QUALITY IN SPORT
eISSN 2450-3118 · Open Access · Peer-reviewed
apcz.umk.pl/QS Nicolaus Copernicus University in Toruń

Cite as: GRZYBOWSKA, Dominika, GRZYB, Weronika, IDZIK, Kamil, JAŚLIKOWSKA, Adrianna, KUBICKI, Adrian, KURNIK, Michał, LEŚNIAK, Maria, NIDERLA, Natalia, RACHWAŁ, Natalia, and RZESZUTEK, Jakub. The Use of Wearable Technology in Monitoring Physical Activity and Training: A Systematic Review. Quality in Sport. 2026;62:73379. https://doi.org/10.12775/QS.2026.62.73379

ARTICLE TIMELINE
Received: 15.06.2026. Revised: 30.06.2026. Accepted: 05.07.2026. Published: 12.07.2026.

The journal has been awarded 20 points in the parametric evaluation by the Polish Ministry of Higher Education and Science (Annex to the announcement of 05.01.2024, No. 32553). Unique Journal Identifier: 201398. Scientific disciplines assigned: Economics and finance (Field of social sciences); Management and Quality Sciences (Field of social sciences).
Punkty Ministerialne z 2019 – aktualny rok 20 punktów. Załącznik do komunikatu Ministra Szkolnictwa Wyższego i Nauki z dnia 05.01.2024 Lp. 32553. Posiada Unikatowy Identyfikator Czasopisma: 201398. Przypisane dyscypliny naukowe: Ekonomia i finanse (Dziedzina nauk społecznych); Nauki o zarządzaniu i jakości (Dziedzina nauk społecznych).

The Use of Wearable Technology in Monitoring Physical Activity and Training: A Systematic Review

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Abstract

Introduction and purpose: Wearable technologies have become widely adopted tools for monitoring physical activity and optimizing athletic training, yet comprehensive evaluations of their accuracy and effectiveness remain fragmented. This systematic review synthesizes evidence on wearable technology in physical activity monitoring and sport-specific training.

Materials and methods: A systematic search of PubMed, Embase, Web of Science, SPORTDiscus, and CENTRAL was conducted for studies published between 2015 and 2025, following PRISMA 2020 guidelines. Systematic reviews, meta-analyses, and primary validation studies were synthesized.

Brief description of the state of knowledge: Step counting reached acceptable accuracy in leading consumer devices (mean absolute percentage error below 25%), and optical heart rate sensors performed well at rest and moderate intensity (MAPE below 10%). Energy expenditure estimation remained inaccurate across all devices (MAPE exceeding 30%). An umbrella review of 39 systematic reviews found that 79% of physical activity analyses favored wearable interventions. A meta-analysis of 23 trials involving 4,566 older adults reported significant improvements in daily step counts and physical activity time, whereas no significant effects were found in youth populations.

Summary: Wearable devices offer acceptable accuracy for step counting and heart rate but not energy expenditure. Standardized validation protocols, algorithmic transparency, and long-term effectiveness studies are needed to maximize clinical and sporting utility.

Keywords: wearable technology; physical activity monitoring; training optimization; measurement accuracy; systematic review; inertial measurement unit

1. Introduction

Physical inactivity remains one of the leading modifiable risk factors for non-communicable diseases globally, contributing to cardiovascular disease, stroke, type 2 diabetes, various cancers, and mental illness. Concurrently, the optimization of athletic training has become increasingly data-driven, with coaches and sports scientists seeking objective, real-time metrics to guide periodization, recovery, and performance enhancement. In this context, wearable technology has emerged as a transformative tool, bridging the gap between subjective self-report measures and laboratory-based assessments. Tracking and documenting physical activity can serve as a means of monitoring and encouraging participation in daily exercise, with increased activity translating into important positive health outcomes, both physical and mental [1]. Wearable devices have been described as effective tools for promoting physical activity, managing stress, and monitoring sleep, empowering individuals to maintain a healthy lifestyle at the intersection of technology and personal health [2].

Historically, physical activity tracking relied on manual methods such as records, logbooks, and questionnaires—indirect approaches that suffer from administrative burden and recall bias [1]. Direct measurement methods, particularly accelerometers and pedometers, eliminated these limitations and became the foundation for modern wearable devices. The process has since become automated, accessible, and digitized with wristband sensors and smartwatches linked to smartphone applications [1]. These devices integrate various sensor modalities—accelerometers, gyroscopes, magnetometers, photoplethysmography (PPG) sensors, global positioning system (GPS) receivers, barometers, and emerging electrochemical biosensors—to capture physiological, kinematic, and biochemical parameters in real time [3, 4].

The consumer wearable market has experienced remarkable growth and diversification. A census of 423 unique consumer wrist-worn devices from 132 different brands released between 2011 and 2017 revealed that sensor support increased substantially each year: by 2017, 71% (27 of 38) of newly released devices included a PPG sensor for heart rate estimation, 50% (19 of 38) included GPS, 39% (15 of 38) incorporated a gyroscope, 34% (13 of 38) a magnetometer, and 32% (12 of 38) a barometer or altimeter. Across the entire period, 38.5% (163 of 423) of all catalogued wearables contained only an accelerometer, while only 2.1% (9 of 423) incorporated all six sensor types [5]. This evolution from single-sensor pedometers to multi-sensor fusion platforms has been accompanied by a corresponding increase in research interest [4]. Wearable devices and remote patient monitoring are increasingly recognized as transforming both sports and healthcare by enabling continuous, real-time monitoring [6].

Despite the rapid proliferation of wearable devices, significant concerns have been raised regarding the gap between marketing claims and scientific validation. Some authors argue that many wearable activity trackers represent advanced marketing rather than advanced technology, pointing to the lack of independent peer-reviewed validation studies [7]. A critical review of consumer-grade wearables concluded that only approximately 5% of the technologies examined had been formally validated [8]. These concerns are compounded by the proprietary nature of the algorithms used to derive metrics such as energy expenditure and sleep quality, making independent verification inherently difficult [9]. Because the algorithms employed by different manufacturers are not available as open-source code, the degree of accuracy and comparability across devices remains ambiguous [9].

Previous systematic reviews have addressed specific aspects of wearable technology, such as the accuracy of wrist-worn devices for particular metrics [10, 11], the effectiveness of activity trackers in promoting physical activity in specific populations [12, 13], or the application of wearable sensors in individual sports [14]. However, no comprehensive review has synthesized evidence across both general physical activity monitoring and sport-specific training applications. This gap is particularly significant given the increasing convergence of consumer-grade and research-grade wearable technologies and the emergence of quality frameworks for evaluating sports technology [15].

The relevance of this synthesis extends beyond academic interest. As wearable devices become embedded in everyday life and clinical practice, their measurements increasingly inform real decisions—from how much a patient is encouraged to walk after surgery, to how a coach manages an athlete's training load, to whether an individual believes they have met their daily activity goal. When the underlying measurements are accurate, these decisions are well founded; when they are not, the consequences range from misplaced confidence to potentially harmful misjudgments about caloric balance or recovery status. A clear, integrated understanding of which metrics can be trusted, in which populations, and under which conditions is therefore of considerable practical and public health importance. This review seeks to provide such an understanding by drawing together the strongest available evidence across measurement accuracy, behavioral effectiveness, and sport-specific application.

The aim of this systematic review is to provide an integrated synthesis of the current evidence on the use of wearable technology in monitoring physical activity and training. Specifically, this review addresses four research questions: (1) What types of wearable devices and sensor modalities are most commonly employed? (2) What is the measurement accuracy of these devices for key physiological and biomechanical parameters? (3) What is the effectiveness of wearable-based interventions across different populations? (4) What are the current limitations, challenges, and future directions for wearable technology in this field?

2. Methods and Literature Selection

2.1. Search Strategy

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines [16]. A systematic search was performed across five electronic databases: PubMed/MEDLINE, Embase, Web of Science Core Collection, SPORTDiscus via EBSCO, and the Cochrane Central Register of Controlled Trials (CENTRAL). The search covered publications from January 2015 to December 2025. Search terms were organized into four conceptual categories combined with Boolean operators (AND/OR): (1) wearable technology; (2) physical activity; (3) training and sport; and (4) monitoring outcomes. Reference lists of included studies and relevant systematic reviews were manually screened for additional eligible articles.

2.2. Inclusion and Exclusion Criteria

Eligibility criteria were structured using the PICOS framework. Studies were included if: (a) participants were human, of any age or health status; (b) the intervention or assessment tool was a body-worn wearable device, excluding smartphone-only applications; (c) the study measured at least one physical activity or training-related outcome, such as step count, active minutes, heart rate, energy expenditure, movement kinematics, or training load; (d) the study design was a randomized controlled trial (RCT), quasi-experimental study, cohort study, systematic review, meta-analysis, or validation study; and (e) the article was published in English in a peer-reviewed journal. Studies were excluded if they focused exclusively on sleep monitoring without physical activity outcomes, used only implantable devices, or were conference abstracts, editorials, or case reports.

2.3. Data Selection and Quality Assessment

Two independent reviewers screened titles and abstracts for potential eligibility, followed by full-text assessment of candidate articles. Discrepancies were resolved through discussion or consultation with a third reviewer. The risk of bias in RCTs was assessed using the Cochrane Risk of Bias tool version 2 (RoB 2). Quasi-experimental studies were evaluated using ROBINS-

I. Validation studies were appraised using a modified QUADAS-2 framework [10]. Systematic reviews were assessed using AMSTAR 2. The overall certainty of evidence was evaluated using the GRADE criteria where applicable.

3. Results: Measurement Accuracy of Wearable Devices

The most comprehensive evidence on the accuracy of consumer wrist-worn wearable devices comes from a systematic review that included 65 primary studies evaluating 72 devices from 29 brands across 14 different outcome categories [10]. Substantial clinical heterogeneity across studies precluded a formal meta-analysis of accuracy data.

3.1. Step Count Accuracy

Step count was the most frequently validated metric. Among consumer-grade wrist-worn devices, the Fitbit Charge and Fitbit Charge HR models consistently demonstrated the lowest error rates, achieving a mean absolute percentage error (MAPE) below 25% across 20 studies [10]. This finding was corroborated by an umbrella review that synthesized 24 systematic reviews collectively covering 653 primary studies; its high-quality subanalysis of Fitbit devices found a mean bias of approximately −3.11 steps per minute when inferior-quality studies were excluded [11]. Regarding research-grade devices, ActiGraph was the most commonly used tracker in large-scale medical research (11 of 27 studies, 41%), followed by Fitbit (15%) and Axivity (11%) [9]. Accuracy varies substantially depending on device model, walking speed, testing environment, and body location, with wrist placement producing greater error than hip placement due to non-ambulatory arm movements being misclassified as steps [17].

3.2. Heart Rate Accuracy

The Apple Watch achieved a MAPE below 10% in 2 studies, representing the best performance among consumer wrist-worn devices for heart rate measurement [10]. PPG-based optical sensors generally demonstrated acceptable accuracy at rest and during low-to-moderate intensity activities, but accuracy degraded during vigorous exercise due to motion artifacts. Factors affecting PPG accuracy include skin pigmentation, device fit, ambient light interference, and tattoo presence. Automated atrial fibrillation classification algorithms are proprietary to each manufacturer and vary considerably in performance, with sensitivity ranging from 58% to 85% and specificity between 69% and 79% across five different devices [17].

3.3. Energy Expenditure Accuracy

Energy expenditure was the least accurately measured parameter. No consumer device achieved a MAPE below 30% in any study, demonstrating consistently poor accuracy across all brands [10]. Both overestimation and underestimation were observed, with the direction and magnitude of error varying by device, activity type, and individual characteristics. While certain armband devices could estimate energy expenditure validly in the general population, they tended to underestimate this parameter during high-intensity exercise exceeding 10 metabolic equivalents (METs) [18]. The opacity of proprietary algorithms was identified as a key barrier to understanding and improving these estimates [9, 18].

Table 1. Accuracy of Wrist-Worn Wearable Devices by Outcome Metric [10]

Outcome	Best Device	Accuracy	No. of Studies
Step count	Fitbit Charge / Charge HR	MAPE <25% across 20 studies	31 of 65 assessed step count
Heart rate	Apple Watch	MAPE <10% in 2 studies	Multiple studies
Energy expenditure	None acceptable	MAPE >30% for all brands	Multiple studies
Data availability	Fitbit Charge HR, Garmin Vivofit	≥75%	11 acceptability studies
Wearing compliance	GENEActiv, Nike FuelBand	89% wearing time	11 acceptability studies

Note. MAPE = mean absolute percentage error. 65 studies, 72 devices, 29 brands [10].

3.4. Kinematic and Biomechanical Measurements

In sport-specific contexts, wearable sensing has been organized across four monitoring dimensions—physiological, kinematic, biochemical, and dynamic—mapped onto three training pillars: physical, technical, and tactical [3]. Field-based IMU kinematics now demonstrate increasing concurrent validity and test–retest reliability compared to optical motion capture systems for running and walking spatiotemporal metrics and joint angles. The 2024 International Society of Biomechanics (ISB) recommendations standardized reference frames, alignment, and reporting, while alignment-free and dynamic-calibration methods have reduced environmental and placement errors [3]. However, integration drift, soft-tissue artifacts, and segment-frame misalignment continue to limit joint-angle accuracy. In a special issue on wearable sensor technology in sports, 8 of 12 published papers focused on inertial measurement units as the primary tool, with both photoelectric and accelerometer devices demonstrating strong reliability for vertical jump assessment [14].

4. Effectiveness of Wearable-Based Interventions

4.1. General Adult Populations

An umbrella review published in The Lancet Digital Health synthesized 39 systematic reviews and meta-analyses encompassing both clinical and non-clinical populations [12]. Among 29 analyses of physical activity outcomes, 23 (79%) favored the wearable intervention, none favored control conditions, and 6 (21%) were non-significant. For physiological outcomes, 12 of 15 analyses (80%) favored intervention. Activity trackers were found to encourage approximately 40 additional minutes of daily walking and to produce a meaningful weight loss of approximately 1 kilogram [12]. The quality assessment using AMSTAR 2 found that most included reviews were rated as low or critically low in confidence, although results remained consistent across reviews with different risk-of-bias ratings [12]. These findings are consistent with earlier meta-analytic evidence that consumer-based wearable activity trackers significantly increase physical activity participation, with reported increases of approximately 1,850 steps per day [19].

4.2. Older Adult Populations

A meta-analysis published in the Journal of Medical Internet Research included 23 RCTs with a total of 4,566 participants [13]. The key findings, presented in Table 2, demonstrate that wearable activity tracker-based interventions significantly increased physical activity time (standardized mean difference [SMD] = 0.28, 95% CI [0.10, 0.47], $p = .003$) and daily step counts (SMD = 0.58, 95% CI [0.33, 0.83], $p < .001$) compared to usual care immediately after intervention. No significant improvement was observed in daily sedentary time. The interventions demonstrated sustained effects on daily step count at short-term follow-up (SMD = 0.23, p < .001). However, no significant effects were found for body composition or physical function measures [13]. The certainty of evidence was rated as low to moderate.

Table 2. Meta-Analysis Results: Wearable Tracker Interventions in Older Adults [13]

Outcome	Effect Size	95% CI	p value	Certainty
Physical activity time (immediate)	SMD = 0.28	[0.10, 0.47]	.003	Low–moderate
Daily step count (immediate)	SMD = 0.58	[0.33, 0.83]	<.001	Low–moderate
Daily sedentary time	MD = −1.56 min	[−10.88, 7.76]	.74	Low–moderate
Daily step count (short-term FU)	SMD = 0.23	[0.11, 0.36]	<.001	Moderate
BMI	MD = 0.40	[−0.08, 0.89]	.11	Low–moderate
Body fat	MD = 0.67	[−0.54, 1.87]	.28	Low–moderate

Note. SMD = standardized mean difference; MD = mean difference; CI = confidence interval; FU = follow-up. 23 RCTs, N = 4,566 [13].

4.3. Children and Adolescents

A systematic review and meta-analysis published in The Lancet Digital Health included 21 RCTs and cluster-RCTs examining wearable activity tracker effects on physical activity in participants aged 19 years or younger [20]. The review found no statistically significant effect on moderate-to-vigorous physical activity (MVPA). Pedometers were the predominant tracker type, used in 15 of 21 studies. The null finding was robust, confirmed by comprehensive sensitivity analyses. The authors attributed the discrepancy with earlier, more optimistic reviews to the exclusion of non-randomized controlled trials that are more prone to overestimating intervention effects [20]. A complementary review examining adolescents in school-based settings found no statistical significance for effects on total daily steps, MVPA, or calorie counts; however, a subgroup analysis revealed that one study using research-grade assessment showed a substantial positive effect on steps [21].

4.4. Sport-Specific Training Applications

In the domain of competitive and elite sport, wearable technologies are being applied across multiple dimensions of athletic performance. A proposed framework maps wearable sensing across physiological, kinematic, biochemical, and dynamic monitoring onto physical, technical, and tactical training pillars [3]. Emerging applications include electrochemical sweat sensors for monitoring lactate, glucose, and electrolyte concentrations during exercise, as well as textile-based strain sensors for non-invasive muscle activity detection [3, 4]. Concerns persist regarding the lack of independent peer-reviewed validation studies coupled with exaggerated marketing claims by manufacturers, a problem compounded by proprietary intellectual property in the algorithms determining performance variables [22]. A sports technology quality framework has been developed to provide structured criteria for evaluating wearable technologies in sport settings [15]. A bibliographic analysis of wearable technology in sport identified 2,568 papers (2015–2023), with the journal Sensors publishing the most studies [4].

5. Discussion

This systematic review synthesizes evidence from multiple high-quality systematic reviews, meta-analyses, and primary studies, providing an integrated perspective on the current state of wearable technology in physical activity monitoring and athletic training.

The finding that measurement accuracy is strongly metric-dependent has significant practical implications. Step counting by leading consumer devices has achieved acceptable reliability for ambulatory activities in healthy adult populations, with the Fitbit Charge achieving MAPE below 25% across 20 studies [10]. Similarly, the Apple Watch demonstrated strong heart rate accuracy at rest and moderate intensities [10]. However, the universally poor accuracy of energy expenditure estimation (MAPE exceeding 30% for all devices) is particularly concerning, given that many consumers rely on caloric estimates for dietary and weight management decisions [10, 7]. This reinforces calls for evidence-based marketing claims [18] and for greater investment in formal validation studies [8]. Because manufacturers do not release their algorithmic methods as open-source code, the degree of accuracy and comparability remains inherently opaque [9]. Clinicians and practitioners should explicitly counsel patients and athletes about the unreliability of device-reported energy expenditure values.

The effectiveness evidence presents a generally encouraging picture for adult and older adult populations. The umbrella review finding that 79% of physical activity analyses favored wearable intervention provides robust, population-level evidence for efficacy [12]. The approximately 40 minutes of additional daily walking and approximately 1 kilogram of weight loss, while modest at the individual level, are clinically meaningful from a public health perspective when scaled across populations [12]. The older-adult meta-analysis strengthens this evidence, demonstrating significant increases in physical activity time and daily step count [13]. However, the absence of significant effects on body composition and physical function suggests that wearable tracker interventions alone may be insufficient to produce comprehensive health improvements without complementary structured exercise programming [13].

The contrasting null findings in youth populations highlight an important gap in the evidence base [20, 21]. The predominantly pedometer-based interventions in these studies may not have adequately engaged younger users accustomed to more sophisticated technology interfaces. In elite and competitive sport, the field is characterized by rapid technological advancement but insufficient independent validation. Frameworks for exercise monitoring [3] and for sports technology quality assessment [15] represent important steps toward systematic evaluation, but the gap between marketing claims and validated scientific evidence remains unresolved [22]. The convergence of wearable sensors with artificial intelligence and remote patient monitoring is expected to further expand applications in both sport and clinical contexts [6].

Several limitations should be acknowledged. First, the rapid pace of device iteration means that accuracy findings from specific models may not generalize to current versions. Second, most included systematic reviews were rated low or critically low on AMSTAR 2, although sensitivity analyses suggested robustness [12]. Third, this review relied substantially on secondary synthesis, which inherits the limitations of the underlying primary literature. Fourth, the exclusion of non-English publications may have introduced selection bias. Fifth, substantial heterogeneity in outcome measures, study designs, and reporting practices complicated cross-study comparisons.

5.1. Practical Implications

The findings of this review carry several practical implications for clinicians, coaches, public health practitioners, and individual users. For health professionals, the evidence supports integrating wearable activity trackers as motivational and self-monitoring tools within structured behavioral change programs, rather than deploying them as standalone interventions [12]. Because the magnitude of benefit is amplified when device use is combined with goal-setting, feedback, and counseling, practitioners should frame the wearable device as one component of a broader intervention strategy. For older adults in particular, the documented increases in daily step count suggest that wearables can be a useful adjunct to physiotherapy and rehabilitation programs, although they should not replace supervised exercise prescription given the absence of significant effects on physical function [13].

For coaches and sports practitioners, the evidence indicates that multi-sensor wearable platforms can provide valuable training-load and physiological monitoring, but device selection should be guided by independent validation evidence relevant to the specific sport and metric of interest [6, 15]. Practitioners are advised to establish internal reliability benchmarks for any device adopted into routine monitoring, and to interpret manufacturer-reported metrics—especially energy expenditure—with appropriate caution. The development of structured quality-assessment frameworks for sports technology represents a promising step toward more evidence-based procurement decisions [15]. For individual consumers, the key practical message is that step count and heart rate at rest can be trusted within reasonable margins, whereas calorie estimates should be treated as rough approximations rather than precise figures suitable for dietary planning [10, 7].

5.2. Future Research Directions

Several priority areas for future research emerge from this synthesis. First, there is an urgent need for standardized, device-agnostic validation protocols that enable direct comparisons across devices, populations, and activity types, reducing the methodological heterogeneity that currently hampers evidence synthesis [10, 11]. Second, longitudinal studies examining the sustained effectiveness of wearable-based interventions over periods exceeding twelve months are needed to determine whether initial behavior changes translate into durable health outcomes, since most existing trials report only short-term follow-up [13]. Third, the development and validation of multi-sensor fusion algorithms that integrate physiological, kinematic, and biochemical data streams could substantially enhance measurement precision and clinical utility [3, 4]. Fourth, equity-focused research addressing the accuracy of optical sensors across diverse skin tones, body compositions, and demographic groups is essential to ensure that wearable technologies do not inadvertently widen existing health disparities. Finally, the integration of artificial intelligence and edge computing with wearable sensors holds considerable promise for real-time adaptive feedback, personalized training recommendations, and early injury detection, although rigorous prospective validation in ecologically valid field settings remains a prerequisite for clinical and sporting adoption [6].

6. Summary and Conclusions

Wearable technology has established itself as a valuable and increasingly sophisticated tool for monitoring physical activity and informing athletic training decisions. This systematic review demonstrates that current devices provide acceptably accurate step counting and heart rate measurement for most practical applications, while energy expenditure estimation remains unreliable across all tested devices [10].

Regarding measurement accuracy, step counting and heart rate have reached acceptable levels in leading devices, but energy expenditure estimation fails across all brands [10]. Regarding intervention effectiveness, wearable-based interventions produce meaningful increases in physical activity, with 79% of analyses favoring intervention in the most comprehensive umbrella review [12] and significant improvements documented in older adults [13], although effectiveness in youth populations remains unproven [20, 21]. Regarding limitations and future directions, the field requires standardized, device-agnostic validation protocols, transparent algorithmic reporting by manufacturers, longitudinal studies exceeding 12 months, equity-focused research on sensor accuracy across diverse populations, and prospective validation of AI-enhanced analytics in ecologically valid field settings. Addressing these priorities will be essential for fully realizing the transformative potential of wearable technology in promoting population health and optimizing human performance.

Disclosure

Author Contribution

Conceptualization, D.G. and J.R.; methodology, D.G. and K.I.; software, A.K. and M.K.; validation, D.G., N.N., and N.R.; formal analysis, D.G. and W.G.; investigation, D.G., M.L., and A.J.; resources, K.I. and N.N.; data curation, D.G. and A.K.; writing—original draft preparation, D.G.; writing—review and editing, D.G., W.G., K.I., A.J., A.K., M.K., M.L., N.N., N.R., and J.R.; visualization, M.L. and N.R.; supervision, D.G. and J.R.; project administration, D.G. All authors have read and agreed to the published version of the manuscript.

Funding Statement: This research received no external funding.

Institutional Review Board Statement: Not applicable. This study is a systematic review of previously published literature and did not involve human participants or animals.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data sharing is not applicable to this article, as no new data were created or analyzed in this study. All data discussed are available in the cited published sources.

Acknowledgments: The authors received no administrative, technical, or material support beyond that provided by their affiliated institutions.

Conflict of Interest Statement: The authors declare no conflicts of interest.

Declaration of the Use of Generative AI and AI-Assisted Technologies in the Writing Process

During the preparation of this work, the authors used an AI-assisted tool solely for text formatting and language editing. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the substantive content of the publication.

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