published and distributed. The most important scientific results and contributions in alignment with the research objectives per thesis group level are shown in Table 2.1, and are as follows:

Table 2.1: Research objectives' (RO) fulfilment per thesis groups and per scientific results and contributions

Research objectives	Fulfillment of objectives	
ID and short RO description	Thesis group	Thesis IDs
RO1: Enhancement of real-time diagnostics and monitoring	S1, S2, S3	1.1, 1.5, 1.2, 2.1, 3.3
RO2: AI-based health and performance prediction	S1, S3	1.6, 1.5, 3.1, 3.2
RO3: Development of multilingual and multimodal collaboration tools	S1	1.1, 1.3, 1.4
RO4: Optimization of training and rehabilitation processes	S1, S2, S3	1.6, 1.7, 2.1, 2.4, 3.4
RO5: Integration of AI in strategic sports analysis	S2	2.3, 2.4
RO6: Innovative approaches to disease detection and prevention	S1, S3	1.7, 3.3
RO7: Psychological and mental health monitoring	S3	3.5, 3.6
RO8: Gamification and adaptive training enhancements	S3	3.4
RO9: Comprehensive data analysis for performance improvement	S2	2.2, 2.4

The connectivity between the research questions (RQ1 to RQ11) and the primary research objectives (RO1 to RO9) is illustrated in Table 2.2. This table determines whether the research questions were addressed and analyzed, and if the scientific objectives were successfully accomplished.

Table 2.2: Research questions (RQ) interconnectivity with the research objectives (RO)

Research question (RQ)	Research objective (RO)	Thesis Group
RQ1	RO2, RO3	S1, S2, S3
RQ2	RO1, RO4	S1, S2, S3
RQ3	RO3, RO5, RO9	S1, S2
RQ4	RO1	S1, S2, S3
RQ5	RO1, RO5	S1, S2, S3
RQ6	RO4, RO8	S1, S2, S3
RQ7	RO1..RO9	S1, S2, S3
RQ8	RO4, RO6	S1, S2, S3
RQ9	RO7	S3
RQ10	RO2, RO8	S1, S3
RQ11	RO9	S2

2.1 New scientific results and contributions

These findings have important multidisciplinary consequences for improving current technology pipelines, methodologies, workflows, and the practicality of ML-based methods in the field of preventive sports safety in performance sports. Each thesis makes significant contributions and proposals to one or more respective fields and introduces novel approaches and methods for addressing the challenges of sensors, distant diagnostics, sports safety, injury prevention, and health condition prediction. Theses have a global impact and local relevance and their findings have been published in several relevant publications.

Thesis Statements Group I.

Thesis Group I (S1): Advanced Distance Diagnostics Techniques and Sensors

Own publications related to this research direction: [P1], [P2], [P3], [P4], [P5], [P6], [P7].

Thesis 1.1

Research objectives (RO): RO1, RO3

Importance: global impact, local relevance

Relevant publications: [P1], [P2], [P3]

I proposed a near real-time pipeline with DETR for visual and textual data recognition to support future translation of multi-user, multi-language video-conferences and to improve the effectiveness of distance diagnosis. The Textual and VOD investigation analyzed different scenarios to provide reliable outcomes for a new collaborative working model. In the case of multilingual conferences, the proposed design can be used to prepare a feasible visual (textual) object detection model with a modest number of specific training datasets using the DETR model in order to support further data processing, such as neural multilingual translation translation. When it comes to adjusting the efficacy level, it depends on clustering or object classes, quality, and quantity of training data. Experiments have shown that it is possible to use the DETR model for a restricted number of training data sets with real-time collaboration tools to strengthen multilingual collaboration with multilingual translation.

Thesis 1.2

Research objectives (RO): RO1

Importance: global impact, local relevance

Relevant publications: [P1], [P2], [P3]

I conducted a thorough analysis of the most promising real-time object detector models YOLO, Detectron, and DETR, each with different model variations to determine their performances in relation to the specific task and dataset at hand, resulting in a comparison analysis that can be adopted into multilingual collaborative tool-based real-time VOD experiments.

Thesis 1.3

Research objectives (RO): RO3

Importance: global impact, local relevance

Relevant publications: [P1], [P2], [P3]

I conducted research experiments with synthetic, multilingual training CRNN and SVTR model architectures for ML-based OCR engines to (1) test the possibility of custom-generated or synthesized multilanguage recognition and (2) to increase the accuracy and efficiency of real-time OCR systems. Both CRNN and SVTR offered innovative features in comparison to conventional OCR engines. The proposed ML model setups performed consistently, and they recognized the multilanguage/hybrid texts with high accuracy. The highest precision scores were 93.89%, 91.35%, and 90.25% respectively.

Thesis 1.4

Research objectives (RO): RO3

Importance: global impact, local relevance

Relevant publications: [P1], [P2], [P3].

I proposed a visual controller method, encompassing vocabulary, distribution, and generation of single / multiline datasets that facilitates precision tuning of the set of multilingual / synthesized vocabulary and distribution preparation. This precision improves the accuracy of recognition across a wide range of languages and scripts. The OCR system can recognize and assimilate certain visual characteristics of each language by carefully choosing diverse and representative examples for the training dataset. This causes a significant increase in text recognition accuracy and a decrease in errors, distinguishing it

from traditional methods. The adaptability of the system is the source of its originality. The method performs consistently better because of continuous monitoring of the OCR model’s performance, modification of the multilingual vocabulary set, and distribution preparation. Furthermore, it exhibits notable versatility to handle new languages, scripts, or domain-specific text, which is a great step forward in OCR technology.

Thesis 1.5

Research objectives (RO): RO1, RO2

Importance: global impact, local relevance

Relevant publications: [P4], [P5], [P6]

I proposed a sensor-based pipeline to estimate energy expenditure remotely. Using a combination of medical radar sensor and three-axial accelerometer data allows for more accurate estimates of energy expenditure, which can help monitor an athlete’s condition level and recovery status. In addition, this method allows the athlete to monitor his physiological state and physical activities non-invasively and continuously during training and competition. This will provide valuable information for coaches and trainers to optimize performance and prevent injuries. The RPAI with METs, RPE, sRPE, and ACWR can be used to control the intensity of training sessions, ensuring that the athlete is not overtraining or undertraining.

Thesis 1.6

Research objectives (RO): RO2, RO4

Importance: global impact, local relevance

Relevant publications: [P7], [P5], [P6]

I proposed a precognition model for AI-assisted fatigue and stamina control that can be adapted to performance sports, which uses the dataset from IMU-generated multivariate time series data and yields several substantial conclusions with far-reaching implications on sports science and athlete performance management. The LSTM model exhibits competent ability in handling the classification task at hand, and its performance suggests a balanced approach to classifying binary classes. However, given the complexity and the “black box” nature of LSTM models, a careful examination and potential comparison with other ML models, including simpler ones, would be prudent, particularly in contexts where interpretability and computational efficiency are

crucial. The application of the precognition model extends to optimizing rest periods and recovery protocols. By predicting the trajectory of an athlete's recovery process, the model provides evidence-based recommendations for rest durations and recovery activities that are custom-fitted to the athlete's physiological needs, thus maximizing recovery efficiency and effectiveness.

Thesis 1.7

Research objectives (RO): RO4, RO6

Importance: global impact, local relevance

Relevant publications: [P7], [P5], [P6]

I formulated an AI-based “3D human pose estimation” method that contributes to strategic planning in training and competition in performance sports, to enhance athletic performances. By predicting the trajectory of an athlete's recovery process, the model provides evidence-based recommendations for rest durations and recovery activities that are custom-fitted to the athlete's physiological needs, thus maximizing recovery efficiency and effectiveness. Predictive insights into an athlete's stamina and fatigue thresholds enable coaches to make informed decisions about training intensity, competition schedules, and even strategic pacing strategies in competition. These IMU sensors are connected to athletes' equipment and provide critical biomechanical data, such as acceleration and angular velocity. Using AI on top of this data enables non-invasive performance tracking and fine-tuning. Coaches who have received training in data interpretation can utilize this information to provide prompt feedback, optimize the intensity and technique of training in real time, and improve the effectiveness of the sessions while avoiding excessive strain.

Thesis Statements Group II.

Thesis Group II (S2): Sports safety and injury prevention

Own publications pertaining to this research direction: [P1], [P2], [P5], [P8], [P9], [P10], [P11], [P12].

Thesis 2.1

Research objectives (RO): RO1, RO4

Importance: global impact, local relevance

Relevant publications: [P8], [P1], [P5]

I proposed an AI-assisted method for the rehabilitation process and the performance hardening. The AI-controlled framework applied to the proposed sports safety pipeline demonstrated marked efficiency in boosting athletic proficiency when juxtaposed with conventional training paradigms (e.g., deep analysis of exercises after an injury). In addition, its application appears promising in precluding potential injuries by discerning and amending sub-optimal training patterns and biomechanical lapses. When addressing post-injury scenarios based on the feedback of sports safety specialists, AI-integrated interventions appear to accelerate the rehabilitation process, while simultaneously increasing the quality of recovery. This may be the most important outcome. Furthermore, personalized training, tailored to the distinct biomechanical and physiological attributes of athletes, has become a tangible reality with AI's adaptability. A significant improvement was observed in the real-time feedback mechanism, enabling instantaneous technique adjustments. These innovations not only help athletes push their limits safely, but also ensure that they get the most out of their training sessions, remain injury-free, and achieve peak performance during competitions.

Thesis 2.2

Research objectives (RO): RO9

Importance: global impact, local relevance

Relevant publications: [P9], [P10], [P12]

I proposed a brain injury detection pipeline for performance sports for real-time detection of lesions and tumors after severe head injuries. The proposed technological pipeline with YOLO8 and YOLO-NAS models aims to make transformative outcomes in performance sports (like American football, rugby, or ice-hockey). I expanded the technological pipeline with YOLO9 to be able to detect pneumonia on time. The ability to detect problems quickly and correctly in real time could significantly accelerate medical intervention, improving recovery times and long-term results for athletes. The additional added value of the proposed pipeline and the proposed future implementations such as a comprehensive version of NAS and Explainable AI could lead to continuous model improvement and greater adoption due to greater trust and understanding of AI decision-making processes.

Thesis 2.3

Research objectives (RO): RO5

Importance: global impact, local relevance

Relevant publications: [P1], [P2]

I proposed a pipeline and a method for extracting sports strategies. The pipeline, using YOLO or YOLO-NAS, detects and tracks players and objects in real time, providing comprehensive data on their movements and interactions. Secondly, it seeks to extract strategic elements and patterns from the tracked data to aid in performance analysis and strategy development. Additionally, YOLO-NAS specifically aims to optimize the network architecture for improved tracking and strategy extraction, to analyze the feasibility of ML-based strategy extraction, and secondly to validate if – in terms of retrospective-type learning methods – athletes and coaches can leverage historical video data to identify trends, analyze past performances, and develop targeted predictive, AI-assisted training programs or adaptive strategies for future competitions. These results will facilitate a novel data-driven approach to athletes and team development, improving performance and strategic decision-making in sports.

Thesis 2.4

Research objectives (RO): RO4, RO5, RO9

Importance: global impact, local relevance

Relevant publications: [P10], [P1], [P11]

I formulated a method for retrospective-type learning for sports safety and training management in performance sports (with a focus on rehabilitation and hardening) as a support AI asset. By using the proposed method, athletes and coaches will have data-driven insights that will enable them to make informed decisions, optimize strategies, and improve overall performance in sports. Value propositions: (1) athletes and coaches can use historical video data to analyze past performances, identify trends, and evaluate the effectiveness of strategies and tactics used in previous games or drills; (2) by analyzing historical data, athletes and coaches can identify recurring patterns, both at the individual and team level, which can help to understand strengths, weaknesses, and areas of improvement; (3) retrospective learning allows athletes and coaches to adapt strategies based on analysis of past performances. By understanding what has worked well in similar situations, they can modify game plans and make more informed decisions during future competitions; (4) analyzing historical video footage can provide insight into an athlete's progress and skill development over time, helping coaches design personalized training programs and target specific areas for improvement; (5) retrospective learning methods can be used to establish performance benchmarks based on historical data, enabling athletes and coaches to set realistic goals and track progress over time.

Thesis Statements Group III.

Thesis Group III (S3): Predictions of health conditions

Own publications pertaining to this research direction: [P13], [P4], [P14], [P15], [P11], [P1], [P16], [P17].

Thesis 3.1

Research objectives (RO): RO2

Importance: global impact, local relevance

Relevant publications: [P13], [P4]

I proposed a “Condition lie detector” method that can help coaches get objective feedback on athletes’ health, stamina and condition (at individual and group level). The AI-based sRPE and ACWR prediction models have the potential to be applied in various sports and populations, including amateur athletes, recreational sports enthusiasts, and different age groups. As one of the future development lines, AI-based ACWR prediction models can benefit from incorporating more data sources, such as physiological markers, sleep quality, nutrition, and psychological factors. These additional data sources can help create more comprehensive and accurate models, improving the predictive capacity for ACWR and fatigue scores.

Thesis 3.2

Research objectives (RO): RO2

Importance: global impact, local relevance

Relevant publications: [P14], [P15], [P11]

I formulated an enhanced methodology proposed for the HPC environment to first validate the correlation between sentiment analysis and stamina, followed by a multivariate analysis of the correlation between stamina, text-based sentiment, and fatigue to assess their combined effect.

Thesis 3.3

Research objectives (RO): RO1, RO6

Importance: global impact, local relevance

Relevant publications: [P16], [P15], [P14]

I formulated a complex AI-supported pipeline method that combined the most advanced feature extraction methods (e.g., HNR, MFCCs, pitch of a voice, Jitter and Shimmer) to detect disease using a fully customized feature extraction on voice samples. I started with COVID-19 and after that expanded the research with other diseases and detection of health anomalies. Based on the experiments conducted, voice-based disease detection using AI shows promising results and provides a novel, non-invasive, cost-effective, and scalable approach to identify and monitor various diseases (e.g., COVID-19 and other contagious respiratory diseases). The biggest result of the proposed method is that it not only supports professional sports staff in predicting disease from the voice sample in near real time, but prevents cross-contamination in sports events.

Thesis 3.4

Research objectives (RO): RO4, RO8, RO9

Importance: global impact, local relevance

Relevant publications: [P4], [P7], [P13], [P14], [P11], [P17]

I developed a motivating asset concept for performance sports by combining the synergistic effects of gamification, generative AI and reinforcement learning (RL). This technique is distinctive in that it enhances psychological involvement by incorporating gamified features and physical training through tailored dynamic situations. It effectively addresses both the physical and mental aspects of sports performance within a comprehensive technology-driven framework. The integration of gamification and GenAI into performance team sports is revolutionary because it combines psychological motivation and adaptive technology innovation in a synergistic manner. GenAI systems enhanced with reinforcement learning (RL) improves and fine-tunes real-time training parameters such as intensity, duration, stamina. This is achieved by evaluating large amounts of individual performance data, including subjective rating of perceived exertion (sRPE), metabolic equivalent (MET) and ACWR. Gamification improves athlete motivation, resulting in a 20-30% increase in completion rates without requiring additional requests from coaches. This, in turn, improves the effectiveness of training preparatory processes.

Thesis 3.5

Research objectives (RO): RO7

Importance: global impact, local relevance

Relevant publications: [P14], [P15], [P11]

I formulated a method to identify burnout at an early stage in performance sports through written communication combined with sentiment analysis. This research is essential to understanding the psychological signs of burnout and the methods to measure it, coupled with the expertise in NLP and sentiment analysis techniques. Collecting athletes' textual data, such as logs or post-training interviews/feedback, is crucial, along with possible metrics of stamina or fatigue. The role of AI, in particular significantly advanced models like BERT or GPT-3, is to analyze these texts, discerning underlying sentiments that may indicate burnout. AI can identify impending burnout patterns by correlating text-derived sentiments with physical metrics. I investigated the feasibility of an AI-driven approach to proactive intervention, allowing timely measures to prevent burnout. Furthermore, the proposed method allows athletes to customize their training to their mental and physical health, thus extending their careers. The predictive capabilities of AI can identify early signs of burnout, even before obvious symptoms manifest themselves. This enables timely interventions, potentially preventing burnout and improving overall athlete welfare. The model showed that there is significant variability in the way individuals respond to training loads and stressors. A universal approach to training and recuperation may not be effective. Personalized insights and recommendations, tailored to each athlete's unique profile, are vital.

Thesis 3.6

Research objectives (RO): RO7

Importance: global impact, local relevance

Relevant publications: [P1], [P14], [P11], [P1]

I formulated a complex, ML- and NLP-based non-invasive methodology to identify the early markers from written text, combined with sentiment analysis of mental health disorders (such as depression, anxiety, psychotic disorders, Alzheimer’s disease, and dementia) and neurodegenerative disorders (such as Parkinson’s disease). The implemented pipeline of AI-parsed text and sentiment analysis appears to be a promising next-generation mental health anomaly detection tool for the early detection and ongoing monitoring of mental health and NDD. However, these methods are complementary and cannot replace the nuanced clinical evaluation process in the current stage. Future research must refine AI algorithms to account for linguistic diversity and context, while also addressing ethical considerations regarding data use and privacy. The expected results of the method in the sports domain are becoming increasingly vital, particularly for the early recognition of mental health concerns and the precursors to NDD among athletes. The intense physical demands, psychological stress of competition, and high-impact nature of many sports can precipitate or aggravate conditions such as depression or anxiety.

Thesis 3.7

Research objectives (RO): RO7

Importance: global impact, local relevance

Relevant publications: [P9], [P10]

To detect pneumonia in real time, I formulated a complex, non-invasive approach. Using YOLOv9 in a real-time diagnostic system to detect early pneumonia symptoms in athletes could improve respiratory care. The precision of YOLO 9 was high after rigorous training and validation, suggesting its reliability in sports performance situations. By promptly and precisely interpreting chest radiographs, the approach reduces the impact of pneumonia on athletes’ health and careers. The results promote sports medicine and pulmonology and set a precedent for AI integration into other preventive medicine sectors, promising a future in which AI and medical expertise improve high-performance sports health outcomes.

Perspectives and future research directions

3.1 Perspectives

I started to understand sports safety and AI-based anomaly detection before I commenced my doctoral studies in Computer Science (UMFST) and Health Sciences (UMA). With a steep learning curve, the cotutelle PhD course has helped me comprehend this heterogeneous subject from the perspectives of sport, medicine, informatics, and psychology. The early detection of anomalies, lesions, mental health and neurodegenerative disorders, or diseases related to sports, combined with the use of sensors (e.g., medical radar sensors, 3-axial accelerometers, IMUs) to study fatigue, stamina, recovery/rehabilitation, boosted with AI, has opened up many new research directions in fatigue prediction, injury mitigation, and performance optimization. After years of perseverance and passion in this journey, the PhD program is just one stage and will continue in the postdoctoral phase.

The new research cycle will provide new challenges (see Section 3.2.4), such as knowledge-intensive investigation of mental and neurodegenerative disorders, the first phase of which is given in related parts and publications of “Thesis Statements Group III”. I plan to continue the initiated research trials in a supercomputing (HPC) environment, supplemented by audio and then video samples, with special focus on geolocation and spoken languages to improve the sentiment analysis efficacy. In general, the duration of the intervention, the parameterization of the sentiment analyses for a given focus group, the characteristics of the datasets, and the computational capacity required made it difficult to analyze the data on a broader scale (e.g., geolocation or language segmentation), making it impossible to include it in a PhD thesis that coincided with a pandemic and the resulting constraints. However, the significance of the study’s findings makes it one of the doctorate section’s primary axes. Another major goal of the postdoctoral phase is to create an infrastructure and a real-time AI algorithm for the early detection and remote prediagnosis of trauma, lesions, or health anomalies caused by collisions (e.g., ice hockey, American football, rugby) to prevent future complications or more serious problems. This approach could improve sports safety in team sports with high risk of injury.

In terms of anomalies, I intend to create an ambulatory severity stratification and recovery/rehabilitation index that will allow competitive sports patients to be stratified according to the severity of their condition, as well as the possibility of involving patients at various stages of the processes and proposed methodologies discussed in the theses of

“Thesis Statements Group II” of this dissertation. Another future direction to consider (“Thesis Statements Group I”) is the development of a collaborative remote knowledge transfer diagnostic system that allows the collaboration of specialists who work in different fields and even speak different languages to support the early and rapid diagnosis and analysis of complex diseases, as well as the development of effective and personalized treatments (see Section 3.2.1). Another future trend to consider is the management of fatigue by increasing endurance in competitive sports through the validation of questionnaires and tests commonly used in research and clinical practice but not subjected to the psychometric analysis required to gain a deeper understanding of the properties of their use by geolocation and age group.

Similarly, the publications included in the thesis (related to Thesis Statements Group I, II, and III) highlight the lack of methods and techniques for direct in vivo evaluation of in vivo exercise, which are applicable both in research and clinical practice, as well as the potential of artificial intelligence. As a result, the investigation and development of novel cross-disciplinary methodologies utilizing AI should be pursued. Finally, in addition to the study of the application of practices, research, and related developments, the work done during the doctoral thesis and related residencies resulted in the formation of an internationally recognized team of competitive sports professionals with whom the research can be continued, methodologies and processes developed, and validated in various sports disciplines. This procedure allows for the continued development of the retrospective learning methodology and the multimodal learning approach. This line of research, which complements the PhD thesis on early detection of mental health and neurodegenerative disorders, has begun with preliminary research in a supercomputer environment, which will prepare the modeling of datasets for optimal synthetic language teaching in a multidisciplinary collaboration. Metalinguistic language anomalies, mental and neurodegenerative disorders should not only be recognized but also understood in terms of patterns and specificities. In the postdoctoral phase, this line of study will seek to create new methods, improved models, publications, and specialized tests and procedures for the implementation of protocols and asynctial interventions.

3.2 Future research directions

3.2.1 Future plans in remote consultancy and collaborative diagnosis

In the postdoc phase, I would like to expand the thesis experiments to an HPC environment, where it will be used for federated learning and distributed data processing, combined with domain adaptation and unsupervised learning methods using dynamic data sampling and the continuous model improvement approach.

3.2.2 Future directions with medical radars & triple axis accelerometers

In the long term, in collaboration with university teams (e.g., Toyo University from Japan) and using the ecosystem I plan to implement a research program – on fatigue and stamina control based on multivariate time series (MTS) datasets – that improves athlete health and performance longevity. Improving the overall health of athletes and prolonging the longevity of their performance careers through a data-driven approach to training load management is a critical objective. The AI-assisted model supports sustainable high-performance training practices by continuously adapting to the physical state of the athlete. This pillar of the thesis on AI-assisted fatigue and stamina control for performance sports, based on the analysis of multivariate time series datasets generated by IMU, is expected to lead to discoveries. The prospective development lines and innovative outcomes of this research are specific to significantly influence sports science, athlete training, and broader AI applications. Potential future development lines are the following: (1) *Algorithmic advancement with hardening* and (2) *Sensor integration*.

3.2.3 Proposed research trajectories on pneumonia detection in sports

Several strategic priorities have been identified to improve the effectiveness and utility of the AI-based pneumonia detection system: (1) it is essential to add more diverse chest radiographs from athletes to the training data set. This increase will make the model more robust and able to generalize across sports populations, allowing physiological differences due to sports disciplines, training regimes, and genetics; (2) adding diagnostic characteristics such as wearable health monitoring data could improve diagnosis. The AI system could detect tiny irregularities that X-rays cannot detect by connecting physiological data, such as heart rate and respiration rate, with image data; (3) model development will improve real-time processing to reduce latency. Finally, applying this AI pipeline to stress fractures and heart abnormalities could have a tremendous impact on sports medicine.

3.2.4 Proposed research trajectories on disease and injury prevention

One of the main future objectives of this thesis line is to conduct a comprehensive investigation using a validated dataset while improving the model by incorporating speech analysis within a high performance computing environment (HPC). The present investigation stage encounters constraints within the Google Colab Pro platform. Future AI development lines will offer a more sensitive, specific and timely identification of mental

health and NDD, ultimately leading to better patient outcomes through early and personalized care. The trajectory of AI in the precognition of mental health and NDD is trending towards several specific lines of development, which are proposed to be analyzed: (1) *Voice analysis expansion*; (2) *Contextual and idiomatic language understanding*; (3) *Neuroimaging integration*; (4) *Genomic correlations*; (5) *Real-time wearable monitoring*; (6) *Digital phenotyping*; (7) *Ethical data governance*, and (8) *AI education*.

Each of these development lines aims to *enhance the precision, reliability, and ethical integrity of AI applications* in the care of mental health and neurodegenerative diseases, promising a future of personalized and proactive healthcare solutions for performance sports platforms and sports safety solutions. *Future development idea as the next phase of burnout detection*: the aim is to investigate in detail with a validated dataset on the correlation between sentiment analysis and stamina or fatigue in an HPC environment. The current phase of the research reached its limits in the Google Colab Pro environment. *Future development idea of personalized recovery*: first, I plan to deepen collaborations between AI developers and sports psychologists to develop tools that offer insight into the mental well-being of athletes. Personalized training regimens are expected to use DL models to interpret biometric data. Solutions for early adopters have been designed to overcome these obstacles. I intend to explore the synergies between AI and genomics to revolutionize sports training with genetic predisposition insights in later phases. The convergence of NNs and biomechanics can help athletes optimize performance by improving movement patterns. Wearable tech may return as data collectors and intelligent interpreters with actionable advice.