The Interplay Between Physical Activity and Mental Health in Children: A Survey

Abstract

This survey paper explores the multidisciplinary research area examining the interplay between physical activity and mental health in children, utilizing GPS technology and environmental psychology principles. The study highlights the cognitive, emotional, motor, and psychosocial benefits of physical activity, while addressing domain-specific impacts and measurement challenges. GPS technology is pivotal in tracking movement patterns, offering precise data that enhances understanding of physical activity behaviors and environmental contexts. This precision supports targeted interventions and long-term outcome evaluations, as demonstrated by methodologies estimating mHealth policy outcomes. Environmental psychology provides insights into how environmental factors, including school environments and teacher-student relationships, influence physical activity and mental health outcomes. The application of trajectory analysis offers a robust framework for examining behavioral changes over time, informing effective intervention design. Advanced statistical models, like the Additive Quantile Mixed Model (AQMM), show promise in analyzing clustered data related to children's physical activity and mental health. Future research should leverage wearable device data and software development kits to enhance methodologies, exploring just-in-time adaptive interventions and machine learning algorithms to further elucidate the complex dynamics between physical activity and mental health. This comprehensive approach aims to develop effective public health strategies promoting well-being across diverse populations.

1 Introduction

1.1 Importance of Studying Physical Activity and Mental Health in Children

Understanding the relationship between physical activity and mental health in children is crucial due to its significant implications for both immediate and long-term health outcomes. Physical inactivity ranks as the fourth leading risk factor for global mortality, highlighting the urgent need to assess its effects on children's mental health [1]. This relationship is further complicated by a decline in physical activity among children in the United States, where obstacles such as distance, traffic safety, and neighborhood design hinder active commuting to school [2].

Research demonstrates that physical activity benefits not only physical health but also cognitive development and stress management, which are essential for mental well-being [3]. The Canadian Guidelines endorse physical activity as a strategy for maintaining overall health, emphasizing its long-term benefits for children's mental health [4]. Additionally, the rising prevalence of obesity among youth underscores the intricate interactions between individual behaviors and environmental factors [5].

Mobile health (mHealth) technologies and personalized medicine approaches are revolutionizing the monitoring and promotion of physical activity through mobile sensing apps, addressing existing knowledge gaps [6]. Personalization of self-tracking interventions is essential for fostering physical
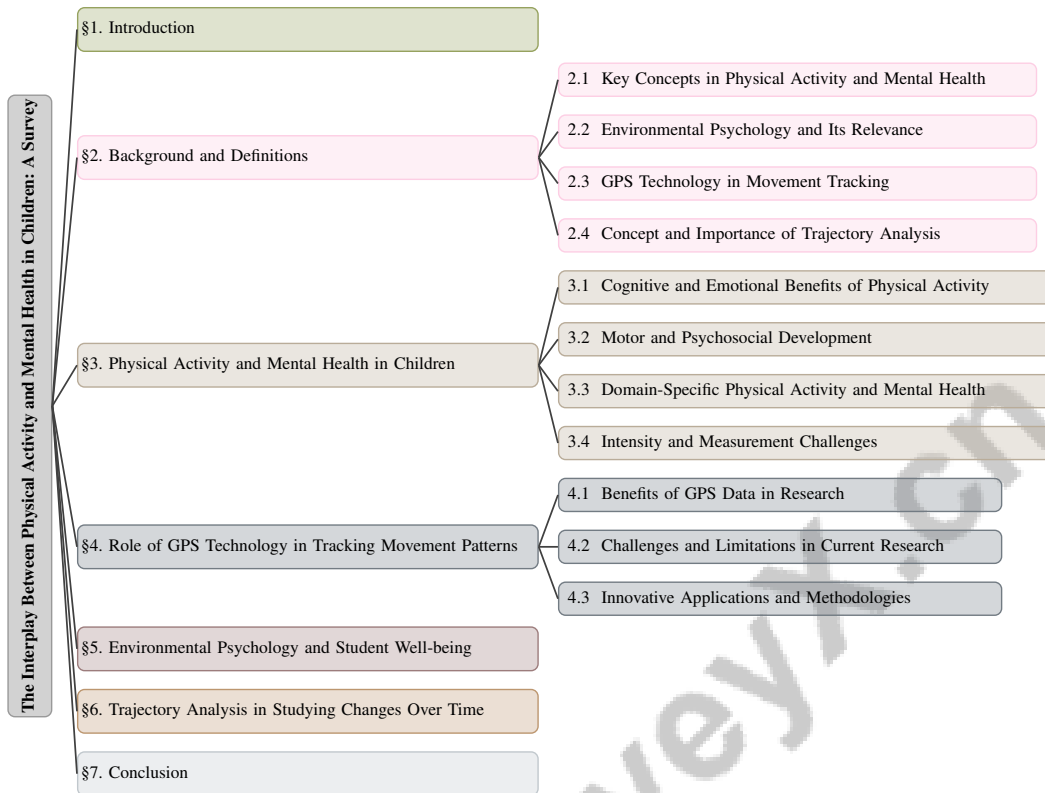
Figure 1: chapter structure

activity across diverse user segments [7]. Large-scale analyses utilizing smartphone data provide insights into global physical activity patterns, tackling the epidemic of physical inactivity and its associated health risks [8].

The long-term ramifications of insufficient physical activity include various health risks, such as obesity, cardio-metabolic disorders, and mental health issues [9]. Evaluating long-term outcomes in mHealth interventions highlights the potential health benefits of physical activity [10]. Public health policies should therefore advocate for physical activity to enhance cognitive function throughout the lifespan [11].

Investigating the link between physical activity and mental health in children is vital for developing targeted interventions that promote healthier lifestyles and improve mental health outcomes from an early age. A significant proportion of adolescents globally do not meet recommended activity levels, which may lead to various health issues, including mental health disorders. Engaging in physical activity not only supports physical well-being but also enhances cognitive functions and emotional resilience, necessitating evidence-based strategies to encourage active lifestyles among children and adolescents [12, 13, 9]. By leveraging technological advancements and addressing environmental barriers, we can better promote the health and well-being of children.

1.2 Role of GPS Technology and Environmental Psychology

The integration of GPS technology and environmental psychology provides a comprehensive framework for examining the intricate relationship between physical activity and mental health in children. GPS technology captures detailed movement patterns, enabling researchers to collect objective data on physical activity levels, which is essential for determining the optimal amount of physical activity necessary for healthy growth and development [14]. Analyzing GPS mobility patterns allows researchers to infer psychological states, underscoring its critical role in mental health studies [3].

Advanced systems like HealthPrism, which combine context and motion data, illustrate the importance of utilizing cutting-edge technologies to explore the interplay between physical activity and mental

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health [15]. These technologies facilitate the collection of extensive behavioral data, aligning with GPS's role in understanding the nuances of this relationship [16].

Environmental psychology enhances this understanding by examining how various environmental factors influence physical activity levels and mental health outcomes. This field provides insights into the contexts that affect children's participation in physical activities, thereby impacting their mental well-being. The categorization of research based on physical activity domains and their differential effects on mental health outcomes underscores the necessity of considering environmental factors in these studies [13]. Proposed methods involve building predictive models that correlate local environmental attributes with anticipated physical activity levels, further illustrating the interaction between environment and behavior [5].

Moreover, mobile ecological prospective assessments (mEPAs) leverage youth's digital literacy and smartphone access to gather real-time moderate-to-vigorous physical activity (MVPA) data, bridging the gap between technology and environmental psychology [1]. The synthesis of GPS technology with environmental psychology principles offers a holistic approach to studying the dynamic interactions between physical activity and mental health, paving the way for tailored interventions that can effectively enhance children's mental well-being.

1.3 Structure of the Survey

This survey is structured into several key sections to systematically explore the interplay between physical activity and mental health in children, emphasizing the integration of GPS technology and environmental psychology principles. The introductory section establishes the significance of studying this relationship and highlights the roles of GPS technology and environmental psychology. The subsequent section provides a comprehensive background, defining essential concepts such as physical activity, mental health, and environmental psychology, and elucidating the importance of GPS technology and trajectory analysis in this research domain.

Following the background, the survey delves into a detailed literature review on the impact of physical activity on mental health in children, examining cognitive, emotional, motor, and psychosocial development aspects, along with the challenges of measuring physical activity intensity. The exploration of GPS technology's role in tracking movement patterns highlights its multifaceted impact on various applications, including augmented reality and self-tracking for health behavior change. This analysis underscores the benefits of precise geolocation data, such as enhanced user engagement and physical activity, while addressing critical limitations like data inaccuracy, which can adversely affect user experience and usability. Furthermore, innovative applications in research demonstrate how tailored interventions can improve the effectiveness of behavior change systems by accommodating diverse user needs, ultimately fostering better health outcomes [17, 7].

The survey further investigates environmental psychology's contribution to understanding how different environments affect student well-being, analyzing the impact of environmental factors and the role of technology in this field. The section on trajectory analysis discusses its methodological approaches and applications in studying behavioral changes over time.

Finally, the conclusion summarizes key findings, emphasizes the interdisciplinary nature of this research area, and suggests future research directions. This structured approach facilitates a thorough exploration of the intricate connections between physical activity and mental health in children, highlighting significant findings that can inform future interventions and research efforts aimed at addressing the rising levels of physical inactivity and its associated mental health challenges among youth [12, 14, 13, 9].The following sections are organized as shown in Figure 1.

2 Background and Definitions

2.1 Key Concepts in Physical Activity and Mental Health

Physical activity in children, characterized by diverse behaviors in volume, duration, intensity, and type, significantly influences health indicators such as adiposity, motor skills, psychosocial health, cognitive development, and overall fitness [14]. Understanding these variations is crucial for assessing its developmental role [18]. Factors like gender and the built environment contribute to disparities in activity levels, correlating with obesity prevalence [8].

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Technological advancements in wearables have transitioned from mere surveillance tools to devices that enhance agency and well-being, promoting physical activity [19]. Moreover, social media discussions provide insights into physical activity patterns, necessitating analyses beyond traditional methods [20]. Predictive models based on local environmental attributes further complicate this domain [5].

Mental health, encompassing emotional, psychological, and social dimensions, is intricately linked to physical activity. Engagement in sports and physical activities correlates with improved self-rated health and mental health outcomes during young adulthood [21]. This relationship is influenced by personal, familial, and environmental factors [15] and affects cognitive outcomes, impacting cognitive function and brain health across various demographics [11].

In child development, physical activity is vital for physical health, cognitive, and psychosocial growth, laying the foundation for a healthy adulthood. Different domains, such as leisure-time and school sports, impact mental health outcomes variably, necessitating a comprehensive understanding of these relationships [13]. Overcoming barriers to active commuting and using mHealth technologies can enhance both physical and mental health in children, fostering a healthier future generation.

2.2 Environmental Psychology and Its Relevance

Environmental psychology explores interactions between individuals and their environments, offering insights into how contexts like natural and built environments impact physical activity and mental health outcomes. Research categorization into domains such as leisure-time, school sports, and physical education reveals gaps, especially in less-explored areas like work-related activities [13], emphasizing the need for a comprehensive approach considering diverse environmental influences.

Integrating environmental psychology with technology, such as self-tracking devices, enriches the field by providing new opportunities to study behavioral patterns. Devices designed for safety, connectedness, and health promote physical activity and enhance mental well-being [19]. Inclusive research addressing demographic factors like age, gender, and health conditions underlines the importance of tailored interventions [7].

Environmental psychology principles help understand how factors like urban design and recreational space access influence behaviors related to physical activity and mental health, informing public health strategies aimed at enhancing community well-being [5, 20, 13, 22, 9]. This understanding is crucial for developing interventions leveraging environmental contexts to promote physical activity and improve mental health, contributing to both theoretical advancements and practical strategies for fostering healthier lifestyles among children.

2.3 GPS Technology in Movement Tracking

GPS technology has transformed physical activity research by providing precise spatial and temporal data, enhancing movement pattern tracking accuracy. This technology is vital for understanding the spatial distribution and temporal dynamics of physical activity [23]. Combining GPS data with wearable devices like accelerometers allows comprehensive analyses of physical activity, addressing limitations of self-reported measures [4].

GPS technology facilitates objective physical activity measurement, critical for public health policy implications, by assessing activity distribution and influencing factors like gender and the built environment [8]. Innovative methods, such as additive quantile regression, use GPS data to explore physical activity patterns' effects on mental health outcomes, providing nuanced insights into the movement-well-being interplay [24].

Beyond movement patterns, GPS technology predicts physical activity levels based on environmental attributes, informing targeted interventions to enhance activity among children and adolescents [5]. Integrating GPS data with contextual variables supports developing just-in-time adaptive interventions (JITAIs) crucial for promoting physical activity in specific contexts [25].

The significance of GPS technology is further highlighted in mixed-method approaches, such as social media analytics, contributing to a holistic understanding of physical activity behaviors [20]. Despite challenges related to data quality and privacy, incorporating GPS technology in movement tracking continues to enhance research capabilities, providing robust data essential for designing

effective interventions aimed at improving physical activity and mental health outcomes across diverse populations.

2.4 Concept and Importance of Trajectory Analysis

Trajectory analysis is a methodological approach for studying dynamic changes in behaviors and outcomes over time, offering insights into the longitudinal patterns of physical activity and mental health. This approach is crucial for understanding complex interactions influencing health outcomes, allowing identification of distinct behavior and health trajectories over extended periods. Integrating trajectory analysis in physical activity research enhances understanding of diverse activity patterns and their effects on mental health outcomes, enabling tailored interventions [4, 20, 13, 9].

The significance of trajectory analysis is underscored by the need to address gaps in understanding the frequency, intensity, and type of physical activity required for health benefits, particularly in young populations like infants and toddlers [14]. Employing trajectory analysis captures the temporal dynamics of physical activity and its health effects, facilitating age-appropriate guidelines and interventions.

Advanced modeling techniques, such as Bayesian hierarchical modeling and two-dimensional functional mixed-effect models, enhance trajectory analysis by accounting for individual health attributes and spatial-temporal dependencies. These models enable precise assessments of physical activity patterns and their connections to mental health outcomes, facilitating thorough evaluations of behavioral changes across populations and timeframes. Findings indicate that moderate-to-vigorous physical activity enhances cognitive function and potentially mitigates mental health disorder risks, especially among adolescents [26, 11, 20, 13, 9].

Unsupervised machine learning approaches, like Hidden Semi-Markov Models (HSMM), offer adaptable methods for quantifying physical activity [27]. This innovation enables identifying optimal activity patterns associated with positive mental health outcomes, enhancing intervention precision.

The hierarchical approach to categorizing sports participation illustrates trajectory analysis's utility in examining health outcomes based on sport type [21]. Such frameworks allow exploration of various sports' differential impacts on mental health, providing a more detailed understanding of physical activity's role in promoting well-being.

Trajectory analysis is vital for studying behavioral changes over time, offering a robust framework for examining the interplay between physical activity and mental health. Methodologies such as social media analytics and self-tracking technologies enhance theoretical understanding and provide critical insights for designing tailored interventions that improve health outcomes among diverse populations, addressing individual differences in demographics, lifestyle, and health conditions [15, 20, 7].

In recent years, there has been a growing body of literature examining the multifaceted impact of physical activity on mental health, particularly among children. This exploration reveals a complex interplay of benefits and challenges that can significantly influence various developmental domains. Figure 2 illustrates the hierarchical structure of these benefits and challenges, emphasizing cognitive, emotional, motor, and psychosocial development. Additionally, it highlights the importance of domain-specific activities and the measurement challenges that researchers face in this field. By visualizing these components, we can better understand the intricate relationships at play and the implications for promoting physical activity as a means to enhance mental health in young populations.

3 Physical Activity and Mental Health in Children

3.1 Cognitive and Emotional Benefits of Physical Activity

Physical activity plays a crucial role in enhancing cognitive and emotional development in children, with regular participation linked to improved attention, memory, and executive functions, essential for academic achievement [11]. The diversity and intermittent nature of physical activities contribute to cognitive and emotional well-being by promoting emotional regulation and psychosocial health [9]. Engagement in sports and structured activities is associated with better health outcomes and reduced depression in adolescents, highlighting the emotional advantages of physical activity [21]. These activities encourage social interaction, teamwork, and resilience, which are vital for emotional health [15]. The Additive Quantile Mixed Model (AQMM) provides insights into how different levels of
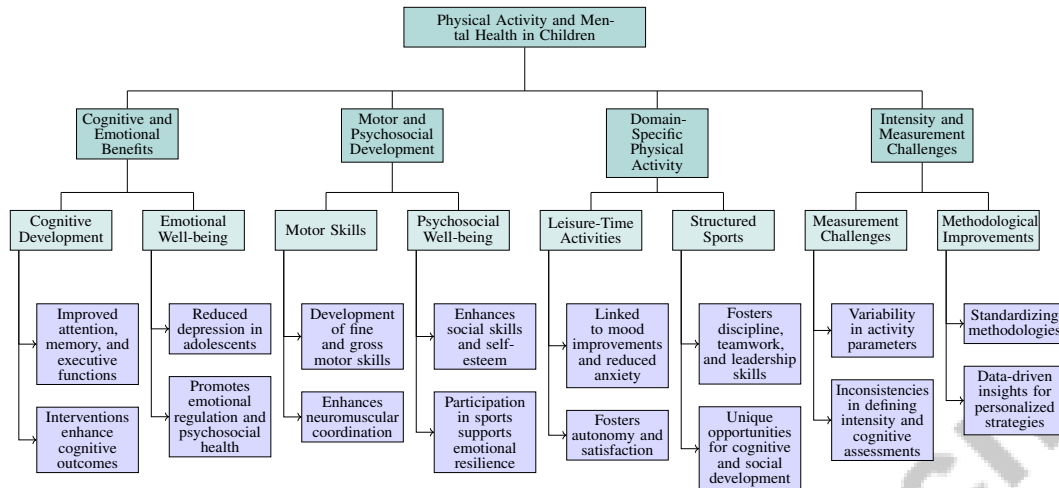
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Figure 2: This figure illustrates the hierarchical structure of the benefits and challenges of physical activity on mental health in children, emphasizing cognitive, emotional, motor, and psychosocial development, as well as domain-specific activities and measurement challenges.

physical activity influence cognitive and emotional well-being, emphasizing mobility data's role in understanding stress [24, 3]. Interventions offering activity suggestions can enhance physical activity levels, thus improving cognitive and emotional well-being through timely prompts [25]. Addressing activity inequality, particularly among females, is crucial for reducing disparities in cognitive and emotional outcomes related to physical activity [8]. Integrating physical activity into children's routines is vital for fostering cognitive and emotional growth, with implications for their overall development and well-being. Evidence-based interventions can enhance cognitive outcomes, such as memory and processing speed, while reducing the risk of cognitive decline and mental health issues in future generations [12, 20, 11, 13, 9].

3.2 Motor and Psychosocial Development

Physical activity is essential for developing motor skills and psychosocial well-being in children, influencing both fine and gross motor skills through varied activities [14]. Diverse physical activities enhance neuromuscular coordination and physical capabilities, crucial for growth. The variability in children's physical activities reflects the interplay between motor and cognitive development, facilitating motor skill refinement and adaptive responses to environmental changes [18].

As illustrated in Figure 3, the hierarchical structure of motor and psychosocial development in children emphasizes key areas such as motor skills development, psychosocial growth, and the role of technology and interventions. Each category is supported by relevant research citations, underscoring the interconnected nature of physical activity, emotional well-being, and technological advancements. Additionally, physical activity supports psychosocial development, enhancing social skills, self-esteem, and emotional resilience. Participation in sports offers opportunities for social interaction and teamwork, contributing to emotional and social well-being [21].

Wearable technologies and self-tracking devices highlight the importance of personalized interventions in promoting motor and psychosocial development [19]. Tailoring activities to individual preferences enhances engagement and motivation, leading to improved developmental outcomes. Advanced analytical methods, such as additive quantile regression, allow for detailed examinations of the relationship between physical activity and psychosocial outcomes, enabling targeted interventions [24]. By fostering environments that encourage diverse physical activities, we can enhance children's holistic development, equipping them for sustained health and well-being throughout their lives [19, 14].
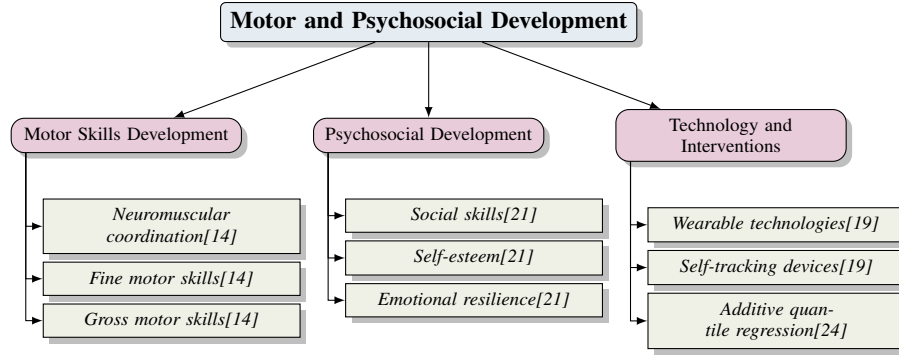
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Figure 3: This figure illustrates the hierarchical structure of motor and psychosocial development in children, emphasizing the key areas of motor skills development, psychosocial growth, and the role of technology and interventions. Each category is supported by relevant research citations, highlighting the interconnected nature of physical activity, emotional well-being, and technological advancements.

3.3 Domain-Specific Physical Activity and Mental Health

Physical activity's impact on mental health is domain-specific, with leisure-time activities linked to positive mental health outcomes, including mood improvements and reduced anxiety and depression [13]. The voluntary nature of leisure activities fosters autonomy and satisfaction, contrasting with work-related physical activity, which may lead to fatigue and burnout, adversely affecting mental health [13]. Despite the benefits of leisure-time physical activity, understanding how different activities affect cognitive functions remains limited. Further research is needed to identify optimal conditions and types of sports that best promote cognitive development [12]. Structured sports and physical education programs offer unique opportunities for cognitive and social development, fostering discipline, teamwork, and leadership skills. Disparities in the quality and accessibility of mental health programs highlight the need for targeted interventions to ensure equitable access to mental health resources [25, 13, 15, 22, 10]. Understanding the domain-specific effects of various physical activities on mental health is crucial, as different forms of exercise uniquely contribute to psychological well-being and cognitive function across populations. Tailored interventions that leverage the benefits of leisure-time activities while mitigating stressors from work-related activities can enhance mental health outcomes and promote a balanced lifestyle [21, 11, 20, 13].

3.4 Intensity and Measurement Challenges

Benchmark	Size	Domain	Task Format	Metric
BiodivAR[17]	54	Biodiversity Education	Usability Testing	SUS, HARUS
MRT[25]	37	Health Behavior Change	Behavioral Intervention Evaluation	Causal Excursion Effect

Table 1: This table presents a summary of representative benchmarks used in studies related to biodiversity education and health behavior change. It includes details on the size, domain, task format, and metric used for evaluating each benchmark, providing a comprehensive overview of their characteristics and applications.

Measuring physical activity intensity and its effects on mental health presents challenges due to variability in activity parameters and diverse research methodologies. Calibration of cut points for different subpopulations complicates longitudinal studies, limiting the generalizability of findings [27]. Inconsistencies in defining physical activity intensity and cognitive assessment methods further exacerbate these challenges, complicating definitive conclusions [11]. Missing accelerometer data distorts subject-specific summaries and hinders accurate analysis of physical activity patterns [28]. Additionally, difficulties in measuring health variables related to metabolic activities underscore the need for effective methods to analyze mobile health data [23]. Overcoming these measurement challenges requires standardizing methodologies, improving data collection, and developing innovative analytical approaches. By thoroughly investigating the interplay between physical activity intensity and mental health outcomes, researchers can gain a comprehensive understanding of this complex

relationship. This knowledge is essential for developing targeted interventions that promote mental well-being among diverse populations, addressing the unique needs of different demographic groups. Data-driven insights from meta-analyses and exploratory studies can inform personalized behavior change strategies to enhance engagement and efficacy across various user profiles [7, 20, 13]. Table 1 provides a detailed overview of representative benchmarks utilized in the context of biodiversity education and health behavior change, highlighting their relevance to the challenges discussed in measuring physical activity intensity and mental health outcomes.

4 Role of GPS Technology in Tracking Movement Patterns

The utilization of GPS technology has become integral in analyzing movement patterns, particularly with respect to physical activity and mental health. This section outlines the advantages of GPS data, detailing its capacity to provide precise, real-time insights into movement and environmental interactions. It then addresses the challenges and limitations of using GPS technology in research and explores innovative methodologies that are transforming physical activity studies.

4.1 Benefits of GPS Data in Research

GPS data integration significantly advances research in physical activity and mental health by offering precise, real-time insights into movement patterns and environmental contexts. This precision enables accurate predictions of population behavior based on environmental data, facilitating targeted public health interventions [5]. The data helps identify supportive environments, such as schools, which are crucial for promoting adolescent physical activity [9]. Moreover, GPS data supports the development of methodologies for evaluating long-term impacts of physical activity on mental health, enhancing the understanding of mHealth policies' outcomes [10]. It also aids in conducting micro-randomized trials (MRTs), allowing real-time adaptations in digital interventions to improve effectiveness [25]. Advanced statistical models like the Additive Quantile Mixed Model (AQMM) utilize GPS data to model complex relationships, providing more accurate estimates of physical activity's impact on mental health [24]. GPS technology's advantages in capturing movement patterns, understanding environmental influences, and evaluating interventions underscore its critical role in enhancing research on physical activity and mental health. Integrating findings from wearable devices and software development kits can guide the creation of effective, evidence-based interventions tailored to diverse populations [7, 20, 13, 4].

4.2 Challenges and Limitations in Current Research

The use of GPS technology in physical activity and mental health research presents several challenges and limitations. Observation bias due to finite observation windows can restrict comprehensive tracking of children's movement patterns [18]. Inaccuracies in location data can lead to incorrect conclusions about movement patterns and mental health implications [16]. Many GPS-based studies are observational and cross-sectional, limiting causal inferences between physical activity patterns and mental health outcomes [13]. The large-scale, heterogeneous nature of GPS data complicates analysis and interpretation [15], and current actigraphy methods may not capture detailed patterns in high-frequency, longitudinal data [26]. Real-time data capture failures and contextual factors influencing moderate-to-vigorous physical activity (MVPA) further complicate accurate activity level reporting [1]. Privacy concerns and user retention issues pose additional barriers, affecting data accuracy and effectiveness [6]. Irregularly sampled data requires estimation adjustments for accurate analysis [29], and noise in self-reported data can hinder stress and psychological factor measurement [3]. Current research often neglects children's perspectives, focusing more on parental interests [19]. To overcome these limitations, a collaborative approach is essential, focusing on advanced methodologies and technological support systems, such as software development kits and wearable devices, to enhance data collection and user engagement across diverse populations [19, 20, 7, 4].

4.3 Innovative Applications and Methodologies

The integration of GPS technology in research has spurred the development of innovative methodologies and applications that deepen our understanding of physical activity and mental health. Real-time interventions like just-in-time adaptive interventions (JITAIs) use location-based data to provide

timely prompts to increase physical activity [25]. GPS data combined with machine learning algorithms enables the identification of complex physical activity patterns, with methods like Hidden Semi-Markov Models (HSMM) being used to assess their impact on mental health [27]. Mixed-method approaches, combining quantitative GPS data with qualitative insights from social media or surveys, offer a comprehensive view of physical activity behaviors and their psychosocial correlates [20]. The HealthPrism visual analytics system exemplifies innovative use of GPS technology to explore the interplay between context, motion data, and mental health [15]. These applications and methodologies, leveraging precise location data and sophisticated analytics, enable tailored interventions that promote physical activity and improve mental health outcomes across demographic groups. Studies utilizing social media analytics, large-scale physical activity data, and self-tracking technologies emphasize the importance of personalization in health interventions, addressing activity inequality to enhance intervention effectiveness [7, 20, 13, 8].

(a) Augmented Reality App: Deer in a Park[17]

(b) Layer 4 Mean Attention Weights Across All Heads[26]
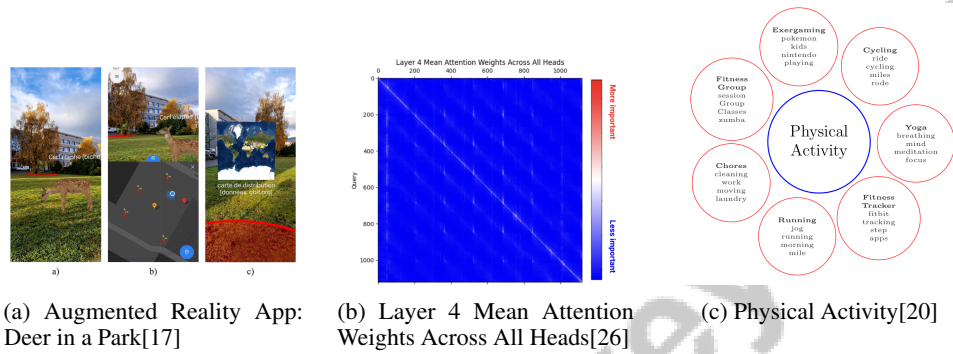
(c) Physical Activity[20]

Figure 4: Examples of Innovative Applications and Methodologies

As depicted in Figure 4, the integration of GPS technology into various applications has transformed movement pattern tracking and analysis. Augmented reality (AR) applications, such as the "Augmented Reality App: Deer in a Park," allow users to interact with their environment through a smartphone interface that overlays digital information onto real-world settings. This app visualizes a deer's location within a park and traces its movement path, enhancing wildlife tracking engagement. Advancements in artificial intelligence, demonstrated by the "Layer 4 Mean Attention Weights Across All Heads" heatmap, highlight the processing of GPS data within neural networks, emphasizing attention mechanisms in interpreting spatial information. The "Physical Activity" circular diagram underscores GPS technology's diverse applications in promoting health and fitness by monitoring various physical activities. These examples illustrate the versatile applications of GPS technology in enhancing our understanding of movement patterns across domains, from wildlife monitoring to fitness tracking [17, 26, 20].

5 Environmental Psychology and Student Well-being

5.1 Impact of Environmental Factors on Physical Activity

Environmental factors play a crucial role in determining physical activity levels and mental health outcomes. Supportive environments, such as walkable urban designs, significantly address disparities in physical activity and obesity rates [8, 9]. Access to safe exercise spaces like parks is essential for regular physical activity, benefiting both physical health and mental well-being. In educational settings, teacher well-being directly influences student mental health, affecting psychological distress levels [22]. Positive school environments, characterized by supportive relationships and adequate resources, enhance student mental well-being and encourage physical participation. Holistic approaches integrating physical and psychosocial elements are necessary to create environments that promote physical activity. Additionally, the availability of diverse sports influences family decisions on health optimization, with research highlighting the health benefits of various sports to align family choices with children's interests and health goals [21]. By understanding environmental influences on physical activity, stakeholders can develop interventions and policies that promote active lifestyles and improve mental health outcomes across diverse populations.

5.2 Role of Technology in Environmental Psychology

Technology integration in environmental psychology offers valuable insights into individual-environment interactions, particularly regarding well-being. Wearables and digital platforms enable real-time data collection on physical activity and environmental interactions, enhancing psychological assessments. These tools facilitate diverse data collection, such as social media analytics and multimodal health information, deepening our understanding of how demographics, socioeconomic status, and lifestyle behaviors affect mental health outcomes. Methods like topic modeling and interactive visual analytics help identify patterns and correlations that inform targeted interventions [15, 20]. Technology also allows monitoring of environmental variables and their effects on well-being, providing insights into how supportive educational environments promote mental health. By leveraging digital tools, researchers can evaluate teacher-student interaction quality and its influence on psychological distress, informing interventions aimed at enhancing educational settings. Moreover, technology facilitates exploration of how urban design and recreational space accessibility influence physical activity and mental well-being. GPS and wearable technologies allow detailed mapping of movement patterns, identifying barriers and facilitators affecting physical activity levels. This approach informs personalized, evidence-based physical activity guidelines. Software development kits and interactive self-tracking devices offer insights into user behavior and intervention effectiveness, promoting better health outcomes [7, 4]. This data-driven strategy provides a comprehensive understanding of health determinants, paving the way for targeted strategies that encourage active and healthy lifestyles. Technology's integration into environmental psychology represents a significant advancement in understanding well-being, particularly through interactive self-tracking devices and social media analytics that promote positive health behaviors and enhance personal agency. Research underscores the importance of personalized and inclusive design in behavior change systems, highlighting wearables' potential to empower children and families by fostering healthy habits and improving communication. Addressing diverse user needs, these technological innovations substantially contribute to individual and collective wellness outcomes [19, 20, 7]. Robust data collection and analysis tools enhance our capacity to understand and address environmental factors influencing mental health, facilitating effective interventions and policies for improving well-being across diverse populations.

5.3 Teacher-Student Relationships and Environmental Influence

The quality of teacher-student relationships and the broader school environment significantly impact students' mental health outcomes. Teacher well-being strongly correlates with student outcomes, with presenteeism and relationship quality as critical mediators [22]. Supportive school environments foster strong teacher-student relationships, essential for promoting students' psychological well-being. Teacher presenteeism, where teachers are physically present but disengaged due to stress, negatively affects the learning environment and student mental health. Supportive relationships characterized by mutual respect and understanding mitigate adverse impacts on students' mental health, fostering a sense of security and belonging crucial for overall well-being and academic success. Positive teacher-student interactions enhance students' emotional resilience and contribute to improved mental health outcomes, creating a conducive learning environment supporting academic achievement and personal development [2, 22, 30]. This relational dynamic is vital for cultivating a positive school climate that enhances emotional resilience and coping skills. Moreover, the school environment, encompassing physical and social aspects, significantly affects students' mental health. Schools prioritizing inclusivity, safety, and resource access foster an atmosphere conducive to learning and personal growth. Such environments encourage active participation in physical activities, known to improve mental health outcomes. By addressing relational dynamics among educators and students and environmental factors influencing school settings, educators and policymakers can develop multifaceted strategies that enhance student well-being and promote academic success. Research indicates teachers' mental health substantially impacts students' well-being, while improvements in school connectivity can encourage active commuting, increasing students' physical activity levels. Comprehensive strategies should integrate mental health support, infrastructure enhancements for walking and biking, and technology, such as wearables, to foster a healthier school environment supporting students' holistic development [19, 2, 20, 22, 9].

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6 Trajectory Analysis in Studying Changes Over Time

6.1 Methodological Approaches

Method Name	Data Sources	Analytical Techniques	Impact Factors
MMSMA[20]	Social Media	Topic Modeling	Environmental Contexts
PM-PAL[5]	Smartphones, Smartwatches	Predictive Models	Environmental Factors
QFR[28]	Accelerometer Data	Functional Regression	Environmental Contexts

Table 2: Comparison of methodological approaches in trajectory analysis, highlighting the diverse data sources, analytical techniques, and impact factors used in studies of physical activity patterns and their mental health implications. This table provides an overview of three distinct methods: MMSMA, PM-PAL, and QFR, each utilizing unique data sources and analytical techniques to explore the influence of environmental contexts on physical activity.

Trajectory analysis utilizes diverse methodologies to explore the dynamic evolution of physical activity patterns and their impact on mental health. Table 2 presents a comprehensive comparison of various methodological approaches employed in trajectory analysis to study the dynamic evolution of physical activity patterns and their impact on mental health. An innovative approach involves analyzing exercise-related tweets through topic modeling and qualitative coding, offering insights into public perceptions and behaviors regarding physical activity [20]. This method enriches trajectory analysis by incorporating social media data, providing contemporary behavioral insights. Another notable strategy involves predictive modeling that correlates local environmental characteristics with anticipated population behaviors, elucidating how environmental contexts influence physical activity patterns [5]. This highlights environmental factors' critical role in trajectory analysis, offering a comprehensive view of physical activity determinants. Quantile functional regression further advances this field by modeling activity profiles as distributional outcomes, allowing for a nuanced examination of physical activity variability across different quantiles [28]. Collectively, these methodologies enhance trajectory analysis's ability to capture the intricate relationship between physical activity and mental health. By leveraging diverse data sources, including social media and employing advanced techniques like meta-analysis and structural equation modeling, researchers can thoroughly assess the evolution of physical activity patterns and their significant implications for mental health outcomes [20, 13].

6.2 Applications of Trajectory Analysis

Trajectory analysis provides a robust framework for exploring behavioral trends related to physical activity and mental health. Utilizing advanced statistical models, such as the Additive Quantile Mixed Model (AQMM), researchers can gain insights into the evolution of children's physical activity patterns and their subsequent mental health implications [24]. This approach facilitates the examination of distributional changes in activity levels, revealing dynamics in physical activity behaviors. The utility of trajectory analysis is further exemplified through methods leveraging data from wearable devices, which track health trends and assess spatial energetics, offering a comprehensive view of how physical activity influences health outcomes over time [23]. By integrating wearable technology data, researchers can identify critical patterns and shifts in physical activity essential for understanding long-term health trajectories. Additionally, trajectory analysis is crucial for evaluating intervention impacts on physical activity levels. Future research could utilize this analytical approach to assess targeted interventions' effectiveness, yielding insights into behavioral changes and informing the development of effective public health strategies [31]. By capturing the temporal dynamics of physical activity, trajectory analysis enhances our understanding of behavioral trends and aids in designing interventions that promote sustained improvements in mental health and well-being.

6.3 Future Directions

Future research in trajectory analysis should refine methodologies to enhance precision and applicability, particularly concerning physical activity and mental health. One promising direction involves optimizing Hidden Semi-Markov Models (HSMM) to broaden their applications and incorporate energy expenditure estimates, increasing their relevance in health studies [27]. Enhancing estimation procedures for irregularly sampled data, as indicated by the potential applications of the two-dimensional functional mixed-effect model (2dFMM), could extend its applicability beyond

Method Name	Methodological Enhancements	Contextual Integration	Privacy and Engagement
HSMM[27]	Optimizing The Hsmm	Diverse Geographical, Environmental	Ethical Approvals
2dFMM[29]	Nonparametric Covariance Structure	Geographical Environmental Socioeconomic	Wearable Devices Assessments
TCO[2]	Combinatorial Optimization Techniques	Residential Developments Design	-
PM-PAL[5]	Predictive Models	Environmental Characteristics	Privacy Protection
DL-SP[3]	Deep Learning Techniques	Diverse Data Sources	Data Collection Challenges
QFR[28]	Nonparametric Smoothing	Demographic Covariates	Missing Data Adjustment

Table 3: Comparative analysis of various methodological approaches in trajectory analysis, highlighting enhancements, contextual integration, and privacy considerations. The table summarizes the advancements and applications of each method, providing insights into their potential contributions to physical activity and mental health research.

health studies [29]. Expanding research to include diverse geographical regions and integrating greenways as commuting paths for students can yield insights into how environmental factors influence physical activity [2]. Urban planning and policy-making can benefit from models that infer spatial distributions of physical activity, underscoring the importance of considering additional influencing factors [5]. Addressing data fidelity and privacy concerns remains critical, necessitating the exploration of new methodologies for effective user engagement [6]. Future studies should also focus on equitable access to self-tracking technology, examining socioeconomic impacts on user engagement and ethical considerations surrounding data privacy [7]. Developing wearables that support children's self-tracking and enable collaborative parent-child tracking can enhance engagement with health data, fostering proactive health management [19]. Innovative intervention strategies, including eHealth and mHealth approaches, should capture the complexities of adolescent lifestyles and the influences of social and environmental contexts [9]. Refinements in randomization processes and the integration of contextual variables could enhance the adaptability of just-in-time adaptive interventions (JITAIs) [25]. Clarifying dose-response relationships, exploring biological mechanisms, and ensuring consistency in cognitive assessment methods are crucial for advancing our understanding of the interplay between physical activity and mental health [11]. Lastly, expanding the feature set and exploring individual tailoring of models can further advance trajectory analysis, aligning with potential developments in personalized health interventions [3]. Future research should explore refinements to the method, including its application to high-frequency data and the investigation of additional covariate effects [28]. Addressing these areas will enable trajectory analysis to provide valuable insights into the complex dynamics of physical activity and mental health, ultimately informing effective interventions and public health strategies. Table 3 presents a comprehensive overview of the methodological advancements in trajectory analysis, illustrating their contextual applications and the associated privacy and engagement considerations.

7 Conclusion

This survey has explored the multifaceted relationship between physical activity and mental health in children, emphasizing the integration of environmental psychology, GPS technology, and trajectory analysis. The research underscores the cognitive, emotional, motor, and psychosocial benefits of physical activity, while also addressing the challenges in assessing its varied impacts across different intensities. GPS technology emerges as a pivotal tool in capturing movement patterns, offering precise data that enhances the understanding of physical activity within its environmental context. This precision is crucial for crafting targeted interventions and assessing long-term outcomes, as evidenced by advanced methodologies in mHealth policy evaluation.

Environmental psychology provides critical insights into how school settings and interpersonal dynamics influence physical activity and mental health, enriching this interdisciplinary investigation. Trajectory analysis further bolsters this framework by examining behavioral changes over time, guiding the development of effective intervention strategies. The use of sophisticated statistical models to analyze clustered data offers promising directions for future research.

Continued exploration should leverage data from wearable technologies and software development tools to refine research methodologies, deepening the understanding of the relationship between physical activity and health outcomes. By overcoming current limitations and exploring innovative approaches such as adaptive interventions and machine learning, researchers can better elucidate the

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complex dynamics at play. This comprehensive approach will support the creation of more effective public health strategies and policies aimed at enhancing well-being across diverse groups.

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